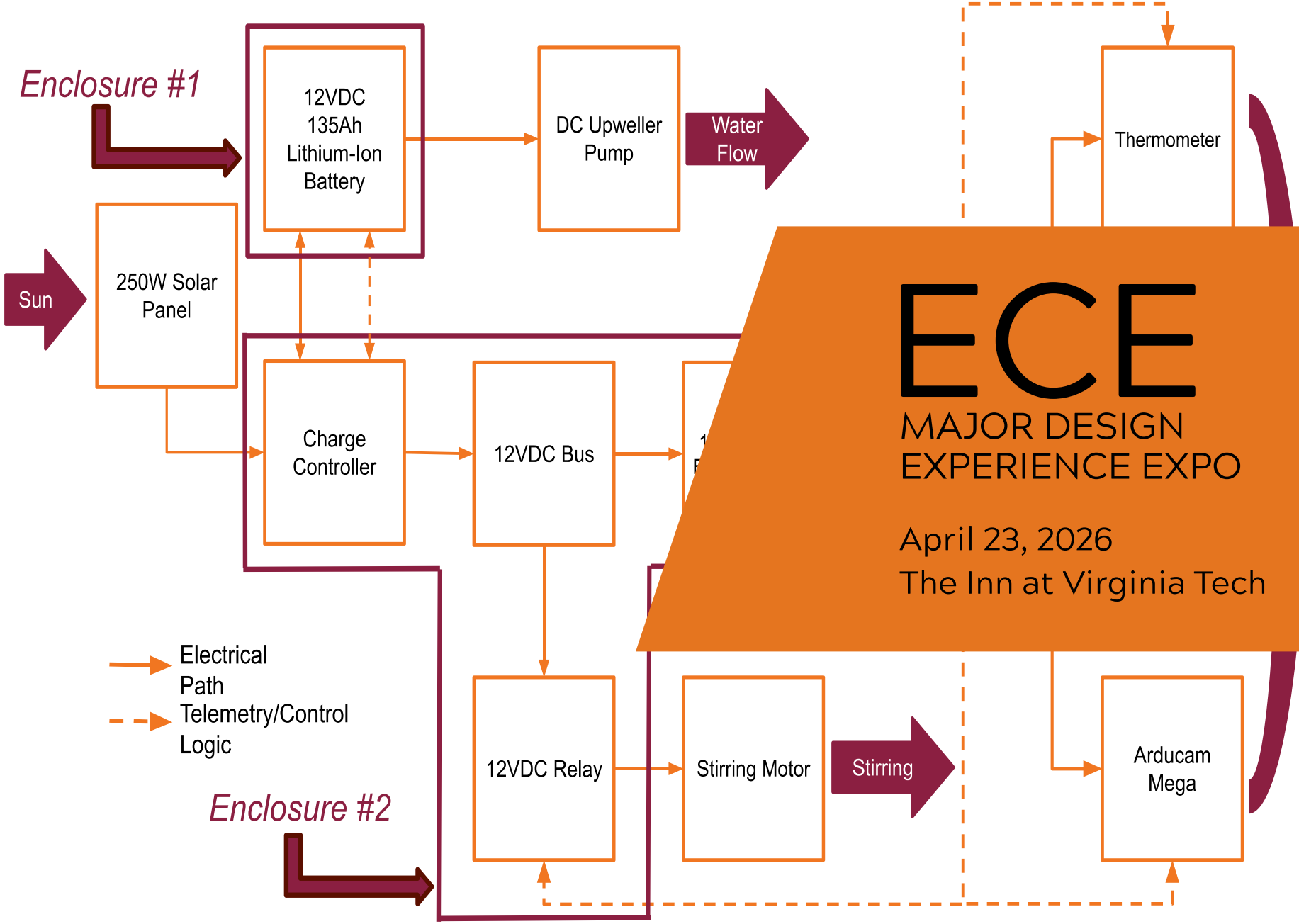

ECE

MAJOR DESIGN EXPERIENCE EXPO

April 23, 2026

The Inn at Virginia Tech

COLLEGE OF ENGINEERING

BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

VIRGINIA TECH

Agenda

Registration	8:00am–9:00am
Welcome	9:00am–9:15am
Tracks	9:30am–12:30pm
Lunch	12:30pm
Posters	1:00pm–3:00pm
Awards	3:00pm–3:30pm

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Germanium NSFETs With Ferroelectric Materials for Use in High-Speed, Ultra-Low-Power Applications	Best in Track #1	pg. 12
Tunable Wavelength Germanium Tin (GeSn) Laser		pg. 14
GaN FET Based DC-DC Buck Converter		pg. 16
Quantum Dot Laser Diode Process Design and Fabrication		pg. 18
Modernizing Impulse Clock for the Digital Age		pg. 20
Into the Flow: A Neuro-Adaptive System for Creative State		pg. 22
Freaky Frequencies: A Programmable Neuro-Optic Flicker System		pg. 24
Track 2-Duck Pond		
Low-Cost Neural Network Spoof Detection for Unmanned Aerial Systems		pg. 26
Optimus Semi-Autobot		pg. 28
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Low-Cost Newborn Hearing Screener Using Auditory Brainstem Response	Best in Track #5	pg. 76
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ShredConnect™: Remote Monitoring System		pg. 82
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VIPC | VIRGINIA INNOVATION PARTNERSHIP CORPORATION

Connecting Innovators with Opportunity

The Virginia Innovation Partnership Corporation (VIPC) sponsored the MDE Expo Book and the team award plaques. The MDE Program greatly appreciates VIPC's generosity.

Welcome to our Spring 2026 ECE Major Design Experience (MDE) Exposition. Each semester, we come together and take a few hours to review and celebrate the accomplishments of our undergraduate student teams. The MDE is intended to be the culmination of the students' entire undergraduate engineering educational journey. Today's MDE Expo showcases the results of 195 students, each working and learning together as a member of a design team finishing their second semester of work on their teams' unique projects. This year's students come from Virginia, 23 other states and 12 other countries.

Today, 39 exciting projects are showcased and each is a unique, open-ended, technical challenge defined by our industry partners. Each student team has engineered their own solution to their project with facilitation from our faculty subject matter experts (SMEs). Whether a student's career takes them to work in industry, to continue towards an advanced degree, or to pursue roles in our national labs, their MDE capstone will impact much of their approach to making contributions to their technical communities and, more broadly, throughout society.

Today's ECE MDE Expo offers us an opportunity to examine and celebrate each project team's outcomes and results. Once you have seen today's demonstrations, posters, and technical presentations, I think you will agree that all our students have learned much and most have delivered some very inspiring and useful projects.

This would not have been possible without the support of our industry partners, our subject matter experts, and a host of other professionals committed to providing our students with these exceptional educational engineering experiences. Thanks to all.

In addition, the MDE Program gratefully appreciates the Virginia Innovation Partnership Corporation (VIPC) for its sponsorship of the MDE Expo books and the student award plaques.

Congratulations to each of the students; their dedication and diligence is evidenced in these 39 projects. On behalf of these students, and from me personally, thanks again to our industry sponsors, our subject matter experts, and our MDE faculty for their tremendous support in developing our next generation of engineers.

Rose Hu
Department Head
Bradley Department of Electrical and Computer Engineering

Sponsors

We greatly appreciate their support.

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Project Leadership

This class is only possible because of the commitment, dedication, and spirit of the following Customers and Subject Matter Experts. Thank you!

Sponsor	Customer	Project	Subject Matter Expert (SME)
7x24 Exchange Ashburn, Virginia	Jeff McWhirt	Peak Shaving Power Supply for AI Loads	Liyan Zhu
Analog Devices Greensboro, North Carolina	Jeff Chambliss	Broadening Airspace Awareness through RF Drone Detection	
Annapolis Aquaculture	Richard Youngk	Solar Powered Offshore Oyster Nursery	Yiming Feng
Annapolis Aquaculture	Richard Youngk	Autonomous Aquaculture	
Arcfield	Mike Miller	On-Premise Audio Transcription and Analysis	
Framatome Lynchburg, Virginia	Kenneth Ritchey	Framatome Quadrature Inclinometer Design	
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Bill Smith	8-Element X-Band Digital Phased Array with RFSoC	Brad Davis Joseph Gaeddert
NAWC Patuxent River, Maryland	Andrian Jordan and Israel Jordan	Low-Cost Neural Network Spoof Detection for Unmanned Aerial Systems	Ryan Williams
Northrop Grumman	Randy Spicer	GaN FET Based DC-DC Buck Converter	Dan Sable
Roanoke County Roanoke, Virginia	Uma Marques	Enterprise Architecture Optimization for Roanoke County	
Scout Space Reston, Virginia	John Beutter	Rendezvous, Proximity Operations, and Docking (RPOD): Rover Bot	
Scout Space Reston, Virginia	John Beutter	Rendezvous, Proximity Operations, and Docking (RPOD): Charging Bot	

Sponsor	Customer	Project	Subject Matter Expert (SME)
Shalom Farms **Richmond, Virginia**	Amber Albee	Automated Soil Measurement and Amendment Calculation	
Shred Electric	Nick Planson	ShredConnect™: Remote Monitoring System	Tim Talty
Southwest Research Institute	Camden Ertley	Real-Time Digital Event Decoder and Visualization Interface for MCP Detectors	Camden Ertley
Southwest Research Institute	Todd Veach	Low SWaP Imaging System for Wildfire Detection	Todd Veach
TEAM Malawi **Blacksburg, Virginia**	Robert Stone and Andre Muelenaer	Low-Cost Newborn Hearing Screener Using Auditory Brainstem Response	Robert Stone Andre Muelenaer
TMEIC **Roanoke, Virginia**	Darren Honaker	Water Cooling Skid Simulator	Robert Mioduszewski
Virginia Spaceport Authority **Norfolk, Virginia**	Sidnee McGee	Multi-Protocol Launchpad Integration SCADA for Virginia Spaceport Authority	Walter Taraila
Virginia Tech, Architecture **Blacksburg, Virginia**	Bobby Vance	FutureHAUS AI: Power System	Bobby Vance
Virginia Tech, Architecture **Blacksburg, Virginia**	Bobby Vance	FutureHAUS AI: Smart Home System	Bobby Vance
Virginia Tech, Biomedical Engineering **Blacksburg, Virginia**	Robert Stone and Andre Muelenaer	Low-Resource Preeclampsia Screener	Robert Stone Andre Muelenaer
Virginia Tech, ECE **Blacksburg, Virginia**	Mantu Hudait	Tunable Wavelength Germanium Tin (GeSn) Laser	Mantu Hudait
Virginia Tech, ECE **Blacksburg, Virginia**	Scott Midkiff	Sensor System for LoRaWAN	
Virginia Tech, ECE **Blacksburg, Virginia**	Christiana Chamon Garcia	Quantum-Resistant Cryptographic System	
Virginia Tech, ECE **Blacksburg, Virginia**	Christiana Chamon Garcia	Smart Waste Management	
Virginia Tech, ECE **Blacksburg, Virginia**	Daniel Connors	Modernizing Impulse Clocks for the Digital Age	

Sponsor	Customer	Project	Subject Matter Expert (SME)
Virginia Tech, ECE Blacksburg, Virginia	Christiana Chamon Garcia	PacketVigil: AI-Powered Cyber Attack Detection	
Virginia Tech, ECE Blacksburg, Virginia	Joe Adams	Robotic Swarm for Mapping	
Virginia Tech, ECE Blacksburg, Virginia	Joe Adams	Optimus Semi-Autobot	
Virginia Tech, ECE Blacksburg, Virginia	Christiana Chamon Garcia	AI for Emergency Power Management	Sadman Saif
Virginia Tech, ECE Blacksburg, Virginia	Jeff Walling	Hybrid Array Beamforming: Radio & Algorithm Design	Tarun Cousik
Virginia Tech, ECE Blacksburg, Virginia	Luke Lester	Quantum Dot Laser Diode Process Design and Fabrication	Purv Bavishi
Virginia Tech, ECE Blacksburg, Virginia	Mantu Hudait	Germanium NSFETs With Ferroelectric Materials for Use in High-Speed, Ultra-Low-Power Applications	Mantu Hudait
Virginia Tech, ECE Blacksburg, Virginia	Leyla Nazhandali	Freaky Frequencies: A Programmable Neuro-Optic Flicker System	Leyla Nazhandali
Virginia Tech, ECE Blacksburg, Virginia	Leyla Nazhandali	Into the Flow: A Neuro-Adaptive System for Creative State	Chris Wyatt
Virginia Tech, ECE Wireless@VT Blacksburg, Virginia	Carl Dietrich	Location and Mapping of a Non-ADSB Aircraft Using RF DoA	
Wiley Wilson Lynchburg, Virginia	Gary Li	VT Athletic District Microgrid and FLISR Simulation	Ali Mehrizi-Sani
Zeta Associates Fairfax, Virginia	Michael Drescher	Portable Electronic Device Detector	Louis Beex

Peak Shaving Power Supply for AI Loads

LEFT to RIGHT: Ian Martin, Tom Daggett, Noemy Mendoza, Jenna Duffy, Muhammad Bilal, Will Kese

SME: Liyan Zhu

CHALLENGE

Our objective was to develop a line interactive peak shaving power supply that will reduce power spikes created by AI loads in data centers. The system will monitor circuit power, detect threshold exceedances, and supply supplemental power with solar assisted recharging when available. This effort aims to improve upstream UPS reliability, reduce battery stress, and provide power smoothing for high-density AI applications.

7X24 Exchange Washington, D.C. The end-to-end reliability forum.

Customer: Jeff McWhirt

Muhammad Bilal Lorton, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I hope to start my career as an electrical engineer designing and improving power and electronic systems.

Course Comment: This course gave me a good experience with working in a team and helped me improve my communication and presentation skills.

Tom Daggett Nazareth, Pennsylvania

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: After graduation, I plan to work in the renewables industry. Specifically, I will be working with solar by troubleshooting and maintaining inverter-based arrays. I plan to work in the field, gaining experience with pre-existing and new systems.

Course Comment: This course has given me the hardest challenges I've faced at Virginia Tech. This project was much more in-depth and complicated than I originally anticipated, which gave me a lot of real experience that I plan to utilize throughout my career.

Jenna Duffy Richmond, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to get my PE certification and work immediately upon graduation

Course Comment: It's been really nice to spread my wings with all the knowledge gained over the course of my degree

Will Kese Goode, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation, I aspire to start my career at a well-respected company where I can learn and use my education to continuously grow as an engineer.

Course Comment: This course has provided me with a real, industry-like project that has given me experience working with a customer to deliver a product that meets their needs. I have learned a lot from this course that will carry over to my future career.

Ian Martin Kuantan, Malaysia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: Have a good and satisfying career in nuclear power or engineering in general and leave a net positive impact on the world

Course Comment: This course has provided real-world experience providing a valauble mix of experience of working in a team and learning new technical topics

Noemy Mendoza Linden, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: My goal is to take and pass the FE exam and eventually earn my PE license. I hope to use my engineering background to work on electrical design and drawings for data centers, contributing to reliable power distribution and infrastructure that will support large scale computing systems.

Course Comment: This course gave me valuable experience working on a long-term project and applying technical concepts learned into a real design problem. It helped me learn project management skills while also improving my teamwork and refining important concepts.

Peak Shaving Power Supply for AI Loads

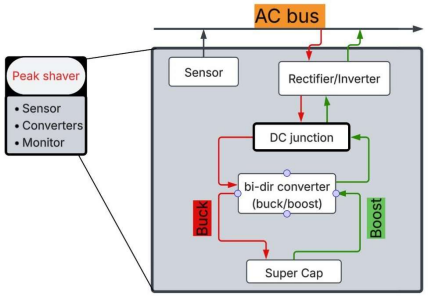
Sponsor: Jeff McWhirt, Jason Clark **Mentor:** Kelley Andrews **SME:** Liyan Zhu

Team: Noemy Mendoza, Muhammad Bilal, Jenna Duffy, Tom Daggett, Will Kese, Ian Martin

Background

- AI server loads can cause power spikes up to 125% to 150% of the rated load
- Short-duration spikes cause stress on upstream UPS systems and can risk overload conditions
- This device is designed to be a line interactive rack-level device that will be installed between the Power Distribution Unit (PDU) and the server load
- The system will perform continuous real-time power monitoring to prevent overload conditions by delivering supplemental power from storage

System Architecture



High-Level System Architecture of Peak Shaver

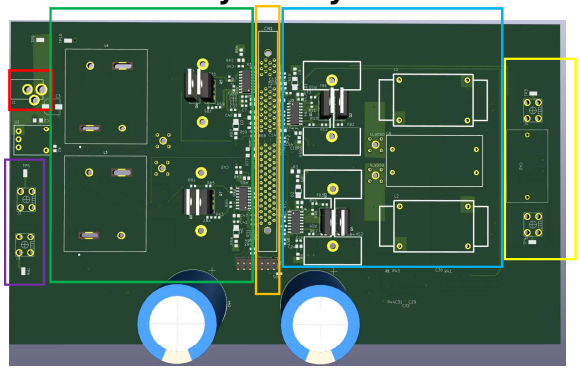
Conclusion

- This solution presents a peak-shaving power supply designed to reduce short-duration AI load spikes seen in data center racks
- The system uses a supercapacitor-based energy storage, power conversion hardware, and control logic to detect overload conditions and supply power during demand peaks
- The design reduces stress on upstream UPS infrastructure and improves power stability for high-performance computing loads

Features

- Real-time Spike Detection and Control
- Supercapacitor-Based Energy Storage
- Supports Load Spikes up to 150% of Rated Power
- Bidirectional Power Conversion
  - Buck/Boost operation for charge and discharge
- Rack-Mount Unit
  - Fits in a standard 19” wide x 1.75” tall server rack slot
- Three Shutdown Conditions
  - Overcurrent, Overvoltage, Temperature

Physical System



Printed Circuit Board Layout with Labeled Sections

- 9V Input
- Inverter
- Control Card
- Buck/Boost Converter
- System Output
- System Input

Future Work

- Integrate solar charging capability to allow energy storage to be charged from renewable sources
- Validate performance under real AI server loads and higher power conditions
- Improve system efficiency and thermal management for long-term operation
- Expand the design for larger loads or multi-rack implementation

Acknowledgements

A heartfelt thank you to the professors and industry experts who have helped us along the way:

Industry Partners:
7x24 Exchange
Digital Realty
Mr. Jeff McWhirt
Mr. Jason Clark

VT ECE Department:
Joe Adams
Daniel Connors
Kelley Andrews
Liyan Zhu
VT Data Center Staff

Germanium NSFETs With Ferroelectric Materials for Use in High-Speed, Ultra-Low-Power Applications

Track 1 Winner

LEFT to RIGHT: Shawn Lewis, Samantha Bower, Chaitrali Samant, Woongjae Lee, Anshu Pathak, Aleksandr Babich

CHALLENGE

Our challenge was to design and simulate a germanium-based ferroelectric nanosheet field-effect transistor for low-power applications. By combining a nanosheet architecture with ferroelectric material, this design has the potential to surpass the scaling limitations of conventional FinFETs while addressing increasing power and performance demands.

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VIRGINIA TECH

SME: Mantu Hudait

Customer: Mantu Hudait

Aleksandr Babich — Minsk, Belarus

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan to pursue a career in the semiconductor industry as a device or process engineer, working on advanced transistor architectures. My goal is to be an engineer who can operate across device physics, circuit design, and fabrication — bridging the gaps that slow innovation. Depending on the direction my graduate studies takes me, I would also love to contribute towards a PhD work

Course Comment: I truly enjoyed working with my team, thanks for everyones effort and time

Sam Bower — Wilson, North Carolina

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduation, I will begin working as a Process Controls Systems Engineering Intern while continuing my studies in Virginia Tech's master's program. After completing my graduate studies, I plan to pursue a career in the microelectronics field.

Course Comment: MDE has provided me with the opportunity to work on industry-relevant projects, and the unique opportunity to work in a cleanroom environment.

Woongjae Lee — Goyang, South Korea

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduation, I plan to return to Korea and pursue a career in digital circuit design and FPGA system. I am interested with digital hardware and learining more about digital sytems

Course Comment: The MDE course helped me to understand modern transistor technologies and device architectures. I also learned how engineering team projects work in practice.

Shawn Lewis — Chester, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduation, I plan to pursue graduate studies in Electrical Engineering, completing both a Master's degree and a PhD with a focus on semiconductor device research. My long-term goal is to advance semiconductor technology through research, whether in academia or industry research and development.

Course Comment: MDE has taught me how industry approaches complex engineering projects and the processes required to succeed as an engineer.

Anshu Pathak — Fredericksburg, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: My future aspirations are to continue my education in Graudate School, and work towards starting and completing my Graduate Studies. I hope to eventually recieve my PhD with a focus on Semiconductor Devices, and drive Semiconductor Technology forward in new directions.

Course Comment: MDE has taught me how industry conducts research and design projects, and has given me the skills necessary to not only be a competent engineer and researcher, but also to work in a team environment with complex, evolving specifications and results

Chaitrali Samant — Hopkinton, Massachusetts

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Following graduation, I plan to complete a co-op in Product Quality at AMD and pursue my Master's degree in Electrical Engineering. Eventually, I aspire to work in processing or industrial AI at a semiconductor company.

Course Comment: On this project, I have learned a lot about device physics and design. I am grateful for this opportunity to work with both industry and academia.

Germanium NSFETs With Ferroelectric Materials for High-Speed, Ultra-Low-Power Applications

Customer: Dr. Mantu Hudait SME: Muntasir Mahdi Mentor: Kenneth Schulz
Members: Anshu Pathak, Shawn Lewis, Chaitrali Samant, Aliaksandr Babich, Samantha Bower, Woongjae Lee

Introduction

Moore's Law: The number of transistors on an integrated circuit *doubles every two years.*

- In recent years, the scaling Limits of conventional Transistors have been approached.
- We propose that: New geometries + New materials = Continuation of Moore's Law

Enable Ultra-Low-Power applications, maintain fast switching times

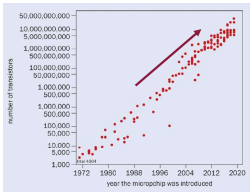


Fig. 1. Moore's Law [1]

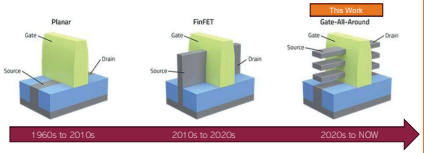


Fig. 2. Timeline of Transistor Design [2]

Designing a Transistor

Key Parameters → Simulation Setup → Performance Analysis → Fabrication proof of concept

Key parameters were chosen, and our design's physics were simulated in ***Synopsys Sentaurus TCAD***. Once our design was simulated, we analyzed the results and compared the performance to other similar devices in industry. We fabricated a device that has similar material choices as our device to show the benefit of using that material.

What is a FET?

FETs, or Field Effect Transistors, are electrical components that operate similarly to faucets (or switches).

The **gate** is like the knob that turns the faucet on and off. The **source** is where the water (current) comes in, and the **drain** is where it leaves from.

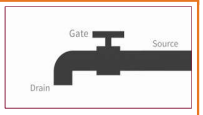


Fig. 3. Transistor Example [3]

Applications

Artificial Intelligence

With the increase in use of AI, ultra-low-power transistors are necessary to meet power demands.

High Performance Computing

Germanium NC-NSFETs show fast switching times which is optimal for high performance computing.

Material Stack

What is the Ferroelectric Effect?

When certain materials exhibit a ***spontaneous electric polarization*** that can be reversed by an applied electric field. This creates a Negative Capacitance Effect(NC).

In transistors, ferroelectric (FE) materials can improve energy efficiency.

Spontaneous Polarization creates internal voltage amplification, allowing the device to ***switch at lower voltages*** and therefore ***consume less power***. [4]

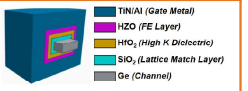


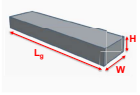
Fig. 4. Material Stack

Layer	Material	Thickness (nm)	EOT (nm)
Gate Metal (NFET/ PFET)	Al / TiN	6	—
Ferroelectric	$Hf_{0.47}Zr_{0.53}O_2$	1.5	0.234
High-κ Dielectric	HfO_2	1.5	0.2925
Interfacial Layer	SiO_2	1	1.0
Channel	Ge	—	—

Key Variables

Metric	Units	Target Value	Description
Subthreshold Slope (SS)	mV/dec	≤65	Transistor "turn-on" speed.
I_{OFF}	nA/μm	≤100	Current "leakage" during Off state.
I_{ON}	μA/μm	≥100	Drive current during On State.
Threshold Voltage (V_{TH})	V	~0.25	Minimum voltage to turn on transistor.

Parameter	Value
Gate Length (L_g)	12 nm
Nanosheet Width (W) × Height (H)	6 nm × 2 nm



Results

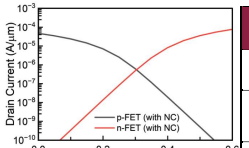


Fig. 10. NC PMOS/NMOS Crossover

Device	I_{ON} (A/μm)	I_{OFF} (A/μm)	I_{ON}/I_{OFF} Ratio	SS (mV/dec)
3-p-NSFET AR=1/3	1.24×10^{-4}	1.81×10^{-9}	68,617	67.6
3-p-**NC**-NSFET AR=1/3	1.32×10^{-4}	1.53×10^{-9}	86,374	65.2
3-n-NSFET AR=1/3	2.17×10^{-4}	2.51×10^{-9}	86,346	65.7
3-n-**NC**-NSFET AR=1/3	2.32×10^{-4}	2.10×10^{-9}	110,606	64.6

Results Explained

With the chosen variables, in simulation, there is a decrease in I_{OFF} an increase in I_{ON} and a decrease in SS. This means that there is less current leakage, better current flow when ON, and the device is faster.

Device Optimization

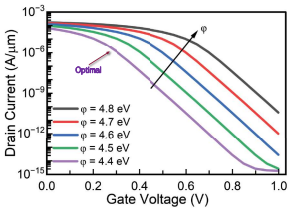


Fig. 5. PMOS Work Function

Workfunction (φ): Minimum energy required to remove an electron from the metal surface.

Important for determining the **Threshold Voltage (V_{th}),** when we transition from ON/OFF states.

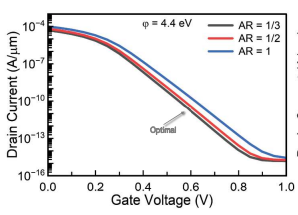


Fig. 6. PMOS Aspect Ratio

Aspect Ratio (AR): Ratio of the gate's Height vs. Width.

Impacts **how current flows** through the FET device, which directly affects **switching speed**.

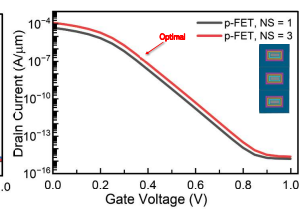


Fig. 7. PMOS Nanosheet Count

Nanosheet (NS) Count: How many gates are "stacked" vertically in order to drive more current.

We find the sheet count with the **best I_{ON}/I_{OFF} ratio**, optimal for digital design. So, **3 sheets** were selected.

Fabrication

Gate-All-Around Process Flow

The process flow shown by Figure 11 shows how a NSFET is Fabricated. For the device in this work, the materials used and some steps are modified.

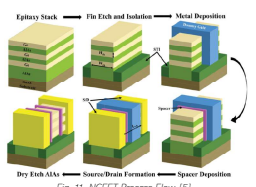


Fig. 11 NCFET Process Flow [5]

The substrate for this work would be Germanium, and the Gate stack would include the HZO Alloy. The ferroelectric Hafnium-Zirconium-Oxide (HZO) Layer is added to the NSFET, through Atomic Layer Deposition(ALD), before the gate metal layer is deposited. The ALD will deposit the appropriate composition of HZO onto the device. The rest of the process flow is as shown in Figure 11.

Inverter

CMOS inverters made up of p-FETs and n-FETs are the basis for all digital logic.

For digital design applications, the **most important parameters** are:

- High and Low voltages (V_{OH}, V_{OL})
- Logic threshold voltage (V_{TH})
- Rise and Fall times (t_{Rise}, t_{Fall})

Figure 8 displays the arrangement of the **three-nanosheet NC-FETs** that make up the inverter. This layout serves as a realistic reference for future fabrication efforts, providing a visual representation for process steps.

Nanosheet stacking, Gate-All-Around encapsulation, and ferroelectric layer placement all influence manufacturability of the NSFET inverter.

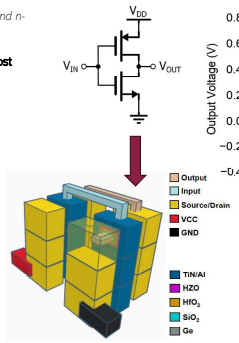


Fig. 8 Inverter Model

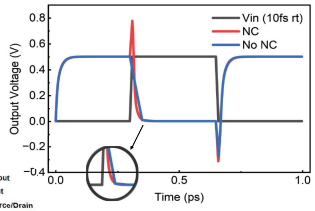


Fig. 9 Inverter Comparison

Figure 9 shows that with NC the **fall time is ~52% lower** than without NC, showing a significant improvement in switching speed. With a faster pull-down, the HZO ferroelectric layer directly **boosts efficiency** and **reduces leakage**.

Conclusions

This project presents the design, optimization, and circuit-level demonstration of a Ge-on-AlAs nanosheet FET, and the viability of a ferroelectric gate stack for ultra-low-power logic.

- The integration of a ferroelectric HZO layer into the gate stack enabled **lower current leakage and faster switching speed.**
- **Threshold Voltage was aligned** near the center of the operating range for both p-type and n-type devices.
- An inverter was created using the optimized parameters, demonstrating viability for digital design applications.

The combined improvements in power consumption and switching speed make NC-NSFETs a strong candidate for extending Moore's Law.

❖ **Manuscript "Negative-Capacitance Germanium-on-AlAs Nanosheet FETs for Ultra-Low-Power Logic Applications" under review in *Semiconductor Science and Technology (SST-111628)***

References and Acknowledgements

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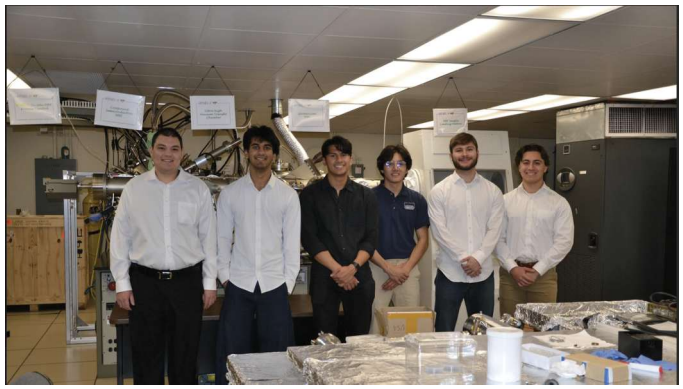
We gratefully thank Dr. Mantu Hudait, Mr. Muntasir Mahdi, Prof. Kenneth Schulz, Mr. Donald Leber, Dr. Moheb Sheikhi for their guidance, expertise, and support they generously provided over the course of this project.

Tunable Wavelength Germanium Tin (GeSn) Laser



LEFT to RIGHT: Noah Witherell, Dhruv Amin, Christian Cherukuri, Angel Hernandez, Noah White, Griffin Price

CHALLENGE

Study the effects that carrier lifetime, tin composition, and quantum well thickness have on threshold current density, optical gain, and internal quantum efficiency of a germanium tin quantum well laser. This research aids the development of implementing semiconductor lasers onto silicon for CMOS compatibility.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

SME: Mantu Hudait

Customer: Mantu Hudait

Dhruv Amin — Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: After graduation, I want to pursue higher education in photonics, specifically photonic integrated circuits for communication applications. I also want to enhance my knowledge and skills in semiconductor fabrication and better understand the full design flow, from design to fabrication.

Course Comment: Something I enjoyed about the course was the opportunity to work in a research setting for our project. I learned a lot about cutting-edge research on quantum well lasers, and I believe this experience will help me pursue similar work in the future.

Christian Cherukuri — Nashville, Tennessee

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduation, I am joining Texas Instruments as a Control Systems Engineer, and eventually I hope to transition to a design role. After about a year or so, I plan on pursuing higher education in VLSI and microelectronics.

Course Comment: This project really expanded my knowledge on photonics, a field I previously had little to no knowledge on. Additionally, I learned even more about semiconductor physics and gained valuable insight into R&D workflows.

Angel Hernandez — Peachtree City, Georgia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: I plan to work on Pulsed Power Electronics with applications in nuclear fusion. I want to contribute to a technology that will revolutionize the renewable sector and provide abundant energy for the world.

Course Comment: I learned a lot about semiconductor physics and working with physics simulations. I feel more comfortable setting up and conducting semiconductor simulations.

Griffin Price — Clarks Summit, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I'm looking forward to my experience working for Huntington Ingalls Industries as an Electrical Engineer in their Advanced Capabilities Submarine Department. I hope this job gives me the opportunity to grow and learn as an entry-level engineer in order to solve bigger and better problems throughout my career.

Course Comment: This course has been very important in helping me develop professional skills, as well as learning how a real-world engineering project is structured and how it develops over the course of a year. Overall, this project was one of the most valuable parts of my Virginia Tech undergraduate experience.

Noah White — Chesapeake, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: I will be starting a Master's degree in applied electromagnetics at Virginia Tech in the fall. After graduating, I will be working as a civilian RF engineer with the U.S. Navy.

Course Comment: This course gave me real experience with an engineering team of different technical backgrounds and with industry level semiconductor software to provide a meaningful solution to a customer.

Noah Witherell — Flemington, New Jersey

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: I will be starting a Master's degree in optical science in the fall. I will use my degree to pursue a position in R&D working on CMOS-compatible semiconductor lasers or metrology.

Course Comment: This project has increased my desire to learn more about optical science and given me valuable experience in the field of integrated photonics.

Tunable Wavelength Germanium Tin (GeSn) Laser

Customer: Dr. Mantu Hudait of ADSEL at Virginia Tech **SME:** Muntasir Mahdi
Team members: Dhruv Amin, Christian Cherukuri, Angel Hernandez, Griffin Price, Noah White, and Noah Witherell

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Background

Introduction

- **Bandwidth Bottleneck:** Conventional electrical data transfer is reaching its ceiling → Limits speed and efficiency → Need optical components
- **Silicon Limitation:** Si remains the foundational material for integrated circuits → Indirect bandgap renders it highly inefficient as an on-chip light source
- **Material Breakthrough:** GeSn and ε-Ge active layers offer a viable solution as an efficient on-chip light source
- **Direct Bandgap Transition:** Alloying Sn with Ge & ε-Ge → Band structure transitions to a direct bandgap semiconductor → Enables efficient lasing
- **Effect of Carrier Lifetime on Laser Performance:** Impact of carrier lifetime on GeSn laser performance → Has never been studied before

Applications for Tunable Wavelength GeSn Quantum Well Laser

- Quantum Computing
- Energy Efficient AI and Data Centers
- Optical Communication

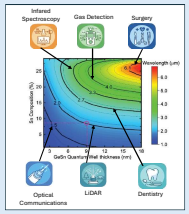


Figure 1. Tunable wavelength GeSn laser for different applications

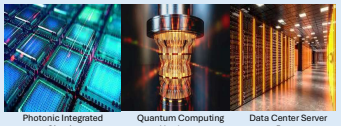


Figure 2. GeSn Laser Applications

Device Structure

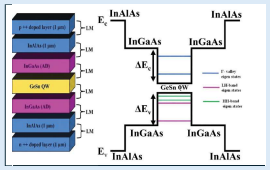


Figure 3. III-V/GeSn/III-V QW Laser Structure

GeSn and ε-Ge QW Laser Structures

(i) Electron and hole supply
(ii) Lattice match barriers for carrier and optical confinement
(iii) Tunable Sn composition and strain to modulate bandgap
(iv) Tunable QW thickness to vary emission wavelength

Laser Performance Analysis by TCAD

(i) Vary Sn composition (10-18%) and strain (0.2-3.1%)
(ii) Tune quantum well thickness (8-12 nm)
(iii) Sweep carrier lifetime (0.2 ns – 100 ns)

Performance Metrics

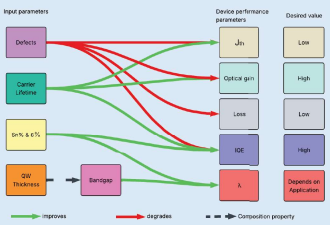


Figure 4. Input parameter vs device performance graph.

Design Parameters
Sn Composition (10-18%)
Carrier Lifetime (0.2 ns – 100 ns)
Quantum Well Thickness (8-12 nm)
Defects (Negligible due to lattice matching)
Laser Performance Metrics
J_{th}↓: Current required to turn on device
IQE↑: Efficiency of the laser
Optical Gain↑: How much light is amplified
Loss↓: How much light is attenuated
Wavelength ↔: Relates to frequency of light

Validation

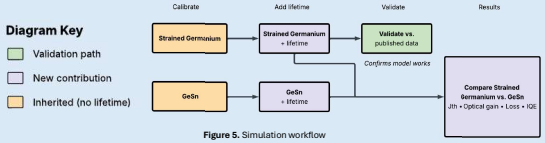


Figure 5. Simulation workflow

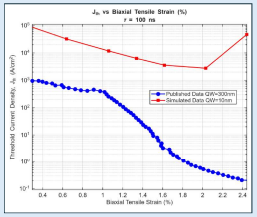


Figure 6:
J_{th} (TM mode) vs strain % comparing Bulk Germanium laser [Stanford] and ε-Ge QW laser [Virginia Tech]

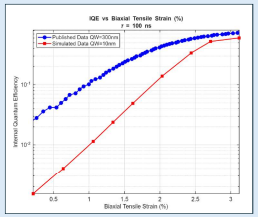


Figure 7:
IQE (TM mode) vs strain % comparing Bulk Germanium laser [Stanford] and ε-Ge QW laser [Virginia Tech]

Conclusions

- Higher carrier lifetime results in lower J_{th} and improved IQE
- Lifetimes > 35 ns result in a marginal increase in device performance
- GeSn has superior laser performance for both TE and TM modes compared to ε-Ge

Manuscript titled: "Impact of Carrier Lifetime, Tensile Strain, and Sn Composition on Ge and GeSn Quantum-Well Laser Performance" to be submitted to IEEE JSTQE [April 2026]

Acknowledgements

We would like to thank Dr. Mantu Hudait, Mr. Muntasir Mahdi, and Mr. Ken Schulz for advising and supporting us throughout this project. Authors acknowledged for partial support NSF ECCS-2430393

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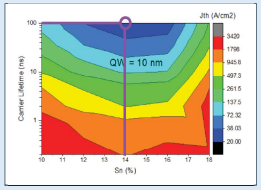
Results



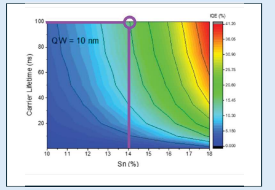


Figure 8:
Effect of Minority Carrier Lifetime (MCL) and Sn% (inputs) on J_{th} , IQE, gain & loss, wavelength (outputs) at Quantum Well (QW) = 10 nm

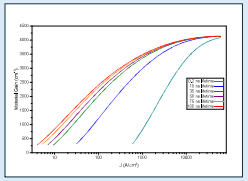


Figure 9:
Effect of τ on Material Gain vs Current Density relationship for TE mode

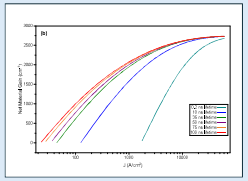


Figure 10:
Effect of τ on Net Material Gain vs Current Density relationship for TE mode

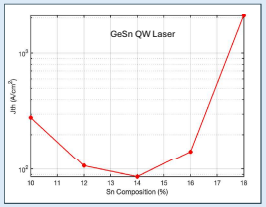


Figure 11:
J_{th} (TM mode) vs Sn % for 10 nm QW and τ = 100 ns in GeSn

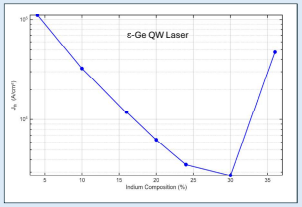


Figure 12:
J_{th} (TM mode) vs In % for 10 nm QW and τ = 100 ns in Strained Ge

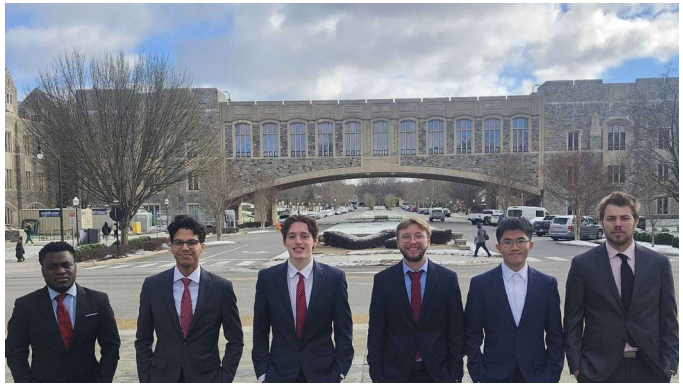
Selected design

Metric	0.2 ns	35 ns	100 ns
$J_{th}\left(\frac{A}{cm^2}\right)$	1759.86	44.97	23.12
$IQE\ (\%)$	0.43	10.30	15.12
$Net\ Optical\ Gain\ (cm^{-1})$	22.50	22.62	22.69
$Wavelength\ (\mu m)$	2.59	2.59	2.59

Degraded performance

Table 1:
Example device design based on parameters selected from Fig. 8

GaN FET Based DC-DC Buck Converter



LEFT to RIGHT: Bright Sona, Chris Howard, Trey Vogele, Casey Knudsen, Bryan Pham, Alexander Ablozhey

SME: Dan Sable

CHALLENGE

Northrop Grumman has tasked our team with developing a highly efficient DC-DC buck converter that leverages Gallium Nitride (GaN) technology that will work across a wide range of input and output voltages. This converter was to be designed for use in space/satellite devices, which constitutes radiation-hardening for all components. By serving as a universal converter, this device will reduce cost and complexity for future satellite designs.

NORTHROP GRUMMAN

Customer: Randy Spicer

Alexander Ablozhey — Woodbridge, Connecticut

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation I intend to work full time while pursuing an MBA.

Course Comment: Senior Design gave me a very valuable design experience that helped me polish many skills such as soldering, finding faults in systems, and PCB Design work.

Chris Howard — Leesburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduating, I will be working with Boeing in the defense industry while pursuing an MS in EE part time. My goal is to eventually pursue work in the IC design industry once I complete my graduate degree.

Course Comment: MDE gave me more insight into an industry related experience, especially as our sponsor was Northrop Grumman, I gained a valuable experience understanding the design process of a large defense contractor.

Casey Knudsen — Plymouth, Michigan

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduating I will start work at Northrop Grumman's Mission Systems in Baltimore, MD. My goal is to continue working with design and applications of radar systems.

Course Comment: This course gave me valuable experience in relating school concepts to a professional environment. The project greatly enhanced my skills in circuit design and problem solving.

Bryan Pham — Springfield, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduating, I am considering going to graduate school on top of actively pursuing employment. My goal is to be able to pursue a career in embedded systems.

Course Comment: This course has given me experience in working with a team long-term to solve a non-trivial problem.

Bright Sona — District Height, Maryland

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation, I intend to work or go for masters

Course Comment: Senior design has provided me with ample confidence in solving real world problems, from problem ideation to pcb bring up.

Trey Vogele — Georgetown, Texas

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: My time at Virginia Tech helped me realize that I want to work in the semiconductor industry after graduating. I plan to persue the path that will best suit the trajectory of my career. This involves either obtaining a master's degree, or directly jumping into the industry.

Course Comment: Major Design Experience gave me an insight into how industry works. I'm also grateful for the team that I was placed on this year. This course helped me improve both of my teamwork and problem solving skillsets to the point where I'm more prepared for the real world.

GAN FET BASED DC-DC BUCK CONVERTER

Team Members: *Alex Ablozhey, Chris Howard, Casey Knudsen, Trey Vogele, Bryan Pham, Bright Sona*
Sponsor: *Dr. Randy Spicer - Northrop Grumman*
SME: *Dr. Daniel Sable* | Mentor: *Dr. Janice Burr*

BACKGROUND INFO

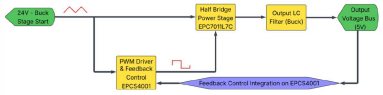
- Gallium Nitride Field Effect Transistors (GaNFETs) are a type of MOSFET that can stably operate at high switching frequencies, specifically in the 1-3MHz range. The reason they can perform stably at this frequency is due to the materials electron mobility properties, specifically its bandgap. GaNFETs are often qualified as HEMTs (High Electron Mobility Transistors), which signify their ability to switch quickly. This high switching frequency allows for high efficiency DC-DC converters, as well as low output ripple effects which lowers unintended AC effects on their outputs.

KEY REQUIREMENTS

Our project relies on the key requirements listed below, which highlight the functional requirements of the buck converter:

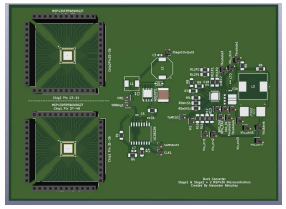
- Three different input buses (12V, 28V, 36V) ±10%
- Four discrete output voltages (3.3V, 5V, 12V, 28V)
- Components must have rad-hard equivalents
- The efficiency is to be at least 80%, with a goal of achieving 90% or greater
- Capability to interface with heat dissipation array, already equipped on satellite
- Achieve low voltage ripple on output (≤1%) for less strain on the load

BUCK STAGE

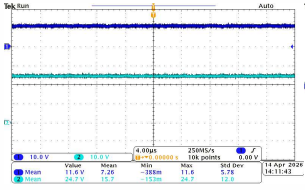


- Buck stage accepts 24V input bus (minimum 17 volts) from either boost converter or directly depending on setup.
- Utilizes EPCS4001 PWM Controller and EPC7011L7C Half Bridge Power Stage (GaN Component).
- EPCS4001 manages duty cycle via closed loop feedback from the output voltage bus.

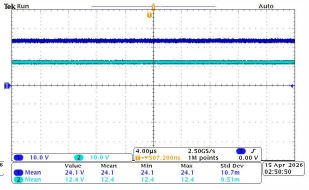
FINAL DESIGN IMAGES/WAVEFORMS



Final PCB Design

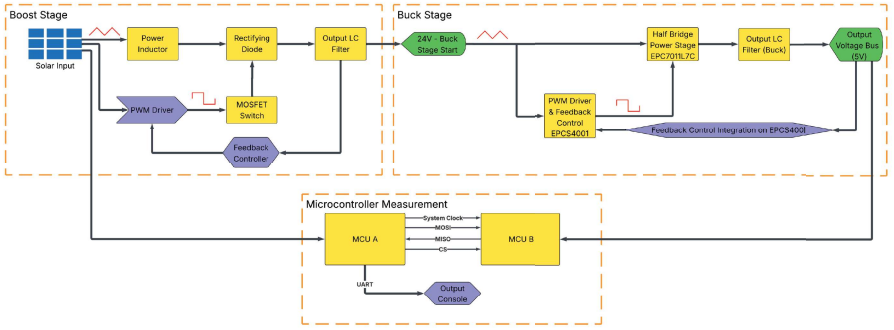


Boost Stage Input v Output

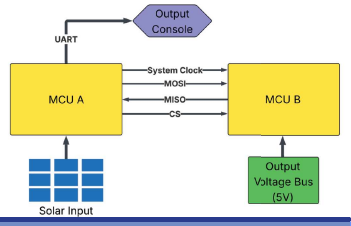


Buck Stage Input v Output (EPCSC401)

BLOCK DIAGRAM

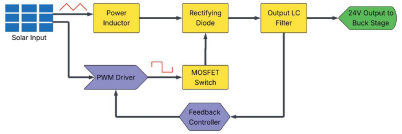


MCU INTEGRATION



- Two MSP430FR5969 microcontrollers are used to independently measure voltages at the input and output of the converter
- SPI protocols are used to communicate information between the two microcontrollers
- Calculations are done using the shared information to output the power efficiency to a console

BOOST STAGE



- For lower input voltages, a boost is necessary to meet power requirements of buck stage
- Boost converter operates at 380kHz with a nominal duty cycle of 50%
- Nominal Output voltage of 24V

CONCLUSION

- After completing the design process, we can conclude that our model is capable of accommodating all three discrete input voltage levels, as well as all four discrete output voltages on the condition of a high enough input voltage. In addition, we were able to design and order a PCB, as well as the components selected for our initial prototype. Unfortunately, due to soldering issues and prototype assembly, physical testing was limited which affected the results of our project

FUTURE WORK

- Implementing input filter to reduce voltage spike and improve component longevity.
- Converter operation validation at varying input and output bus voltages.
- Interfacing with thermal solution on varying satellites.
- Test operational capability at higher switching frequencies and observe possible increases in circuit efficiency.

ACKNOWLEDGEMENTS

We would like to give our utmost thanks to Dr. Sable for guiding and assisting us throughout the course of this project. We would also like to thank Dr. Spicer and Dr. Burr for always believing in us and monitoring our progress.

Quantum Dot Laser Diode Process Design and Fabrication

LEFT to RIGHT: Sammy Craypoff, Awida Neji, Nick Baker

CHALLENGE

Design and fabricate a quantum dot laser diode with 100x100 micron contact pads that allow for lasing in near-infrared around 1300nm wavelength. Create a planarized insulator layer to hold and pad, and prove electrically continuity from the metal pad to the ridge. Create a process flow which can be used by other process engineers that outline the fabrication steps taken to create the laser.

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SME: Purv Bavishi

Customer: Luke Lester

Nick Baker Charlottesville , Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduation, I plan to pursue a career in semiconductor devices/processing and possibly return for my masters later after working in industry

Course Comment: This course gave me useful experience in project management for a complicated project with many moving parts.

Sammy Craypoff Herndon, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After I Graduate, I plan to enter the semiconductor insdustry for a few years to gain experince with the current technology. After that, I hope to go aboard for my Master's in Electrical Engineering.

Course Comment: This course gave expenince of managing long term projects and dealing with unfrorseen delays.

Awida Neji Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I plan to pursue a master's degree in Electrical Engineering here at Virginia Tech.

Course Comment: This project solidified my interest in fabrication and working in the Micron Cleanroom has been eye-opening.

Quantum Dot Laser Diode Design and Fabrication

Team: Sammy Craypoff, Nick Baker, Awida Neji
Customer: Dr. Luke Lester **Subject Matter Expert:** Purv Bavishi
Mentor: Dr. Daniel Connors

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Background

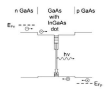
Quantum dot (QD) lasers offer key advantages in modern photonics, including low threshold currents and reduced temperature sensitivity. Our goal is to create a planarization process for an insulating layer along on a AlGaAs ridge with a probable metal pad on top.

Objectives

- ❑ Create a contact pad that allows for easy probing
- ❑ Isolating PMMA layer is sufficiently planarized
- ❑ Complete wrapping of metal contact around the ridge
- ❑ Backside metallization of the laser wafer

Distributed-Feedback QD Laser

The image illustrates the energy band structure and transition physics of the quantum dot semiconductor.



The diagram represents a p-i-n junction where the intrinsic or active region contains an InAs quantum dot surrounded by AlGaAs.

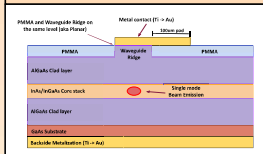
The effective bandgap is determined by the bulk material properties plus an additional quantum confinement term.

$$E_g^{1D} = E_g + E_c^{111}$$

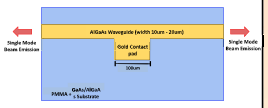
QD gap energy

This equation shows that by changing the physical size of the dot, we can precisely tune the color of the emitted light.

Device Structure



Cross-Section view



Top down view

The InAs/InGaAs Core layer acts as a lateral waveguide, while the waveguide ridge confines the light horizontally.

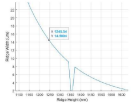
The ridge widths on the actual mask will alternate between 25um and 50um. Gold pad is on top of the insulating PMMA layer

Simulation

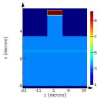
Simulated Ridge

A design objective is single-mode operation with careful engineering of the waveguide geometry, specifically the ridge height and width. We used ANSYS Lumerical's eigenmode solver (FDTD) for detailed analysis of the various possible mode profiles.

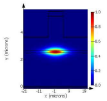
Simulation involved characterizing wafer designs, each with slightly different material properties and layer thicknesses. The foundation of this analysis is the treatment of the ridge waveguide as a 4-layer asymmetric dielectric slab waveguide. The figures show the specific results for one of wafer types (ZLG-1009).



Maximum ridge width vs ridge height for ZLG-1009



Structural and layer composition



Mode confinement and shape

Process Overview

Our process for fabricating the quantum dot laser can be simplified into 4 key processing steps:

- ❑ Formation of the ridge waveguides
- ❑ Deposition and planarazition of the insulating PMMA layer between ridges
- ❑ Frontside metallization
- ❑ Backside metallization

Simplified Process Flow

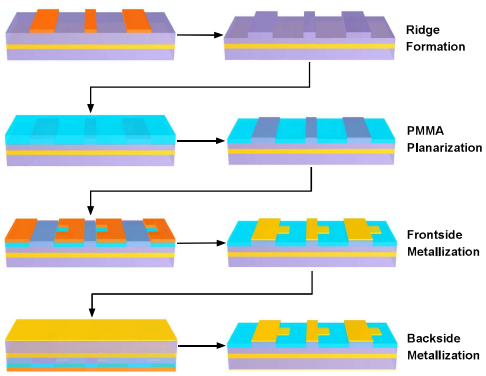
Below is a diagram illustrating our basic process flow for fabricating a quantum dot laser diode.

Areas unprotected by photoresist (orange) are etched downwards with acid to create rectangular ridges.

PMMA (blue) is spun over the whole wafer. It is then etched back with an O2 plasma until just the tops of the ridges are exposed.

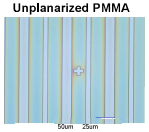
Photoresist outlines the future metal area. Metal is then deposited, and any metal on top of the photoresist is lifted off.

The wafer is flipped over, and the frontside is protected with photoresist. Metal is then deposited on the entire backside.



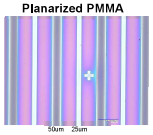
Wafer with unetched PMMA coating the surface. When PMMA is spun on, it is not perfectly flat but instead conformal to the ridges. Note the height difference between the smaller and larger ridges.

Unplanarized PMMA

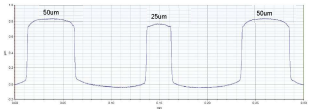


Wafer after the etchback. Residual PMMA left on the large ridge while the small ridge is completely exposed. After etching back the PMMA, the surface is not perfectly planarized.

Planarized PMMA



Surface Profile Pre Etch Back



Surface Profile Post Etch Back

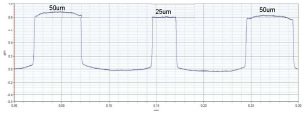
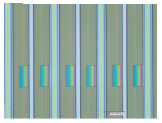


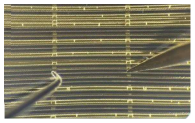
Photo of the wafer after the second photolithography step. Note the different color of the contact pads. This indicates that the pads are correctly sitting above the insulating PMMA layer.

Contact Pads Above PMMA



Microscope photo of the probing process for a finished wafer. This test specifically was for checking electrical continuity along the ridges.

Contact Pad Probing



Test Results

Used an optical workbench to perform operational testing on both a known-good laser diode and our own fabricated laser diodes.

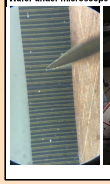
Under the microscope, the cleaved working wafer clearly displays the individual ridges with the pads.

We successfully probed a specific pad on the wafer to establish an electrical connection for the experiment.

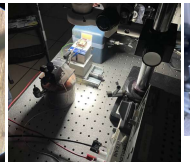
We were able to drive the diode. The experiment confirmed successful emission as we observed active lasing directly on the IR card.

Current ON, Light Before Lasing

Wafer under microscope

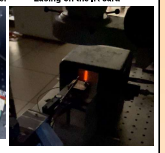


Optical Workbench Setup



Probed a pad on the wafer

Lasing on the IR card

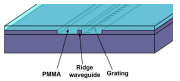


Conclusions

- Successfully created a replicable process flow for fabricating a rectangular waveguide with easily probeable metal contact pads and an isolating dielectric layer that is sufficiently planarized.
- The creation of diodes that are fully functional and capable of producing light similar to a reference diode was a significant milestone in this project, demonstrating the effectiveness of our process flow.
- Our process flow was presented to a satisfied customer, who successfully replicated the procedure and achieved results consistent with our specifications.
- The successful completion of this project has provided valuable insights and expertise that can be applied to future research and development initiatives.

Future Work

- With the PMMA planarization step complete, our work will then be used in a new process flow for a updated designs.



- The next step in our project is to hand off this work to our SME Purv Bavish to integrate the PMMA layer with grating technology to create a high-performance optical laser with low beam divergence for future publishing.

Acknowledgements

Our team would like to thank the following people for their support throughout the project:

- Dr. Luke Lester (Client)
- Purv Bavishi (SME)
- Don Leber (Virginia Tech Micron Cleanroom Manager)
- Dr. Daniel Connors (Mentor)

Modernizing Impulse Clocks for the Digital Age

LEFT to RIGHT: Walter Pereira-Cruz, Elisabeth Presley, Bill Tang

CHALLENGE

Our team was tasked with modernizing 20th-century impulse clocks by replacing legacy hardwired control systems with a wireless solution. To achieve this, we designed a system where a central transmitter wirelessly communicates with receiver units, generating precise voltage pulses to advance each clock.

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Customer: Daniel Connors

Walter Pereira Cruz — Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My career goal is to use what I have learned and the skills I have acquired to do meaningful work as an engineer.

Course Comment: This course has provided me important experience with working on developing a project whilst working with such a great team. The skills I developed will be forever useful in my future endeavors.

Elisabeth Presley — North Tazewell, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I am extremely interested in electromagnetics and physics. I plan to pursue graduate study after completing my undergraduate degree, with the goal of someday becoming a professor.

Course Comment: Working on this project has given me valuable experience in circuit design and troubleshooting real-world engineering problems. This course as a whole has reinforced the importance of collaboration with a team, documentation, and iterative testing when designing and developing complex systems.

Bill Tang — Lorton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: To be able to help others and to give back what my family gave to help me get to where I am.

Course Comment: It has been a very eventful and educational year where I have learned beyond just the major itself, but also team management, documentation, preparation, and communication skills that are crucial to any career.

Modernizing Impulse Clocks for the Digital Age

Sponsor: Dr. Daniel Connors

Members: Bill Tang, Elisabeth Presley, Walter Pereira Cruz

VIRGINIA TECH

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Background

What are 20th century impulse clocks?

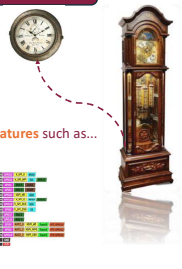
Impulse clock systems, **first invented in 1839**, were historically **deployed in large establishments to ensure synchronized timekeeping** throughout the entire building. A **central timing unit generates periodic electrical pulses that are distributed via hardwired connections to remote wall clocks,** advancing each clock mechanism in step.

What are the constraints?

Although reliable, these archaic systems are **constrained by fixed wiring and a lack of adaptability to modern requirements**. They are **not portable and do not support automatic time synchronization, Daylight Saving Time (DST), or resilience to power disruptions**. With the ever-increasing demand for wireless, low-power, and flexible infrastructure, these systems offered an opportunity to **modernize these legacy systems while maintaining their core functionality and aesthetic.**

Requirements/System Overview

Requirements
- Create a **wireless** system
- Control clock's **transmitter sends a signal**
- **Signal triggers a voltage pulse**
- **Pulse advances receiver clocks** by one minute



System Structure
- Both **receiver and transmitter use the ESP32**, which has **features** such as...
  - Wi-Fi
  - Bluetooth
  - Power-saving mode
  - Low energy consumption

Code
- We are using the **Arduino IDE**
  - Supported by **ESP32**
  - Has a **large library** from which to gather **resources and help**

ESP32 dev board pinout

Challenges

PCB Design
- Difficulty arranging components without **trace overlap**
- **Tight component placement necessary for boost loop** to minimize parasitic inductances
- **Custom footprints** necessary

PCB for our boost circuit

Boost circuit
- Initial operating **frequency too low**
  - Energy transferred to the output less often
- **Difficulty acquiring NMOS transistor** with necessary parameters
  - Eventually selected AOSS32334C

AOSS32334C NMOS

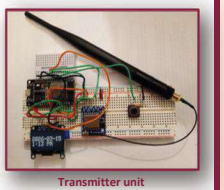
Other
- **Issue receiving signals** in power-saving mode
- **Difficulty locating battery** for transmitter backup system

Lithium-Ion battery for transmitter backup power

Transmitter

Transmitter Unit

Function
- **Connects to internet** after user inputs Wi-Fi info to custom-made HTML page
- **Sends three 915 MHz radio pulses on the minute** to nearby (~30 m) receiver clocks
- **Resynchronizes internal clock time** at the start of every day
  - If the current time and date falls within the DST period, then **an offset is applied to the time** to account for it
- **Internal clock continuously advances and updates the display** each second



Transmitter unit

User Interface
- When powered on, the device **creates a Wi-Fi network** to which user connects from their browser (http://192.168.4.1/)
  - **Any information related to network can be entered**, such as...
    - Time zone
    - Whether to display 12 or 24-hour time
  - Once submitted, **automatic function begins** until powered off

HTML WI-FI information Set Up

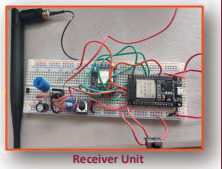
Features
- **Displays current time** on OLED display
- **Back up** battery system
- **Daylight Saving Time** feature

Receiver

Receiver Unit

Function
- **Defaults to sleep mode to conserve power** while waiting to receive 915 MHz signal
- **Upon receiving signal**, it wakes up and...
  - Starts the boost circuit
  - Increases the 6v battery to 12/24v output depending on voltage level required by receiver clock

User interface
- Voltage switch
  - Allows user to **select between an output of 12V and 24V**
  - Potentiometer
    - Allows user to **control the duration of the output pulse**



Receiver Unit

Boost Circuit
- **ESP32 port 5** is used to **set pulse width modulation and frequency**
- All components rated for **up to 60 volts**

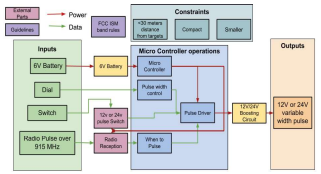
Code
- **Reads values of voltage switch and potentiometer** before boosting voltage
  - Upon receiving one signal...
    - Any **additional signals are ignored**
    - Proceeds to **start up the boost circuit**
- If using Arduino IDE, **displays information** for...
  - Pulse duration
  - PWM
  - On/Off time

Arduino IDE output for receiver

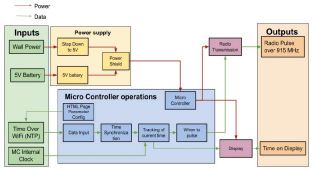
Conclusion

In summary, we...
- Developed a **two-part system consisting of transmitter and receiver units**
- Enabled **wireless synchronization of multiple clocks** via Wi-Fi
- **Modernized** legacy impulse clocks with **digital control**
- **Achieved long-term operation** with **low-power, battery-powered receivers** (~1 year)
- **Improved system reliability** through **back-up power setup**
- Provided **user control and system configurability**
- **User control** for voltage pulse amplitude and duration

Diagrams



Receiver Unit



Transmitter Unit

Impact

Antique clock collectors
- Foundation to **implement our design**
  - Allows for **keeping original legacy clock hardware** intact

Future students
- Potential for **additions to our design**

Acknowledgements

We would like to sincerely thank our mentor Dr. Connors for his **invaluable support and mentorship** as we worked to complete this project. Dr. Connors **supplied us with the legacy clocks used by our system** and **equipped us with** both **the knowledge to operate them and an appreciation for their timeless value and appeal.**

We would also like to thank our friend and classmate Sebastian Marrufo for **aiding us in our soldering endeavors** throughout the course of this project.

Into the Flow: A Neuro-Adaptive System for Creative State

LEFT to RIGHT: Jonathan Colon, Mahin Atturu, Keenon Shields

CHALLENGE

Develop a neuro-adaptive system using an EEG headset that dynamically provides auditory and visual feedback based on real-time brainwave activity in the theta, alpha, and beta bands. The system must continuously process and classify incoming EEG signals, map relaxation levels to appropriate feedback modalities, and adapt its response in real time to guide the user toward a desired relaxation state.

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SME: Chris Wyatt

Customer: Leyla Nazhandali

Mahin Atturu — Glen Allen, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I will be working after college and I plan on getting my MBA to eventually become a manager/supervisor at an engineering company.

Course Comment: This course has given me insights and experience with leading an engineering team to designing a solution to an arbitrary problem. It has helped me practice deconstructing an abstract idea into clear and concise roles, while giving my teammates both enough space and direction to accomplish their tasks. Additionally, it has helped me learn how to professionally communicate with our mentor and customer, as well as how to operate unfamiliar technologies to achieve our planned solution.

Jonathan Colon — Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I'm planning to continue my education towards a master's degree while working in industry. I'm scheduled to take the FE licensing exam in June with plans to take the PE exam at first avaliability. I aspire to eventually start my own engineering firm.

Course Comment: This course has tested more than just my engineering problem solving skills. It has helped me hone my team building and customer relation skills in a more professional, engineering focused enviroment. It has also helped in teaching me way's to narrow the scope of an open ended project with little direction.

Keenon Shields — Richmond, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I am looking forward to working at the intersection of Signal Processing and Controls and pursuing a master's degree within the next couple years to further deepen my expertise in this area.

Course Comment: This course has further prepared me to work in a professional engineering environment. Additionally, this course has enhanced my ability to communicate with teammates and other stakeholders, plan and strategize effectively, and manage time-sensitive deadlines..

Into the Flow: A Neuro Adaptive System for Creative State

Sponsor: Dr. Leyla Nazhandali **Mentor:** Janice Burr

Team: Mahin Atturu, Jonathan Colon, Keenon Shields

Background

- Stress and anxiety are rising; 43% of U.S. adults report increased anxiety
- Meditation reduces stress, but many struggle to maintain focus
- Lack of feedback and distractions make relaxation difficult
- EEG enables real-time monitoring of brain activity
- Opportunity for adaptive, brain-driven environments

Features

EEG Headset:

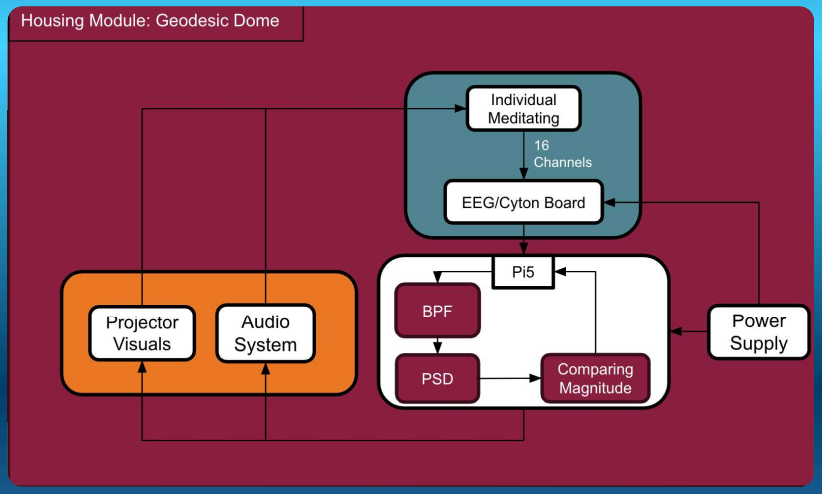
- 16-channel OpenBCI Cyton + Daisy Module for real-time brainwave acquistion
- Wireless streaming via Bluetooth
- Integrated with a Raspberry Pi with the Brainflow API

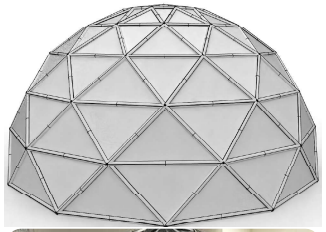
Relaxation Metric:

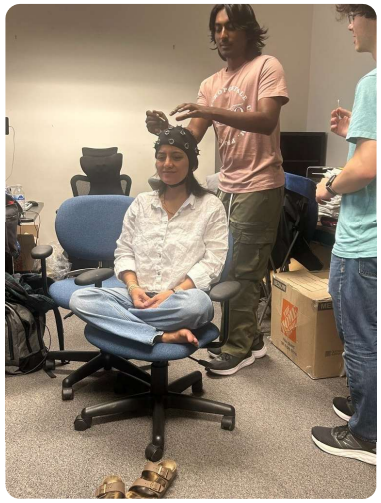
- Log Ratio comparision between Alpha+Theta and Beta bandpowers
- Value between 0 and 1 indicates degree of relaxation

Geodesic Dome and Media Output:

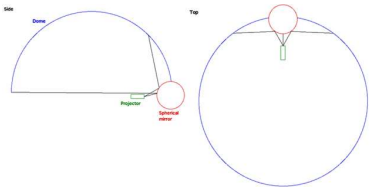
- Assembled a 2V blacked out structure to create an immersive distraction-free environment
- Supports 360° projected visuals
- Relaxation Metric adjusts volume of media in real time.





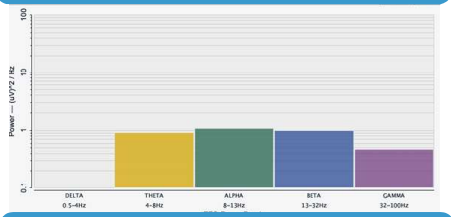


Visual Mapping



- Visuals are projected onto hemispheric mirror and reflected onto interior.
- Images are warped before projection.

Brainwave Band Powers



Conclusion

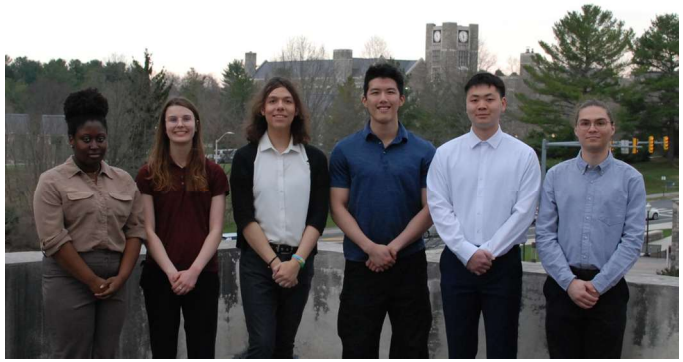
- Developed a relaxation metric using an EEG to classify a user's mental state.
- Developed a Geodesic dome to prevent extraneous distractions
- Developed a feedback system using audio and visuals to enhance meditation.

Acknowledgements

We'd like to thank these individuals

- **Sponsor:** Dr. Nazhandali, VT ECE
- **Researcher:** Paul Bourke, Swinburne University
- **Mentor:** Janice Burr, GE Vernova

Freaky Frequencies: A Programmable Neuro-Optic Flicker System



LEFT to RIGHT: Afia Konadu, Lydia Newhouse, Camila Molinares, Michael Liang, Chris Qiu, Alex Halloran

CHALLENGE

Dr. Leyla Nazhandali's newly-founded TAMINA lab is looking to do research on the neurological effects of strobe light therapy. Our challenge was to develop a prototype for an affordable, programmable, and open-source strobe light device that is suitable for a research lab environment. The device will be applicable for research on brainwave entrainment and anxiety reduction in adolescents.

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VIRGINIA TECH

SME: Leyla Nazhandali

Customer: Leyla Nazhandali

Alexander Halloran — Willow Springs, North Carolina

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I intend to pursue a career focusing on new technology and embedded systems.

Course Comment: This course allowed me to broaden my skill set and apply previously learned ideas to different applications. I enjoyed learning android development as well as the process of integration with the rest of the project.

Camila Molinares — Woodbridge, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I will be pursuing my M.S. in Computer Science on Virtual Reality systems. After my time at VT, I wish to focus my career in biomedical technologies, and pursue my interest in creative technologies and tool development.

Course Comment: Working with a dedicated team on a captivating project for social good has been one my favorite experiences in the ECE department. This course allowed me to experiment and learn about topics outside my comfort zone and previous experience wtih a tangible product to showcase it.

Afia Konadu — Reston, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am looking to focus my career in embedded systems after graduation.

Course Comment: Being able to work collaboratively on a real-world project from start to finish has been the highlight of my experience here at VT. Challenging myself to learn new tools and skills creates a real sense of accomplishment.

Michael Liang — Chantilly, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I intend to continue developing my electrical engineering skills in industry after graduation. I have a job where I will be designing PCBs for radio systems in Germantown, Maryland. I hope to get a master's degree while working in the next few years.

Course Comment: Senior design allowed me to expand my practical work skills and work on a very interesting project. I learned how to design PCBs, work with new circuit components, and coordinate with a team over the course of the year. The class has been a great way to end my undergraduate degree.

Lydia Newhouse — Lexington, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I plan to pursue a career working with embedded and control systems. After graduation I will be working for Eastman as a plant engineer. I also wish to follow my dreams of becoming my own game developer as a hobby.

Course Comment: This course has given me valuable experience working with a team consisting of different fields of expertise. Figuring out how to integrate different parts of a project is a skill that will help me in my career as an engineer my whole life.

Chris Qiu — Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Wireless Communications & Signal Processing

Aspirations: I plan on finding a job after graduation before pursuing a masters.

Course Comment: I enjoyed the process of working with a larger team and designing a system to meet customer needs.

Freaky Frequencies: A Programmable Neuro-Optic Flicker System

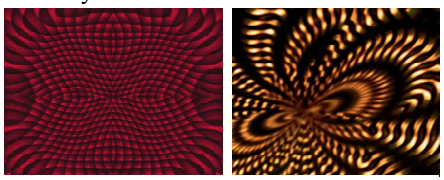
Team: Alex Halloran, Afia Konadu, Michael Liang, Camila Molinares, Lydia Newhouse, Chris Qiu
Customer & SME: Dr. Leyla Nazhandali **Mentors:** Professor Kelley Andrews & Dr. Dan Connors

VIRGINIA TECH

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Background

- Strobe light therapy is an active research area for medical use, or for meditation / relaxation
- Commercial devices exist, but are costly
- Dr. Ali's newly founded TAMiNA Lab looks to research the technology's use in anxiety treatment for adolescents



Above: Images showing possible visual experiences during strobe light therapy.

Problem Statement

- Researchers lack affordable & programmable strobe light devices
- Restricts research development
- Need an effective device at a lower cost, is programmable, and open-source
- Needs to run continuously in lab setting

High Level Requirements

- Accurate control of brightness & frequency of at least 8 lights (min. upper bound of 50 lumens)
- Run for at least 2 hours at a time
- Safe to operate by one person in lab environment

Final Design

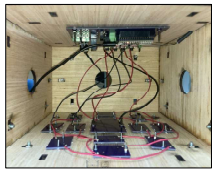
- Our final design consists of two parts, the physical device with the LEDs and an android application to control it
- Both parts include safety features to shut off the device in case of an emergency to protect the user's health

Physical Device

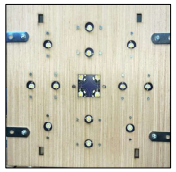
- 16 high-power LEDs in 4 controllable sections
- Uses an ESP32 microcontroller to set the brightness and frequency of each light section
- Connects to the android application with bluetooth
- Error handling functions will send a command to the application indicating an error
- Has a physical switch which will cut off all power to the LEDs in case of an emergency

Android Application

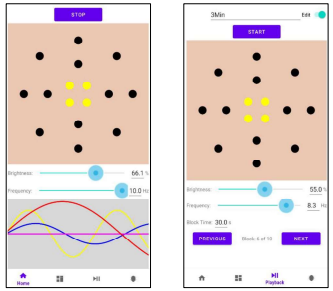
- The application can control the device in real-time with a GUI
- A set of actions at different times can be created, saved, and sent as a session
- Uses a modular design to create the GUI based on the location of LEDs in the physical device
- Has a button to send a command to the device which will turn off all LEDs in case of an emergency



Above: Interior of the housing of the physical device.



Above: Exterior of the physical device showing the LEDs



Left: Real-time mode with visualization. Right: Session-editing mode.

Conclusions

- Our device was able to successfully recreate the experience one has when using similar commercial devices
- Calming and euphoric effects observed by customer when used
- Live demo allows for experimentation for flashing patterns that create better calming experiences
- Pre-recorded sessions allow for researchers and users to replicate experiences

Next Steps

- Minor component adjustments and PCB layout can be updated for next iteration
- "Closing the loop" by incorporating external modules for additional inputs / outputs
- Use in research for the effects of light therapy

Acknowledgements

We would like to thank our customer Dr. Leyla Nazhandali for providing feedback and supporting our project, our mentors Kelley Andrews and Dr. Daniel Connors, and Dr. Joe Adams. We also thank the TAMiNA Lab for its resources and space.

TAMiNA Lab
Tech-Assisted Mindfulness & Neuro-adaptive Atmospheres Laboratory

Low-Cost Neural Network Spoof Detection for Unmanned Aerial Systems

LEFT to RIGHT: Carl Holmberg, Kush Parmar, Isabella Burley, Sachel Jetly, Drew Schineller, Will Field

SME: Ryan Williams

CHALLENGE

NAWCAD has tasked our team with developing a low-cost LiDAR spoof detection system for UAVs. The platform simulates realistic LiDAR data and spoofing techniques within a controlled Unreal Engine 5 environment, streaming sensor data to an onboard edge device for neural network-based detection of malicious environmental manipulation. This approach combines advanced drone simulation with edge AI to deliver a scalable, cost-effective solution that enhances the security and reliability of autonomous systems.

Customers: Andrian Jordan and Israel Jordan

Isabella Burley — Leesburg, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Post-graduation I will be working to provide support in creating secure systems that operate in high-reliability and defense-critical environments. I am particularly interested in advancing cybersecurity and systems engineering solutions that protect mission-critical infrastructure. I am motivated to take on technically challenging roles where I can continue growing as both an engineer and collaborative leader.

Course Comment: It was valuable to relate my professional experience to the concepts covered in this course.

Carl Holmberg — Port Republic, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I will begin working for AMEWAS, a DoD Contractor specializing in modeling and simulation software applications.

Course Comment: This course helped bridge the gap between my academic work and my future career, providing me with invaluable experience through the challenges of collaboration and the lasting impact of our project.

Will Field — Rochester, New York

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: After graduation, I will be working at Boeing as a Mission Systems Engineer. I'm excited to continue building my technical skills while contributing to the defense industry. As part of the ECE UG/G program, I may also pursue a part-time master's degree. Long term, I'm interested in either moving into a corporate/management role or starting my own company within defense.

Course Comment: This course has helped me improve my time management and discipline while working on a very open-ended technical project. For students interested in entrepreneurship after graduation, senior design is a great stepping stone. I currently run a company, and I would have greatly benefited from a course like this before starting my first venture.

Sachel Jetly — San Diego, California

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After graduation, I plan to pursue a career in embedded systems or firmware engineering, focusing on developing low-level software for real-time hardware systems and integrating machine learning into embedded platforms.

Course Comment: Senior Design was a great opportunity to apply the skills I have learned throughout my degree to a real project. It also helped me gain experience working through challenges as a team and managing a long-term engineering project.

Kush Parmar — Seattle, Washington

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Post grad I plan to pursue a career in operating systems and kernel development. I am particularly interested in low level system design, resource management, and the interaction between hardware and software. My long term goal is to contribute to the development of reliable and high assurance operating systems.

Course Comment: It was quite valuable and I strongly recommend any senior to take this class

Drew Schineller — Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Post-graduation, I'll be interning at Google in the summer then will return to Virginia Tech in fall to continue my masters' degree in Computer Engineering. In my career, I plan to pursue a career in machine learning engineering.

Course Comment: This course prepared me for seeing through a long-term engineering project from start to finish and collaborating with external stakeholders to produce a satisfactory product.

Low-Cost Neural Network Spoof Detection for Unmanned Aerial Systems

Team Members: Will Field, Isabella Burley, Kush Parmar, Carl Holmberg, Drew Schineller, Sachel Jetly
Customer: NAWCAD - Mentor: Dr. Janice Burr

Background

LiDAR gives unmanned aircraft detailed 3D views of their surroundings, but these signals can be copied and faked.

- False returns can be injected to create misleading 3D scenes.
- These spoofed signals often look real and may be hard to spot without advanced or machine learning-based tools.

Requirements

- Generate a framework to create and simulate spoofed LiDAR signals
- Detect and analyze spoofed signals
- Log and process sensor input data
- Utilize NN with hardware-based inputs

Impacts

Our **solution** can:

- **Generate** varied LiDAR spoofing data
- Perform modular **low-cost detection**
- **Support** many mission goals.

Data Transfer

To successfully transfer the UE5 generated LiDAR data to the neural network for training, we utilize TCP to transfer files over a local network.

To improve on this technique, a Raspberry Pi was inserted into the network. The Pi acts as a buffer and enables future data manipulation without hindering performance on other subsystems.

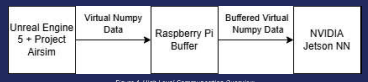


Figure 4. High Level Communication Overview

Project & System Overview

- System delivers virtual data from Unreal Engine to the ML model on the Jetson via TCP
- Raspberry Pi provides data control and manipulation without sacrificing performance on other subsystems

System Steps	
1	UE 5 Data Writing
2,	RPi Buffer
4	Jetson Packet
5	ML Classification
6	Neural Network

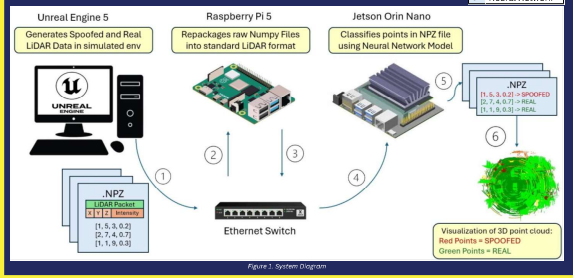


Figure 1. System Diagram

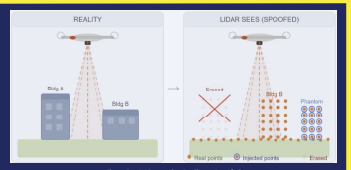


Figure 2. UAV Perception Reality vs Spoofed

- **Virtual LiDAR Ray tracing in Unreal Engine 5:** Cast virtual time-of-flight LiDAR pulses to generate point clouds
- **Detection & processing:** Model segments LiDAR scan into objects, classifies objects as spoofed by its point positions and intensity
- **Spoofing:** Any anomalous object or material injected into physical or virtual LiDAR sensor

Data Set Generation

- Built on **Unreal Engine 5 + Project Air Sim** (open source platform)
- **Realistic UAV physics and control**

Sensor & Environment Simulation

- LiDAR + camera simulation with noise and latency
- Fully customizable environments (terrain, objects, materials)

Versatile Data Generation:

- Generates labeled perception data for ML pipeline
- Acts as a sandbox for creating adversarial scenarios via material & geometric properties

Figure 5. Unreal Engine Drone & Environment Capabilities

Neural Network

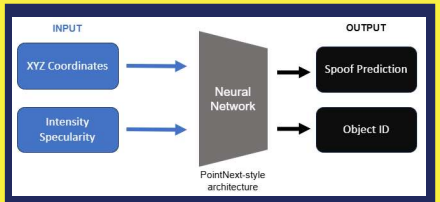


Figure 6. Neural Network Process

Low-latency, edge-based AI improves system resilience without cloud dependency

- Performs **real-time** neural network inference
- **Classifies objects** as spoofed/unspoofed based on material properties (intensity) and position (XYZ coordinates)
- Provides **confidence scores** & system telemetry
- Enables **onboard decision-making** & autonomy
- Model **segments point cloud** into discrete objects

Results

- Model trained on **68,977 LiDAR scans** across **30 distinct scenarios** using supervised learning
- Correctly classified spoofed objects with **99% accuracy**
- **Real-time inference rate** of **100Hz** from input to output deployed on Jetson Orin Nano

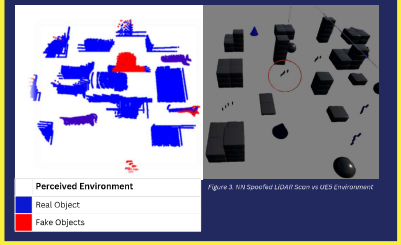


Figure 3. NN Spoofed LiDAR Scan vs UE5 Environment

Next Steps

1. **Define Operational Requirements**
2. **Simulate Real World Signals**
3. **Update NN Detection Maturity**
4. **Real World Integration & Testing**

Move from simulated anomaly detection to a real-time, onboard LiDAR integrity system with validated detection performance and autonomous response capability

Acknowledgement

We would like to thank the following individuals for their support throughout the project:

- **Dr. Janice Burr,** *Team Mentor*
- **Andrian Jordan,** *NAWCAD*
- **Israel Jordan,** *NAWCAD*
- **Dr. Ryan Williams,** *Subject Matter Expert*

Optimus Semi-Autobot

LEFT to RIGHT: Gavin Chiorazzi, Adli Qanadilo, Christian Font, Jackson Childers, Joshua Jones, Daniel Kang

CHALLENGE

Our challenge is to design and develop a semi-autonomous wheeled robot capable of performing simultaneous localization and mapping (SLAM). The robot must be able to receive user-defined points of interest from a hub and autonomously navigate to those locations while dynamically mapping its environment and avoiding obstacles along the way.

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VIRGINIA TECH

Customer: Joe Adams

Jackson Childers — Victoria, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to begin working in Research and Design at UFT (United Flow Technologies) and eventually return to school to complete a Masters or Doctorate program.

Course Comment: Great real world experience while still having fun designing aspect.

Adli Qanadilo — Ashburn, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I am currently studying Computer Engineering with a focus on machine learning, controls, robotics, and autonomy. I plan to pursue a Master's degree in Computer Engineering at Virginia Tech, specializing in machine learning. After graduate school, I aim to work in industry, collaborating with teams to develop innovative solutions in the machine learning and AI space.

Course Comment: I really enjoyed the process of planning and designing a project with a team of aspiring engineers and bringing it to life. It was rewarding to apply the concepts I've learned throughout my ECE studies. I also enjoyed presenting our work. I hope that working in industry will provide a similar experience.

Christian Font — Hampton, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to earn my Master's of Electrical Engineering at Virginia Tech while working as a Field Engineer for Dominion Energy. I also plan to obtain my Professional Engineering license once I have gained sufficient experience. With a strong passion for power generation and transmission, I aim to contribute to the development of the small modular reactors currently under development.

Course Comment: This class was an amazing experience and really taught me a lot about working in a team with capable engineers. I also gained valuable technical and time management skills that will surely benefit me in the future.

Joshua Jones — Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to complete my Master's of Electrical Engineering at Virginia Tech before entering the workforce.

Course Comment: Good exposure to real world team project collaboration.

Daniel Kang — West Haven, Utah

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to pursue and complete my Master's of Science here at Virginia Tech, where I can deepen my expertise in robotics and embedded systems design while also exploring machine learning. I am motivated to work in a field where I can contribute to the development of innovative technologies and have a meaningful impact on the industry. Looking ahead, I am excited about the potential integration of robotics and quantum technologies, and I hope to be a part of shaping their future applications.

Course Comment: Excellent individual and collaborative learning experience.

Gavin Chiorazzi — Columbia, South Carolina

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I aspire to apply what I've learned from this course and from my major, specifically Micro/Nano Systems, to applications in industry.

Course Comment: This course is a great preparation for real world experience and provides a great introduction for team environments in the industry.

Optimus Semi-Autobot

Team Members: Christian Font, Gavin Chiorazzi, Joshua Jones, Daniel Kang, Jackson Childers, and Adli Qanadilo

SME / Customer: Dr. Adams, VT

Mentor: Dr. Shelly Stover

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Motivation

- Semi-autonomous navigation is critical for applications in exploration, surveillance, and delivery.
- Manual robot control limits operational range and requires constant human attention.
- Real-time mapping enables robots to operate in unknown environments safely.

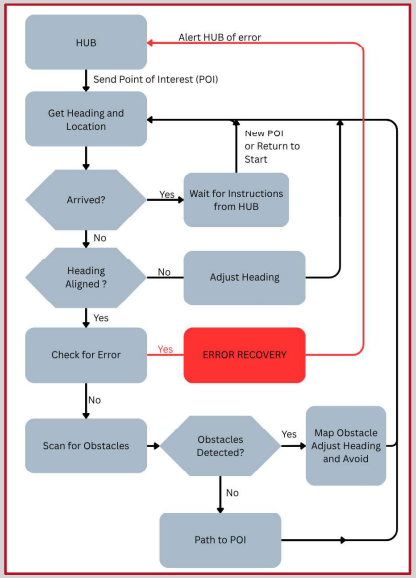
Objectives

- Autonomously navigate from Homebase to Points of Interest.
- Achieve 0.5-meter arrival tolerance using sensor fusion.
- Detect and avoid obstacles in real-time.
- Wirelessly communicate mapping data and status updates to Hub.

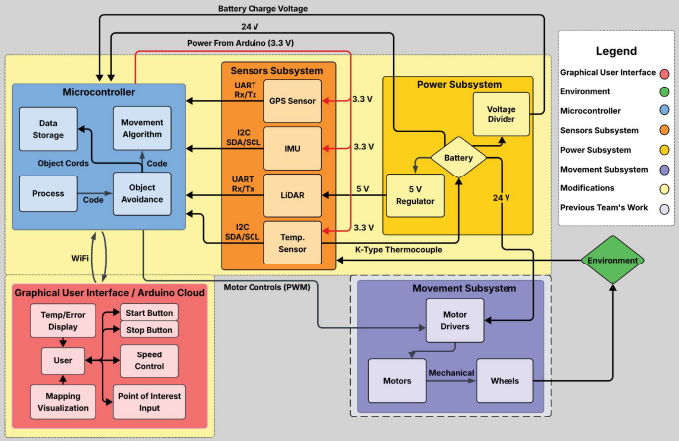
Features

- Rotational LiDAR obstacle detection.
- Wireless communication of Points of Interest (x, y) via Wi-Fi from Hub.
- Sensor fusion of IMU and GPS data through Kalman Filter.
- Object avoidance pathing via Follow the Gap algorithm.
- Communication of robot location even with GPS loss via Dead Reckoning.
- Reliable heading direction through use of IMU magnetometer compass.
- Live updates of 2D occupancy grid mapping.

Operation Flow Chart

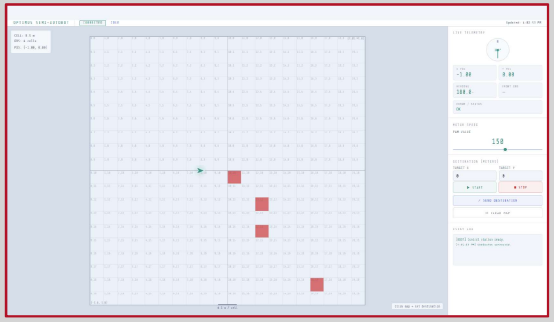


Functional Design



Final Design

Hub Interface



- Red blocks indicate areas with detected obstacles.
- Green arrow indicates the robot position and direction.

Analysis and Conclusion

The following conclusions were made from our experiments.

- From testing we determined that the 24V battery is excess for our operation and should be replaced with a 12V battery with appropriate amperage.
- Component placement has led to magnetic interference from the motors affecting the compass of our IMU sensor, resulting in slight delays during sensing.
- The rotating LiDAR added additional computational complexity for obstacle detection. Static LiDAR or a TOF sensor may have been more effective.
- The Kalman Filter for the IMU and GPS provides a positional accuracy well within our requirements when outdoors.
- Motors and motor drivers performed exceptionally well. Speed limiting was necessary as the maximum speed of the motors was well beyond what the sensors could handle.

Future Plans

- Implement a more efficient object detection method.
- Implement Static mapping that will let robot to store maps in system.
- Implement embedded architecture.
- Implement trip scheduling capabilities to enable automated operation of the robot.
- Add built-in lighting for obstacle illumination.
- Add a suspension system to provide a smoother ride over rough terrain.

Acknowledgements

We would like to add a special thanks to the following people and groups for their contributions to our project:

- VT CRO
- Dr. Joe Adams
- Kim Medley
- Dr. Shelly Stover
- Previous Project Team
- Friends and Family

*This work is not intended to infringe upon or associate with any trademarks which are the property of their respective owners.

Rendezvous, Proximity Operations, and Docking (RPOD): Rover Bot

LEFT to RIGHT: Umesh Andaluri, William van Deusen, Benjamin Hart, Angelina Joynes, Alyssa Copiaco

CHALLENGE

Design and build a mission-capable rover that detects low battery conditions and autonomously locates, approaches, and docks with a mobile charging robot to recharge. This project addresses the valuable mission time lost with manual recharging and increases efficiency for remote rover missions in hazardous environments. By leveraging vision-based navigation, it provides a reusable framework for future space missions that require autonomous docking and in-field recharging.

SCOUT

Customer: John Beutter

Umesh Andaluri — Syosset, New York

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: After graduating, I will work as a hardware engineer in Saint Louis and get my masters, and I want to learn more about power electronics, controls, and analog circuit design.

Course Comment: This course taught me how to work efficiently in a team, plan deadlines, time management, collaborate, and work on my technical writing skills for future work, in a different way that my other technical courses haven't.

Alyssa Copiaco — Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Upon graduation, I will be working as an engineer at Hill Air Force Base in Ogden, Utah. I am especially interested in robotics and embedded systems where I can contribute to impactful, mission-driven technology. Long-term, I hope to eventually step into leadership roles where I can mentor others and create spaces where people feel supported to grow and succeed.

Course Comment: Major Design Experience allowed me to step back and look at the bigger picture of an engineering problem and not just the nitty-gritty technical details which I really enjoyed. I like understanding how the work we do as a team connects to a larger purpose and contributes to helping the world in some way.

Benjamin Hart — Pearisburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I will be working as a software developer as well as working on my own startup, developing web applications and software solutions for various industries.

Course Comment: ECE Major Design Experience prepared me for the work force in ways that other courses haven't. I gained experience working with a team and exercising engineering design techniques without a specific rubric.

Angelina Joynes — Onley, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My goal is to work in the space industry, helping design and innovate technologies that push the boundaries of what we can achieve. I hope to travel the world and contribute to projects that I am truly proud of while continuing to grow professionally.

Course Comment: This course showed me how challenging yet rewarding teamwork can be. Through collaborating with others, I gained valuable hands-on experience and developed practical skills that I can carry forward into my future career.

William van Deusen — Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I hope to pursue a career as an FPGA design or embedded systems engineer, ideally working internationally and gaining experience outside of my hometown.

Course Comment: This project taught me that starting work early and working on it consistently makes large projects much easier to manage. Spending time understanding how the different parts of the project fit together, instead of focusing only on my own section, helped me contribute more effectively to the overall design.

Rendezvous, Proximity Operations, and Docking (RPOD): Rover Bot

VIRGINIA TECH

SCOUT

Sponsor: Scout Space **Mentor:** Dr. Joe Adams
Team: Benjamin Hart, Angelina Joynes, William van Deusen, Alyssa Copiaco, Umesh Andaluri

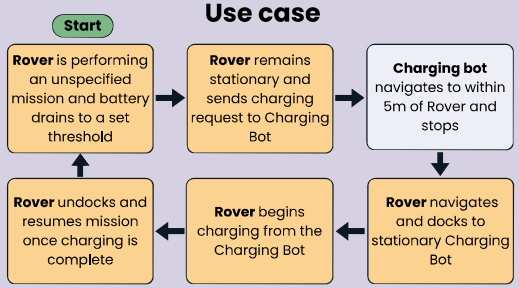
Background

Issue: Space rovers on long-duration missions lose valuable time traveling to fixed charging stations and often operate in unpredictable environments where human intervention is limited, unsafe, or unfeasible

Solution: A two-team ground-based simulation of reliable and precise autonomous docking used for mid-mission charging

Impact: This docking approach enables autonomous missions to operate longer, safer, and more efficiently

Use case



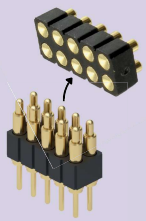
Achieved Requirements

- Rover can dock to Charging Bot from a 5m range in a 2 minute timeframe with ±10mm precision
- Fully autonomous
- Works in various light enviroments (300 - 1000 lux)
- Engineering principles used are scalable to orbital and space environments
- Uses primarily visual navigation with no terrain-based cues

Charging

Battery Managment System (BMS)

- Uses FETs to cut off and protect the battery in instances of overcurrent, undervoltage, or general faults
- Passively balances the 4 LiPo battery cells during charge, discharge, and rest
- Allows for DC charging of a multi cell battery using programmable and regulated charging specifications
- Monitors various battery values such as voltage, current, and temperature

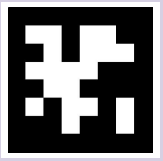


Charging Connection: Pogo Pins

Vision-Based Closed-Loop Docking

AprilTag Detection:

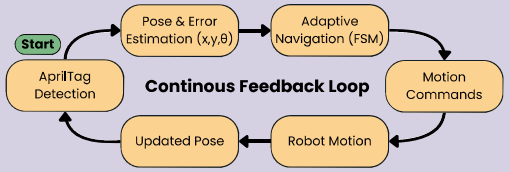
- AprilTag: A fiducial marker used as a reliable visual reference
- Unique ID enables unambiguous target identification
- Known tag size enables pose estimation from image



Relative Pose Estimation:

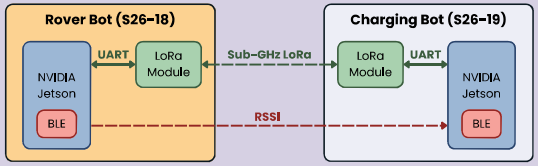
- Computes:
  - Distance (forward error)
  - Lateral offset (distance from approach path)
  - Yaw error (angular misalignment)
- Converts vision into actionable spatial measurements

Closed-Loop Control & Docking:



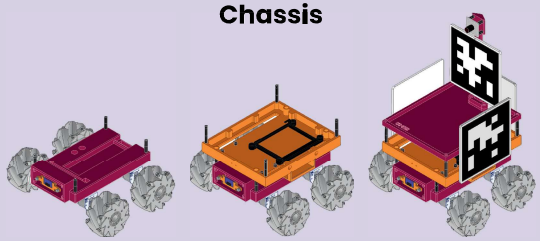
- Continuous feedback loop converts pose error into motion commands
- Robot trajectory is continuously corrected in real time
- Adaptive state machine based on live error metrics
  - (Search → Align → Strafe → Approach → Dock)
- Achieves precision docking using only onboard vision systems

Communication



- The Jetson NVIDIA onboard low energy Bluetooth module (BLE) broadcasts a received signal strength indicator (RSSI), enabling the charging bot to estimate its proximity to the rover
- The LoRa module enables reliable long-range sub-GHz communication for the charging request and state coordination
- Communication is integrated into the main control loop, synchronizing behavior between Rover and Charging Robot

Chassis



Bottom Layer **Middle Layer** **Full Chassis**

- Heat-set inserts were used to prevent thread wear and loosening under vibration, while enabling repeatable assembly
- Mecanum wheels provide omnidirectional motion, allowing precise positioning and alignment during docking

Conclusion

- Developed a fully autonomous rover capable of multi-stage docking and undocking with a secondary robot
- Combined vision-based navigation, regulated power transfer, and inter-robot communication
- Achieved precise alignment and reliable electrical connection during docking
- Demonstrated the feasibility of fully autonomous docking systems using vision based navigation
- Established a scalable framework for future space missions

Future Work

- Develop a real-time GUI dashboard to display battery state of charge and current docking stage
- Incorporate additional sensors such as wheel encoders and light sensors to improve motion accuracy and enable adaptive control in varying conditions
- Expand testing to include diverse terrain and surface conditions
- Extend the system to support mission-specific operations

Acknowledgements

We would like to give special thanks to John Beutter, Kevin Hopkins, and Jared Moreno from Scout Space for sponsoring us and providing us with a fun and meaningful project, as well as the resources to support it. We would also like to thank our mentor, Dr. Joe Adams, for always being there to guide and support us. Additionally, thank you to Austin Jobin for providing us with PCB design support and to Kim Medley for ensuring our ordered parts arrived safe and sound.

Rendezvous, Proximity Operations, and Docking (RPOD): Charging Bot

Track 2 Winner

LEFT to RIGHT: Johnny Crain, Scott Milloy, Katherine Shvodian, Hannah Lexer, Shaan Gupte, Ryan McDonnell

CHALLENGE

Our team is developing an autonomous rover that can locate and charge another rover to mitigate power limitations in space missions. The system operates without terrain-based cues, using LoRa communication and onboard obstacle detection to enable reliable navigation and coordination.

SCOUT

Customer: John Beutter

Johnny Crain — Newport News, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: In my professional career I aspire to contribute to innovative solutions that solve problems that have a real impact on the world outside of tech. I aspire to work in either robotics or quantum computing to create tools that could support the average person through assistance or medical care.

Course Comment: This course has been very engaging by providing a challenging hands on task that yields true satisfaction because of its length and the commitment to the course. This also gives a greater understanding and appreciation for teamwork and communication.

Katherine Shvodian — McLean, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: No matter where I end up in the electrical engineering field, I want my career to be fulfilling and something I can be proud of. I hope to apply what I've learned here at Virginia Tech while continuing to grow, develop my skills, and learn from all of the people I meet along the way.

Course Comment: I am very grateful for the opportunity to work with a group of my peers to solve a real-world engineering problem. Being able to work through the entire engineering process while receiving support and guidance from my professors and other experts is something that is truly unique about this class. I appreciate the experience and will carry the skills I have learned with me into my future career.

Hannah Lexer — North Wales, Pennsylvania

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After completing my degree, I will begin my career as a Network Performance Engineer with Verizon in Nashville. I aspire to continuously expand my expertise as networking, automation, and robotics evolve, positioning myself at the forefront of emerging technologies.

Course Comment: I thoroughly enjoyed this course because it closely mirrored the real-world experience of working as an engineer balancing client communication with independent project developed. It also allowed me to bring the skills that I have developed throughout my degree and apply them to a tangible product, reinforcing how my academic preparation translates directly to industry practice.

Shaan Gupte — Ho-Ho-Kus, New Jersey

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After graduation, I plan to continue my studies at Virginia Tech as a master's student. Then, I plan to pursue a career in industrial automation. Using my skills in robotics and controls, I aspire to work on systems in lights-out manufacturing.

Course Comment: This course has been an enjoyable experience so far, allowing me to apply my technical skills to hands-on project while working within a professional environment. It has been rewarding to find solutions to some of the problems that we've encountered this year.

Scott Milloy — Maple Shade, New Jersey

Bachelor of Science in Computer Engineering
Computer Engineering

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I look forward to finding a job that is engaging and stable, regardless of what specific field I ultimately pursue. I enjoy hands-on engineering work and hope to continue developing my technical and problem solving skills. In the near future, I am excited to contribute to meaningful projects and grow within a professional engineering environment.

Course Comment: This course is one of the best ways to prepare for the industry. Students gain valuable work experience with top-of-the-line equipment and collaborate directly with professional engineers. The projects are challenging, rewarding, and genuinely exciting to build. Working alongside peers with similar interests also helps form a strong network of newly graduated engineers.

Ryan McDonnell — Goochland, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspirations are to apply the knowledge and skills I've learned to the realms of hardware desing, computer architecture, and embedded systems while continuing to be a lifelong learner.

Course Comment: This course has proven to be a valuable not only for improving technical skills, but also soft skills such as teamwork, communication, and project organization.

S26-19: Rendezvous, Proximity Operations, and Docking (RPOD): Charging Bot

Johnny Crain, Shaan Gupte, Hannah Lexer, Ryan McDonnell,
Scott Milloy, and Katherine Shvodian

Mentor: Dr. Joe Adams

Sponsor: Scout Space

Background

Problem:
- Vehicles in space have a limited amount of power
- Recharging is time consuming and expensive

Solution:
- Create an autonomous multi-robot charging system.
- This will extend the lifetime of rovers and lower expenses.

Goals

Develop an autonomous system capable of recharging rover units

- Detect and navigate to a target rover
- Execute a complete docking and charging sequence in under 2 minutes
- Undock and return to the mothership after charging
- Operate reliably in varied lighting and environmental conditions

Technical Challenges

Challenge	Solution
Use no terrain-based markers	AprilTags with camera-based location
Docking precision of +- 5mm	Electromagnet system to correct misalignments
Suitable for space applications	LoRa as a standalone communication protocol
Low visibility operating conditions	Time-of-Flight sensing for obstacle detection

Key Components

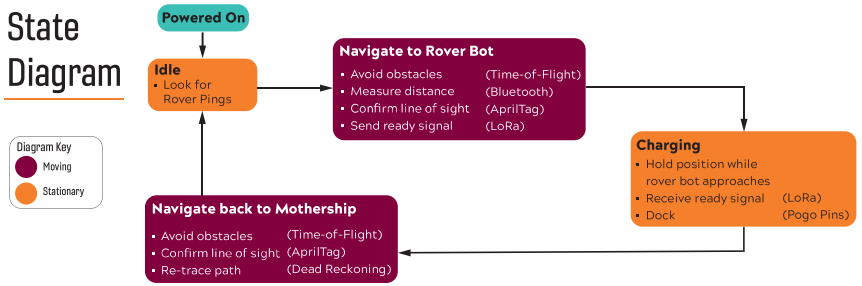
Pogo Pins
- Electrical charging interface
- Enables reliable contact during docking

Time-of-Flight
Pololu VL53L0X
- LIDAR Distance Sensor
- Detects obstacles

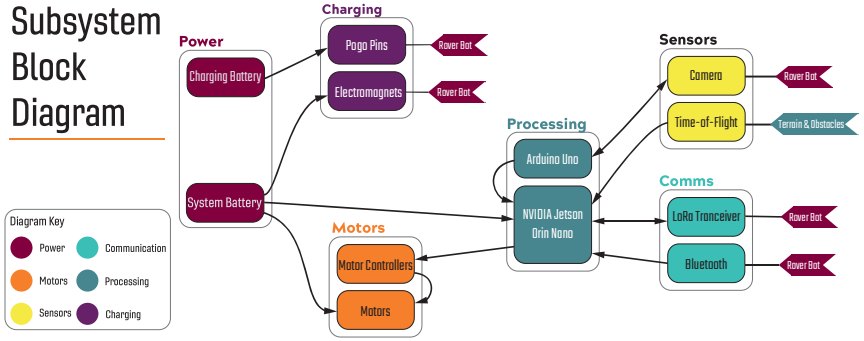
Adafruit 5V Electromagnet
- Passive alignment during docking
- Maintains physical connection while charging

Camera and AprilTag
- Visual localization of target rover.
- Enables pose estimation for docking.

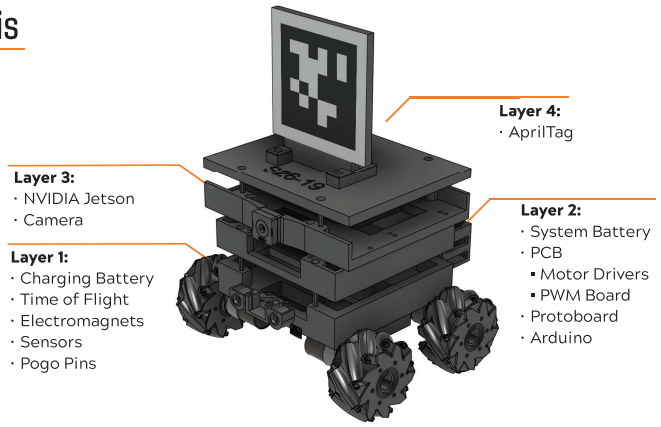
State Diagram

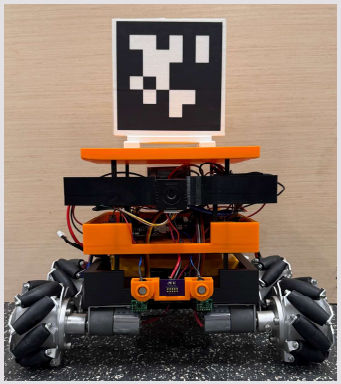


Subsystem Block Diagram



Chassis





Conclusion

- Demonstrated an autonomous charging rover
- Integrated LoRa, Bluetooth, and Time-of-Flight sensing
- Successfully validated navigation and docking systems

Future Work

- Develop a standardized LoRa communication protocol
- Extend system capability to support multiple rovers
- Incorporate dynamic obstacle detection and tracking
- Add fault detection and recovery mechanisms

Acknowledgements

Many thanks to our mentor, Dr. Adams for his guidance and support. We also appreciate Jared, John, and Kevin from Scout Space for providing the opportunity to design, prototype, and develop a functional system aligned with their mission.

Smart Waste Management

LEFT to RIGHT: Marvin Okotie, Callie Vinzant, Trisheka Panikker, Sheona Jerin, Charan Sama

CHALLENGE

Our project develops a smart waste management system that uses sensor data to monitor dumpster fill levels in real time and improve waste collection efficiency. The system generates optimized collection routes to reduce fuel consumption, operational costs, and environmental impact. It is designed to integrate with existing infrastructure while remaining scalable for deployment across residential and campus environments.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Customer: Christiana Chamon Garcia

Sheona Jerin — Chantilly, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to grow as a software engineer by building scalable systems and contributing to impactful technology that solves real-world problems.

Course Comment: This course has taught me a lot about working effectively with a team. I also gained valuable experience collaborating with a customer and considering stakeholder needs throughout the design process while turning a design idea into a fully implemented solution.

Marvin Okotie — Lagos, Nigeria

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to build embedded and real-time systems that interact directly with the physical world to improve how people live and work.

Course Comment: This course reinforced the importance of structured planning and iterative design in engineering projects. It also provided valuable experience working in a team environment, coordinating responsibilities, and integrating individual contributions into a cohesive system

Trisheka Panikker — Dubai, United Arab Emerites

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to build AI-powered tools that reach the people and places most technology leaves behind.

Course Comment: This course has given me experience to work in industry as well as collaborate with a multidisciplinary team for achieving a target with common goals.

Charan Sama — Richmond, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: In the future, I plan to work as a software engineer where I can build and use reliable systems that integrate AI. I want to continue improving my technical skills while working on projects that solve real-world problems.

Course Comment: This course has made me learn how to work through a design process while developing our Smart Waste System project. Working with a team helped me improve communication and gave me experience integrating and planning a real-world system.

Callie Vinzant — Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: In my career, I plan to continue building my skills in power systems engineering and support the growth of sustainable energy. I also hope to obtain my PE license to advance in my career professionally.

Course Comment: This course taught me a lot about communicating with customers, colleagues, and mentors. I learned how to synthesize information into digestible pieces that are easier to understand, and what information is relevant to communicate.

Smart Waste Management

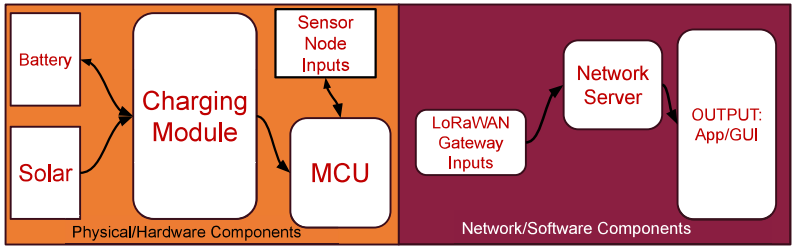
Sheona Jerin, Marvin Okotie, Trisheka Panikker, Charan Sama, Callie Vinzant
Mentor: Dr. Joe Adams Customer: Dr. Christiana Garcia

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

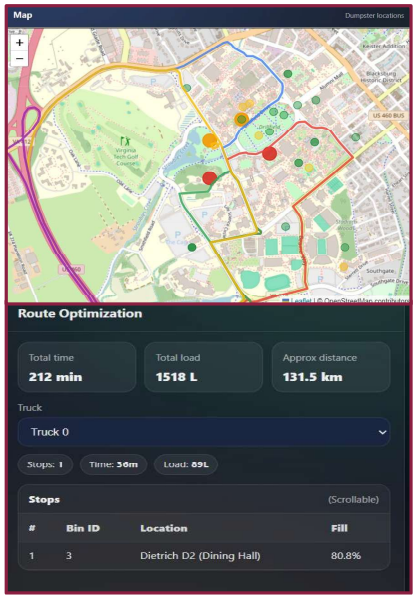
Problem Statement

- Inefficient and redundant waste collection routes increase fuel consumption and operational costs.
- Overflowing bins lead to pollution, odors, and pest issues, impacting public health.
- Existing systems lack real-time monitoring, placing burden on workers and residents.
- Continuous waste generation requires a smarter, data-driven collection approach.

Top Level Diagram



GUI



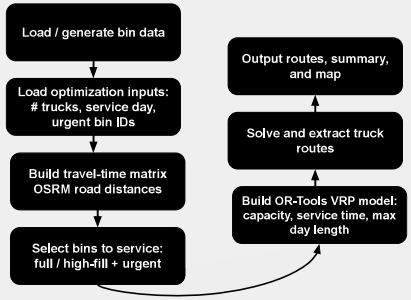
Requirements and Specifications

- Real-time fill-level sensing using embedded sensors
- Reliable long-range communication (LoRaWAN)
- Cloud-based data storage and processing
- Predictive fill-level modeling
- Route optimization using real-world constraints
- User-friendly dashboard for monitoring and alerts
- Fill-level accuracy ≥ 95%
- Communication range ≥ 300–500 m
- Battery life ≥ 5 days (no solar), extended with solar
- Dashboard latency ≤ 1 hour (target near real-time)
- System cost ≤ $100–$200 per node
- Operating temperature: −10°C to 65°C

Power System

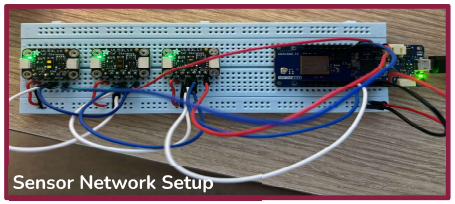
- Provide reliable, low-power operation for sensor nodes
- Solar panel + Li-ion battery backup (off-grid operation)
- TP4056 charging module for power management
- Regulated 3.3–5V output to MCU and sensors
- Low duty-cycle design to extend battery life

Route Optimization



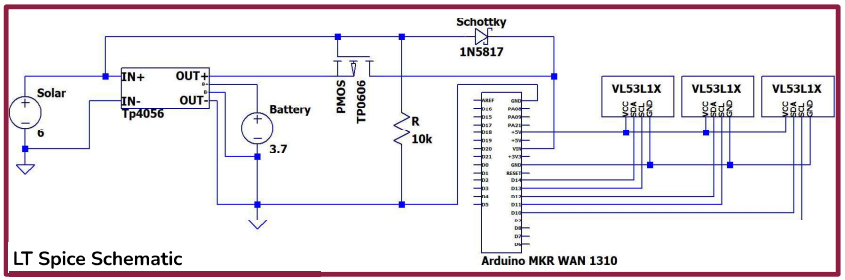
Sensor Network

- Collect and transmit real-time waste bin data
- VL53L1X ToF sensor for accurate fill-level detection
- Arduino MKR WAN 1310 for data processing
- LoRaWAN communication for long-range, low-power transmission
- Cloud integration via The Things Network (TTN)



Challenges

- Sensor accuracy affected by trash type and reflectivity - clear line of sight required
- Power constraints in low-sunlight environments
- Must maintain long-term operation with minimal maintenance
- LoRaWAN connectivity limitations across campus
- Scaling optimization algorithm with large bin datasets
- Integrating real-time data with routing system
- Environmental exposure (water, impact, debris) affecting hardware



Future Work

- Deploy system across entire Virginia Tech campus
- Improve prediction models using historical data + ML
- Integrate real-time traffic data into routing
- Enhance hardware durability (weatherproofing, enclosure)
- Mobile app for drivers with live navigation
- Expand to smart city-scale deployments

Acknowledgements

We would like to thank our mentor Dr. Adams, our sponsor Dr. Garcia, and Meridian for their assistance and guidance throughout the project. We would not have been able to succeed without their help.

Low SWaP Imaging System for Wildfire Detection

LEFT to RIGHT: Timothy Mills, Marliana Marraccini, Mohja Fifil, Alexis Jerde, Alexander Lacaden

SME: Todd Veach

CHALLENGE

Design and develop a low-size, weight, and power (SWaP) imaging system for the Southwest Research Institute to support its space-based wildfire observation mission. The approach is to implement a compact, versatile, and low-noise control system for a CMOS detector using an FPGA for data processing and transfer.

SOUTHWEST RESEARCH INSTITUTE

Customer: Todd Veach

Mohja Filfil New Kent, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: After graduation, I plan to work as an engineer focused on integrated circuits, FPGAs, and chips.

Course Comment: This project has definitely allowed me to see how FPGAs are worked with a project rather than an assignment, and it has been super enjoyable to work with a team that has many different skills and are excited to bring them all together.

Alexis Jerde Bristow, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: After graduation I am pursuing a master's in biomedical engineering. I aspire to become an R&D engineer within a medical imaging, devices, or diagnostics space where I can directly address patient needs.

Course Comment: I have enjoyed the opportunity to challenge myself with this project with a very hardworking and diversely-talented team.

Alexander Lacaden Falls Church, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: After graduation I will pursue a part-time master's in electrical engineering while working, and I aim to work in environment focused on radio wave systems or photonics.

Course Comment: This course has provided unique technical skills and hands-on experience that no other course has taught me. One of the most important experiences have been collaborating with a talented team.

Marliana Marraccini Waterford, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After graduation I plan to build a career in sales engineering

Course Comment: This course has been an engaging and challenging experience, and I think it has been a meaningful way to end my undergraduate career!

Timothy Mills Manassas, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: After graduation, I hope to get to work in the fields of Embedded System Design, Electronics, or Analog/Digital Communications.

Course Comment: I have really enjoyed getting to experience the design process of a large scale project, especially in an interdisciplinary team.

Low SWaP Imaging System for Space-Based Wildfire Detection

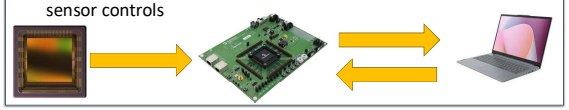
Team Members: Marliana Marraccini, Alexis Jerde, Mohja Filfil, Timothy Mills, Alexander Lacaden
Customer: Southwest Research Institute (SwRI) **SME:** Dr. Todd Veach **Mentor:** Dr. Shelley Stover

Motivation

Wildfires are growing in scale, and existing orbital assets are too large, expensive, and slow to re-task. Early detection from space enables faster ground response. A low-cost, low-power imaging system could expand coverage.

Objectives

- Capture a 512×512 ROI at 22.5 fps using the CMV4000 CMOS sensor
- Process and compress pixel at ProASIC3 FPGA
- Stream over 100BASE-TX Ethernet
- Display the feed on a Python/PyQt ground station GUI with sensor controls



Theory of Operations

FPGA Pipeline

- CMV4000 outputs raw pixel data over LVDS
- ProASIC3 receives the data and applies a 512×512 ROI
- 10-bit pixels are packed into a data stream
- Each frame is split into 256 packets
- Every packet includes a 16-byte application header

Ground Station GUI

- Python/PyQt app receives UDP packets
- Parses the 16-byte header
- Reassembles packets
- Unpacks the 10-bit pixel data

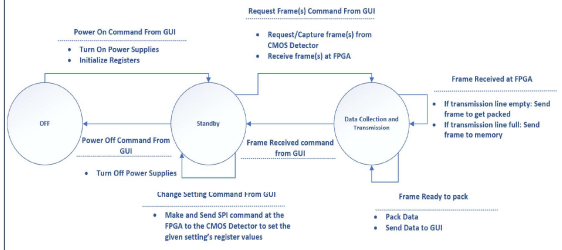


Fig 1. State Diagram

System Design

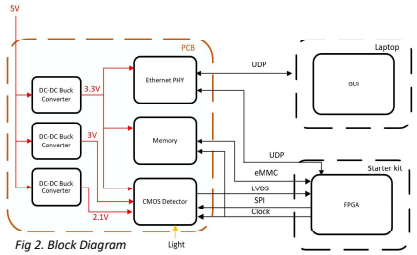


Fig 2. Block Diagram

- Custom 4-layer PCB designed for system power and interfacing
- Provides regulated power to the CMOS detector, Ethernet PHY, and memory
- Supports LVDS, Ethernet SPI, and clock connections to the FPGA
- Creates a hardware platform for image capture, buffering, and data transfer

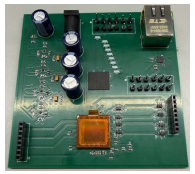


Fig 3. Fully soldered PCB

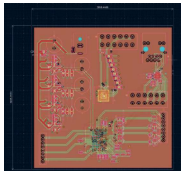


Fig 4. KiCAD Layout

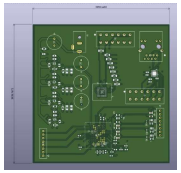


Fig 5. 3D model

Test Results

- Initial PCB tests show correct operation of power distribution and separate devices
- Verilog testbenches for pre-synthesized designs

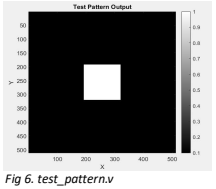


Fig 6. test_pattern.v

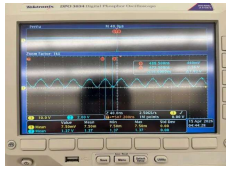


Fig 7. Internal clock of Ethernet PHY

Software Verification

The ground station software pipeline was fully developed and verified in simulation prior to hardware integration. A packet injector script mimics the FPGA's exact output format.

Analysis and Conclusion

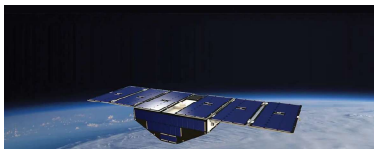
- Bandwidth analysis confirms 512x512 at 22.5 fps is achievable over 100BASE-TX Ethernet, validating the ROI and 10-bit packing strategy
- The full software pipeline is complete and verified
- Live GUI display is confirmed in simulation
- Custom 16B application header enables drop-safe frame reassembly
- The system demonstrates that a complete live-streaming spaceborne imaging pipeline is achievable within a Low-SWaP, single-PCB form factor

Lessons Learned

- Building schedule margin for communication delays and PCB fabrication timelines improves execution
- Using dedicated power planes for buck converters helps reduce parasitic inductance and improve power integrity
- Maximizing reflow soldering improves assembly consistency, efficiency, and solder joint quality
- Reaching out to SMEs early helps resolve subsystem challenges more effectively
- Including LEDs and switches for the overall system would have facilitated PCB troubleshooting

Future Plans

- Replace commercial grade components with radiation-tolerant equivalents for flight qualification
- Implement on-FPGA wildfire detection algorithm to reduce dependency on ground station processing
- Upgrade to Gigabit Ethernet to support full 2048×2048 sensor resolution at higher frame rates

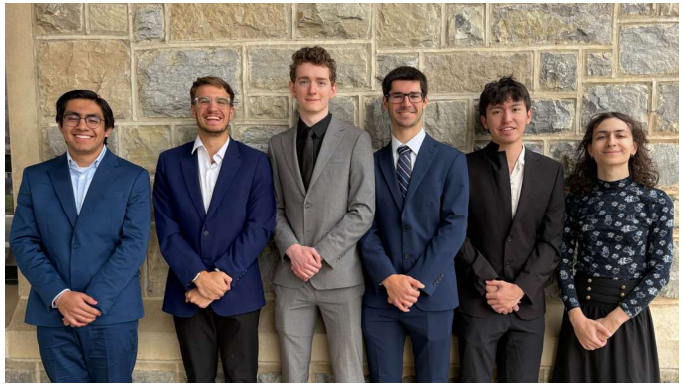


Acknowledgements

We would like to thank the following people for their continued support:

- Dr. Todd Veach (customer/SME)
- Dr. Shelley Stover (mentor)
- Dr. Arthur Ball
- Professor Jason Thweatt
- Dr. John Stone (SwRI)

Real-Time Digital Event Decoder and Visualization Interface for MCP Detectors



LEFT to RIGHT: Diego Velazquez Correa, Zack Kreitzer, Connor Balint, Anthony Marcic, Tyler Hayworth, Maya Moss

SME: Camden Ertley

CHALLENGE

Our challenge is to develop a real-time digital readout and visualization system for Microchannel Plate (MCP) detectors with cross delay-line (XDL) anodes. The system includes an FPGA-based event decoder that intakes and processes digitized XDL waveforms to extract the position, timing, and magnitude of events. The event decoder uses a bidirectional data link to interface with a host computer running our custom GUI for data visualization and user control.

SOUTHWEST RESEARCH INSTITUTE

Customer: Camden Ertley

Connor Balint — Haymarket, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I hope to continue learning and developing as an engineer. I plan to pursue graduate studies, after which I hope to begin my professional career. In the long term, I would like to build a career where I have the opportunity to take on meaningful challenges and make a positive impact.

Course Comment: This course provided a valuable opportunity for me to apply what I have learned throughout my studies to a practical project. Working on this project helped me to improve my teamwork, problem-solving, and communication skills as well as my technical abilities. This course was a meaningful experience, both in terms of the project's impact and the skills it helped me develop.

Tyler Hayworth — Ashburn, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: My goal is to get my masters in ECE and continue to learn and grow challenging myself in all aspects of life. I hope to work on projects that have major positive contributions to new technological developments.

Course Comment: This course gave me experience not only in developing skills in HDL and GUI design, but also taught me how to work with a team and navigate the design process in a real collaborative environment.

Zachary Kreitzer — Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to pursue excellence in the workforce starting as a software engineer and build upon my skills to become a vital technical resource on high stakes projects.

Course Comment: In this course, I experienced a shortened, industry-like experience and learned to prep, build, iterate, and execute on a plan to solve a complex, open-ended engineering problem.

Anthony Marcic — Pasadena, Maryland

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: My aspirations are to receive a Master's degree and do well in my career.

Course Comment: This course is challenging, but it's an excellent opportunity and experience.

Maya Moss — Richmond, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal after graduating is to pursue a career in computer engineering and improve upon the skills I have learned in college.

Course Comment: This course gave me experience that no other course could: working with a proper customer. Courses may try to simulate it but nothing can give you as good experience as the real thing.

Diego Velazquez Correa — Ashburn, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: After graduation, I aspire to be a telecommunications/DSP engineer working on interesting/meaningful work utilizing and improving upon the skills I gained during my undergrad. In the future, I also hope to return to school and obtain my master's in ECE.

Course Comment: This course has given me the opportunity to challenge myself and put all the skills I've learned to the test. It has also allowed me to gain valuable experience working as part of a team tasked with creating a product to meet customer requirements.

Real-Time Digital Event Decoder and Visualization Interface for MCP Detectors

Team Members: Connor Balint, Tyler Hayworth, Zack Kreitzer, Anthony Marcic, Maya Moss, Diego Velazquez Correa
Customer & SME: Dr. Camden Ertley, SwRI **Mentor:** Prof. Shelly Stover

Motivation

Microchannel plate (MCP) detectors are a type of imaging detector widely used in space instrumentation and scientific imaging. When an incoming photon or particle strikes the detector, the MCP generates and amplifies a measurable cascade of electrons. In detectors with a cross delay line (XDL) anode, this electron cascade is collected on two orthogonal delay lines. Event information such as x-y position, magnitude, and timing can be determined from measuring the signals at both ends of each delay line.

Current analog solutions to decode event position, timing, and magnitude are constrained by bulk, limited resolution, and power consumption. This motivates us to create a digital solution with improved size, resolution, and power efficiency.

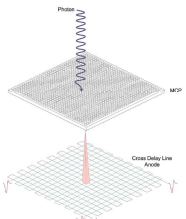


Fig. 1. Visual of MCP Detector

Objectives

- Develop and simulate a digital implementation for constant fraction discriminator (CFD), charge integration, position calculation, and timing on a ProASIC3 A3 eval board that accepts 12-bit ADC values from a 4-channel input.
- Output processed event data from the FPGA to a host computer via UART bridge using a defined packet structure.
- Develop a cross-platform GUI to display live event data, facilitate user interaction, and output event data as HDF5 files or FITS images.
- Validate system performance using simulated artificial data.
- Deliver:
  - Verilog modules with simulated testbenches.
  - Cross-platform GUI with standard/test modes.

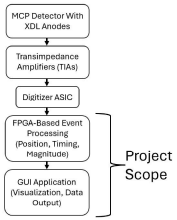


Fig. 2. Diagram of Project Scope

Algorithm Theory

Constant Fraction Discrimination

- Threshold-based pulse detection suffers from time walk due to varying rise slopes.
- CFD triggers at a constant fraction of the pulse height.
- CFD uses a bipolar pulse produced from summing a delayed signal and an attenuated, inverted copy of the original pulse.
- The bipolar pulse zero-crossing marks the arrival time.

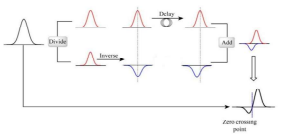


Fig. 3. CFD Algorithm Visualization

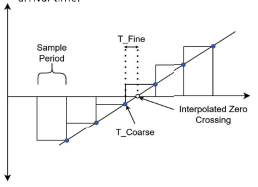


Fig. 4. Linear Interpolation

- Basic digital CFDs lose timing accuracy when zero-crossing falls between samples.
- Linear interpolation is used to estimate the zero-crossing.
- A fractional offset (T_Fine) is computed using the samples before and after the crossing.
- T_Fine represents the fraction of the sampling period where the signal crosses zero.
- Adding T_Fine to the coarse sample index yields a more accurate estimate of the arrival time.

- Noise can cause samples to fluctuate around zero creating false zero crossings, meaning the first detected zero crossing may not represent the true arrival time.
- Requiring a certain number of consecutive negative samples before a zero-crossing is accepted helps filter out noise-induced crossings and improves timing reliability.

Position Calculation

- CFD is used to extract the pulse arrival timings from each of the four XDL anode channels.
- Position is determined by using the time difference between pulses at each end of the delay line.
- Each time difference is multiplied by half the corresponding propagation speed to obtain the reconstructed x and y position of the original event.

Top-Level Design

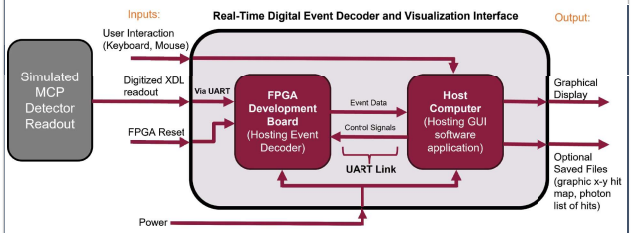


Fig. 5. Top-Level System Design

GUI

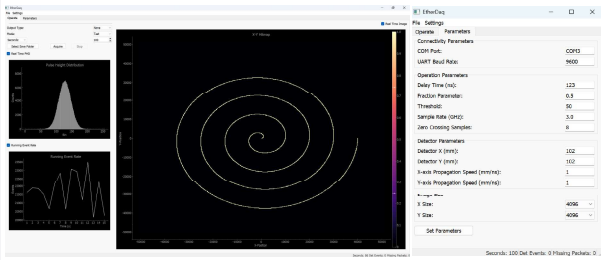


Fig. 6. GUI Main Window

Fig. 7. GUI Parameters Tab

User can:
- Configure an output file (Photon List or FITS image)
- Select the save folder
- Set mode of operation of system
- Set duration of acquisition in time or events
- View live event data through pulse height distribution histogram, running event rate graph, and x-y hitmap

User can:
- Set connectivity parameters for board communication
- Set operation parameters for CFD
- Set detector parameters for event decoding
- Set graphical image size

Experimental Setup

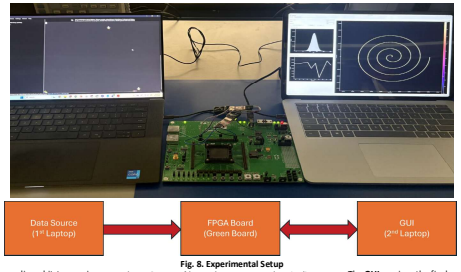


Fig. 8. Experimental Setup

The **Data Source** supplies a bitstream via UART in a format that represents ADC sample data. This data is buffered and fed to the beginning of the Event Decoder pipeline.

The **FPGA Board** hosts the Event Decoder pipeline, receives sample data from the Data Source, processes it, and sends it to the GUI. It also receives user parameters from the GUI to adjust calculations.

The **GUI** receives the final output of the Event Decoder and displays the results. It also sends user-defined parameters to the Event Decoder.

Results

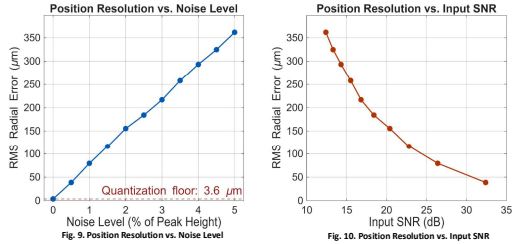


Fig. 9. Position Resolution vs. Noise Level
Fig. 10. Position Resolution vs. Input SNR
(Simulated 200-500 mV pulses with 44 ns rise time, sampled at 3 GSa/s)

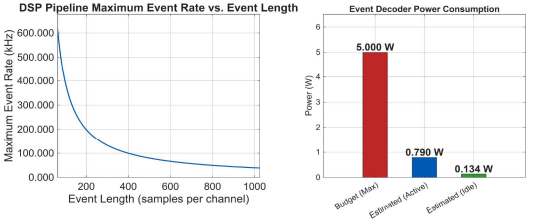


Fig. 11. DSP Pipeline Maximum Event Rate vs. Event Length

Fig. 12. Budgeted vs. Estimated Event Decoder Power Consumption

Analysis and Conclusion

1. The DSP pipeline correctly extracts event information while introducing negligible positional error of its own. As shown in Fig. 9 and 10, positional accuracy is dependent on the quality of the input data and minimal error is introduced by the DSP pipeline.
2. As illustrated in Fig. 11, the design exhibits high throughput inversely proportional to the number of samples per event. Throughput could be improved by utilizing multiple instances of the DSP pipeline to process multiple events in parallel, which is made possible by the design's low area utilization (<40% of the A3PE1500-PQ208's resources utilized per DSP pipeline).
3. Current overall throughput is bottlenecked by I/O, with UART's data rates moderately limiting the throughput of decoded events and severely limiting the input of raw XDL data. Swapping to a higher throughput method such as Ethernet would vastly improve system throughput.
4. The power consumption of the digital system is significantly lower than that of traditional analog systems. Fig. 12 shows that the power efficiency requirement was exceeded by a wide margin.
5. These results illustrate the feasibility of a digital FPGA-based event decoder for MCP detectors with XDL anodes, providing a strong proof of concept and establishing a baseline which future digital event decoding methods can be compared against.

Future Plans

- Develop the hardware interface required for the board to accept and process input from a NALU ASoCv3 digitizing ASIC.
- Implement Ethernet capability to the system to enable higher data throughput and more robust communication compared to UART.
- Move beyond simulated data by integrating the system with a real MCP detector system in a controlled lab environment.
- Investigate more advanced CFD techniques, including machine learning-based approaches, cross-correlation methods, and other waveform-based interpolation techniques.
- Investigate the feasibility of using SpaceWire as an alternative to Ethernet for data communication.

Acknowledgements

We would like to thank the following individuals for their continued support and guidance throughout this project:

- Dr. Camden Ertley
- Dr. Guy Grubbs
- Prof. Shelly Stover

We would also like to give a special thank you to SwRI and the VT ECE department for making this project possible.

Robotic Swarm for Mapping

LEFT to RIGHT: Avi Patel, Victor Rouzer, Ryan Convery, J. Cian Capacci, Nadeem Huang

CHALLENGE

Design and implement an enhanced swarm robotic system by modifying an existing robot chassis to extend battery life, integrate robust communication protocols, and improve environmental mapping capabilities. This system aims to provide a low-cost, scalable, and accurate solution for search-and-rescue missions, enabling efficient area coverage while reducing risk to first responders in hazardous environments.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Customer: Joe Adams

J. Cian Capacci — Denver, Colorado

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: My goal is to continue studying swarm robotics in graduate school, and to one day use them to enact positive change in the world. I hope to continue learning and developing my skills, and to keep seeking the unknown and integrating it into my practice as an engineer.

Course Comment: This course was an excellent opportunity to work with real hardware, and think through the full integration of a complex system with a long-term timeline. I have enjoyed the experience of working in a multidisciplinary team, and look forward to doing so in my eventual time in industry. I also enjoyed the challenge of being able to iterate on a previously set design, shaping and improving it for our task as we went.

Ryan Convery — Gloucester Township, New Jersey

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I hope to build a career designing, developing, and integrating complex engineering systems that bring comfort, reliability, and security to the people who rely on them. I look forward to continuing to grow as an engineer and contributing to technologies that have a meaningful real-world impact.

Course Comment: This Course provided me with an invaluable experience to both apply skills I have learned the last 4 years as well as learn new ones. Our team was giving the freedom to expand our design as far as we could, which pushed me to fully invest myself in the project.

Nadeem Huang — Vienna, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My aspiration is to build a career where I can apply my engineering background, particularly in embedded systems and software-hardware integration, to develop innovative solutions to real-world challenges. I look forward to continuing to grow as an engineer, collaborating with talented teams, and contributing to impactful technologies across a variety of industries.

Course Comment: Senior design provided valuable experience working on a complex engineering project from concept to implementation. It strengthened my technical skills while teaching me the importance of teamwork, communication, and iterative design when solving real engineering challenges.

Avi Patel — Clifton, New Jersey

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to be an engineer who transforms ambitious ideas into working solutions through thoughtful system design and innovation. By blending hardware and software, I hope to develop integrated technologies that are efficient, intelligent, and capable of making a lasting difference in everyday life and the future.

Course Comment: The ECE Major Design course gave me the opportunity to take on an open-ended, industry-like engineering challenge beyond the classroom. Through designing, building, and refining a real project as part of a team, I strengthened both my technical skills and my ability to communicate, collaborate, and adapt in a real engineering environment.

Victor Rouzer — Alexandria, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My goal is to become an engineer who develops efficient, reliable systems to solve meaningful real-world problems. I am especially interested in automation, computing systems, and embedded systems.

Course Comment: ECE Major Design Experience gave me the opportunity to apply what I learned over four years of classes to a real engineering project with meaningful design challenges. It helped me grow as both a student and an engineer by strengthening my communication, teamwork, technical decision-making, and ability to turn ideas into a working solution.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Robotic Swarm For Mapping

Team Members: Avi Patel, J. Cian Capacci, Nadeem Huang, Ryan Convery, Victor Rouzer
Customer and Mentor: Dr. Joe Adams

VIRGINIA TECH

Problem

Problem Statement:

- First responders must manually search hazardous, structurally compromised environments
- Process is slow, inefficient, and dangerous
- Need for a scalable robotic system to safely explore and map these areas

Problem Impact:

- Low-cost, rapidly deployable robotic system supports rescue operations
- Provides real-time intelligence from hazardous environments
- Reduces risk to personnel
- Enables faster, more informed decision-making
- Helps prioritize search areas
- Increases chances of locating and rescuing survivors

Requirements

Battery Life	Positioning and Object Detection	Cost
• Bot battery life at least 30 minutes • Bot is capable of completing a single search	• Bot to Beacon accuracy within 10cm • Bot locatable distance greater than 15m • Detection of obstacles as short as 1.5cm	• Bot material cost less than $150 • Damaged bots are easily replaceable

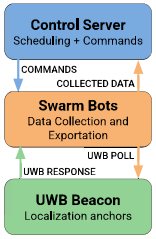
Communications

Bluetooth Low Energy (BLE)

- Sends command and data packets between the control server and each Swarmbot
- Maintains active communication links with connected Swarmbots
- Supports both broadcast and individual robot messaging

Ultra-Wideband (UWB)

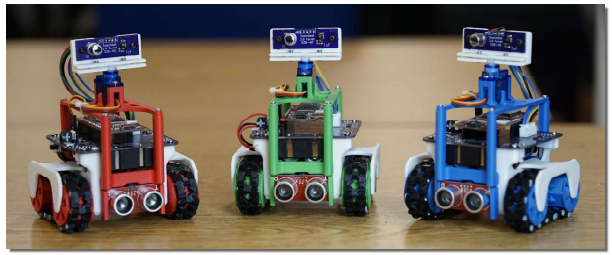
- Provides precise indoor positioning for each swarm bot
- Uses time-of-flight (ToF) measurements for distance estimation
- Uses scheduled transmissions to reduce signal interference



Unit Price

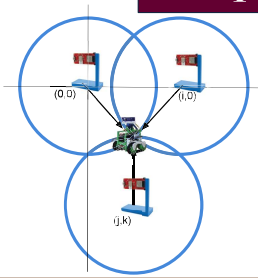
$125 per Robot

Swarmbots

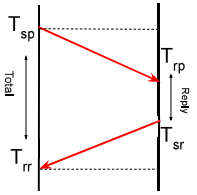


Previous Swarmbot model was upgraded with servo-mounted "turret" for scanning, onboard sensors and power regulation, a new microcontroller with localization capabilities, and a new chassis design.

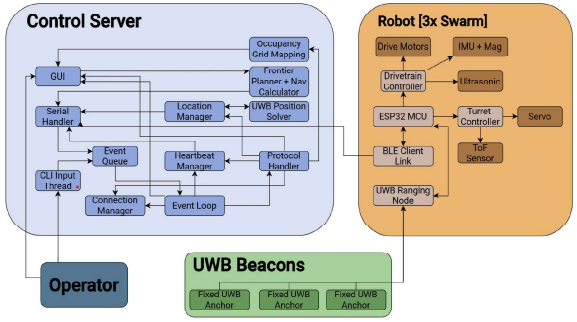
Positioning



- Trilateralization positioning using fixed beacons and distance ranging.
- Ranging to each beacon is done by Single Sided - Two Way Ranging using ToF.
- This system allows for 14cm of Euclidean accuracy with 10cm of Swarmbot-Beacon ranging accuracy.



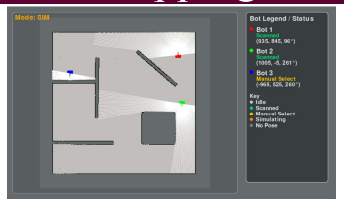
System Diagram



Battery Life

- Onboard 3,500mAh batteries with regulator circuitry provide local power supply with 5v and 3.3v levels
- Subsystems designed for low power draw and disabled when not in active use, totaling 250-300mA of max draw during active scans and drivetrain usage
- Given runtime testing and further projected power draw calculations, estimated battery life of **10+ hours**

Mapping

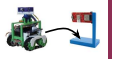


- Visualizes the live occupancy map generated by the swarm
- Highlights the most recent scan returned by each bot
- Shows current bot position, heading, and status
- Allows manual NAVIGATE commands when autonomous planning fails

Future Work

Beacon Deployment

- Deploy beacons for real world application
- Beacons in doorways improves line of sight to bots

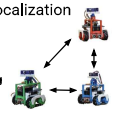


Improve Pathing

- Increase the number of steps a robot can plan to reach a target
- Prioritize the spread of the bots to increase map coverage per scan

Relative Localization

- Alternative to using Beacons
- Have bots use each other for determining localization



More Bots

- Double current number of bots
- Test speed up ratio and efficiency of mapping

Acknowledgments

We would like to thank the following individuals for their support in the completion of our project:
-
Dr. Joe Adams - Customer/Mentor
Kim Medley - Procurement

AI for Emergency Power Management

LEFT to RIGHT: Aidan Sablan, Riley Stone, Sean Stafford, Alexander Toskey, Eshaan Salvi, Pablo Galvez

SME: Sadman Saif

CHALLENGE

Develop an automated, multi-stage machine learning pipeline to predict the occurrence, scope, and duration of power outages across Virginia by integrating real-time weather forecasts with live utility data. The system utilizes optimized XGBoost models and a custom SHAP-based explainability framework to provide users with transparent, feature-level justifications for every live prediction. By bridging the gap between complex predictive modeling and actionable emergency response, our project aims to enhance grid resilience and resource allocation during severe weather events.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Customer: Christiana Chamon Garcia

Pablo Galvez Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My plan is to move to New York City to begin my career at BNP Paribas CIB, where I will work on their machine learning team.

Course Comment: This course allowed me to bring together everything I've learned throughout my time at Virginia Tech and build something with genuine real-world value alongside a talented team of engineers.

Aidan Sablan Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I plan to move to Northern Virginia to continue my education toward a Master's in Computer Engineering. I hope to further study Computer Systems.

Course Comment: This course has granted me the chance to identify and solve a real-world problem using the engineering principles I was taught while working in a team-based environment.

Eshaan Salvi Johns Creek, Georgia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My goal is to build impactful technologies that solve real world problems at scale. I'm interested in the intersection of artifical intelligence, software engineering, and data driven systems, and I aspire to create tools that empower people to make better decisions and access more opportunities.

Course Comment: This course allowed me to apply all of the knowledge I've gained thus far and create a project that will postively impact a wide scope of people.

Sean Stafford Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I intend to return to Virginia Tech next year to pursue a Master's Degree in Computer Engineering. I will continue to study Machine Learning.

Course Comment: This course has provided me the opportunity to perform hands-on work in the field I am pursuing. I worked with a team of other students for two semesters and our work culminated in a successful capstone project that solves a complex, real-world problem.

Riley Stone Leesburg, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: As a computer engineer, I m interested in the intersection of machine learning, computer vision, and embedded systems. I aspire to develop intelligent technologies that can interpret data and interact with the physical world.

Course Comment: This course gave me the opportunity to apply my computer engineering knowledge to a real-world problem while gaining valuable experience in system design, teamwork, and project development.

Alexander Toskey South Riding, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After graduation, I'm looking forward to return to Zeta Associates this summer as a computer engineering intern, and I'm excited to pursue a Master of Engineering in Computer Engineering at Virginia Tech s Innovation Campus in Alexandria this fall.

Course Comment: This course provided valuable experience working on a real-world engineering project with open-ended requirements and constraints. It challenged my team and I to apply our technical knowledge, collaborate effectively, and communicate our ideas to our customer.

AI for Emergency Power Response

Sponsor: Virginia Tech ECE, Dr. Christiana Garcia

Pablo Galvez, Aidan Sablan, Eshaan Salvi,
Sean Stafford, Riley Stone, Alexander Toskey

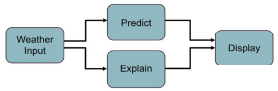
COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Problem Statement

During severe weather events, utilities can struggle to maintain reliable electrical service due to demand surges and grid equipment failures. An AI-driven system can provide utilities with useful outage insights so utilities can be better prepared to respond to grid failures due to extreme weather.

Objectives

- **Predictions:** Develop a low-cost, open-source machine learning system capable of predicting power outage occurrences at the county-level in Virginia along with outage scope and duration predictions.
- **Explainability:** Include model feature importance to provide justification for predictions made.
- **Visualization:** Create a user-friendly dashboard to display current and forecasted predictions using real-time weather data.



System Overview

Requirements

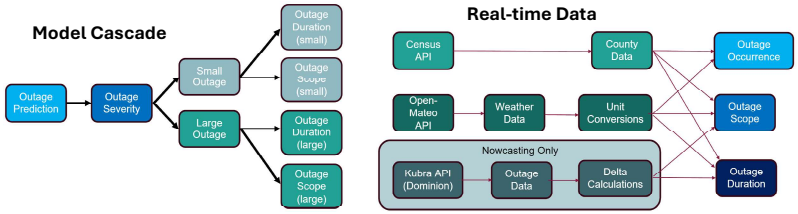
Performance/Technical Requirements

- >60-80% outage classification recall
- >60-80% scope classification accuracy
- >70-90% duration classification accuracy
- <15-25% scope regression error (within MAPE range)
- Production/API cost < $100

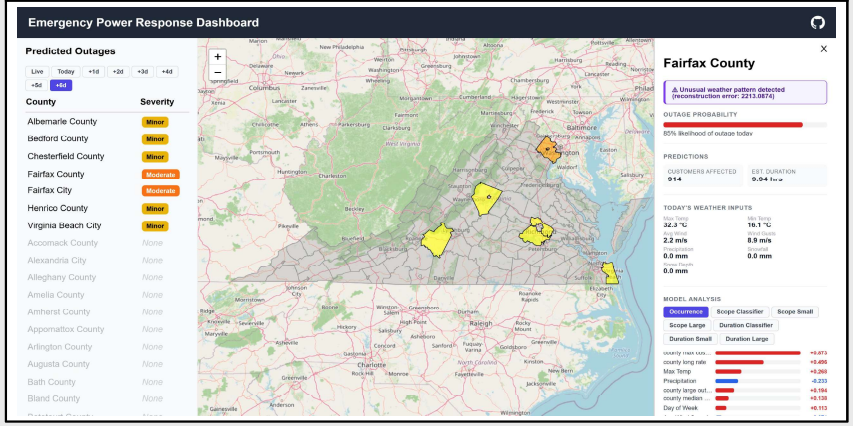
Challenges

- Dataset merging
  - **Solution:** Merge NOAA, Eagle-I, and GHCN
- Scope and duration models struggled with high affected populations (>500).
  - **Solution**: Break occurrence into two stages: outage/no outage classification and small/large classification
  - Include anomaly detection

System Pipeline



User Interface



Resources

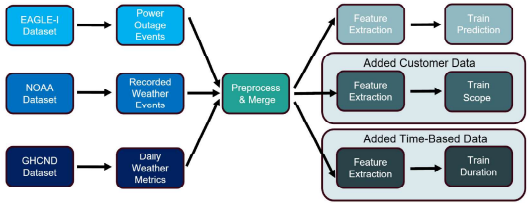
Software/ML Frameworks

- XGBoost – Extreme Gradient Boosting
- SHAP - SHapely Additive exPlanations
- PyTorch

Datasets

- NOAA (Weather)
- Eagle-I (Outages)
- GHCN (Climate)

Training Pipeline



Validation

Occurrence Model	Scope Model	Duration Model
Accuracy: 81%	MAE: 47.5 customers	MAE: 124 minutes
Precision: 87%	RMSE: 499 customers	RMSE: 359 minutes
Recall: 86%	MAPE: 20.45%	MAPE: 73.8%

Conclusions

- Our solution provides a free and open-source power outage prediction tool
- **Scope accuracy:**
  - Small outages (<500 customers): 93.8%
  - Large outages: 43.8%
- **Duration accuracy:**
  - Small outages (<4 hrs): 72.7%
  - Long outages: 57.9%
- Our models met our performance requirements for small/short outages, however, there is still room for improvement for large/long outages

Future Work

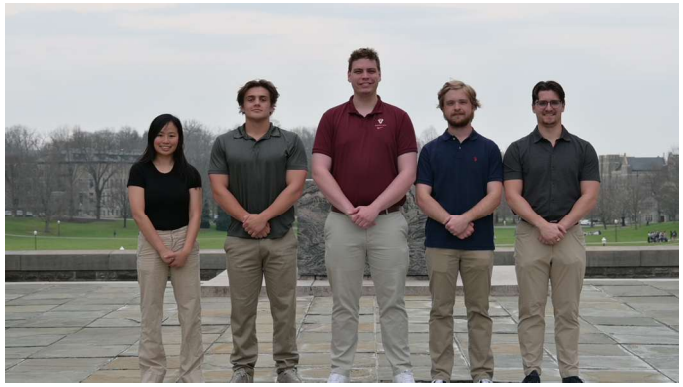
- **Quantile Regression**: For scope and duration, move to uncertainty ranges instead of single numbers
- **Topological/Spatial Features:** Model comparisons between different counties
- **Rate of Change Features:** Add velocity and acceleration features to help with forecasting explanations.
- **Beyond Virginia:** Extend system to include other states

Acknowledgements

We would like to thank the following individuals for their support:

- Dr. Christiana Garcia (Sponsor)
- Janice Burr (Mentor)
- Sadman Saif (Subject Matter Expert)
- Mohammadreza Saghafi (Subject Matter Expert)

On-Premise Audio Transcription and Analysis



LEFT to RIGHT: Victoria Chin, Ethan Avery, John Sylvia, Joshua Harrell, Thomas Gibbs

CHALLENGE

Our challenge is to develop a solution that transcribes trainee conversations during Navy training exercises for supervisors to better understand how decisions and outcomes are reached in scenario-based environments. The system will leverage existing microphones already integrated into the customer's systems and process the audio to isolate each voice for accurate transcription. Key challenges include filtering background noise and minimizing cross-talk between speakers.

ARCFIELD™

Customer: Mike Miller

Ethan Avery — Greenland, New Hampshire

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation, I aspire to jointly use my skills in electrical and computer engineering to making meaningful contributions to interesting and innovative work. I would like to apply my skills in a variety of different fields.

Course Comment: This class gives good exposure for students to learn what working on a realistic larger scale project is like, and what working within a team for a long period of time entails.

Victoria Chin — McLean, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I would like to apply my degree in the engineering field and then become a patent attorney.

Course Comment: This course is a good opportunity for students to gain experience with teamwork, communication, and work in a professional setting.

Thomas Gibbs — Eagleville, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I will continue my schooling at Virginia Tech in their Masters Program. I intend to broaden my knowelge of Computer Engineering and Quantum Computer Engineering in my last years of schooling.

Course Comment: This course provided experience in what a product development cycle of a company truly is. It also strengthened my teamwork and collaboration skillset, which is fundemental for creating new an innovative technology.

Joshua Harrell — Smithfield, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to apply my electrical engineering skills to solve real-world problems and contribute to innovative projects. I hope to continue developing my technical knowledge while growing professionally through new challenges and experiences.

Course Comment: This course provided me with valuable experience in developing an engineering solution to a real-world problem. It also strengthens key skills needed for a professional engineering career.

John Sylvia — Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Wireless Communications & Signal Processing

Aspirations: My goal is to obtain my licenses after I graduate and eventually own my own company.

Course Comment: Team communication is important and having the mentor meetings really keeps communication consistent.

On-Premise Audio Transcription and Analysis

Team Members: Victoria Chin, John Sylvia, Joshua Harrell, Ethan Avery, Thomas Gibbs
Mentor: Dr. Daniel Connors Sponsor: Arcfield

Problem

Supervisors can only make judgements based on final outcomes after holding a training sessions.
A live recording system that provides insight into trainee decision making may allow for better real-time monitoring and post-training debriefing.

Objectives

- Create an audio listening system capable of transcribing at least 5 voices simultaneously.
- Create an audio listening system that can capture conversations that will be analyzed post execution to understand decision making process.

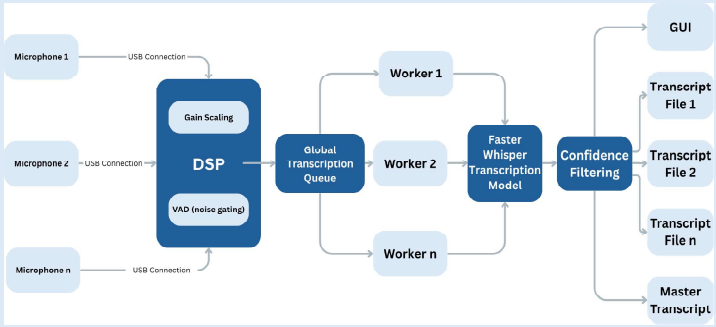
System Constraints

- Must complete transcription within 1 minute of speech
- Must have an accuracy rate of 80% minimum
- Must operate entirely offline

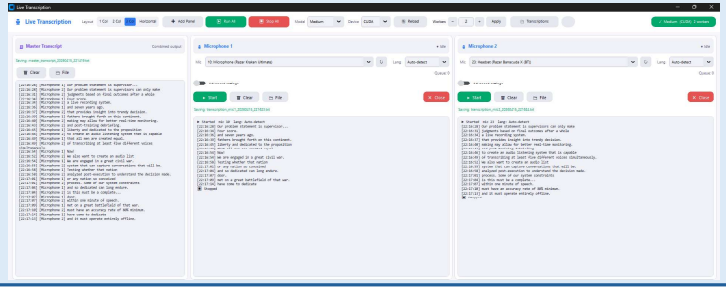
System Requirements

- Multi-Channel Audio Capture
- Speaker Separation (Cross talk)
- Speech to Text Transcription
- Live Processing

System Diagram



GUI



Challenges

- **Cross Talk –** Our primary challenge was reducing crosstalk, which we mitigated using confidence-based filtering.
- **Project Redesign –** Halfway through the course, we shifted from a hybrid hardware/software approach to a fully software-based solution, overcoming challenges with support from Dr Connors and Arcfield.
- **Hardware –** Limited to lower-quality microphones without ambient noise cancellation due to budget restraints, our system's success demonstrates strong performance with higher- end technology.

Architecture

- **Faster Whisper –** ML audio to text python library
- **Sound Device –** Library used to stream audio from the microphone to a buffer
- **Threading –** Used to run 5 whisper models in parallel across multiple threads. Allows for simultaneous audio transcription
- **CustomTkinter–** GUI library used to display the simultaneous speaker transcriptions

Results

- Transcribed speech on a .txt file for each microphone
- .txt file of a compilation of each microphone with timestamps of each transcribed text and organized by time
- Simple GUI for presentation and analysis

Conclusion

Our solution provides the user with a live, fast, and accurate transcript of everyone speaking within a room.

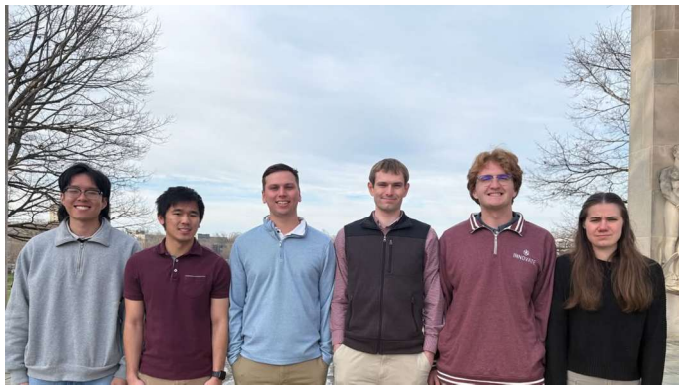
Future Work

- Expand the system to transcribe conversations for up to 30 individuals
- Add an AI feature that can pinpoint important lines of dialog showing how decisions were made.

Acknowledgements:

We would like to thank our sponsors, Brandon Carvalho, Alexander Multon, and Thomas Santos at Arcfield, and our MDE mentor, Dr. Daniel Connors, for all their assistance with the completion of this project!

Enterprise Architecture Optimization for Roanoke County



LEFT to RIGHT: David Tran, Brandon Nguyen, Carter Elliot, Nick Pierce, Jack Teff, Kasey O'Brien

CHALLENGE

Roanoke County's Enterprise Geographic Information System (GIS) relies on a hybrid infrastructure with on-premises storage approaching capacity and no unified architectural model to guide future decisions. Our team was tasked with inventorying the current environment across all infrastructure layers, identifying cost and performance inefficiencies, and proposing an optimized target architecture supported by cost and risk analysis.

ROANOKE COUNTY VA

Customer: Uma Marques

Carter Elliott Kennett Square, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: After graduation, I want to join the workforce in the Cybersecurity sphere to help companies defend their important information and develop secure software.

Course Comment: This course experience has helped me learn how to solve complex engineering problems for a client while working with a team of similar minded peers.

Brandon Nguyen Vienna, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Upon graduating, I plan to join the workforce as a Systems Engineer, helping to bridge the gap between technical domains of Software, DevSecOps, and Cybersecurity to all stakeholders using Model-Based Systems Engineering practices.

Course Comment: This course has been extremely value as it helped me to be able to combine the academic skills from my class and apply them to real applicable projects that have a real user base. The project in conjunction with working with a team has helped me improve my communication, collaboration, and presentation skills having to communicate with stakeholders of varying technical knowledge.

Kasey O'Brien Conshohocken , Pennsylvania

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Upon graduating, I plan to join the workforce as a Project Engineer focused on integrating machine learning tools to improve engineering systems and workflows.

Course Comment: This course has been very helpful in allowing me to better understand how I can apply my educational background to solving a practical engineering problem. This course also helped futher develop my skills in working with a team, which is an essential skill needed in the workforce.

Nick Pierce Salem, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Upon graduating, I plan to join the workforce as an IT Consultant, helping to ensure reliable access to data and securing information across various systems.

Course Comment: This course has helped me to develop professional skills, giving me an opportunity to work collaboratively with others on an open-ended problem. It has also allowed me to use the knowledge and skills I have gathered over the years on a long-term project containing many deliverables and deadlines.

Jack Teff Butler, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Upon graduating, I plan to join the workforce in the field of Cybersecurity to help protect critical systems and data through the application of my skills and education.

Course Comment: I've valued this course because it has allowed me to gain experience working on a long-term project with professional partners. It has helped me develop my technical skills with networking and IT, as well as communication and presentation that comes as part of a team.

David Tran Centreville, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Upon graduating, I will be joining the workforce as a Cybersecurity Consultant in different areas such as Cyber Strategy and Risk, Identity & Access Management, and Cloud Security.

Course Comment: This course has been a huge learning experience. I was able to combine my learning from coursework into hands-on experience with IT and enterprise architecture. I increased and developed my communication and collaborative skills through this course.

Enterprise Architecture Optimization for Roanoke County

Sponsor: Roanoke County
Mentor: Dr. Joe Adams, Ph.D.
Team S26-17: Brandon Nguyen, Nick Pierce, Jack Teff, David Tran, Kasey O'Brien, Carter Elliott

MOTIVATION

- IT Infrastructure split between two on-premises data centers and various cloud applications
- On-premises storage is reaching capacity, with growth exceeding projections
- Project delivers a systematic approach to document the current state, engage stakeholders, and produce actionable architecture recommendations.

75% On-Premises Systems

25% SaaS Cloud Hosted

30+ Public-Facing GIS Apps

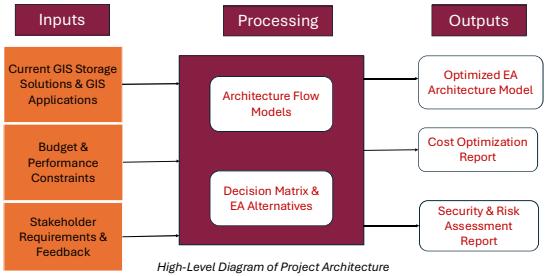
OBJECTIVES

- Document and inventory the current Enterprise GIS architecture including hardware, software, hosting, and integrations
- Engage stakeholders across IT, Finance, and HR to capture constraints and requirements
- Model current & proposed architectures using ISO/IEC/IEEE 42010 compliant ArchiMate notation
- Evaluate on-premises, cloud, and hybrid deployment alternatives with multi-criteria scoring
- Create a reusable optimization framework for other County enterprise systems

PROJECT PHASES

1. **Planning & Scope:** Define application metadata, identify stakeholders, build collection templates.
2. **Data Collection:** SME interviews, LANsweeper network scans, cross-validate with county docs.
3. **Modeling & Validation:** ArchiMate diagrams (current & proposed), stakeholder validation via SmartSheet.
4. **Analysis & Optimization:** Decision matrix, cost-benefit, risk, and performance comparisons.
5. **Reporting & Roadmap:** Final EA model, cost report, risk assessment, and phased schedule.

SYSTEM ARCHITECTURE



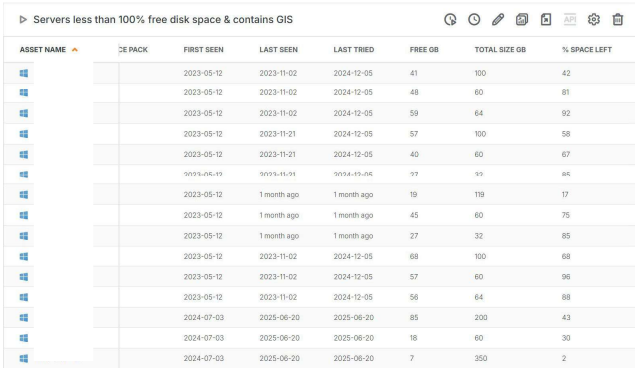
High-Level Diagram of Project Architecture

TOOLS & STANDARDS

Software: LANsweeper , Modelio, SmartSheet
Programming Languages: Jython
Standards: ISO/IEC/IEEE 42010, ArchiMate 3.1, TOGAF, NIST CSF

LANSWEEPER

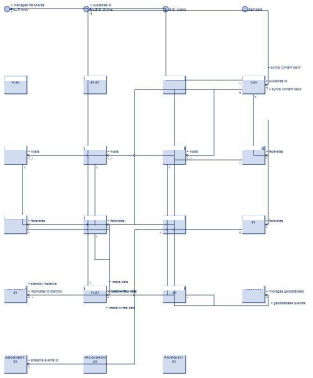
- Network discovery and asset inventory tool used to automatically scan Roanoke County's IT environment and catalog all hardware, software, and network-connected devices
- Collected key metadata for each system including hosting type, software versions, network topology, and application dependencies, which formed the baseline dataset for the entire EA analysis
- Exported inventory data in standard formats (CSV, JSON, XML) for import into ArchiMate modeling and further analysis



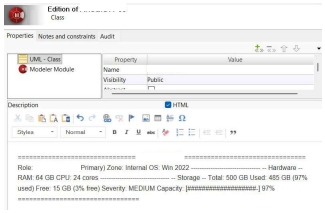
Status of ARCGIS servers that will be exported from SQL Report

MODELIO

- Enterprise architecture modeling tool used to create ISO/IEC/IEEE 42010-compliant diagrams representing both the current-state GIS architecture
- Built multi-layered viewpoints spanning the business layer (department workflows), application layer (GIS and integrated systems), and technology layer (servers, storage, hosting) to give stakeholders a complete picture of the environment
- Generated system relationship maps showing integration links and data flows between GIS applications and dependent County systems



Enterprise Architecture that shows server connections



Server Element Description that contains GIS Server Specifications

KEY DELIVERABLES

Current State Architecture Model
Comprehensive LANsweeper derived inventory mapped into Modelio viewpoints covering business, application, and technology layers for Enterprise GIS and all connected County systems.

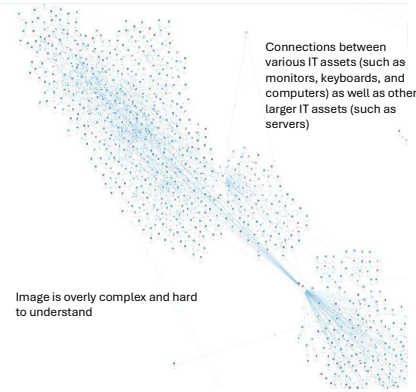
Performance Report
Complete performance testing of script from extraction to completion to ensure that product works in a timely manner for a basic specification work laptop from Roanoke County.

Risk Assessment
FMEA-based risk register covering data migration challenges, integration inconsistencies, system downtime, and unauthorized access each with severity scoring and mitigation plans.

Tool Usability Guide
Comprehensive word document that covers how to properly use the tool across the organization.

LESSONS LEARNED

- Effective EA requires continuous stakeholder involvement
- GIS complexity necessitates comprehensive visualization before proposing architectural changes
- Proactive risk identification across technical, operational, and strategic dimensions is critical



Network Topology Graph that shows all IT assets with network connectivity

FUTURE WORK & RECOMMENDATIONS

- Apply optimization framework to other major County enterprise systems
- Implement automated feedback collection for real-time user insights
- Expand performance testing to peak-load stress scenarios

ACKNOWLEDGEMENTS

We would like to express our gratitude to the following individuals for their support and guidance throughout the course of this project:
- Dr. Joe Adams, Ph.D (Mentor)
- Steve Munsey (Customer)
- Rachel V. Smith (Customer)

Water Cooling Skid Simulator

LEFT to RIGHT: Jet Kok, Douglas Soriano, Andrija Eremic

CHALLENGE

Build a compact, fully functional simulator of a TMEIC variable frequency drive water cooling skid for software validation and operator training. The closed-loop system circulates deionized water through a heat source, redundant pumps, radiator heat exchanger, and resin filter, with real-time sensor monitoring and alarm logic managed by an Arduino controller.

TMEIC

SME: Robert Mioduszewski

Customer: Darren Honaker

Andrija Eremic — Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: My goal is to become an electrical engineer in the power industry, helping design and improve critical infrastructure. I look forward to working on renewable energy projects.

Course Comment: MDE has been a meaningful experience that allowed me to work with new people, and apply engineering concepts to an authentic real-world project.

Jet Kok — McLean, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I look forward to gaining experience in the cybersecurity industry within the public sector. Importantly, I want to learn from engineers from different backgrounds and specializations to get a better idea of what interests me. Finally, I hope to work on electric vehicles in the future.

Course Comment: The senior design course has been a great experience to meet new people, see how companies perform real engineering on meaningful projects, and work from the ground up to build something the team can all be proud of.

Douglas A Soriano — Burlington, New Jersey

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I intend to pursue a master's degree in computer engineering. Once I graduate, I hope to work in either the embedded systems or image processing field in California, contributing to the development of innovative technologies. Later in life, I would like to teach and mentor the next generation of engineers.

Course Comment: Over the past several months, I have learned more about the engineering process by developing a product to address a specific issue. Interacting with my team on a day-to-day basis has given me valuable skills that I hope to carry forward into my professional career.

Water Cooling Skid Simulator

Team Members: Andrija Eremic, Douglas Soriano, Jet Kok
Customer: Darren Honaker **Mentor**: Prof. Kelley Andrews

Motivation

- Toshiba Mitsubishi-Electric Industrial Systems Corporation (TMEIC) manufactures variable frequency drives (VFDs) that are cooled by large closed-loop water cooling skids managed by PLCs.
- Full-scale cooling skids are too large, costly, and risky to use for PLC software validation and hands-on training.
- TMEIC needs a safe, compact, and cost-effective platform to verify PLC code before deployment to production equipment worth hundreds of thousands of dollars, and to train engineers and client personnel on realistic cooling system behavior.

Objectives

- Design and build a miniature closed-loop water cooling system that replicates the thermal and control behavior of a full-scale TMEIC cooling skid.
- Maintain water conductivity ≤ 1 µS/cm @ 25°C using a mixed-bed DI resin tank.
- Keep simulated VFD inlet temperature ≤ 45°C with a target ΔT of 6°C across the heat exchanger.
- Implement redundant pump failover in < 2 seconds.
- Achieve all sensor readings within 5% of calibrated instruments and alarm response within 1 second.

Theory of Operations

- Thermal Simulation: Uses a submersible resistive heater to mimic the heat generated by a VFD with a compact, open-frame training platform.
- Redundant Circulation: Employs two 24VDC pumps and automated solenoid valves to ensure continuous water flow and immediate switchover during a primary pump failure.
- Thermal & Purity Management: Rejects heat through a 360mm radiator with PWM-controlled fans while maintaining water quality via a mixed-bed DI resin tank.
- Integrated PID Control: Features a controller that monitors RTD temperature, conductivity, pressure, flow, and level sensors to monitor operation of the water loop.
- Power Architecture: Runs on a standard 120VAC outlet, utilizing a 24VDC power supply and a 12VDC step-down converter to power the fans.

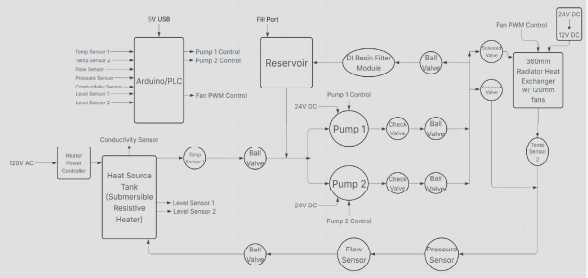


Figure 1: High Level Block Diagram of the loop with components and flow diagram

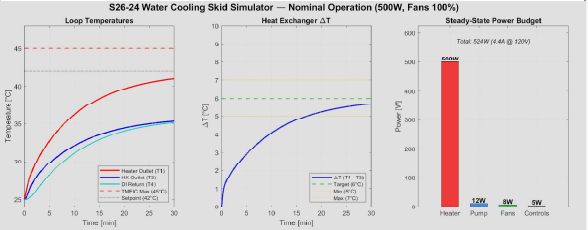


Figure 2: MATLAB simulation of the system

Test Setup

- Subsystem-level verification was performed on individual modules (power, sensors, pumps, heater, heat exchanger) before full integration.
- Full-system integration testing with all subsystems operating together in a closed loop.
- Thermal performance tested at the rated heat load to verify inlet temperature and ΔT targets.
- Pump redundancy validated by simulating primary pump failure and measuring switchover time.
- All alarm and interlock scenarios tested: low water level, over-temperature, pump failure, and high conductivity.

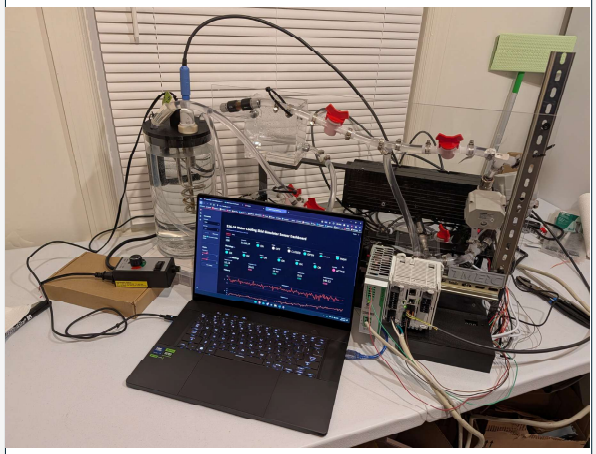


Figure 3: Our system during a live heating/cooling test

Test Results

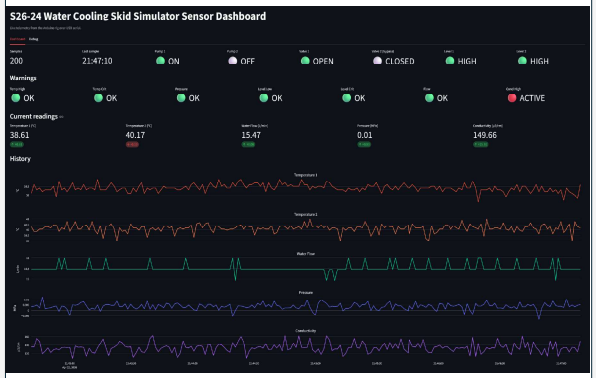


Figure 4: Temperature, Flow, Pressure, and Conductivity measurements over a heating cycle with active cooling (500W load, 100% fans)

Analysis and Conclusion

Results Analysis

We set up a Python Streamlit dashboard to monitor all sensors for our testing, using serial to retrieve results from the Arduino output.

Requirement	Target	Measured
VFD inlet temp	≤ 45°C	40.2°C @ 60 min
Pump failover	< 2 s	1.16 s
Heat exchanger ΔT	6°C	2–3°C
System power	524 W	~520 W

Key findings: Over a 60-minute run at 500W load, the loop stayed below the 45°C limit with a ΔT of 2–3°C across the heat exchanger, below the 6°C target. Pump switchover completed in 1.16 s, well within the 2 s requirement. Total wall power matched the simulated budget. Conductivity testing deferred due to lack of lab-grade DI water.

Design Challenges

- Due to our electronics and sensor setup, there was significant noise for the temperature, pressure, and flow sensors which can be improved with smoothing in the GUI display software or with higher quality components.
- Fitting everything on a desk-sized open frame while maintaining serviceability was difficult. The integration of two loops on the frame created challenges in routing and fitment for components.
- Sourcing components for such a complex loop to fit under our $500 budget was difficult as many industrial grade devices would have put us over budget.
- The component choice for the mixed bed resin cartridge is likely not enough resin to clean such a large amount of water, but budget issues restricted our choices.
- Designing a safe method to heat the water required careful CAD modeling and testing to ensure no section of the heater tank reaches dangerous temperature levels.

Conclusion

- The system successfully demonstrates realistic fluid/thermal behavior suitable for PLC code verification and operator training.
- The system met most performance and specification requirements set by our team and the sponsor.

Lessons Learned

- DI water compatibility required careful material selection so all copper and brass components had to be replaced with stainless steel or plastic alternatives.
- Achieving the 45°C system temperature limit required iterative tuning of the PID loop and fan configuration.
- Integrating mixed-signal sensors (4-20 mA analog and digital) required level shifting and noise control measures that we did not initially account for.
- System integration revealed challenges not apparent in individual subsystem testing so thorough integration testing is essential.
- As most of our team had never worked on industrial water cooling loop hardware before, the completion of the project required both research in fluid and thermodynamics as well as hands-on training with our components.

Future Plans

- Additional testing with different heating power, heat exchangers, and PID configurations
- Transition the controller from the Arduino-based prototype to a TMEIC-specified PLC for production use. Implementation of solenoid valve heat exchanger bypass.
- Further develop the HMI interface for increased real-time monitoring and control.
- Expand data logging capabilities for long-duration test sessions.
- Enable remote monitoring and control for off-site training scenarios.
- Produce documentation and training materials for TMEIC client use.

Acknowledgments

- Robert Mioduszewski (TMEIC) — SME
- Darren Honaker and David Anderson — TMEIC POC & SME
- Professor Kelley Andrews — Project Mentor
- Virginia Tech Bradley Department of Electrical and Computer Engineering

Multi-Protocol Launchpad Integration SCADA for Virginia Spaceport Authority

Track 3 Winner

LEFT to RIGHT: Gabriel Gonzalez, Aaron Kanefsky, Jai Ravula, Tanish Wangoo, Arjab Sinha, Sulaiman Alharbi

SME: Walter Taraila

CHALLENGE

Our challenge was to design and implement a unified Supervisory Control and Data Acquisition (SCADA) system for the Virginia Spaceport Authority (VSA). The VSA is a government organization that maintains several launchpads for a variety of customers across their entire facility. With each of these launchpads, all the hardware utilizes a different protocol, limiting cross-site visibility for operators conducting multi-pad operations. We developed a centralized control architecture that integrates each diverse system into one cohesive interface, enabling real-time monitoring and control. This solution enhances operator visibility, improves safety, and supports a more accurate data collection pipeline.

VIRGINIA SPACEPORT AUTHORITY
GATEWAY TO THE UNIVERSE

Customer: Sidnee McGee

Sulaiman Alharbi — Khobar, Saudi Arabia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I look forward to completing a master's degree in computer engineering at Virginia Tech and then pursuing a career in hardware design.

Course Comment: During this course, I learned a lot about project management and real-world engineering work flows. It gave me an opportunity to experience how to tackle real-world engineering problems and manage working with many stakeholders.

Gabriel Gonzalez — Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After Graduation I am going to Charlotte to work as a Software and AI engineer for Wells Fargo. I am also going to continue as the Technical Founder at a startup that I have been working on with a couple friends from home.

Course Comment: MDE was a great experience it allowed me to get experience in fields of Computer Engineering that I may not have otherwise gotten experience in.

Aaron Kanefsky — Bristow, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Controls Engineer in Themed Entertainment (especially Roller Coasters and Animatronics)

Course Comment: MDE offered my the opportunity to work on a once in a lifetime project with a great team of fellow engineering students.

Jai Ravula — Ashburn, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: Upon graduation, I plan to start my career in software engineering while pursuing a Master's degree in Computer Engineering here at Virginia Tech. I aspire to make an impact advocating for the safe, regulated, and responsible use of AI for the future of society.

Course Comment: This course served as an excellent opportunity to work with a customer to deliver a practical, real-world solution. Throughout the project, I strengthened both my engineering and communication skills. Overall, the course has absolutely served as an invaluable and rewarding experience.

Arjab Sinha — Santa Clara, California

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I aspire to build a career advancing complex aerospace systems. I am eager to apply my technical expertise to develop highly effective, innovative solutions that push the boundaries of the field and make a tangible impact in the industry.

Course Comment: This course was both challenging and highly educational, especially in navigating a client-oriented project environment. It strengthened my ability to keep work moving by clarifying requirements quickly and independently confirming critical details.

Tanish Wangoo — Patiala, India

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: While I don't have a specific industry in mind, I would love to work at the intersection of technology and people. Understanding client needs and tailoring tech led solutions to their problems.

Course Comment: I liked the blend of hands-on and theoretical work the course offered. We were learning complex technologies while simultaneously building applications around them - which gave us a holisitc exposure of production-level engineering.

Multi-Protocol Launchpad Integration SCADA for Virginia Spaceport Authority

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Team Members: Aaron Kanefsky, Arjab Sinha, Gabriel Gonzalez, Jai Ravula, Sulaiman Alharbi, Tanish Wangoo
Customer: Mr Walter Taraila, VSA
Mentor: Dr Joe Adams

VIRGINIA SPACEPORT AUTHORITY
GATEWAY TO THE UNIVERSE

Problem Statement

Design and implement a **unified Supervisory Control and Data Acquisition (SCADA) system** for the Virginia Spaceport Authority (VSA). Each launchpad utilizes hardware with **different protocols, limiting cross-site visibility** for operators conducting multi-pad operations, creating **safety concerns and critical failures**.

Objectives/Goals

- Develop Centralized Control Architecture for one launchpad and one facility
- Unify multiple protocols into a single ingestion platform
- Display ingested values onto custom GUI
- Create Identity and Access Management controls to secure data for approved use only
- Set up a database to securely store every ingested value.

Ignition! READY

Challenges

- Protocols can't natively communicate
- Requires deployment across multiple VSA production servers
- Servers are locked behind secure internet requiring VPN access
- One server only has Python 2.6
- Required translation layer for custom proprietary TCP packets from Pad 0A

Implementation

- Sensor data is ingested from Pad 0A and Payload Processing Facility to a centralized processing server.
- The data is converted to the BACnet protocol and forwarded to a server hosting Ignition Gateway (the main software supporting the SCADA system).
- Server unpacks BACNET objects and feeds data as structured tags to Ignition.
- The Ignition deployment is containerized and orchestrated within a Kubernetes cluster, enabling high availability through continuous health monitoring, automated failover protection, and self-healing via container restarts.

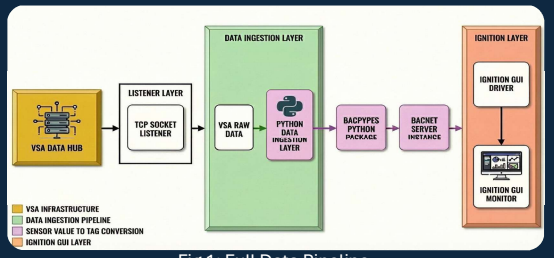


Fig 1: Full Data Pipeline

Results

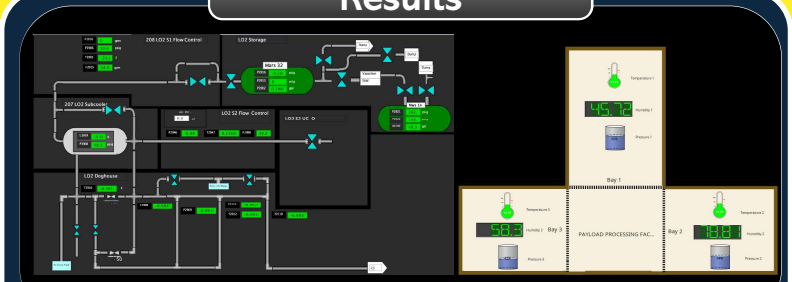


Fig 2: Pad 0A GUI

Fig 3: Payload Processing Facility GUI

- Our system implementation culminates in a user-interface to visualize the data ingestion from Pad 0A and Payload Processing Facility sources.
- Sensor data communication via BACNET are correctly ingested and displayed on the frontend, proving the system can support data transmission over the BACNET protocol.
- System is fully orchestrated within a Kubernetes cluster with failover protection to ensure maximum uptime for all services.

Conclusion and Lessons Learned

Our SCADA system:

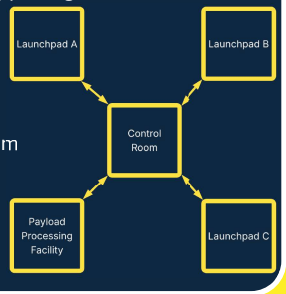
- **Ingests the various types of data used for launch pad operations**
- **Updates and populates** data onto the GUI
- Developed a **data ingestion pipeline with Ignition Vision**

What we learned:

- Learned about **various industrial protocols** and how to integrate them in **one platform**.

Future Work

- The rest of the work on this project will be carried out by future teams, extending our design to work for multiple launchpads
- This will include supporting two more launchpads, and additional communication protocols
- Add maintenance management system



Acknowledgements

We would like to extend a large thank you to the following people, who helped make this project possible

- Dr. Adams, Professor and Mentor
- Walter Taraila, VSA Customer and Technical Lead
- Nick Counts, VSA Technical Expert

PacketVigil: AI-Powered Cyber Attack Detection

LEFT to RIGHT: Dheeraj Indela, Sully Mrkva, Al Taber, Aiden Wang, Siri Rao, Joshua Manuel

CHALLENGE

Modern networks face an ever-evolving threat landscape where attacks unfold rapidly -- yet most detection systems remain ineffective against stealth attacks, flagging threats based on known signatures rather than underlying structure. The goal of this project is to design and build an AI-powered intrusion detection system that monitors live network traffic in real time, autonomously identifying and flagging threats the moment they emerge. By leveraging machine learning at the network edge, this system aims to shift security from reactive to proactive.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Customer: Christiana Chamon Garcia

Dheeraj Reddy Indela — Aldie, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I'm interested in building a career in networking and cybersecurity after graduation. I enjoy learning how networks work and how different security tools help protect systems from cyber threats. I also like understanding how attacks happen and how they can be prevented. My goal is to keep learning and develop the skills needed to help organizations keep their networks secure.

Course Comment: This course gave me a good opportunity to work on a real project with a team. It helped me see how networking and cybersecurity concepts are used in real situations. I also learned how important teamwork and communication are when working on technical projects. Overall, the experience helped me better understand the field and how these skills can be used in my future career.

Aiden Wang — Guilford , Connecticut

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I want to gain experience in the cybersecurity field and develop the technical skills needed to defend systems and sensitive data. Ultimately, I hope to work in cybersecurity roles that focus on protecting people and maintaining trust in digital systems.

Course Comment: The course allowed us to gain valuable experience working in an organized team environment that resembles a professional setting.

Joshua Manuel — Chantilly, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I enjoy working with software and exploring how computing systems can be used to solve engineering problems. I'm especially interested in areas like software development and machine learning, where smart systems can improve real world situations. My goal is to continue developing my technical skills while building solutions that are impactfu

Course Comment: This course offers a great opportunity to apply machine learning concepts in a hands-on project while collaborating with a team. It helps connect classroom knowledge to real-world applications and provides valuable experience working through the full development process from start to finish.

Sully Mrkva — Clearwater, Florida

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My passion lies in cybersecurity, with an emphasis on national security and networks. I love to analyze systems, find the cracks, and build the fixes. I aim to apply my skills to protect the country – securing systems and protecting citizens.

Course Comment: This course gave me a great opportunity to combine all my classroom knowledge into a full hands-on project, allowing me to work with a team and channel my creativity into a final product

Siri Rao — Apex, North Carolina

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I enjoy developing software and exploring machine learning techniques to solve complex problems. I'm particularly interested in building intelligent systems that can improve real world applications. I aim to apply my skills to create practical and impactful solutions while challenging myself and making a tangible impact.

Course Comment: The course provides a valuable experience applying machine learning concepts to a real world project in a collaborative environment.

Al Taber — Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I want to gain experience working in the cybersecurity field after graduating. I'm especially interested in penetration testing and learning more about how companies defend networks from attackers trying to exploit their systems. My goal is to eventually work as a penetration tester, helping identify vulnerabilities before they can be exploited.

Course Comment: I really enjoyed having the opportunity to work with a team on a project that will prepare me for my future career. It helped me develop teamwork and problem-solving skills that I know will be useful in my work after graduation. The project also deepened my knowledge in cybersecurity and confirmed that my interests and skills align with my career path.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

PacketVigil: AI Cyber Attack Detection

Sully Mrkva · Aiden Wang · Al Taber · Siri Rao · Joshua Manuel · Dheeraj Indela

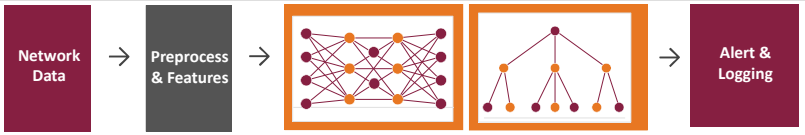
THE PROBLEM

Cyber threats are growing in complexity and frequency. **Signature-based IDS miss stealthy attacks** — they rely on known patterns, failing against novel attack vectors using non-standard ports or random intervals. Most open-source models and intrusion "detectors" operate exclusively offline. Models operate purely on offline datasets — not live data. Therefore, open-sourced real-time IDS systems are not only scarce—but critically needed.

OUR SOLUTION

A real-time, hybrid machine-learning-based detector combining an Autoencoder (anomaly detection) with a Random Forest classifier (attack classification), operating on live packet-level network traffic.

FULL SYSTEM PIPELINE



NETWORK INGESTION & FEATURE EXTRACTION ENGINE

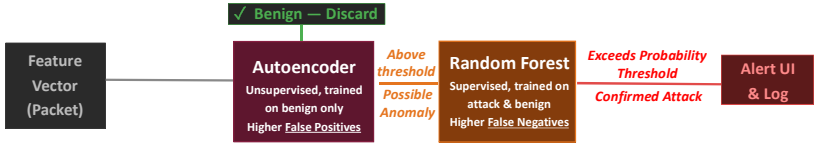
1 Packet Capture — *Dumpcap*
- High-performance capture engine

2 Packet Dissection — *Dpkt*
- Layer-by-layer parse
- Via binary pcap streams
- Ethernet - IP/ARP - TCP/UDP

3 Feature Extraction — *Inspired by Kitsune (Mirsky et al. 2018)*
- 115 behavioral features/pkt
- 5 traffic dimensions
- Exp. decay over 5 time-windows
- Cython-optimized

4 Flow Statistics & Inference — *Behavioral vectors*
- Packets not stored nor inspected
- Hash-tables updated/pruned
- Vectors sent for inference

ML CORE



Autoencoder *learns how to compress & reconstruct benign data, higher reconstruction error indicates anomaly.*

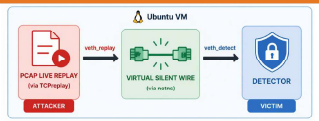
Random Forest *creates ensemble of decision trees to map features, classifies via weighted voting.*

PERFORMANCE RESULTS – ON 6/7 DATASETS:

>90%	>95%	~1200	0.7ms
Recall	Precision	pkt/s Throughput	FE+ML latency/pkt

OFFLINE BENCHMARKING TESTBED

ONLINE TESTING SETUP

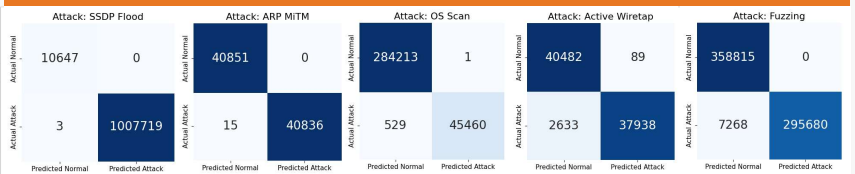


TESTING SUITE

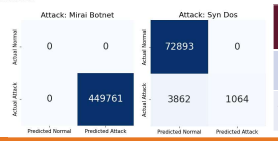
Attack Type	Man-in-the-Middle	Denial of Service	Reconnaissance	Malware
Description	Intercepts & manipulates network traffic	Overloads services to disrupt availability	Gathers information about hosts and services	Delivers malicious payloads
Datasets	Kitsune: **ARP MitM** Kitsune: **Active Wiretap**	Kitsune: **SSDP Flood** Kitsune: **SYN DoS**	Kitsune: **OS Scan** Kitsune: **Fuzzing**	Kitsune: **Mirai Botnet**

Kitsune datasets are open-source **PCAP** network captures with labeled attacks, generated from **real** host–attacker **interactions** using diverse tools.

CONFUSION MATRICES



AE reduces RF load as high-recall filter	
SSDP Flood	*Filters out **99%** benign flows*
OS Scan	*Filters out **85%** of benign flow*



Online Replay Snapshot: OS Scan	
Resource Usage	*On a 3 core VM, max **~570 MB** of Ram & **8%** of CPU*
Avg Throughput & Latency	***697** pps & **0.7**ms*

FUTURE WORK

*Our system is capable of **extracting** real-time network data and making very **accurate** detections on a per attack basis.*

- **Perform** robust cross-attack testing to evaluate full IDS generalization.
- **Explore** alternative decision logic approaches to fine-tune performance for cross-attack testing.
- **Implement** adaptive, real-time re-training at set intervals using our existing network data to training data scripts.
- **Optimize** AE structure, i.e., ensemble of autoencoders
- **Strengthen** feature extraction, less sensitive to timing/jitter artifacts
- **Research** protocol-specific feature extraction for richer traffic characterization.

Special thanks to our Customer – **Dr. Christiana Garcia**, Mentor – **Dr. Joe Adams, and Yisroel Mirsky et al --** for their open-sourced work on "*Kitsune…" NDSS '18*

VT Athletic District Microgrid and FLISR Simulation

LEFT to RIGHT: Connor Haymaker, Ethan Hogue, James Stilwell, Cohn Betz, Luke Payne, Tianlin Huang

SME: Ali Mehrizi-Sani

CHALLENGE

Design and simulate a loop distribution system serving the Virginia Tech Athletic District in Blacksburg. The system is capable of fault location, isolation, and service restoration (FLISR) and can run in both grid-connected and islanded modes. The project consists of two major components: a physical model that represents the system as if it were implemented in the Virginia Tech Athletic District and a graphical user interface (GUI) that allows users to interact with the system, simulate different scenarios, and display the status of all equipment and loads.

Wiley|Wilson®
Constant Progress

Customer: Gary Li

Connor Haymaker — Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I will be working in the power distribution industry and am excited to be a part of modernizing and improving our nation's infrastructure. My goal is to become a well-rounded engineer who understands the complexities of electrical infrastructure and how the power grid operates.

Course Comment: This class gave me the opportunity to take a deep dive into a topic that I am truly interested in. Having the ability to work on a project that ties very closely with the work that I intend to do in the future has been a very nice change of pace from typical prerequisite coursework. It also drives home the importance of working with a team and presenting oneself in a professional manner.

Luke Payne — Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: Once I graduate Virginia Tech I hope to make a difference in the world through my expertise as an electrical engineer. I want to become a well-rounded engineer so that I can be relied on by my peers. I wish to innovate the electrical grid and strive to improve the lives of everyone around me.

Course Comment: Dr. Adams and Dr. Connors are the perfect professors for the Major Design Experience course. The course flowed smoothly from one module to the next and truly prepared me for the real-world. I will take every lesson I learned in the class into the next chapter of my life.

Tianlin Huang — Wuhan, Hubei, China

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I hope to get a job in the United States or join the military. I will work my best to prove my value as an electrical engineer in industry or as a 12P in the army system.

Course Comment: This course allowed me to explore a topic closely related to my future career interests, making the learning experience much more engaging than typical prerequisite classes. I especially appreciated the guidance and support from both professors, whose teaching helped connect the material to real-world engineering practice while emphasizing teamwork and professional communication.

James Stilwell — Mechanicsville, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I will begin a career in the power industry. I am excited by the ever-changing nature of the power grid and increasingly important role it plays. Throughout my career, I hope to play a role in modernizing the power grid and ensuring it continues to provide customers with reliable energy.

Course Comment: I would like to thank our professors, mentors, customers, and subject matter expert for their help with this project. They have provided us with necessary advice and helped us create a project we can be proud of. I would also like to thank the team. It has been a privilege to work with you all and I wish you all the best in your careers.

Cohn Betz — Baton Rouge, Louisiana

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I intend to pursue a career in MEP engineering with a focus on power distribution, protection systems, and low-voltage electrical design. I hope to continue developing my technical knowledge and practical experience while taking on greater responsibility in complex projects.

Course Comment: MDE 4806 has been a great experience. Dr. Adams and Dr. Connors, along with our SME and mentor, provided valuable industry insight that helped prepare me for work after graduation. I look forward to applying the advice, techniques, and skills learned in this class throughout my professional career.

Ethan Hogue — Pittsburgh, Pennsylvania

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I plan to start my career in electrical engineering focusing on green solutions in the energy sector. My goal is to move to a specialized power systems engineering role, where I can apply my technical knowledge to make impactful decisions, while mentoring younger engineers as they begin their careers.

Course Comment: MDE has been a great course for exploring and understanding emerging technologies while emphasizing hands-on experience. Our mentor, SME, and customer have helped the team and me develop relevant industry skills that we can carry into our early careers.

VT Athletic District Microgrid and FLISR Simulation

MENTOR: Prof. Kelley Andrews **SME:** Dr. Ali Mehrizi-Sani
TEAM: Luke Payne, Ethan Hogue, Cohn Betz, Tianlin Huang, James Stilwell, Connor Haymaker

Background

- Modern power systems are increasingly vulnerable to faults and growing load demand. These disturbances can cause outages and unreliable power if not dealt with quickly and effectively.
- A fault location, isolation, and service restoration (FLISR) system aims to handle these disturbances by autonomously detecting faults and isolating them from the system, while continuing to provide power to unaffected loads.
- Microgrids are becoming a key solution for enhancing power system resilience, as they can operate in both grid-connected and islanded modes. These capabilities make it a good fit for implementing the FLISR protection logic to ensure reliable power.

Problem Statement

- Design, simulate, and model a loop distribution system with FLISR capabilities that serves ten buildings located within the Virginia Tech Athletic District.
- The system must respond to changes in real time, automatically rerouting power to keep as many loads energized as possible.
- If available power generation is unable to meet the demand, loads must be shed based on a defined priority list.

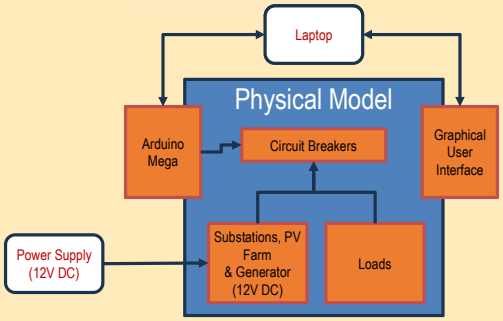
Features

- A tabletop model of the VT Athletic District consisting of the buildings/loads, status LEDs, relays, Arduino Mega, and DC power supplies.
- Automatic reconfiguration based on changing system conditions.
- Responds to the following scenarios:
  - Generator failure
  - Single and dual utility source outages
  - Day and night operation
  - Load shedding
- A graphical user interface (GUI) shows the real-time statuses of all equipment (breakers, loads, utility sources, PV farm, generator) and power flow information.
- A microgrid capable of operating in islanded or grid-connected mode.
  - In islanded mode, the system runs from a PV farm and a fossil fuel generator.
  - In grid-connected mode, the system runs from two utility power sources.

Challenges

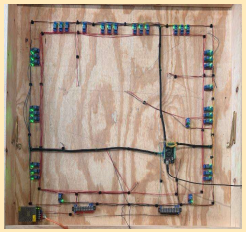
- Converting the AC model of the VT Athletic District from PSCAD simulations to a simple DC circuit.
- Implementing power flow and fault handling logic into an Arduino microcontroller.
- Eliminating memory corruption issues impacting communication between the Arduino and GUI.
- Implementing a functional, low-latency, visually appealing GUI.
- Limiting current to <10mA to ensure safety of operators and components.

Our Solution

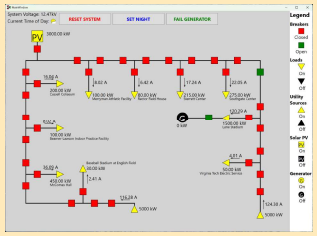


System Block Diagram

Physical Model



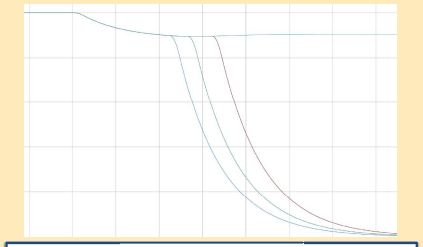
Physical Model Underside



Graphical User Interface

Design Process

Initial system designs and simulations were conducted using Power Systems Computer-Aided Design (PSCAD). These simulations aided the team in determining the ability of the system to respond to various disturbances and events.



PSCAD Simulation

Due to the ease of working with DC circuits and safety concerns surrounding the injection of fault current into the circuit, all power flow calculations and fault propagation logic is handled in the Arduino. The Arduino sends signals to circuit breakers, causing the physical model to reflect the simulated status of the distribution system.

Use Cases

The model is intended to demonstrate the operation of a microgrid loop distribution system in a clear, simple manner. It can be used to

- Teach students the basics of system controls, fault propagation, microgrid operation, and FLISR systems.
- Introduce members of the general public to power system operation in an engaging and interactive simulation.

Conclusion & Next Steps

This project shows the feasibility of a microgrid with FLISR capabilities for the Virginia Tech Athletic District and provides a clear image of how it could be implemented. This solution increases power reliability, and the area will experience fewer interruptions, especially to critical facilities. As microgrids become more standard in modern power systems, the grid will become safer, reliable and more robust.

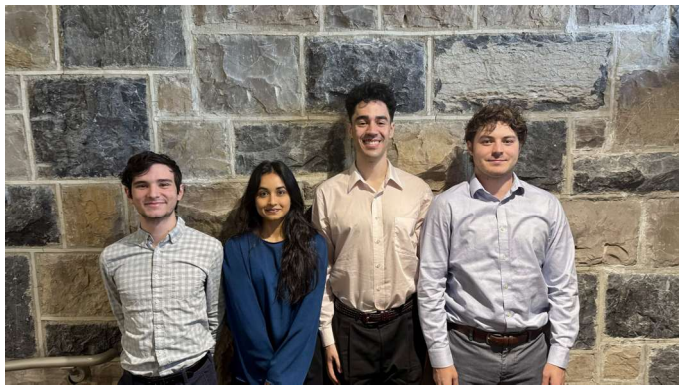
In the future, this system could be revisited to

- Expand the scope of our simulation to include reactive elements.
- Determine appropriate switchgear sizing for each load.
- Identify correct control relays for a more realistic protection scheme.
- Develop real-time SCADA control logic.

Acknowledgments

Special thanks to Prof. Kelley Andrews, Dr. Ali Mehrizi-Sani, and the team at Wiley|Wilson: Gary Li, Dan Morton, Mark Atkinson, and Chuck Niedermayer for their guidance and support throughout this project.

Quantum-Resistant Cryptographic System



LEFT to RIGHT: Aiden Wiehn, Aarushi Sinha, Yassin Lahrime, Samuel Stoke

CHALLENGE

Every day, the world relies on encryption for the transmission and storage of sensitive information. However, classical cryptographic methods have been shown to be vulnerable to emerging quantum computing technologies. For our project, we implemented a messaging application that utilizes post-quantum cryptographic (PQC) algorithms resistant to these quantum cyberattack methods.

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BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Customer: Christiana Chamon Garcia

Yassin Lahrime — Arlington, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I would like to never stop learning and building with emerging technologies. Computing and the way we interface with it as people will always hold a dear place in my heart and I would like to shape that future with one project at a time.

Course Comment: I have enjoyed developing my planning, execution, presentation, public speaking, and teamwork skills throughout the collaborative experience of working on this project. Thank you to all mentors and teammates involved.

Aarushi Sinha — San Antonio, Texas

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I want to build technology that doesn't just work, but truly improves how people interact with the world. My goal is to work at the intersection of software, AI, and systems engineering to refine and improve existing technologies, making complex problems simpler and more intuitive to solve.

Course Comment: Working on this project allowed me to bring together the skills I've developed throughout my degree and apply them to a real-world challenge. It was a rewarding experience that strengthened both my technical abilities and my confidence as an engineer.

Samuel Stoke — Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering
Bachelor of Science
Mathematics

Aspirations: I plan to work in research and development for FPGA systems and hardware security. I find these fields particularly interesting as they allow me to combine my knowledge from computer engineering and mathematics backgrounds to produce meaningful solutions.

Course Comment: The Major Design Experience has given me the opportunity to build a complete project from start to finish with realistic requirements and deadlines. I am glad to have this chance to better understand what it is like working on a large-scale project with a team in a work-like environment.

Aiden Wiehn — Leesburg, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I plan on continuing my education by getting my masters and potentially my PhD in Computer Engineering. I would love to do research in cybersecurity, more specifically hardware security, and may become a professor in the future to teach the new generation.

Course Comment: Senior Design has helped me bring the skills I obtained through my internship and during my time at VT and apply it towards a real world application. I feel like this course has helped me improve many of my weaknesses as a team member and enjoyed working with others on a team.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Quantum-Resistant Cryptographic System

Aiden Wiehn • Aarushi Sinha • Yassin Lahrime • Samuel Stoke

Sponsor: Dr. Christiana Garcia

Bradley Department of Electrical & Computer Engineering

Virginia Tech · 2025–2026

Team S26-37

Left to Right: Aiden Wiehn, Aarushi Sinha, Yassin Lahrime, Samuel Stoke

Problem Statement

Many systems and industries, such as hospitals, banks, and personal devices, rely on cybersecurity measures for protection against cyberattacks. Standard cryptographic algorithms that were once considered robust are now known to be **susceptible to attacks that use quantum-computing techniques** [1].

Our project implements newer algorithms, which are resistant to these quantum-computing attacks, and verifies their practicality. Specifically, we implemented the **Kyber** [2] and **Dilithium** [3] **post-quantum cryptographic (PQC)** algorithms to benchmark performance and reliability metrics such as key-exchange latency and success rate.

We created a messaging application that can run on a local network and allow multiple users to exchange messages securely using PQC and standard cryptographic algorithms.

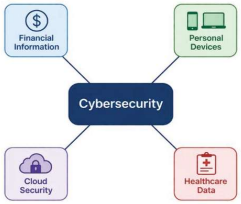

Figure: Applications of Cybersecurity

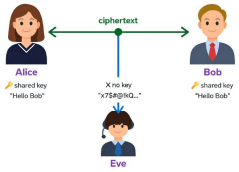

Figure: Alice, Bob, and Eve Diagram

Key Encryption and Authentication

Suppose Alice wants to send Bob a private message. To do this, she will encrypt the message into **ciphertext** using a **secret key** that only she and Bob have access to. When Bob receives the ciphertext, he can decrypt it using the secret key and read Alice's original message. If Eve intercepts the message in transit, she sees only ciphertext and **cannot recover the original message** because she does not have the secret key.

Authentication works similarly, but instead ensures that when Bob receives a message claiming to be from Alice, he can verify it truly came from her and that Eve did not tamper with it along the way.

Post-Quantum Cryptography

Classical schemes like Diffie-Hellman and ECDSA derive their security from problems that a sufficiently powerful quantum computer can solve efficiently using Shor's algorithm (specifically, discrete logarithms and elliptic-curve factoring) [4]. **Kyber** (key exchange) and **Dilithium** (signatures) instead rely on the **hardness of lattice problems**, specifically Learning With Errors (LWE) [5],[6],[7]. No known quantum algorithm offers a meaningful speedup against LWE, making these schemes secure against both classical and quantum adversaries.

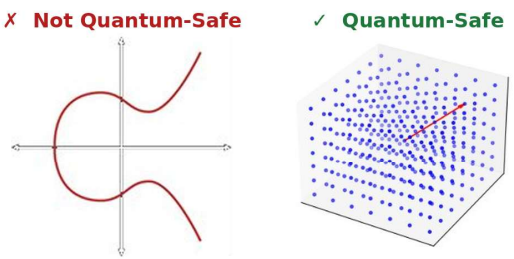

Figure: Elliptic-Curve vs. Lattice-Based Cryptography

Objectives & Requirements

#	Requirement
1	The system shall correctly send and receive messages under high throughput, including key generation, encryption, and decryption.
2	The system shall log all messages and evaluation metrics including CPU usage, latency, and message-pass success rate.
3	The system shall allow users to swap between cryptographic algorithms and compare their performance metrics on a user-friendly dashboard.
4	The system shall use only original or open-source code, with no proprietary dependencies.

Our Solution

We implemented a low-level client-server messaging application written in C, capable of running both classical and post-quantum cryptographic schemes. Users can swap between modes at runtime to directly compare performance metrics.

Role	Classical		PQC
Authentication	ECDSA P-256	→	Dilithium2
Key Exchange	ECDH P-256	→	Kyber-512 KEM
Encryption	AES-256-GCM	→	AES-256-GCM

The system is designed to be **lightweight** and **low-cost**, capable of running on lower-power hardware while still providing quantum-resistant security. Performance is evaluated by simulating message exchanges between users and logging:

- **Latency**: Measures end-to-end handshake time.
- **Key size**: Measures memory overhead of each algorithm's key material.
- **CPU usage**: Measures processing cost of key generation, encryption, and decryption.

Stress Test Results

To test our system, we automated 2000 exchanged messages between two clients across all four modes (NONE, DILITHIUM, KYBER, BOTH), cycling 250 mode visits with message sizes of 16, 128, 512, and 2048 bytes. All sessions were logged to a local JSON file.

Metric	NONE	DILITHIUM	KYBER	BOTH
Auth algorithm	ECDSA-P256	Dilithium2	ECDSA-P256	Dilithium2
KEX algorithm	ECDH-P256	ECDH-P256	Kyber-512	Kyber-512
Median setup cost	3.967 ms	9.584 ms	3.650 ms	9.483 ms
Handshake Size	201 B	3797 B	1704 B	5300 B
Handshake Overhead	1×	∼18.9×	∼8.5×	∼26.4×
Avg CPU usage	0.0%	0.0%	0.0%	0.1%
Peak CPU usage	0.1%	0.2%	0.2%	0.2%

All 2000 messages were successfully transmitted and received by the transmitter and receiver, respectively.

Resource Usage

Our resource planning had two major objectives: to be a lightweight and cheap implementation and to use standardized hardware for our metric evaluations.

Software (All Open-Source)

- **pq-crystals**: Open Quantum Safe library for Kyber and Dilithium primitives.
- **GTK (GIMP Toolkit)**: GUI development in C.
- **Git**: Version control for collaborative software development.

Hardware

- 2× Raspberry Pi 4 Model B (4 GB): Acted as clients to the server, simulating a standardized low-power deployment scenario. Each Pi cost $119.95 giving a total cost of $239.90.

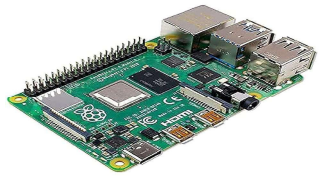

Figure: Raspberry Pi 4 Model B (4 GB)

Conclusions

Standard cryptographic schemes (ECDH, ECDSA) are susceptible to attacks from emerging quantum technology via Shor's algorithm. We implemented a low-level messaging application resistant to these threats by integrating NIST-standardized PQC algorithms (Kyber-512, Dilithium2).

However, PQC comes with a trade-off as handshake sizes are significantly larger. Dilithium adds ∼18.9×, Kyber ∼8.5×, and both combined ∼26.4× the overhead of the classical baseline (201 bytes). Despite this overhead, CPU usage remains negligible across all modes, with peak CPU never exceeding 0.2%.

The authentication cost of Dilithium dominates setup time; Kyber-only mode (3.650 ms) is actually *faster* to set up than the classical ECDSA baseline (3.967 ms).

During stress testing, all 2000 messages were successfully transmitted across all modes, confirming correctness and stability under sustained load on low-power hardware.

Future Work

While this project satisfies all intended goals, there are several open directions for improvement:

- **Larger-scale stress testing**: Extend benchmarks to more client pairs and higher message volumes to evaluate performance under greater concurrency.
- **Additional PQC algorithms**: Integrate other NIST-standardized schemes such as FALCON (signatures) and HQC (key encapsulation) to provide broader algorithmic coverage.
- **Network deployment**: Move beyond localhost to test over real local-area and wide-area networks, measuring the impact of realistic network latency on PQC handshake overhead.

Acknowledgements

The team would like to thank our sponsor, Dr. Christiania Garcia, our subject matter expert, Matthew Eisen, and the Bradley Department of Electrical and Computer Engineering at Virginia Tech.

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[5] O. Regev, "On lattices, learning with errors, random linear codes, and cryptography," *Journal of the ACM*, vol. 56, no. 6, pp. 1–40, 2009.

[6] National Institute of Standards and Technology, "Module-lattice-based key-encapsulation mechanism standard," Tech. Rep. FIPS 203, NIST, 2024.

[7] National Institute of Standards and Technology, "Module-lattice-based digital signature standard," Tech. Rep. FIPS 204, NIST, 2024.

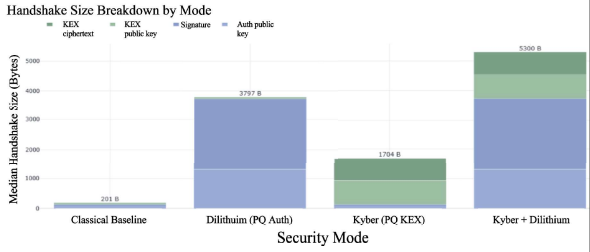
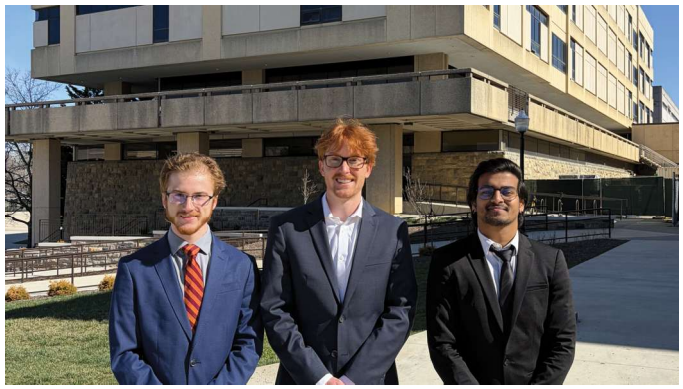


Figure: Our Metric Dashboard

Location and Mapping of a Non-ADSB Aircraft Using RF DoA



LEFT to RIGHT: Will Koeppen, John Henry Ruhl, Siddhanth Lewis

CHALLENGE

The goal of this project is to develop a low-cost system to track aircraft, such as commercial drones, that do not transmit Automatic Dependent Surveillance Broadcast (ADSB) signals with geolocation information. The system should estimate the position of an aircraft in 3D space using RF direction of arrival (DoA) and plot this position on a map alongside the locations of ADSB transmitting aircraft. This forms a more complete picture of local air traffic, therefore improving airspace safety and security.

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Customer: Carl Dietrich

Will Koeppen — Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I intend to pursue a masters degree at Virginia Tech with a focus in electromagnetics. Then, I hope to work in the field as a design or research engineer.

Course Comment: Through senior design, I've learned valuable lessons about working on an engineering team and communicating technical information to a non-technical/adjacently technical audience. I also gained valuable experience with a real-world communications system, and the effects of environmental variables.

Siddhanth Lewis — Dubai, United Arab Emirates

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I aspire to pursue a career in integrated circuit design and contribute to technologies that improve people's lives while driving innovation across multiple fields.

Course Comment: This course provided valuable exposure to leadership and the opportunity to apply my engineering knowledge to a year-long, industry-relevant project. It pushed me to step outside my comfort zone and strengthened both my technical and teamwork skills, making it an important step toward becoming a well-rounded engineer.

John Henry Ruhl — Sterling, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I plan to pursue higher education centered on electromagnetics. Then join the workforce and hopefully contribute to society's quest for knowledge.

Course Comment: This course gave me the opportunity to understand the realities of engineering work in a challenging but reasonable scope. The process of designing, physically implementing, and communicating information about a system provided a well-rounded experience.

Location and Mapping of a Non-ADSB Aircraft Using RF DoA

Team Members: Siddhanth Lewis, Will Koeppen, John Henry Ruhl
Mentor: Dr. Daniel Connors | **Sponsor/SME:** Dr. Carl Dietrich

VIRGINIA TECH
COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH
WIRELESS@VIRGINIATECH

Background

- Recent increase in aircraft that do not transmit an ADSB signal with geolocation information (ex: commercial drones)
- Poses privacy/safety risk, especially around airports
- Need real time location of these aircraft

Requirements

- Continuously estimate the position (coordinates and elevation) of a non-ADSB target using RF signals
- Generate a real-time map of both non-ADSB and ADSB aircraft
- Achieve a total system cost under $1500

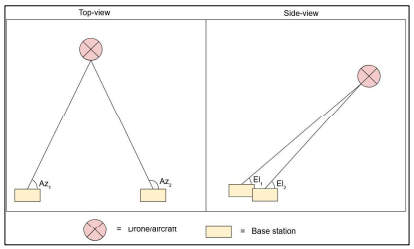
Spec	Requirement
Monitored Volume	125,000 m^3
Maximum Positional Error	10 m
Estimation Rate	5 per second

Assumptions and Scope

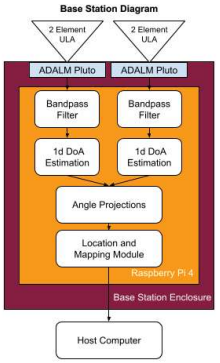
- Single non-ADSB target is tracked at a time using Direction of Arrival (DoA)
- Target is modeled as a continuous wave (CW) transmitter at 2.4 GHz
- Target remains within the forward field-of-view of each base station
- Environment has limited multipath and RF interference
- Base station positions and orientations are known and fixed

Theory of Operation

Each base station estimates RF DoA and forms 3D bearing vectors. The target position is found from their intersection, and an Extended Kalman Filter (EKF) refines the estimate to account for noise and smooth the position estimate over time.



Top Level Design



Base station

Arrays and Filtering:
- Utilizes two collocated λ/2 spaced Linear patch arrays
- Aluminum ground plane added behind arrays to reduce multipath and increase antenna directivity
- Bandpass filters isolate narrowband signal

DoA Estimation:
- MUSIC (Multiple Signal Classification) algorithm with 2 uniform linear arrays
- Estimates cannot be phase coherent due to fundamental hardware limitations
  - Assume angle estimates are taken close enough in time

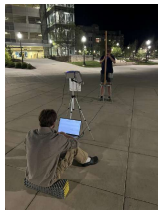
Planar Projection:
- Angles of arrival is computed in incident planes
- Mapping requires azimuth on the plane perpendicular to the array instead
- Corrected using the following equation:

$$\phi = tan^{-1}\left(\frac{\sqrt{1-cos^2\phi^i - cos^2\theta^i}}{cos\phi^i}\right)$$

Localization & Mapping:
- Combines DoA from multiple base stations
- Computes 3D position from bearing intersections
- Extended Kalman Filter (EKF) smooths position over time
- Displays results in real-time GUI

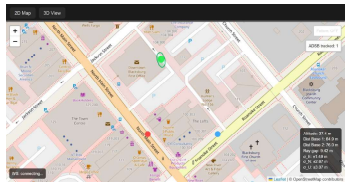
Testing

Base Station Validation:
- Measured DoA accuracy at known positions and elevations
- Testing performed in low-interference outdoor environment
- Results confirm stable and consistent angle estimation



Test in progress at highest tested elevation

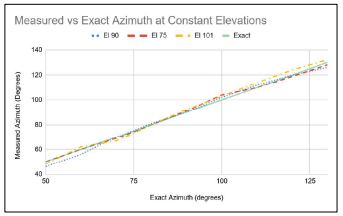
Position Estimation Testing:
- Simulated multi-base inputs used for localization validation
- Verified real-time position estimation and tracking pipeline
- Evaluated performance under varying geometry and noise

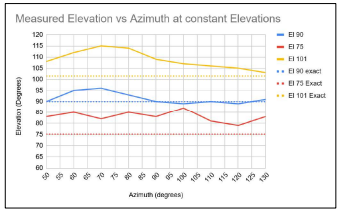


2D view of location and mapping UI

Results

Single Base Station Test:





	Azimuth	Elevation
Mean Error	1.8°	5.7°
Variance	2.3°	16.2°

Conclusions

Although unknown sources of error in the second base station prevented full system assembly, the results of testing the first base station showed that accurate angle measurements can be made at a low-cost. Additionally, our simulations demonstrate the viability of mapping aircraft location with this information.

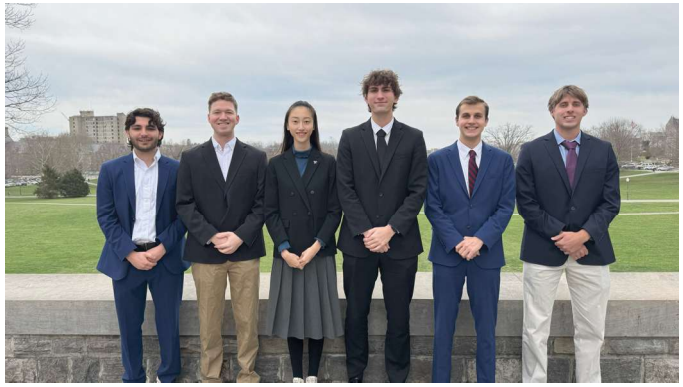
Future Work

- Troubleshoot 2nd base-station and full system integration
- Improve accuracy using phase-coherent SDRs and larger arrays
- Extend system to support multiple targets
- Detect real drone signals instead of CW sources

Acknowledgements

We would like to thank our sponsor Dr. Carl Dietrich from Wireless@VT, our mentor Dr. Daniel Connors, and every other professor or student who provided us with advice and support, including Dr. Majid Manteghi and Dr. Michael Buehrer.

Broadening Airspace Awareness through RF Drone Detection



LEFT to RIGHT: Emile Daniel, Nathan Graves, Apple Zhou, Colin Edsall, Alex Bachman, Brady Falk

CHALLENGE

Our challenge is to develop a radio frequency-based drone identification system to classify commercial off-the-shelf drones as friend or foe. This project demonstrates the capabilities of the ADALM-PLUTO software-defined radio to scan drones in the nearby airspace and decode relevant telemetry data according to the ASTM F3411-22a Remote ID Standard. The designed system must alert the user via a GUI of any detected drones within one second of entering the device's range.

ANALOG DEVICES

Customer: Jeff Chambliss

Alexander Bachman Norfolk, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: After graduation, I plan to start my career in the defense industry, focusing on RF systems. After gaining several years of professional experience, I intend to further my education by pursuing a master's degree.

Course Comment: This course taught me the fundamentals of collaborating with engineers from different disciplines and backgrounds in an industry-like environment. It also strengthened my ability to tackle real-world engineering problems. I'm excited to apply these lessons as I begin my career in industry.

Emile Daniel Gainesville , Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation, I will continue my studies by working toward my Master of Engineering degree, focusing on machine learning. While pursuing this degree, I plan to begin working as a software development engineer.

Course Comment: This course was very exciting and gave me the opportunity to apply the techniques and concepts I learned throughout my time at Virginia Tech to a real-world application. I greatly enjoyed collaborating with my team and look forward to seeing what we all accomplish in the future.

Colin Edsall Richmond, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I plan to start my career as a software engineer focusing on reverse engineering and machine learning applications for FPGAs and hardware design. I hope to make meaningful impacts in the field and grow further as a graduate student.

Course Comment: The Major Design Experience provided direct challenges to our understanding of theory and skills in practice. Throughought the entire engineering process, we discovered that "solving" a problem is easier said than done while learning important skills not taught through courses at Virginia Tech.

Brady Falk Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan on starting a career in either Embedded Systems, FPGA development, or RF systems for defense applications. I want to enter any one of these fields as a humble, passionate engineer who looks forward to learning and contributing as much as I can.

Course Comment: This two semester course gave me industry-like experience where our team was required to design, implement, and test a system for our sponsor's constraints. It was an amazing experience that allowed me to apply skills and knowledge that I gained from throughout my undergraduate studies.

Nathan Graves Houston, Texas

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I will be commissioning into the Army as a Second Lieutenant in the Cyber Branch. I hope to make an impact leading others and using the skills I have learned from Computer Engineering to make a difference in the world.

Course Comment: This course gave valuable experience working in a collaborative effort with other engineers developing a product. It was an excellent culminating course that gave me the chance to use what I have learned from all my previous courses.

Shuyan Zhou Nanjing, China

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I plan to pursue my master's degree in ECE and enhance my knowledge and skills in the field of ECE. I have the desire to pursue my career in RF systems, communications, and semiconductors, contributing to great innovations in the field, while contributing to meaningful innovations while continuing to grow as an engineer and create opportunities to work and collaborate around the world.

Course Comment: The Major Design Experience was especially memorable, as it allowed me to work closely with my teammates, face real engineering challenges, and see our ideas become a working system. Collaborating with my teammates made this experience especially rewarding, and it reminded me that engineering is not only about understanding theory, but about transforming ideas into real systems that solve meaningful problems.

Broadening Airspace Awareness Through RF Drone Detection

Team Members: Alex Bachman[1], Apple Zhou[1], Emile Daniel[1], Colin Edsall[1], Brady Falk[1], Nathan Graves[1]
Customer: Jeff Chambliss[2] | **Mentor:** Dr. Daniel Connors[1]
[1]Virginia Tech Bradley Department of Electrical and Computer Engineering, [2]Analog Devices, Inc.

Background

- Recently, **drone use** in **public airspaces, sporting events, and warfare** have been extremely common.
- Since 2021, non-military drones, commonly referred to as **commercial-off-the-shelf (COTS) drones** are required by the Federal Aviation Authority (FAA) in the United States to broadcast their **unique identifiers and geolocation** from takeoff to shutdown.

- Determining which drones are **authorized** to be in the airspace is challenging due to:
  - **Noise** from multiple devices, such as smartphones and communication infrastructure.
  - No **visible line of sight** (LOS) to the drone.
  - Unknown **transmission channels**.

Our customer wants us to solve this problem using the **ADALM-PLUTO software-defined radio (SDR)** to distinguish authorization from the broadcasted identification.

Problem Statement

The goal of this project is to determine in real time whether a drone is authorized (**friend**) or unauthorized (**foe**) within the range of the ADALM-PLUTO SDR.

- The SDR iteratively **scans all Bluetooth Low Energy (BLE) advertising channels** 37, 38, and 39.
- Extended advertising channels 0-36 are scanned in the same sequence.
- The system decodes the **Open Drone ID (ODID)** packages using the **ASTM-F3411 22a** standard and **classifies detected drones**.

The system is designed to **demonstrate the hardware and software-integration capabilities** of the customer's ADALM-PLUTO.

Hardware

- **ADALM-PLUTO SDR** used to sample RF signals and perform analog-to-digital conversion.
- Configured for maximum instantaneous bandwidth sampling across the Wi-Fi band (2.4 GHz).

- **Raspberry Pi 5** used as the basis for the operating system and processor for algorithms.
- Controls interfacing and decision logic for detection as well as operator interfacing.

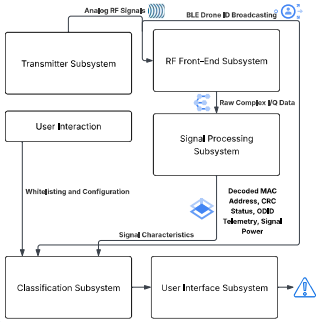
- A **20,000 mAh battery** provides power for the entire system including.
- Configured to be charged during operation or operate in the field.

- **Secure Shell (SSH)** connection for operator control and tweaking while in the field.
- **Whitelisting/Blacklisting** control exists to authorize and deauthorize drones.

The hardware is placed in a **3D-printed enclosure** to ensure portability and function as an integrated unit.

- Upon powering up, the device automatically begins detecting drones.
- The operator may interface using a mouse and SSH.

System Overview



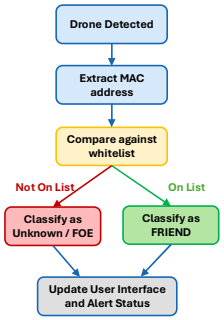
Signal Processing

- The Raspberry Pi processes the RF data in real time.
- Detects BLE packet structures and extracts valid transitions.
- Filters for Open Drone ID (ODID) packets (BLE UUID: 0xFFFA).
- Decodes ODID packets for:
  - MAC address.
  - Drone Identification data.
  - Telemetry.

User Interface and Friend/Foe Classification

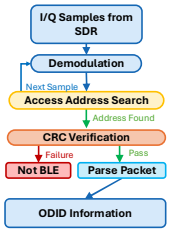
- The user interface will display when a drone is present and if it is classed as a friend or foe.
- The extracted MAC address is compared to a user defined whitelist.
- The user can manually add MAC address to the whitelist when the drone appears.

Friend Vs Foe Decision Flow



System in Operation

ODID Decoding Algorithm

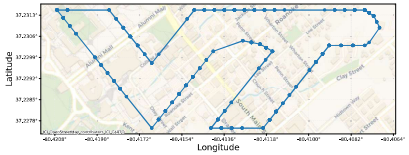


- The UI (right) updates to show the decoded location and its status as a **friend or foe**.
- The **whitelist** can be dynamically updated with operator interfacing to remove or add new drones as friends.
- **Drones are tracked on the map** and their ODID information is decoded on the left panel.

- The operator can see the **relative number of packets** that are rejected and accepted as drones to indicate noise.
- The **live spectrum above the map will indicate abnormal SNRs** to show that there is too much interference for the low-power SDR to pick up ODID packets.

System Testing

Detected Drone Geolocation Tracking Plot



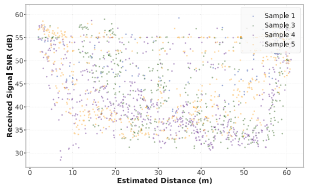
Simulated Drone Flights

- Spoofed flight path (left) using extended advertising packets shows that the receiver subsystem can **detect, track,** and **label** one or more drones at the same time.
- The system can decode legacy and extended advertising packets in the same pass across **40 different broadcasting channels**.

Noise Rejection

- **Most signals (75%) captured as BLE packets are rejected**. This indicates that noise from other devices such as Wi-Fi routers, smartphones, and laptops are properly rejected from our detection suite.
- Since many drones "advertise" and "communicate" on different channels, it is possible that **a drone may exist simultaneously on two BLE channels**, which accounts for about 25% of signals captured in the field.

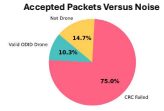
BLE Spoofer Received SNR vs. Estimated Distance



SNR Range Testing

- Power (SNR) of received spoofed signals moving the spoofer away from the receiver during scans.
- We observe **a functional SNR range between 55 and 30 dB** as the acceptable range for accurate detection.
- Real drones may have lower SNR but higher quality signals, pushing the SNR detection floor lower.

Accepted Packets Versus Noise



Conclusions

Successes

- The system can detect COTS drones accurately up to about **100 feet away**.
- Detected drones are **updated** every half-second while staying "detected" for a configurable amount of time.
- Fully compliant ODID information is **decoded** from all received packets and **displayed** to the user.
- The receiving system is completely **passive** and operates automatically with minimal operator interaction.

Limitations

- The ADALM-PLUTO SDR has a fair instantaneous scanning bandwidth, but **it cannot simultaneously scan two frequency bands**.
  - System must **iteratively scan across BLE channels** (shown above).
  - We can "lose" a signal if we do not capture it in the same window.
- The **Pi has limited processing power** and must operate relatively slowly per channel.
- The ADALM-PLUTO SDR may not be receiving enough power from the Pi, causing it to have **lower receiver gain**, limiting range and signal error.

Future Work

Future work to improve the project may include **using an array of SDRs** to increase reception range and accuracy beyond the single SDR at low power.

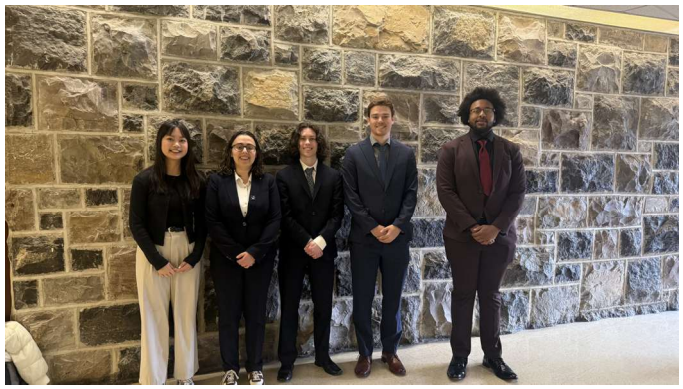
Adding **receiver geolocation capabilities** (such as a GPS module to the Pi) would allow the device to be mobile during operation while tracking itself and drones.

The system may also want improved **quality of life features**, such as **a larger screen or a touch screen**, tracking past and previous locations of **multiple drones at the same time**, and having a longer battery life.

Acknowledgements

1. We acknowledge the funding and guidance provided for this project by the Bradley Department of Electrical and Computer Engineering at Virginia Tech to purchase hardware and support creation of this poster.
2. We thank Analog Devices, Inc. in providing two ADALM-PLUTO SDRs to use in our product free of charge.

Framatome Quadrature Inclinometer Design



LEFT to RIGHT: Timberly Tran, Molly Shear, Max Linville, Alex White, Richard Harrison

CHALLENGE

Our challenge is to reverse engineer a replacement inclinometer PCB for Framatome, based off the obsolete US Digital X3M inclinometer. The inclinometer will be installed within a robot which climbs up the core of a nuclear power plant to inspect welds for quality control, and will measure the angle of this robot very precisely to ensure correct and repeatable movement. The design must be a drop-in replacement for the current inclinometer in the robot and seamlessly integrate with the other measurement and control systems already installed to ensure ease of operation.

framatome

Customer: Kenneth Ritchey

Richard Harrison — Brooklyn, New York

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: To become a hardware engineer specializing in FPGA and ASIC design, with strong expertise in embedded systems and hardware- software co-design. My short-term goal contribute to systems that balance power, cost, and performance and my long-term goal is to transition into entrepreneurship, building modular electronics focused on reconfigurable, well-documented digital systems that are accessible and sustainable.

Course Comment: I enjoyed working with my team, utilizing the skills I'm proficient in and learning from my peers. The we have learned from this project will last a lifetime and be a foundation for our careers.

Max Linville — Leesburg, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Bachelor of Science
Physics

Aspirations: I plan to attend graduate school in Germany and study control systems. I would like to work on automation processes or I&C for nuclear power plants or renewable energy systems. Eventually I hope to have made significant contributions in the advancement andadoption of nuclear power systems, or in hardware infrastructure forquantum computing networks.

Course Comment: I enjoyed working with my team, utilizing the skills I'm proficient in and learning from my peers. The we have learned from this project will last a lifetime and be a foundation for our careers.

Molly Shear — Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Throughout my Computer Engineering degree at Virginia Tech, I have discovered my passion for embedded programming and digital design. More specifically, I enjoy low level programming and digital design. After graduation, I plan to take what I have learned at Virginia Tech and apply it to my career in industry starting this summer.

Course Comment: I enjoyed working with my team, utilizing the skills I'm proficient in and learning from my peers. The we have learned from this project will last a lifetime and be a foundation for our careers.

Timberly Tran — Annandale, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My goal is to contribute and support the shift towards sustainable and green power in the electrical industry. I will be getting my EIT license, and then I will study and work towards getting my PE and LEED AP licenses.

Course Comment: I enjoyed working with my team, utilizing the skills I'm proficient in and learning from my peers. The we have learned from this project will last a lifetime and be a foundation for our careers.

Alex White — Ellicott City, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I intend to pursue a career in industry. Throughout my career, I hope to be able to make meaningful contributions to products which will improve our society as a whole and raise the quality of life for people around the world.

Course Comment: I enjoyed working with my team, utilizing the skills I'm proficient in and learning from my peers. The we have learned from this project will last a lifetime and be a foundation for our careers.

Framatome Quadrature Inclinometer Design

Customer: Framatome
Mentors: Kelley Andrews, Dan Connors
Team Members: Molly Shear, Max Linville, Timberly Tran, Richard Harrison, Alex White

BACKGROUND

MAGNUS Robot

- Most US nuclear power plants are working past expected operating lifetime
- Framatome Performs Non-Destructive Examinations on nuclear power plants
- MAGNUS Robot Inspects welds on reactor cores

- Cannot physically watch the robot move due to the irradiated environment
  - **How do you know if the robot went where you told it to go?**
  - **Use an inclinometer!**

OBJECTIVES

Design and fabricate a replacement for US Digital's obsolete X3M inclinometer

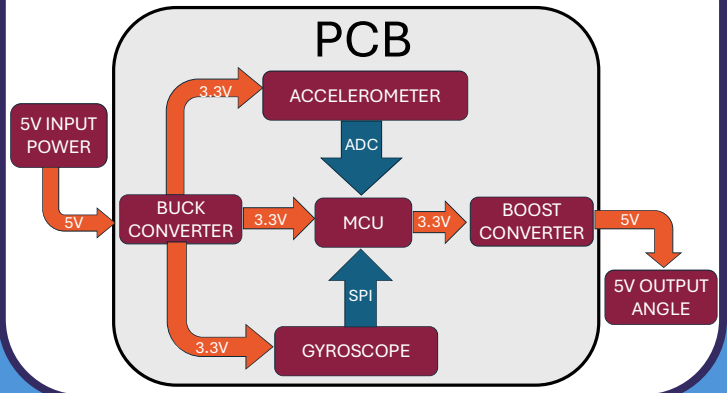
- ±0.2° angular accuracy
- 640 Hz update rate
- Quadrature encoded output
  - Variable counts per evolution from 1-9000
  - 6900 Hz output rate
- 5V Input/Output power
- PCB with the same dimensions as the original inclinometer

Original X3M Inclinometer

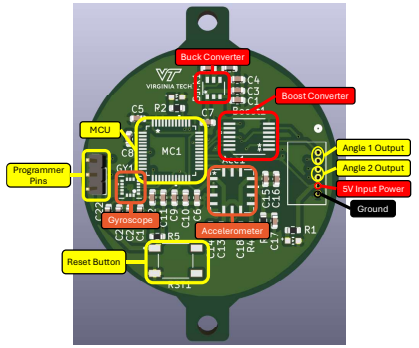
SOLUTIONS

Accelerometer: Measures linear acceleration
Gyroscope: Measures angular velocity
ADC: Input analog data into MCU and oversample from 12-bit to 16-bit accuracy
Kalman Filter: Uses accelerometer and gyroscope data to predict the next data point to increase accuracy

SYSTEM OVERVIEW

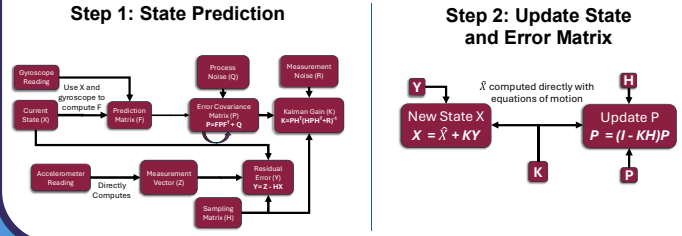


PCB DESIGN

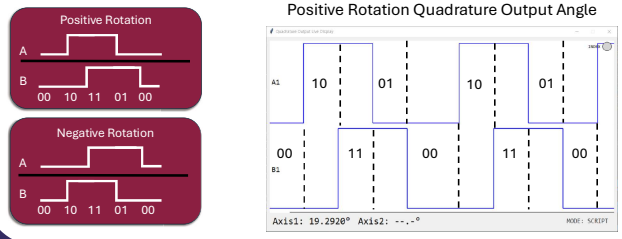


KiCAD 3D Model

KALMAN FILTERING

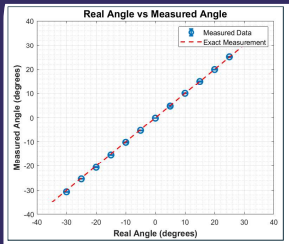


QUADRATURE ANGLE

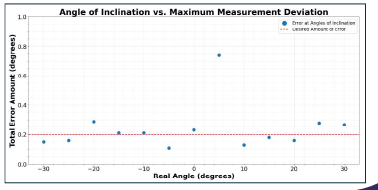


Positive Rotation Quadrature Output Angle

RESULTS



Inclinometer Measured at 30 Degrees



ACKNOWLEDGEMENTS

We would like to acknowledge the contributions of our mentors Kelley Andrews and Dan Connors, our customers Ken Ritchey, Gary Novak, and Erich Thurm from Framatome, Austin Jobin, and the team at the VT Frith Lab. Our project would not have been possible without their support.

Portable Electronic Device Detector

LEFT to RIGHT: Anjala Maddur, Chase Lindal, Evan Preta, Sreeram Ravichandran, Thomas Hurlock, Neha Mehta

SME: Louis Beex

CHALLENGE

Our challenge is to design a portable electronic device detector that can be used in Sensitive Compartmented Information Facilities to alert individuals who try to enter these secure spaces with an electronic device on his or her person. A software-defined radio-based detector in conjunction with an RF shielding enclosure and graphical user interface should detect electronic devices and convey information about detections to users.

ZETA ASSOCIATES

Customer: Michael Drescher

Tommy Hurlock Chesterfield, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Following graduation, I will be joining the team at Norfolk Naval Shipyard to modernize the electrical systems on base. I hope to continue learning through industry and live a comfortable life.

Course Comment: This course was very interesting and gave real experience in working on a long-term project with a team. Through technical and team problems I was able to learn about communication and co-operation.

Chase Lindal King George, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: After graduation, I will commission into the United States Navy as a Nuclear Surface Warfare Officer. In this role, I will have the opportunity to serve something greater than myself while developing valuable leadership and engineering skills within the nuclear field. Looking ahead, I aspire to contribute meaningfully to the advancement of nuclear power while building a life that allows for continued learning, exploration, and the opportunity to travel the world.

Course Comment: The course was beneficial in teaching me the ability to research and execute a product idea given input from subject matter experts and a sponsor. It also offerred a working environment with people of diverse engineering backgrounds to collaborate with. Lastly, the course lecture times facilitated a sleep-wake cycle suitable for the real world.

Anjala Maddur Herndon, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: After graduation, I will intern as a DSP engineer and return to Virginia Tech to complete a master's degree in Electrical Engineering, with a focus in communications. After obtaining my master's degree, I aspire to work in the fields of RF and wireless communications to help bolster communication systems in an increasingly interconnected world.

Course Comment: This course taught me how to navigate the various aspects, both technical and non-technical, of engineering design. Technically, I learned the mechanisms of RF signals and communications systems, and non-technically, I developed professional communication skills in working with the team, mentor, subject matter expert, and customers.

Neha Mehta Clifton, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: After college I will begin work as a DSP engineer with CACI. My goal is to eventually work on technologies or systems that get sent to outer space. Space exploration has always been an interest of mine, and it would be amazing to contribute to that endeavor.

Course Comment: This project taught me a lot about communciations technologies. It was a valuable experience working with people within our group and with external parties.

Evan Preta Great Falls, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to have a successful career as a patent attorney. As an electrical engineer, I hope to bring my technical knowledge into the legal profession and help clients secure protection over their original ideas. Through my work, I wish to encourage engineering excellence to people I currently consider my peers.

Course Comment: This course has provided me the problem solving skills and real-world perspective that I believe will be valuable in my next chapter of life. Through working directly with an industry partner, I've learned the communication style that garners success. I believe this course is essential to the professional development of a young engineer.

Sreeram Ravichandran Dubai, United Arab Emirates

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to start as a Computer Engineer, contributing to innovative and high-performance systems. My long-term goal is to evolve into a technology entrepreneur, leveraging both technical depth and business vision to build impactful ventures.

Course Comment: Senior Design allowed me to bridge the gap between theory and practical implementation. I strengthened my ability to collaborate with others and developed skill sets involving project management and advanced technical development while completing a project.

Portable Electronic Device Detector

Team Members: Thomas Hurlock, Chase Lindal, Anjala Maddur, Neha Mehta, Sreeram Ravichandran, & Evan Preta
Customers: Michael Drescher, Jared Desai, & Randeep Baweja **SME:** Dr. A. A. Beex **Mentor:** Dr. Daniel Connors

Background

The prevalence of personal portable electronic devices (PPEDs) has caused accidental breaches to national security when individuals enter Sensitive Compartmented Information Facilities (SCIFs) with PPEDs on their persons.

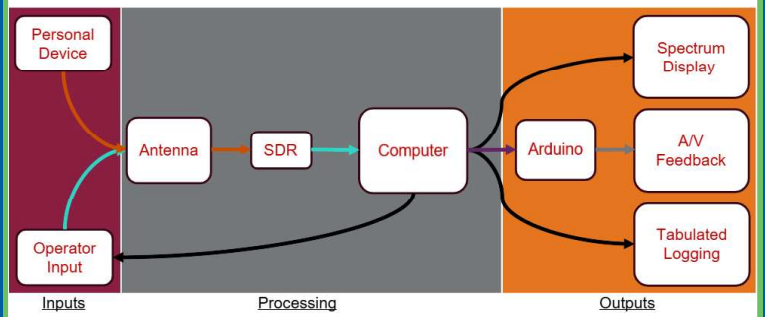
Problem Statement

- To build a portable system that can detect when individuals accidentally attempt to enter a SCIF with a PPED
- The system should consist of an RF isolating enclosure, detection algorithm, and graphical user interface to indicate PPED detections or the lack thereof.

Technical Requirements

- Detect all RF emissions up to 6 GHz within the enclosure.
- Log all detected RF transmissions within a historical table.
- Ensure no more than one false positive detection per hour.
- Create a portable enclosure capable of being moved and setup by an individual.
- Provide audio/visual feedback to operator on detection status.

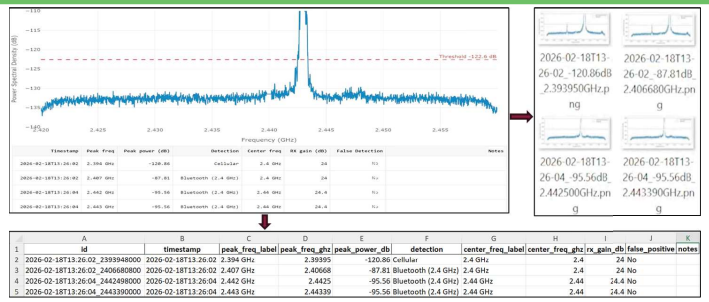
Final Design



Top-level System Diagram

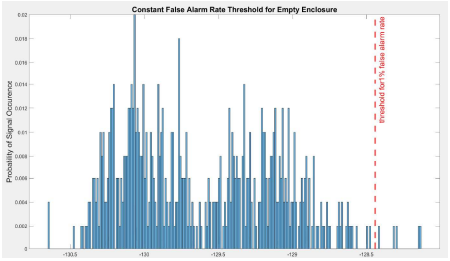
Enclosure Setup

- RF blocking fabric composed of a copper-nickel blend provides the RF isolating effects of the enclosure.
- Magnetic tape seals the open face of the enclosure to maintain RF isolation.
- Enclosure itself is a plywood structure with an attached antenna.



Detection User Interface

System Validation



Power Threshold Level to Ensure <1% Chance of False Detection

Conclusion

- Enclosure and algorithm meet all technical requirements.
- All RF emissions within enclosure are being detected and logged.
- Interface provides real-time feedback on detections and non-detections.

Future Work

- Identify a specific modulation scheme for detected transmissions.
- Create an expanded doorway-shaped enclosure with dedicated entry and exit.
- Add a method of detecting uplink Wi-Fi and cellular signals.

Acknowledgements

We would like to thank Dr. Daniel Connors and Dr. A. A. Beex for their support and guidance throughout the project. We would also like to thank Michael Drescher, Jared Desai, and Randeep Baweja from Zeta Associates for sponsoring our project.

8-Element X-Band Digital Phased Array with RFSoC

LEFT to RIGHT: Daniel Pasicov, Kyle Walker, Nick Bonanno, Joseph Nadeau, Alexander Jellison

SMEs: Brad Davis and Joseph Gaeddert

CHALLENGE

Our team was given the challenge to develop a fully functional X-band Direction of Arrival (DoA) phased array tracking system. Our team is using a Radio Frequency System on Chip (RFSoC) to make a digital phased array for the ability to track multiple targets in the far-field. Our system needs to be fast and reliable to stream in data and update in real time.

Customer: Bill Smith

Nick Bonanno — Falls Church, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I will be pursuing a master's degree in phased array processing at Virginia Tech. After that I will be working in high power microwave systems. My main field of interest is phased array radar analysis and design and I hope to get experience with them in the future.

Course Comment: MDE has been a good opportunity for a "lifelike" end-to-end design experience. I have had a fun time being a "full stack" engineer in this project, doing FPGA, RF, algorithmic, and system level design.

Alexander Jellison — State College, Pennsylvania

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I will be pursuing a masters degree at Virginia Tech in Antennas and Propagation. Following that, I wish to become a engineer in the field of high power microwave, specifically for counter UAS systems.

Course Comment: The major design experience has provided me with a unique opportunity to solve open ended, industry-like problems. Learning to CNC machine, design RF PCBs, and broadband antenna design have set me up for industry like no other course has.

Joseph Nadeau — Chatham, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: Once my undergraduate academic career is finished I plan to keep on the same track continuing into a master's degree to hopefully set me in a nice spot to start a career in RF Engineering.

Course Comment: This class gave me a great look into how Virginia Tech engineers tackle real world problems. Teaching some of us to step out of our comfort zones and take a full project head on. Being able to apply complex topics like FPGA developement and RF circuit designs.

Daniel Pasicov — Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: Upon graduating, I plan to enter industry and pursue a career as an antenna and RF engineer.

Course Comment: This course has provided an excellent transition from pure theory to hands-on experience, which not only improves employability but also builds the confidence to believe that any task is achievable.

Kyle Walker — New Market, Maryland

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: After graduating, I will be returning to Virginia Tech to get my Master's degree. Upon getting my Master's, I aspire to join a cutting edge company as an analog design engineer, and look forward to using the skills I have learned in my time at Virginia Tech to solve important engineering problems.

Course Comment: This course has provided me with an industry-like engineering experience and has allowed me to develop important engineering skills like learning how to use a CNC machine and design PCBs on KiCad. Working in a team setting has also allowed me to grow as a collaborator and see how much more can be accomplished through effective teamwork.

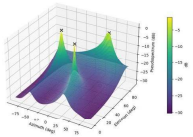
8-Element Digital Phased Array with RFSoC

Sponsor: Bill Smith **SME:** Dr. Joseph Gaeddert and Dr. Bradley Davis
Team: Nicholas Bonanno, Alexander Jellison, Kyle Walker, Joseph Nadeau, Daniel Pasicov

Motivation:

Overcome multi-target tracking limitations of analog phased arrays by leveraging digital phased arrays to determine multiple directions-of-arrival (DoA)

- Real-time tracking
- Improved accuracy and precision
- Digital processing with an RFSoC

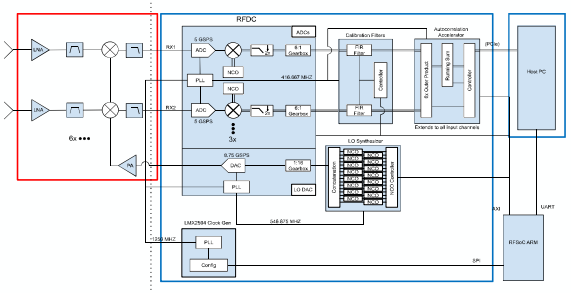


MUSIC 3D Pseudospectrum Simulation

Requirements and Solution:

Technical Requirements:

- X-band (8-10 GHz) receive capability
- Instantaneous Bandwidth of 200MHz
- ±45-degree azimuth and ±10-degree elevation field of view (FoV)
- Real-time processing capabilities

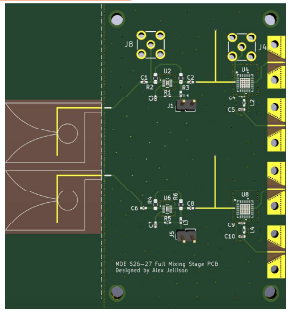


Proposed Solution:

- X-band RF mixing stage
  - Broadband Vivaldi antennas
  - Low noise amplifiers and precise filtering
  - Analog down conversion below 2.5GHz (limited by 5GSPS ADC)
  - Digital to analog converter (DAC) output as local oscillator (LO) for mixing stage
- RFSoC based data processing
  - Sampling and processing of data (80GB per second)
  - Correlation of elements (autocorrelation accelerator)
  - Communication to Host PC (PCie)
- Host PC
  - MUSIC algorithm DoA
  - Intuitive visual display

Design/Fabrication:

- Custom PCB Design
  - Integrated broadband antennas
  - Mixing stage
  - Amplification and filtering
- Simplified integration with RFSoC
  - SMA connections
- Custom housing built to enforce spacing
  - Improves performance of MUSIC algorithm



Custom Designed PCB

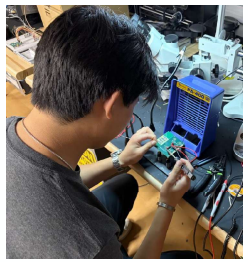
Module Testing

Initial Construction and Testing

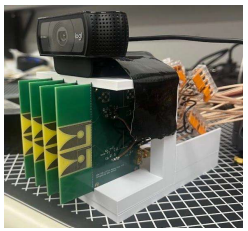
- Initial tests indicated unstable amplifiers and incorrectly cut antennas
  - Boards had to be refabricated
  - Evaluation board for power amplifier was purchased
  - Antennas were cut with laser for initial testing
- SMAs presented poor match
  - SMA type and footprint altered

Iterated Fabrication and Testing

- Adding ground vias beneath LNA pad removed oscillations
- Updated SMAs were solder-free and reduced losses
- 3D-printed enclosure used to hold PCBs
  - 4 total PCBs with two signal paths on each



PCB Soldering



8-Element RF Front End in 3D-printed enclosure

Results:

Front End Results

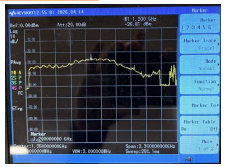
- RF Front End successfully downmixed X-band signals
  - 8-10 GHz signals correctly mixed to 0.25-2.5 GHz
- LNA drew desired amount of current (~70 mA)

Back End Results

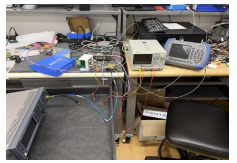
- Digital backend successfully sampled and digitized incoming signals at 5 GS/s

System Integration

- 8 elements of RF Front End connected to receive ports of RFSoC
- Full system test conducted using X-band transmitter



Frequency response of mixer on spectrum analyzer with 7.75 GHz LO



Full system test setup

Conclusion:

Our system provides a streamlined solution to multiple target tracking at X-band utilizing an RF front end and RFSoC based digital backend. The graphical overlay allows users to easily see tracking of multiple targets in real time.

This solution will be used at Virginia Tech's National Security Institute for a multiple sensor tracking project to track signals of interest when optical sensors lose line-of-sight.

Acronyms:

- RFSoC – Radio Frequency System on Chip
- RF – Radio Frequency
- LNA – Low Noise Amplifier
- ADC – Analog-to-digital converter
- PCB – Printed Circuit Board
- SMA – SubMiniature Version A connector
- MUSIC – Multiple Signal Classification

Acknowledgements

Dr. Joseph Gaeddert, Dr. Bradley Davis
Bill Smith, Logan Cypser, Domenic Marcelli, Sean McShane

HUME CENTER FOR NATIONAL SECURITY AND TECHNOLOGY
VIRGINIA TECH

NAVSEA WARFARE CENTERS DAHLGREN

Hybrid Array Beamforming: Radio & Algorithm Design

LEFT to RIGHT: Danial Mahmoudi, Rohit Rangaraj, Charles Early, Eliot Turner, Elias Charron, Fetra Ramiandrisoa

SME: Tarun Cousik

CHALLENGE

The MICS Lab at VT has tasked our team with developing a hybrid beamforming testbed and implementing a novel hybrid beamforming algorithm on it. The testbed needs to have transmit and receive beamforming capability at X and C band frequencies across azimuth and elevation. This project combines algorithmic design, implementation, and antenna design within the constraints of hybrid beamforming.

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Customer: Jeff Walling

Elias Charron — Arlington, Massachusetts

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Really interested in learning more math that goes into DSP, array processsing, and other adjacent fields! Excited to graduate and continue my exploraton of it!

Course Comment: Thanks to my capstone project, I now know what do I want to study in grad school!

Charles Early — New York, New York

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I look forward to pursuing a PhD in computational electromagnetics before starting my career.

Course Comment: This project allowed me to get valuable hands on experience with Antenna design in a challenging and collaborative environment.

Danial Mahmoudi — Ashburn, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I am passionate about digital hardware design, particularly FPGA development and chip architecture. I hope to pursue a career in the semiconductor industry and plan to continue my education with a Master's degree in the near future.

Course Comment: Through this course, I learned more about the technical challenges involved in connecting hardware and software through firmware. It pushed me to challenge myself and apply knowledge from many areas of my computer engineering education, while also giving me a chance to reflect on what I have learned over the past four years.

Fetra Ramiandrisoa — Falls Church, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My main interests in ECE are digital design, digital signal processing, and communication systems. I want to spend a few years in industry after I finish undergrad before I pursue a Master's degree in those fields.

Course Comment: This project has given me the opportunity to work on the bleeding edge of adaptive beamforming research, which has shown me how much I enjoy this field.

Rohit Rangaraj — Coimbatore, India

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I am passionate about learning more about the world everyday. I have had a very exciting experience during my undergraduate studies here, and being involved with design teams and cutting edge research labs has been extremely motivating and provided me with a lot of learning. I am pursuing graduate studies in RFIC design and adaptive signal processing with Dr. Walling here at Virginia Tech.

Course Comment: This class provided me with an opportunity to fully design a system out of my research project making me face the non-idealities of reality with RF systems and giving me an opportunity to engineer my way around them.

Eliot Turner — Pittsburgh, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My interests lie in computer architecture and digital hardware design. I hope to move into industry in those fields, and plan to continue my education and earn a Master's degree in the near future. I'd also love to utilize my Irish citizenship to live and work in the EU and travel the world.

Course Comment: This class helped me develop my application and collaboration skills while gaining valuable engineering experience. Working with the team, customer, SME, and career engineers was both unique and enriching.

Hybrid Array Beamforming: Radio & Algorithm Design

Team Members: Rohit Rangaraj, Elias Charron, Eliot Turner, Fetra Ramiandrisoa, Charles Early, Danial Mahmoudi
Mentor: Dr. Daniel Connors | **Customer:** Dr. Jeffrey Walling
Subject Matter Expert: Tarun Cousik

Motivations

- Recent developments in hybrid beamforming have inspired research at Wireless@VT to develop novel beamforming algorithms
- These algorithms haven't been tested thoroughly in realistic scenarios, due to the lack of proper testbeds

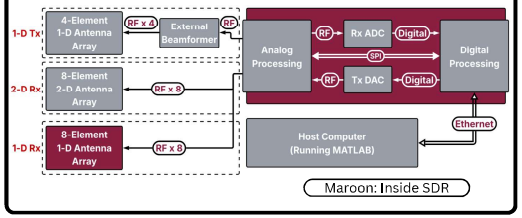
Objectives/Key requirements

We are building a testbed which must be capable of:

- Transmit beamforming in one dimension
- Recieve beamforming in two dimensions
- Operating at 10 GHz & the 5.8 GHz ISM Bands

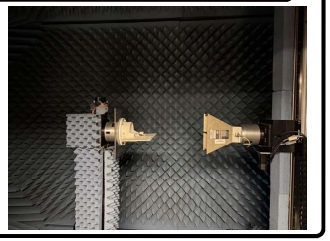
System Overview

- Three testbed configurations:
  - 1-D Transmit
  - 1-D Receive
  - 2-D Receive
- Testbeds are built on the PHASER platform provided by Analog Devices Inc (ADI)
- By enabling additional capabilities of the PHASER, we can provide additional research opportunities to Wireless@VT and MICS in radar and next-gen communications



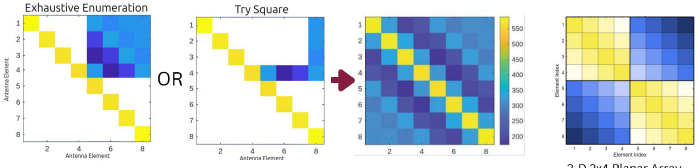
Testing

- Wireless@VT and MICS labs and equipment were used for testing Rx and Tx sub-systems
- Dr. Manteghi's anechoic chamber was used to perform antenna/array measurements



Receive (Rx)

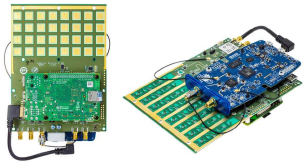
- Implemented Exhaustive Enumeration (EE) sampling strategy to complete the covariance matrix for a hybrid uniform linear array
- Implemented Try Square method to optimize the EE method by reducing required samples
- Used the same principle for a 2D uniform rectangular array, demonstrating 2D calibration and 2D data collection



Transmit (Tx)

- Tx beamforming is desired to improve gain, efficiency, and spatial multiplexing capabilities
- The ADI PHASER platform is limited to Rx beamforming
- An ADI ADAR1000 auxiliary beamforming module was integrated in both hardware and software into the PHASER platform, enabling Tx beamforming

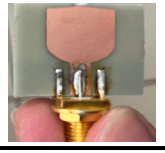
ADI ADAR1000 Eval Board (Transmit Beamformer)



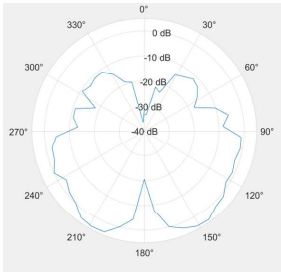
ADI PHASER Board (Core SDR)

Antennas

- The ADI PHASER's antenna array is designed to be operated at 10 GHz
- We designed a dual band array using ANSYS HFSS to operate at both the PHASER's 10 GHz band and the 5.8 GHz ISM band
- Utilizes broadband monopole patches theoretically capable of radiating from 5 to 11 GHz
- Gain between 3-5 dBi
- Has monopole "donut" radiation pattern at both 5.8 GHz & 10 GHz

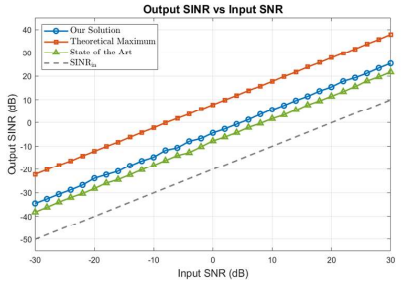


Radiation pattern at 10 GHz



Results

- As a proof-of-concept for our testbed, we've implemented an improved hybrid beamforming algorithm showing signficiant improvements



Conclusions

MICS & Wireless@VT will now have the capabilities to:

- Transmit (Tx) and Receive (Rx) beamforming in 1 dimension (Azimuth)
- Receive (Rx) beamforming in 2 dimensions (Azimuth and Elevation)
- Operate at multiple frequency bands (5.725 - 5.875 GHz and 10 - 10.5 GHz)

Future Work

- Test beamforming algorithms in 5.8 GHz ISM band
- Develop two-dimensional transmit capability
- Modify the antenna array to improve its radiation pattern and reject sides/grating lobes

Acknowledgement

We would like to take a moment to sincerely thank the following individuals and organizations for their support throughout the project. Their guidance, foresight and experience were essential to meet the requirements.

Mentor: **Dr. Daniel Connors**
Customer: **Dr. Jeffrey Walling**
Subject Matter Expert: **Tarun Cousik**
Advisors at Analog Devices: **Jeff Chambliss, Jon Kraft**
Antenna Manufacturing & Testing: **Dr. Majid Manteghi, Shashank Chinnakkagari, Peter Costescu**

Sensor System for LoRaWAN

Track 4 Winner

LEFT to RIGHT: Kieron Skyers, Joandry Santos, Dina Alshehri, Christopher Wiencko, Yusef Mahmoud

CHALLENGE

Our challenge addresses the need for a cost-effective and generalized sensor node system that utilizes LoRaWAN. The fully enclosed, solar-powered device supports data collection through UART, I2C, and SPI communication protocols, in addition to analog and digital voltage. The node transmits encrypted data over the US915 MHz band to The Things Network via a campus gateway, eventually feeding into an application interface. To ensure seamless maintenance, the sensor node supports remote management and configuration directly through the application interface, utilizing LoRaWAN downlink capabilities to update device parameters without requiring in-person intervention.

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Customer: Scott Midkiff

Dina Alshehri — Riyadh, Saudi Arabia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My aspiration is to continue my education through a master's degree in ECE and grow into a successful engineer. Through my journey, I hope to contribute to greater representation of women in engineering.

Course Comment: This course provided me with industry experience and helped me grow both technically and professionally.

Yusef Mahmoud — Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: After earning my degree in Computer Engineering, I plan to leverage my experience with wireless protocols and hardware integration to engineer robust IoT and embedded systems.

Course Comment: A highly rewarding experience that provided practical exposure to complex system design alongside crucial project management and communication skills.

Joandry Santos — Springfield, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am interested in pursuing software roles involving backend development and embedded systems.

Course Comment: This course was a great way to get industry-like experience and understand what it's like working in a team.

Kieron Skyers — Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After graduation I plan to land a position in the semiconductor industry and pursue a Masters after working for a couple of years.

Course Comment: This course is a great way to apply knowledge and further develop skill we learned throughout our time here.

Christopher Wiencko — Winchester, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Bachelor of Science
Mathematics

Aspirations: I aim to be an embedded engineer in the near future.

Course Comment: I greatly appreciated the hands-on engineering experience I gained throughout this course.

Sensor System for LoRaWAN

Team Members: Dina Alshehri, Yusef Mahmoud, Joandry Santos, Kieron Skyers, Christopher Wiencko
Customer: Dr. Scott Midkiff, VT ECE **SME:** Dr. Scott Midkiff **Mentor:** Dr. Shelley Stover

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BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Background

- **What is LoRaWAN:** Essentially a LPWAN (Low Power Wide Area Network)
- **Long Range:** Connectivity of 3+ km easily attainable
- **Low Power:** Minimal energy draw < 100mA on transmission
- **Low Cost:** Utilizes affordable, open-standard hardware minimizing deployment expense

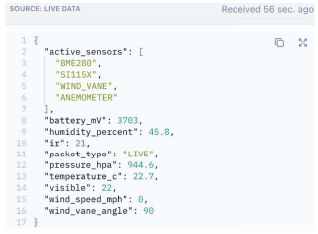
Objectives & Key Requirements

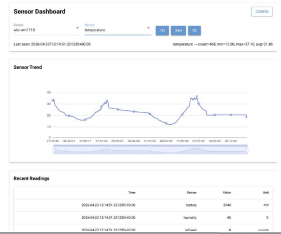
- **Perpetual Power:** Solar-harvesting system engineered for 99.7% annual uptime (under 24 hours total downtime).
- **LoRaWAN US915:** Secure, long-range transmission with high data reliability.
- **Modular Sensing:** Hardware support for four concurrent sensors via a plug-and-play architecture.
- **Wireless Management:** Intuitive UI for remote parameter configuration and field calibration.
- **Industrial Design:** Rugged, pole-mountable, and cost-optimized for rapid, general-purpose deployment.
- **Field Validation:** System proven via a functional weather station.

Challenges

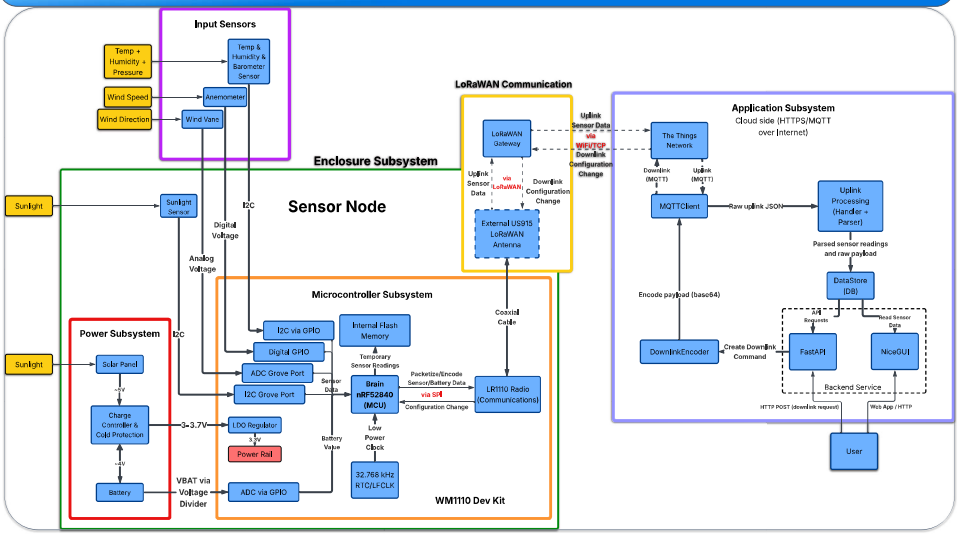
- **nRF5 SDK Complexity:** Extensive learning curve due to a deeply nested architecture and hundreds of file dependencies.
- **Documentation Gaps:** Required manual code tracing and community workarounds to overcome the sparse official documentation.
- **Wireless Protocol Clash:** BLE's greedy nature caused it to take over the processor, frequently blocking critical LoRaWAN operations.

Final Design





Architecture



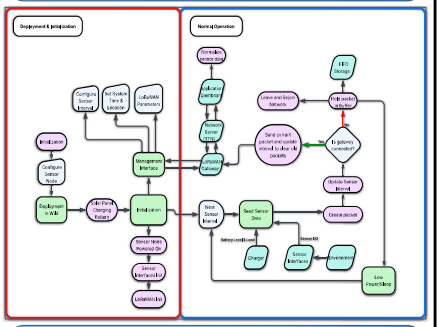
Technologies

Power Subsystem and Inputs
- **LiPo battery & Charger**
- Supplies and regulates energy for continuous solar powered operation.
- Sensor include anemometer, wind vane, air temperature and humidity, and sunlight sensors.

Sensor Node Subsystem
- **Wio WM1110 Dev Kit**
- **LoRaWAN, nRF SDK, SES**
- Collects sensor data, manages low power operation and transmits data via LoRaWAN.

Application Subsystem
- **TTN, MQTT**
- **Python FastAPI, SQLite**
- **NiceGUI, Uvicorn**
- Receives, processes, stores, and visualizes sensor data through a web dashboard.

Concept of Operations



Conclusion

- Designed and implemented a solar-powered LoRaWAN sensor system
- Demonstrated reliable long-range communication and multi-sensor support
- Developed a web-based application for monitoring and configuration
- Power system enables year-round operation
- Provides a low-cost, scalable solution for environmental monitoring

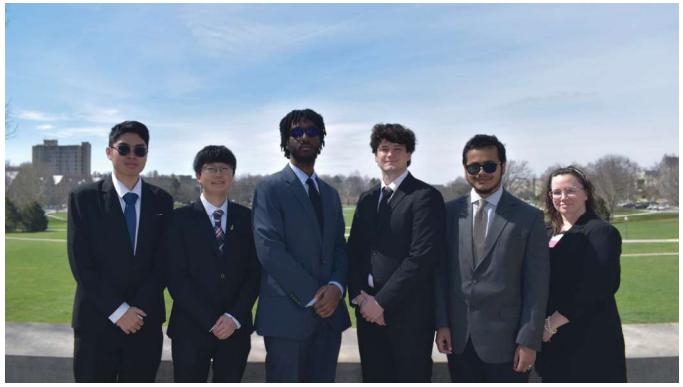
Future Work

- **Protocol Concurrency:** Resolve BLE/LoRaWAN conflicts to enable a local BLE management interface.
- **Application Expansion:** Integrate advanced data visualization and custom user-alerting features.
- **Power Optimization:** Implement a custom solar charging circuit to reduce costs and extend field life.
- **Industrial Design:** Transition to a durable, aesthetic, and weather-resistant enclosure.

Acknowledgements

We would like to thank the following people for their support:
- Dr. Scott Midkiff
- Dr. Shelley Stover
- Dr. Joe Adams
- Dr. Daniel Connors

FutureHAUS AI: Smart Home System



LEFT to RIGHT: Nick Tan, Joseph Leonard, Jordan Talbert, Aaron Simpson, Mohammed Istiaq Hossain, Delaney Theilman

SME: Bobby Vance

CHALLENGE

Our challenge was to design a modular smart home system that integrates artificial intelligence for automated control and real time monitoring. The system utilizes a mesh network of ESP32 devices connected to a Raspberry Pi running a WebSocket server, enabling real-time data communication and processing while interfacing with an AI model to analyze system data, adapt to user behavior over time, and generate personalized recommendations based on observed usage patterns. This integration allows users to seamlessly monitor and control household systems, such as lighting and HVAC, with intelligent automation tailored to their preferences.

futureHAUS™
Virginia Tech Center for Design Research

Customer: Bobby Vance

Mohammed Istiaq Hossain — Chittagong Metropolitan City, Bangladesh

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I wish to develop computer systems and AI models that will help elevate the living standards of everyone. My ultimate goal is to create tools that make life easier for others.

Course Comment: In this course I learned to effectively collaborate with other engineers to create a large scale project. I also learned that engineers have to be careful with resources, for they are limited. I gained knowledge in this course that may not appear in job descriptions, but it would definitely help me navigate real-world projects.

Joseph Leonard — Stafford, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My goal is to pursue a career developing intelligent systems using machine learning and artificial intelligence for real world applications. I am particularly interested in applying artificial intelligence to smart environments, and biomedical imaging and neural activity analysis.

Course Comment: This course provided a valuable opportunity to apply the concepts learned throughout the ECE curriculum to a real world engineering problem. I gained experience collaborating with teammates, communicating technical ideas, and managing project deliverables.

Aaron Simpson — Fairfax, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My goal is to work in the Cybersecurity field. I hope that I can help people using my knowledge of networking and cybersecurity to protect their data, security, and device integrity against the ever changing threats of the future.

Course Comment: This course has been a valuable experience, meeting new teammates and customers while developing a solution to an engineering problem that initially seemed beyond our reach. Throughout the process I was challenged to apply networking concepts to a real systems solution, continuously learning and adapting along the way.

Jordan Talbert — Suffolk, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I wish to combine both my love for personal connection and computer systems to make an impact, however large or small, on the world. The purpose of technology is to serve people and make their lives better, and I wish to be part of any group or company that has this as its top priority.

Course Comment: This course has not only been a joy to experience but has also been invaluable to the development of crucial hard and soft skills. Learning to work within and manage a team environment is a skill set that will assist me in nearly every aspect of my future career. Out of all the courses I have taken, this one feels the most directly transferable to real-world scenarios.

Nick Tan — Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to create products that improve people's well-being and make a meaningful impact on their daily lives. I want my work to provide real, lasting value to others reflecting my creativity, effort, and purpose.

Course Comment: This course has brought immense joy and satisfaction, especially in being able to work on a project that others will use in the future. I found this course to be an excellent introduction to working across teams, collaborating with a customer, and understanding the importance of documentation, testing, communication, and teamwork.

Delaney Theilman — Hampstead, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am passionate about robotics, space and video games. This translates well into my aspirations, as I hope to professionally design rovers and robotic tools that can support NASA's Artemis mission one day.

Course Comment: This course has created an imensely valuable industry-like experience for me and my peers. It has allowed us to showcase our applied academic knowledge, leadership and problem-solving abilities and taught us how to effectively communicate with customers and experts in order to make their desires a reality.

FutureHAUS: Smart Home System

Sponsor: Bobby Vance **Mentor:** Joe Adams
Team: Nick Tan, Delaney Theilman, Aaron Simpson, Mohammad Istiaq Hossain, Joseph Leonard, Jordan Talbert

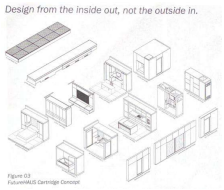
VIRGINIA TECH

futureHAUS
Virginia Tech Center for Design Research

Background

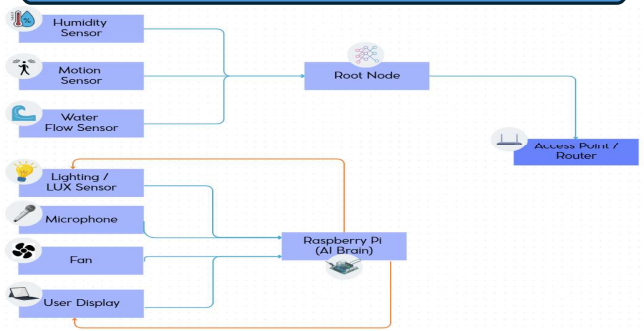
- Rising demand for essential resources is increasing housing costs
  - Household systems include:
    - Electricity
    - Water
    - Lighting
    - HVAC
- Increased resource consumption leads to:
  - Higher costs
  - Reduced access to affordable housing
- There is a need for smarter, more efficient resource management solutions

Key Objectives



- Develop a smart home system to monitor and control critical household systems (Electricity, Water, Lighting, HVAC)
- Establish reliable communication between sensors, microcontrollers, and system components
- Design a network protocol for efficient data transmission
- Implement a server to process and manage real time system data
- Create an intuitive graphical user interface (GUI for user interaction
- Enable real-time monitoring and control of household systems
- Integrate Ai driven automation for intelligent decision making
- Support multiple control methods, including voice recognition and autonomous machine learning

System Architecture



Demonstrated Capabilities

- Able to control the Lights via the touchpad
- The server can send and receive JSON files from microcontrollers and iPad display
- iPad display able to output real time data
- AI adapts to user habits and behaviors
- AI recognize voice commands and act on certain commands

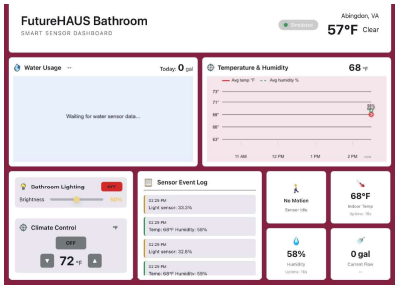
Hardware

- ESP32 Microcontrollers
- Raspberry PI 5
- iPad (User Interface)
- Bluetooth Lightbulb
- Sensors:
  - Motion sensor
  - Flow Sensor
  - Lux Sensor
  - Temperature & Humidity sensor

Software

- Programming Languages
  - C
    - ESP-IDF
  - Python
  - HMTL/CSS/JavaScript
- Integrated Design Environments used
  - Visual Studio Code
  - Kaggle
  - PyCharm
  - Koder
  - Textastic

Display/GUI



Challenges

- Establishing reliable communication between microcontrollers and the central WebSocket server
- Integrating voice recognition for system control
- Ensuring consistent control and responsiveness of lighting systems
- Managing and storing JSON data efficiently in a database
- Maintaining stable connectivity between the system and iPad display Interface

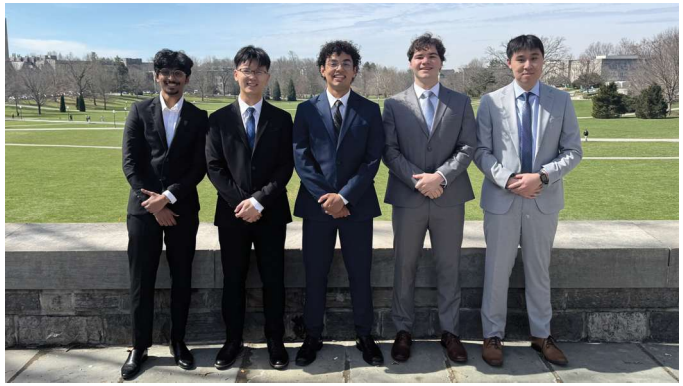
Conclusion & Future Work

- Adding more display functionality
- Recognizable voice lines by the AI
- Redesigned PCB prints
- Integrate into full home
- Add controls and monitoring main HVAC system
- Monitor and manage electricity usage for main system
- Integrate AI control for appliances
- Develop modular implementations for any room
- Implement physical security features

Acknowledgments

We would like to thank Dr. Joe Adams, Bobby Vance, and all supporting teams on this project, for advising, supporting, and enriching us throughout the project. A special thanks to FutureHAUS and Kohler for their contributions to our work.

FutureHAUS AI: Power System



LEFT to RIGHT: Abhinav Terapalli, Danh Le, Juan Martinez-Medina, J.D. Putt, Johnny Huang

CHALLENGE

In support of the upcoming FutureHAUS modular housing concept, our team was tasked with designing and implementing a cost-effective, plug-and-play power distribution system for residential applications. This interface aims to reduce on-site wiring time while enabling individual housing modules ("Cartridges") to connect seamlessly without requiring modifications to existing systems.

futureHAUS™
Virginia Tech Center for Design Research

SME: Bobby Vance

Customer: Bobby Vance

Johnny Huang — South Riding, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I will begin my career in the electric utility industry as a System Metering Engineer. I look forward to supporting the reliability and modernization of power distribution metering infrastructure, particularly as Northern Virginia experiences rapidly increasing electricity demand driven by the expansion of data centers.

Course Comment: This course has provided an industry-like experience of working on a collaborative, multidisciplinary project in a professional manner. Adapting to evolving project requirements and developing solutions was challenging yet rewarding, helping me better understand the importance of teamwork, communication, and problem-solving in an engineering context.

Danh Le — Springfield, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I look forward to what the post-graduation life has in store for me. Using the skills and knowledge I have acquired throughout my undergraduate career while continuing to learn from my future experiences and mentors.

Course Comment: This course has given me the opportunity to collaborate on a multidisciplinary engineering project and apply concepts from my coursework to real-world engineering challenges. It helped me understand the importance of communication, teamwork, problem-solving, and system-level design when working on a complex engineering project.

Juan Martinez-Medina — Chesapeake, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I am very excited to be joining GE Vernova in their Edison Engineering Development Program. Through this opportunity, I will be able to participate in four separate rotations in the company's Wind business while pursuing an MS in Electric Power Systems Engineering at North Carolina State University. I aim to be at the forefront of sustainability and the green transition worldwide.

Course Comment: The MDE project has been an amazing opportunity to contribute to an impactful initiative while collaborating closely with peers that have grown to become good friends. I am confident that I will utilize the skills and knowledge I have gained in the course far into my career.

J.D. Putt — Leesburg, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I am pursuing an MS degree because I have a rare opportunity to contribute to a rapidly evolving power industry. Graduate study will allow me to expand my technical expertise and better understand emerging technologies. In the future, I aspire to help improve the systems that deliver reliable energy to communities. Ultimately, I hope my work will make a meaningful impact on people's lives.

Course Comment: This course has provided me with invaluable experience in all aspects of project work. From time management and planning to addressing unexpected technical challenges and scope changes, MDE has prepared me with tools that I can utilize for the rest of my career.

Abhinav Terapalli — Valsayn, Trinidad and Tobago

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to become a Professional Engineer in the power engineering field, contributing to the design and development of reliable and efficient power systems. I also plan to pursue a master's degree to deepen my technical expertise and expand my understanding of advanced power technologies. Ultimately, I hope to work at the forefront of innovation, helping develop the newest power systems that will shape the future of energy.

Course Comment: This course provided valuable experience working collaboratively on a complex engineering project in a setting that closely resembled a professional environment. Through constant teamwork and communication, we were able to develop inventive solutions that build upon established practices in power distribution. The project reinforced the importance of collaboration, adaptability, and creative problem-solving when tackling real engineering challenges.

FutureHAUS AI: Power System

Team Members: Johnny Huang, Danh Le, Juan Martinez-Medina, J.D. Putt, Abhinav Terapalli
Customer and SME: Prof. Bobby Vance **Mentor:** Dr. Joe Adams

Virginia Tech Center for Design Research

Motivation

- Industrial decline in Central Appalachia has weakened local economies
- Strong grid infrastructure, especially in rural areas, is harder to maintain
- Recent industrial revitalization has sparked the need for affordable housing

Why Modular Housing?

- Built from prefabricated sections manufactured in a factory
- Transported and assembled on-site
- More efficient and affordable compared to traditional construction

This project applies modular housing to:

- Expand affordable housing options
- Improve access to reliable infrastructure
- Reduce overall housing costs through faster deployment and construction
- Enable scalable construction as community and personal needs change

Objectives

- Develop an electrical distribution system that minimizes on-site wiring time
- Enable seamless connection between housing modules without redesign of existing systems
- Implement and validate key system features through a bathroom module prototype

Modular Housing

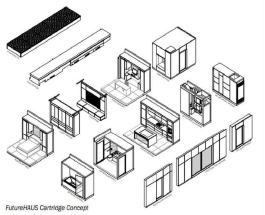


Fig. 1: Cartridge Layouts

Modular Housing Construction:

- Off-site home construction using standard materials and codes
- Reduces waste, shortens construction time, and improves scalability

Module/Cartridge:

- Removable building block with a defined function (e.g., bathroom)
- Can be added, removed, or rearranged as needed

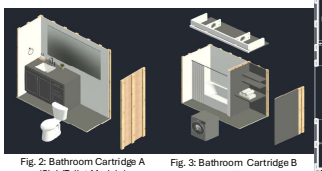


Fig. 2: Bathroom Cartridge A (Sink/Toilet Module)

Fig. 3: Bathroom Cartridge B (Shower/Utility Module)

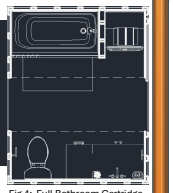


Fig 4: Full Bathroom Cartridge

Bathroom Cartridge:

- A complete bathroom is comprised of two sub-cartridges, which when put together, will function as a standard full bathroom.
- Above the cartridge is an electrical distribution tunnel, where the electrical wiring would be run between each cartridge and are routed to the loads.

Solution: Wire Bundles & Breaker Box

Wire Bundles:

- Plug & Receptable that take in circuits and can be disconnected at will
- Residences are wired as split-phase systems: two 120V lines 180° apart (L1 and L2)
- Each plug contains:
  - 3x 120V circuits (same ϕ) *or*
  - 1x 240V circuit
- A circuit consists of:
  - Hot L1
  - Hot L2 (L1 & L2 only used in 240V)
  - Neutral
  - Ground

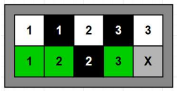


Fig. 5: Diagram of Three 120V Circuits (1-3) in Wire Bundle Plug

Fig. 6: Diagram of One 240V Circuit in Wire Bundle Plug

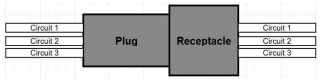


Fig. 7: Wire Bundle Diagram

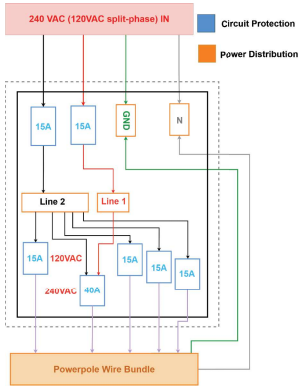


Fig. 8: Breaker Box Diagram

Breaker Box:

- Having a custom breaker box aids with:
  - Early prototyping and cartridge construction via high customizability
  - Meets low power availability criteria for the FutureHAUS bathroom model
    - Allows for a functional bathroom in any presentation environment
  - Showing how Plug & Play functionality would function in a real system

Breaker Box Components:

- 1x 15A primary breaker
- 2x 120V terminal blocks
- 4x 120V – 15A single-pole circuit breakers
- 1x 240V – 40A double-pole circuit breaker
- Neutral terminal block
- Ground terminal block

Distribution:

120V Distribution:

- A three-prong extension cord connects the breaker box to a standard 120V outlet.
- The hot wire is routed through a single main breaker connected to a terminal block, which feed load breakers.
- The neutral and ground wires are routed to their respective terminal blocks, as shown in Fig. 8.

240V distribution:

- A four-prong extension cord connects the breaker box to a 240V outlet.
- Two separate hot wires are routed through a double-pole breaker to individual terminal blocks, which feed 120V and 240V loads.
- Neutral and ground wires routed similarly to the 120V system

Solution: Final Products

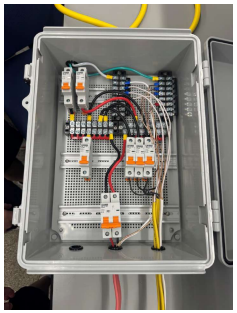


Fig. 9: Implemented Breaker Box wired for 120 V loads

Input:
#10 AWG cord from 120V, 15A outlet w/ hot, neutral, and ground wires

Distribution:

- *Hot* wire (Black): 120V distributed through 15A breaker connected to middle-left terminal block
- *Neutral* wire (White): connected to top-left terminal block
- *Ground* wire (Green): connected to top-right terminal block

Wire Bundle Interface:

- Hot wire is interfaced to 15A load breakers.
- Neutral and Ground wires are connected directly to Neutral/Ground terminal blocks.

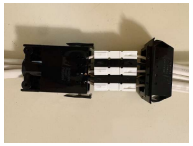


Fig. 10: Exposed Plug-and-Receptacle Interface

- Circuits connected using Anderson Powerpole connectors contained within a plug and receptacle
- Plug and receptacle secured with retaining clips for convenient plug-and-play connection

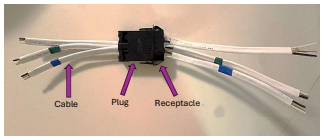


Fig. 11: Pre-wired Cable bundle for Multi Circuit Distribution

Technical Challenges

- **Challenge:** Maintaining the aspect of modularity and minimal on-site construction while providing proper electrical distribution
  - **Solution:** Acknowledging that designers of a specific modular home must know the general location of loads to determine what circuits to include within a cartridge.
- **Challenge:** Adhering to relevant residential codes
  - **Solution:** Make necessary adjustments after reading through residential codes and reaching out to peers with electrician experience to guarantee quality.
- **Challenge:** Multiple scope changes
  - **Solution:** Working closely with the FutureHAUS team to understand any new/updated requirements and adapt our solutions accordingly.
- **Challenge:** Including 240V solutions
  - **Solution:** Separating 120V and 240V circuits into separate receptacles/plugs.

Full Home Integration

For a completed residential space, full integration of our solution would go as follows:

- All cartridges constructed in factory with internal wire bundles terminated on either end with a plug/receptacle
- Cartridges are transported from factory to housing site
- On site, cartridges are lifted into place
- Electrician goes into structure and connects plugs to adjacent receptables, closing loops from breaker box to loads
- Continuity testing is performed to ensure proper construction and long-term safety

Conclusion

Our solution:

- Provides the FutureHAUS team with an affordable and easily scalable plug-and-play electrical distribution system.
- Offers significant flexibility in the design of any modular building.
- Can be interfaced with standard residential electrical equipment and loads.
- Is compliant with all relevant electrical construction codes.

Future Work

We constructed a strong foundation for any further FutureHAUS work, as our solution is:

- Widely applicable to other cartridges
- Simple to implement

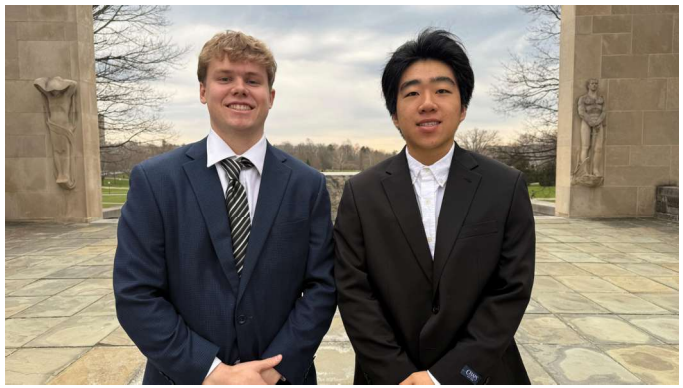
This could include the design of other rooms (kitchen, bedroom, etc.), implementation with renewable energy sources, and with enough success even make an appearance in future real-world housing development.

Acknowledgements

We would like to extend our sincere gratitude to the following people for their guidance and support throughout the course of this project:

- Prof. Bobby Vance (Customer and SME)
- Dr. Joe Adams (Mentor)
- FutureHAUS team (Creative direction)

Low-Cost Newborn Hearing Screener Using Auditory Brainstem Response



LEFT to RIGHT: Justin Morris, Sheng Lu

CHALLENGE

Our project develops a low-cost, portable Automated Auditory Brainstem Response (AABR) hearing screener designed for use in low-resource environments. The system detects auditory responses using signal processing and statistical analysis of EEG signals, providing a clear PASS or REFER result while automatically pausing testing in noisy conditions. This device aims to improve early detection of newborn hearing loss in low-resource environments by offering an affordable alternative to existing solutions.

TEAM Malawi

SMEs: Andre Muelenaer and Robert Stone

Customers: Andre Muelenaer and Robert Stone

Sheng Lu North York, Canada

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My aspiration is to apply my skills to the healthcare sector through the development of devices and systems that help people in need.

Course Comment: This course has taught me how to learn and apply technical skills in a fast paced development environment, how to work professionaly in a multidisciplinary team, as well as how to resolve unexpected setbacks.

Justin Morris Goodview, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My aspirations are to work in the healthcare sector, utilizing technology to improve the quality of people's lives. I am especially interested in developing systems that combine software and hardware to solve real-world medical problems. Through my education in computer engineering, I have developed strong skills in software systems and embedded technologies. I hope to apply these skills to create innovative healthcare solutions that make a meaningful impact.

Course Comment: This Senior Design course has taught me many professional skills through working on a real-world engineering project. It helped me improve my problem-solving abilities, teamwork, and communication while collaborating with my team. Throughout the project, I also gained experience in system design and integrating different technologies together. Overall, the course has prepared me for the challenges of working in an engineering environment.

Low Resource Newborn Hearing Screener

Team Members: Sheng Lu, Justin Morris
Customers & SMEs: Dr. Robert Stone, Dr. Andre Muelenaer
Mentor: Dr. Shelley Stover

Motivation

Many regions around the world lack access to newborn hearing screening due to high cost of commercial devices. Early detection of hearing loss is critical for language and cognitive development. This project develops a **low-cost screening device** to improve access to early hearing evaluation in resource-limited environments.

- **Automated Auditory Brainstem Response (AABR)** is a reliable newborn hearing screening method with low false-positive rates, making it suitable for universal screening
- No affordable newborn hearing screening devices are currently available for LMIC markets.
  Average cost $1,500-$10,000+

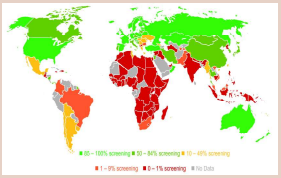


Figure 1. Country Specific Coverage of NIHS Programs

Objective

Design and implement an **Automated Auditory Brainstem Response (AABR) device** that:

- Uses **synchronous averaging** to detect EEG responses
- Maintains total system cost **under $150**
- Use widely available, repairable components
- Operates as a **portable screening device**
- Provides **clear PASS/REFER results**

A gold standard in Newborn Hearing Screening in the U.S. is the Automated Auditory Brainstem Response Test (AABR):

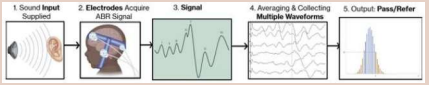


Figure 2. Neurologic auditory pathway measured during AABR testing

Concept Of Operations

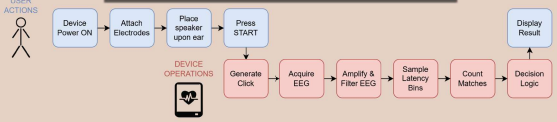


Figure 3. Concept of operations showing the step-by-step workflow of the AABR screening process.

- User powers on the device and attaches electrodes
  - (Positive → forehead, Negative → nape, Ground → mastoid/shoulder)
- User presses **Start** to begin test
- Device generates auditory clicks **(37 Hz)**
- EEG responses are recorded and filtered
- Weighted template computes a **Z-score** to detect auditory responses
- System displays result:
  - **PASS** → Hearing response detected
  - **REFER** → Further testing required

Subsystem Design

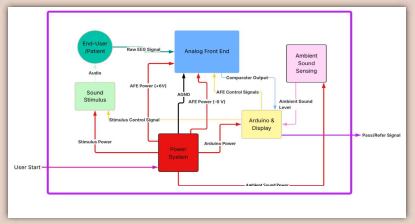


Figure 4. System-level block diagram illustrating signal flow through major subsystems.

Power System
- Lithium-ion battery powers the system
- Boost converters generate +5V and ±6V rails
- Distributes regulated power to analog and digital components

Sound Stimulus
- Click stimulus generated at **37 Hz**
- Speaker delivers auditory stimulus

Ambient Sound Sensing
- Microphone monitors environmental noise
- Testing pauses when noise exceeds threshold

Arduino & Display
- Controls audio output and signal sampling
- LCD displays system status and results

Analog Front End
- Instrumentation amplifier amplifies microvolt EEG signals
- 60 Hz notch filter reduces power-line interference
- Band-pass filtering removes unwanted frequencies

Software Solution

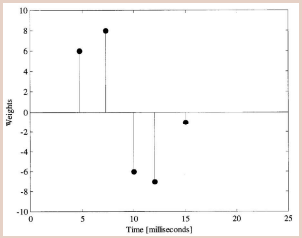


Figure 5. Weighted ABR template showing expected response latencies used for waveform detection.

$$Z = \frac{\sum_{m=1} w_m (x_m - \mu_x)}{\sqrt{Npq \sum_{m=1}^{M} w_m^2}}$$

Figure 6. Weighted Z-score equation used to determine the presence of an auditory brainstem response.

Synchronous Averaging
- Each auditory click produces a **small time-locked EEG response**
- Individual responses are **time-aligned** to the stimulus
- Averaging **reduces random noise** and strengthens the ABR signal
- Signal quality improves as additional responses are averaged

Weighted Template Z-Score Detection
- EEG responses are sampled across **27 latency bins**
- Expected ABR response times correspond to **specific latency bins**
- Each expected bin is assigned a **positive or negative weight**
- The **Z-score** measures deviation from expected noise-only behavior
- A **PASS** occurs when Z exceeds a statistical threshold **(Z ≥ 4)**

Prototyping

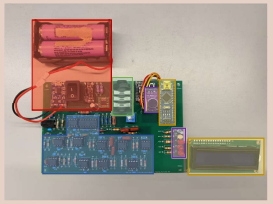


Figure 7. Printed circuit board (PCB) prototype

Sound Stimulus | Power System | Analog Front End | Arduino & Display | Ambient Sound Sensing

Test Results

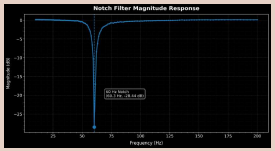


Figure 8. Measured frequency response of notch filter showing attenuation near 60 Hz.

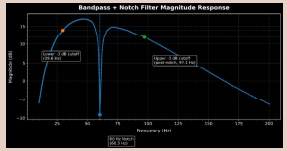


Figure 9. Measured frequency response of the band-pass filter showing desired signal bandwidth

Test Results
- The **60 Hz notch filter** achieved **-28.4 dB attenuation at 60.3 Hz**
- The combined **band-pass + notch filter** produced a usable signal bandwidth from **29.6 Hz to 97.1 Hz**
- Measured frequency response closely match **design targets**

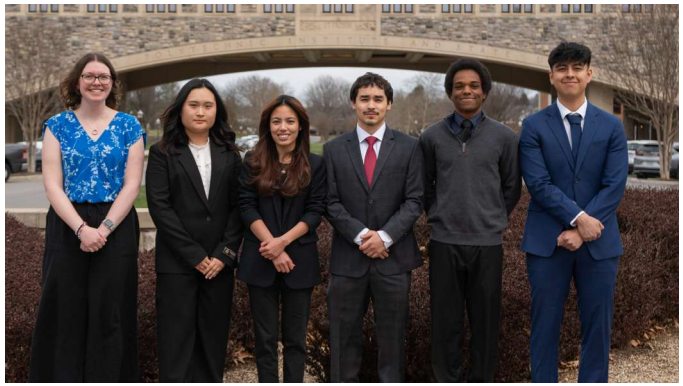
Future Plans

1. Update schematic to be production ready and clinically reliable
2. Conduct clinical testing at Carilion Children's Hospital, Roanoke, Virginia
3. Collaborate with Kamuzu University of Health Sciences, Blantyre, Malawi
4. Collaborate with the Audiology Department at African Bible College-Malawi, Lilongwe, Malawi

Acknowledgements

We would like to thank the following individuals for their support throughout this project:
- Dr. Robert Stone (Customer & SME)
- Dr. Andre Muelenaer (Customer & SME)
- Dr. Shelly Stover (Mentor)
- Bella Rowland (Advisor)
- Kim Medley (Procurement Specialist)

Low-Resource Preeclampsia Screener



LEFT to RIGHT: Allison Hagee, Jisu Lee, Lateisha Shahril, Samuel Thompson, Tolu Kolade, Jordan Vargas

SMEs: Andre Muelenaer and Robert Stone

CHALLENGE

Preeclampsia is a leading worldwide cause of pregnancy complications. Our project addresses this by designing a low-cost, noninvasive monitoring system for rural Malawi, aimed at improving maternal healthcare access in low-resource settings. The system combines a wearable headband with an Android application that wirelessly collects and processes patient data, monitoring blood pressure and providing real-time alerts for potential preeclamptic conditions. It is simple to use, enabling early detection and timely intervention while minimizing patient burden and healthcare expenses.

COLLEGE OF ENGINEERING
BIOMEDICAL ENGINEERING
VIRGINIA TECH

Customers: Andre Muelenaer and Robert Stone

Allison Hagee — Crofton, Maryland

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan to start my career with Johns Hopkins Applied Physics Lab, where I hope to continue to grow my skill set as an electrical engineer in both hardware and software. I would also love to someday work in the field of medical devices and make a positive difference in people's lives.

Course Comment: This course allowed me to apply the skills I have learned to a real challenge in the biomedical industry. I was able to use my technical skills to help people and gain new technical and interpersonal skills in the process. It pushed me to challenge myself and explore new areas of electrical engineering which will greatly benefit me as I begin my career.

Jisu Lee — Tecate, Mexico

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan to continue my academic journey in electrical engineering by joining a research group focused on micro/nano systems for biomedical applications. After completing graduate school, I hope to contribute as an electrical engineer at a company working to create new technologies that combine engineering and medicine.

Course Comment: This course gave me valuable experience applying what I have learned in ECE to a real-world design project, especially by integrating concepts from biomedical engineering into our work. I now feel more ready to enter industry after graduation, willing to learn new skills and tackle challenging design problems.

Tolu Kolade — Front Royal, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to become a firmware and embedded systems engineer or a low-level systems programmer. Next year, I will continue pursuing my master's degree at Virginia Tech, concentrating in computer systems and systems software. I look forward to deepening my technical foundation and applying it to meaningful problems

Course Comment: The MDE course fosters strong team collaboration skills. It has been the largest and longest project I have worked on so far, and I enjoyed developing our product over the course of two semesters. This extended timeframe allowed our team to invest more time and effort into understanding the project requirements.

Lateisha Shahril — Kuala Lumpur, Malaysia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: In the future, I hope to work in sustainability and renewable energy, helping develop technologies that support a cleaner and more sustainable energy system. I want to contribute to solutions that can reach as many communities as possible and make a meaningful difference in people's lives.

Course Comment: Senior Design allowed me to apply the concepts I learned throughout my electrical engineering courses to a real-world project. It helped me strengthen my skills in system design, troubleshooting, and teamwork, while also giving me a better understanding of how engineering ideas develop into practical solutions.

Samuel Thompson — Amissville, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I look forward to becoming an embedded systems engineer, contributing to software and hardware development, particularly in real-time applications. After gaining more technical experience, I'd like to shift into project management.

Course Comment: The ECE Capstone project provided a valuable opportunity to gain practical engineering experience, specifically, in ground-up project development, from requirements analysis to integration and testing. Serving as Project Manager allowed me to further develop my leadership and interpersonal skills.

Jordan Vargas — Burke, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: After graduation, I plan to further both my career and education by working in hardware design at BAE Systems in their Space Systems group. I also hope to become a double hokie by applying and attending the Institute for Advanced Computing at Virginia Tech to obtain my Master's in Computer Engineering.

Course Comment: I'm grateful to the MDE program for giving me the opportunity to work in such an important project for TEAM Malawi as it is such a critical issue that needs addressing. I have had such a wonderful time in collaborating with my hardworking team members over the past year and I now feel more ready to be part of a team as an engineer in my next chapter.

COLLEGE OF ENGINEERING
BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Low-Resource Preeclampsia Screener

Sponsor: VT Biomedical Engineering **Mentor**: Dr. Daniel Connors
Team: Samuel Thompson, Allison Hagee, Tolu Kolade, Jisu Lee, Lateisha Shahril, Jordan Vargas

COLLEGE OF ENGINEERING
BIOMEDICAL ENGINEERING
VIRGINIA TECH

Motivation

- Preeclampsia is a serious pregnancy complication characterized by high blood pressure and organ dysfunction
- Delayed detection can lead to severe maternal and fetal outcomes
- Early and continuous monitoring is critical, but access is limited in low-resource settings (e.g., rural communities)
- Clinical measurements may be affected by white coat syndrome, leading to artificially elevated blood pressure readings
- There is a clear need for an accessible, continuous, and low-resource-friendly monitoring solution that allows early detection and timely intervention

Objectives

- Allow early detection of preeclampsia through continuous blood pressure monitoring
- Develop low-cost and portable preeclampsia screening solution suitable for low-resource settings
- Improve accessibility of maternal health monitoring in rural environments
- Provide timely feedback to support early intervention and risk awareness
- Ensure the system is suitable for real-world, long-duration use (nocturnal / overnight monitoring)

System Features

- Cuffless blood pressure monitoring & physiological sensing
- Signal processing algorithms
- Power management system
- Wireless smartphone communication (Bluetooth app)
- Local data logging & trend detection
- Patient alert system (multi-level urgency)
- Wearable, lightweight, rechargeable design
- No user input required during operation
- Nocturnal continuous monitoring capability
- Low-cost, scalable architecture
- Solar / wireless charging

System Design

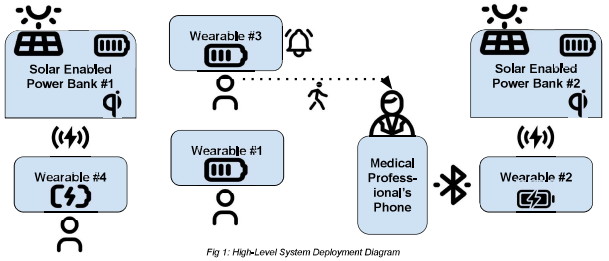


Fig 1: High-Level System Deployment Diagram

- Multiple wearables supported via shared solar power banks
- Medical professional acts as central monitoring hub
- Devices operator independently with wireless reporting
- Alert-triggered devices prompt clinical follow-up

System Hardware

- MCU for control / computation.
- LiPo Battery provides portable energy
- Charging receiver for power from *COTS* solar enabled power bank
- PPG sensor for biometric sensing
- Accelerometer for data quality reference
- Indicators for patient alerts

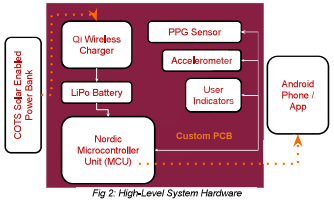


Fig 2: High-Level System Hardware

Photoplethysmography (PPG)

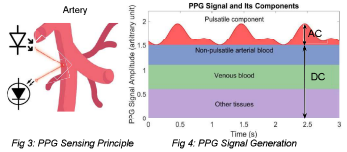


Fig 3: PPG Sensing Principle Fig 4: PPG Signal Generation

- PPG measures blood volume changes using optical sensing
- LED & photodetector capture pulse-induced light variations
- Waveform peaks correspond to cardiac cycles
- Extracted features allow blood pressure (BP) estimation

App Software

- View patient device logged data
- Wirelessly configure patient specific device settings
- Setup for new patients
- Supports multiple device / patient pairs per app

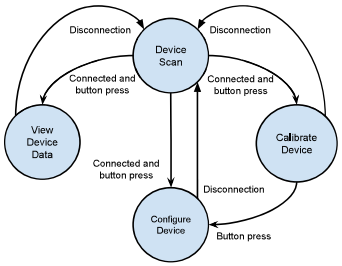


Fig 5: App Operational Diagram

Device Firmware

- Event-driven state transitions (interrupt-based)
- Low-power operation through idle / sleep states
- Autonomous behavior with no patient input required
- State changes triggered by RTC, charging status, and alert conditions

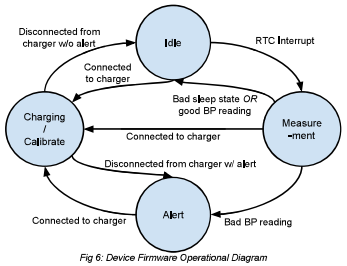


Fig 6: Device Firmware Operational Diagram

Results

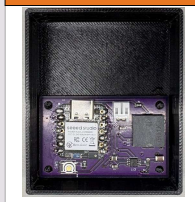


Fig 7: Final wearable prototype integrating custom PCB, sensors, and protective enclosure

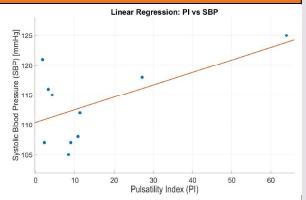


Fig 8: Linear Regression Model for Estimating Systolic Blood Pressure (SBP)

- Developed linear regression models for systolic and diastolic blood pressure estimation
- Built compact wearable prototype with integrated sensing
- Headband form factor allows stable, comfortable measurements
- System supports logging, scheduling, and wireless transmission
- Designed for low-power, rechargeable operation

Conclusions & Recommendations

Project Conclusions

- Demonstrated feasibility of cuffless BP screening system
- Achieved low-cost, non-intrusive wearable design
- Allows early detection in low-resource environments

Recommendations for Further Development

- Ensure compliance with medical device and data privacy standards
- Improve PPG-to-blood pressure modeling accuracy through expanded datasets
- Optimize hardware for reduced size, power consumption, and cost (e.g., additional PCBA version)

Next Steps

- Further testing of the device and system
- Customer product review
- Clinical evaluation and trials
- System field testing and deployment

Acknowledgements

Thank you to our mentor, Dr. Daniel Connors, for his guidance and feedback to our team throughout the project, and thank you to Dr. Bob Stone and Dr. Andy Muelenaer for their support as subject matter experts and project customers.

Automated Soil Measurement and Amendment Calculation

LEFT to RIGHT: Kushal Patel, Jacob Steier, Mohammed Kattoa

CHALLENGE

Throughout Shalom Farms' development, Shalom Farms has measured their soil and calculated their amendments manually. Our objective for this project is to create an automatic solution that accomplishes these tasks with accuracy while being safe and portable.

SHALOM FARMS

Customer: Amber Albee

Mohammed Kattoa Jeddah, Saudi Arabia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: As an electrical engineer, I am driven to use technology and innovation to solve real-world problems and improve people's lives. I hope to contribute to advancements in engineering that support sustainable development, modern infrastructure, and technological growth. Most importantly, I strive to represent my country, Saudi Arabia, with pride and contribute to its progress and global leadership.

Course Comment: This course strengthened my technical thinking and problem-solving skills as an electrical engineer. It helped me better understand how engineering knowledge can be applied to real systems and modern technologies. These skills will allow me to contribute to innovation, sustainable development, and technological advancement in support of Saudi Arabia's Vision 2030 goals.

Kushal Chirag Patel Vadodara, India

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I aspire to become a successful engineer and use my skills to create technologies that contribute to a more inclusive, safe, and development-focused world. I want my work to address real challenges and improve the quality of life for people from all backgrounds. Through innovation and purpose-driven design, I hope to create solutions that leave a meaningful and lasting impact.

Course Comment: This course offered a meaningful real-world experience and allowed me to connect my engineering education with my family's agricultural heritage. It reminded me of the generations before me whose lives and livelihoods were rooted in farming, and it gave me a deeper appreciation for how engineering can support and advance the communities and traditions that shaped my background.

Jacob Steier Greencastle, Pennsylvania

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: After college, my main aspiration is to obtain my consulting engineer certification. This has been a goal of mine for some time, as I want to be able to provide advice to others and become more versatile. I also aspire to use the skills I learned in college to develop my own ideas. Thanks to Virginia Tech and the professors who work there, I now have the knowledge and ability to make the world a better place.

Course Comment: This course allowed me to utilize my skills in a real-world setting that required me to research, design, and problem-solve. It taught me how important it is to communicate regularly with a customer, as communication is key to sucess. Finally, this course introduced me to new applications and websites that will help me reach my goals.

Automated Soil Measurement and Amendment Calculation

Team Members: Kushal Patel, Jacob Steier, and Mohammed Kattoa
Customer: Shalom Farms Mentor: Dr. Joe Adams

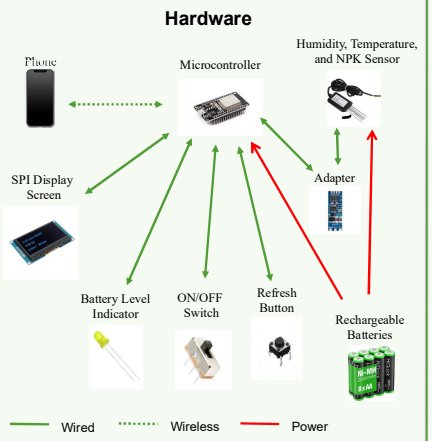
Motivation

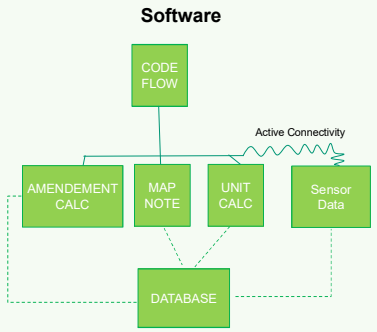
- Shalom Farms currently measures soil conditions and calculates amendment needs manually during crop seasons.
- This process is slow and labor-intensive.
- Manual calculations increase the risk of human error and miscalculations.
- There is a clear need for a more efficient and accurate system.
- A portable, safe, reliable, and automated solution is needed for use at Northside Farm in Richmond, Virginia.
- The project will simplify soil measurement and amendment calculations, saving time, improving accuracy, and making everyday farm operations easier while reducing errors.

Objectives

- **Part 1: (Sensor Network)**
  - Develop a network of distributed sensors that automatically collect soil measurements in real time.
  - Sensors will communicate through a centralized system, enabling seamless data integration.
  - Data will be accessible on a connected device via Bluetooth for easy, on-site use.
- **Part 2: (Software):**
  - Amendment Calculator to automatically determine soil amendment needs based on sensor data.
  - Unit Conversion Calculator to simplify measurement standardization across different units.
  - Data Management System including a note-taking database and record database to store, track, and organize soil and farm data over time for Shalom Farms.

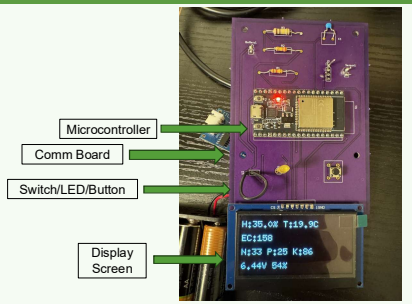
Design



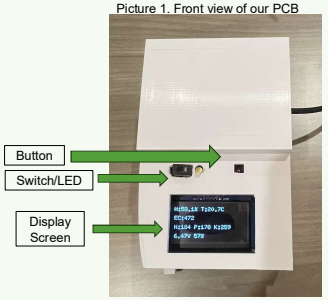


Results

- Successfully developed a functional sensor network capable of collecting soil measurements.
- Achieved reliable data transmission via Bluetooth between sensors and a central device.
- Implemented core software features, including amendment and unit conversion calculators.
- Established a foundation for data storage and tracking through integrated databases.
- Designed a portable power system with battery life exceeding 4 hours of continuous active use in farm conditions.
- Incorporated waterproofing measures to protect electronics from moisture, enabling reliable operation in outdoor farm environments.
- Developed a compact, handheld enclosure for easy use and portability in field conditions.



Picture 1. Front view of our PCB



Picture 2. Full front view of our device

Conclusion

- This project addresses inefficiencies in manual soil measurement and amendment calculations by introducing an automated, integrated solution.
- The sensor network and software system improve accuracy, reduce human error, and save time during crop seasons.
- The solution is designed to be portable, reliable, and easy to use in real farm environments.
- Implementation at Shalom Farms demonstrates its practical value and real-world applicability.
- Overall, this system supports more efficient, data-driven, and sustainable farming practices.

Future Work

- Improve sensor accuracy and durability for long-term field use.
- Enhance Bluetooth connectivity and ensure reliable data transmission.
- Refine the software interface to be more user-friendly for farm workers.
- Explore cloud-based data storage and remote access capabilities.
- Develop predictive analytics for soil health and amendment planning.
- Expand the system for scalable use across multiple sites at Shalom Farms and other farms.

Acknowledgment

We would like to sincerely thank our mentor, Dr. Adams, for his guidance, support, and valuable insights throughout this project, which were instrumental in shaping and refining our approach. We also extend our gratitude to Shalom Farms for serving as our project partner, whose collaboration and real-world perspective helped ensure that our solution is practical, effective, and meaningful for everyday farm operations.

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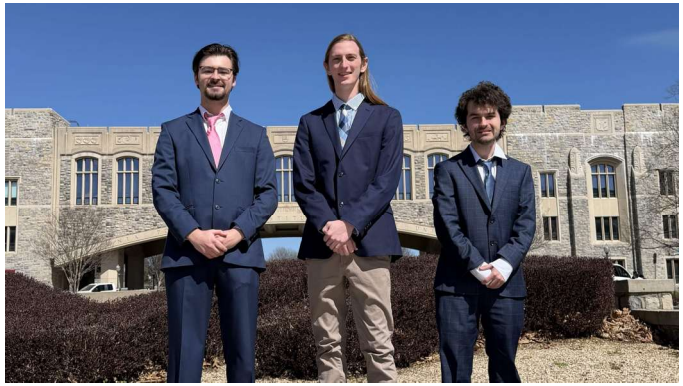
ShredConnect™: Remote Monitoring System



LEFT to RIGHT: Hayden Cooper, Webb Holderman, John-Michael Ballentine

CHALLENGE

Our goal is to design and implement a cost-effective, modular remote monitoring system for off-grid marine battery platforms that reliably collects and transmits environmental and system data. This system is developed in collaboration with Shred Electric to enable real-time monitoring and alert users to potential issues impacting oyster farm operations in remote aquaculture environments.

SME: Tim Talty

Customer: Nick Planson

John-Michael Ballentine — Fredericksburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: When I was going through middle school, I struggled to find out what it was that I had wanted to do. I knew what my main strengths were, which were programming and math-based classes, but I didn't have a direction in which to funnel those skills into. Eventually, during high school, I decided to focus in on engineering, as I enjoyed working to design and build a schematic to properly test. This level of enjoyment carried over into Electrical Engineering, as I took interest in seeing videos of people programming algorithms into games or designing circuits to convert one data type to another.

Course Comment: This course has given me an insight as to how to work with only a set of guidelines and as part of a team. Additionally, it also provided me with the chance to explore and apply what I have learned as an engineer to a field that I wouldn't have thought of at first. I feel that I got to sharpen my skillset, such as documentation and programming, while also discovering where my weak points were, such as verifying what exactly is happening during the test process. These lessons are what I hope to carry with me as I continue to learn and grow as an engineer.

Hayden Cooper — Huntington, West Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan to pursue a master's degree focused on power systems, where I can deepen my understanding of power electronics, energy conversion, and electrical infrastructure while continuing to engage in research and applied engineering projects. I want to develop a personal home workshop full of equipment so that if I need or want to make something, I'll know it can be done myself. I plan to practice woodworking and 3D printing. Pairing that with what I've learned from my degree at Virginia Tech, I believe will allow me to turn my home into a fortress where I can make my own utilities and tools that I'd want to use.

Course Comment: Through this course, I have had the chance to learn, plan, and create a device that someone else would want to use. There was a lot of documentation and a lot of explaining for design choices. I've learned that there is not always going to be a detailed description of what you need to do and how to do it. It's all based off of your own intuition and ability to learn to solve the problem. I think this project has shown me one way to explore solutions and also it has shown me to ask more questions to see what my customer might already know to help me in the design process.

Webb Holderman — Roanoke, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: I hope to use my engineering skills and technical knowledge to find creative solutions to important problems throughout my career. I'm looking forward to continuing to learn and solving more problems in my career as an engineer.

Course Comment: This course has helped me not just in engineering skills, but also in planning, decision making, critical thinking, problem solving, and in navigating the design process as a member of a team. I'm grateful to the Virginia Tech faculty that helped us throughout this project and to Shred Electric for staying in communication with us.

ShredConnect: Remote Monitoring System

Members: Webb Holderman, Hayden Cooper, John Ballentine
Customer: Shred Electric, SME: Dr. Timothy Talty

INTRODUCTION:

- Shred Electric is a company that implements clean energy solutions for businesses.
- They are partnering with oyster farmers to provide both clean energy and remote monitoring.
- Our goal was to design a remote monitoring system for these farms.

PROBLEM AND IMPACT:

- The current system can't monitor sensors and only works over cellular.
- Bad water conditions can kill oysters, causing massive losses to farmers.
- Our data could help aid vital research into oyster diseases.

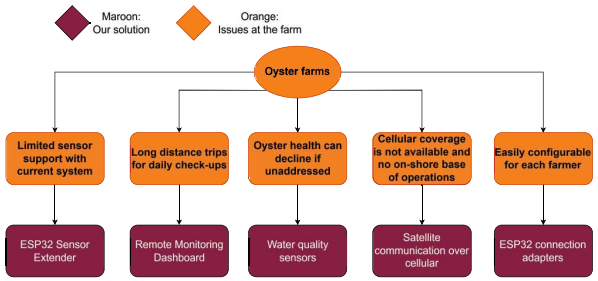
REQUIREMENTS:

- Collect data from water quality sensors
- Communicate data without using cellular service
- Alert user when the data indicates dangerous conditions

ISSUES AND CHALLENGES:

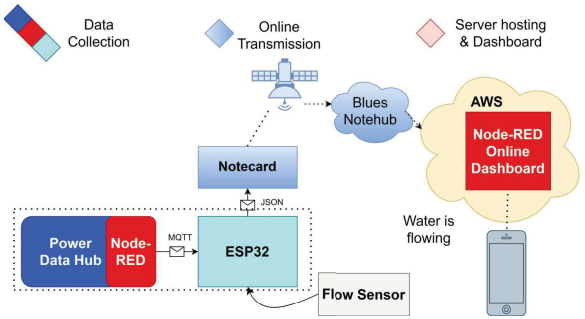
- Communication protocols were limited by location.
- MQTT communication requires a static IP address.
- ESP32 communicating with the Notecard resulted in connection losses.
- Email communication with Node-Red required extensive setup.
- Most sensors were designed for research, not remote monitoring.

DESIGN DIAGRAM:



The target audience, what problems they are facing, and how we solved said problems.

SYSTEM ARCHITECTURE:



An overview of our entire system with a legend located in the top left.

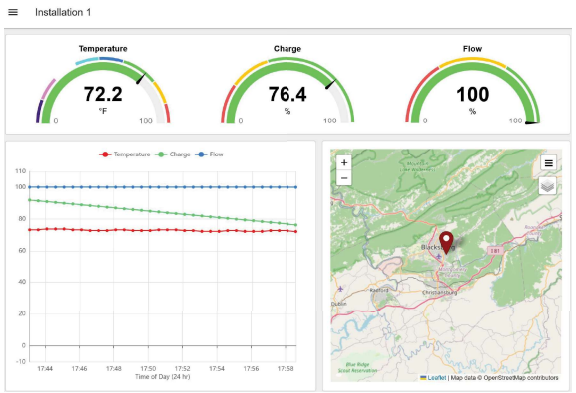
COMMUNICATION PROCESS:

- Victron Cerbo to ESP32 through MQTT.
- ESP32 sends data to Notecard through I2C.
- Notecard to Notehub through satellite.
- Notehub hands off data to AWS-hosted Node-RED.

MONITORING & NOTIFICATIONS:

- If data indicates danger, AWS sends message out to user and Shred Electric.

DASHBOARD DISPLAY:



The data is displayed on a dashboard such as this, with a gauge to indicate the condition.

FUTURE WORKS:

- Add sensors that cover more parameters.
- Design sensor extensions for the ESP32.
- Have a personal server for hosting data on instead of using AWS.
- Add in weather data through an API to the dashboard.
- Design custom sensors for the ESP32.
- Design a mobile app in conjunction with the website.

ACKNOWLEDGEMENTS:

We would like to thank the following:

- Our sponsor, Shred Electric, and their CEO, Nick Planson.
- Our contact, Nicholas Parisi.
- Our SME, Dr. Timothy Talty from Virginia Tech.

Autonomous Aquaculture

LEFT to RIGHT: Janna Weiss, Brendan Roeting, Alexander Mague

CHALLENGE

Our objective was to design an app to work on desktop and mobile devices to facilitate oyster farm operations and to provide remote connectivity for manual adjustments via last year's solution. Adjusting the previous solution to better meet stakeholder needs, we re-designed the microcontroller to allow for seamless connection, whilst also improving the user interface, making the entire system easier to operate and manage at scale.

Customer: Richard Youngk

Mague Mague San Francisco, California

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I believe that engineers are the bridge between science and solution. I aspire to enhance my ability to automate the struggles of every day people one project at a time.

Course Comment: The challenges imposed by this course mimic the hardships of industry. I am eternally thankful for my Lord and savior, Jesus Christ, who gave me the patience and will to persevere throughout the many trials and tribulations encountered during these 2 semesters.

Brendan Roeting Gainesville, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I look forward to starting at Ibeos full-time, where I will be working on their flight computers for satellites. I want to work on operating systems, and more specifically, work on the Linux Kernel, which thankfully I can do at my upcoming job. I hope that in the future, I will become a knowledgeable and reputable Software Systems Engineer.

Course Comment: This course has been challenging, but rewarding at the same time. It has helped me with my teamworking skills and how to follow a project through all the way to the end. It has also allowed me to get very familiar with Qt.

Janna Weiss Easton, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: After graduation I will be working as a Controls Engineer at Barry-Wehmiller Design Group. I hope to continue my career working in automation and traveling as a consultant.

Course Comment: This course has provided the incredible opportunity to work with an actual company while under the guidance of instructors and mentors at Virginia Tech. This has taught me a lot about industry and what to expect, especially going forward with consulting.

Autonomous Aquaculture

Sponsor: Annapolis Aquaculture

Mentor: Dr. Joe Adams

Team: Brendan Roeting, Alexander Mague, Janna Weiss

Problem Statement

- Oyster farming currently relies on significant manual oversight
- Remote management inefficient and unreliable
- Our problem is to develop an app
  - Enable real-time tracking of key conditions
    - Tide, temperature, trends
  - Support remote operation of the farm
    - Basic automation features using condition data
- This solution should reduce labor requirements while improving reliability and data accuracy.

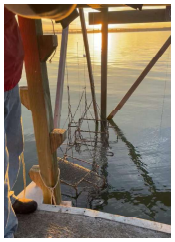


Figure 9: Richard Youngk's oyster farm

Key Objectives

- Build a scalable, one-download app
- Create automation features that can make autonomous adjustments based on tide changes
- Integrate this solution with last year's implementation

Approach

- Hardware:
  - Attach HC-SR04 Ultrasonic sensor to measure tide depth
  - Edit FSM to use environmental factors for automation decisions
- Software:
  - Use the Qt framework to design app
  - Host data on Raspberry Pi 5

Acknowledgement

We would like to thank our customer, Richard Youngk and Virginia Seafood AREC for their support and aquaculture expertise, as well as Dr. Joe Adams and Dr. Daniel Connors for their guidance throughout the development of this project.

Design Diagrams

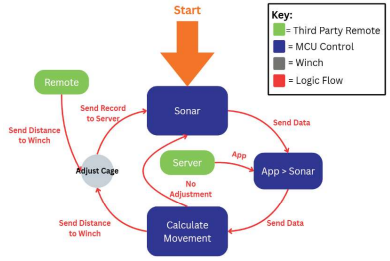


Figure 1: Finite State Machine for the winch

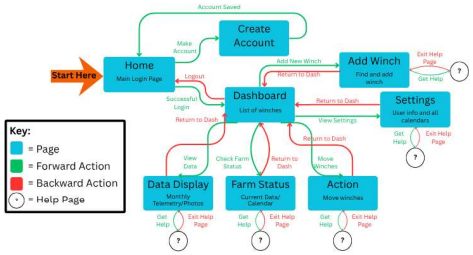


Figure 2: High Level System diagram for the app

Final Design

Figure 3: Main Dashboard page for all operational winches

Figure 4: Settings page for comprehensive schedule and user information

Figure 5: Add nearby winches page

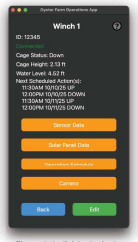


Figure 6: Individual winches page

Figure 7: Operation schedule page (individual and comprehensive)

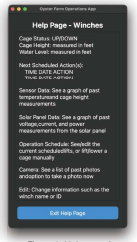


Figure 8: Help page for winches page

Design Solution:
- Developed using Qt6 (C++ GUI Software)
- Compatible on many devices and their operating systems (ex. IOS and Android)

Design implementation:
- Communicates with the server to monitor and control oyster operations remotely via HTTP commands
- Smooth and consistent user experience for easy app navigation
- Updates in real-time to effectively monitor and respond to each winch

Challenges

Challenge: Last year's solution uses a web-based design that does not communicate well with the established server.
Solution: Build a basic module to simulate app connection and command execution

Challenge: Much of the inherited solution's hardware came to us damaged with very little documentation.
Solution: Start from scratch with a new MCU implementation that is easier for user setup and waterproofed.

Challenge: The inherited solution's winch movement is timer-based, which leaves a lot of room for error and damage to the farm, as well as no way to determine whether the oysters are actually in or out of the water.
Solution: Use an ultra-sonic sensor to determine the tide height and keep track of the distance between the cage and the frame, as shown in Figure 10.

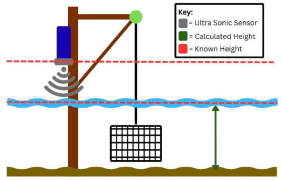


Figure 10: Diagram of Ultra Sonic Sensor solution.

Conclusion

Our goal for this project has been to facilitate the management of oyster farms through automation features and remote monitoring. Our system achieves this through a comprehensive app that allows for the manual and scheduled movement of cages, as well as logging for data such as tide depth and temperature. With our solution, oyster farms can be run with much less human oversight and with increased confidence in safety and adherence to FDA guidelines.

Future Work

- Physical tests with solar power and actual winch motors.
- Implementation of the system on our customer's oyster farm.
- Streamlining of the app installation process.

Solar Powered Offshore Oyster Nursery

LEFT to RIGHT: Joshua Grubb, Anthony Concessi, Alec Crispino, Charles Elliott, Nicholas Burant, Anderson Crouse

SME: Yiming Feng

CHALLENGE

Our challenge is to design, build, and test a scalable solar powered offshore oyster nursery with an increased level of autonomy than traditional systems. The nursery itself will be responsible for growing oyster seedlings to a size where they can be transferred to a farm where their growth will be continued. The combination of a renewable energy solution with decreased maintenance requirements will not only make it easier for oyster farmers to scale their operations, but it will also be easier for them to view and access crucial system information.

Customer: Richard Youngk

Nicholas Burant — Milwaukee, Wisconsin

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I am excited to join the power generation and distribution field and I hope to contribute to the solutions required for the increasingly precarious electrical grid combined with increasingly limited access to traditional energy resources. I aspire to become a leader in the field.

Course Comment: From defining the project scope and requirements to determining key design tradeoffs based project constraints, this course challenges not only one's technical skills, but, more importantly, one's critical thinking and engineering skills.

Josh Grubb — Keedysville, Maryland

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to contribute to combating the climate crisis currently impacting our planet. Through my future work with GE Vernova as a Wind Engineering Edison, I will focus on improving the efficiency, reliability, and robustness of GE Vernova's wind turbines. At the same time, I will pursue my Master's degree in Electrical Engineering with a focus on power electronics and power systems.

Course Comment: This course has given me valuable experience collaborating with fellow engineers to accomplish a large-scale task. Through various stages of design, system testing, and integration, I have deepened my understanding of the skills and theories I have learned in the classroom and have developed the ability to work effectively with others.

Anthony Concessi — Orange, Vermont

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to make a meaningful contribution to climate-change mitigation through a career in the renewable energy industry. I am passionate about designing and implementing technologies that support a more sustainable and resilient electrical grid. Through my future work with Burns & McDonnell, I look forward to contributing to the development of power plants and energy infrastructure that will enable a transition to cleaner power generation.

Course Comment: Senior design has provided me with the experience of going through a long-term project as a member of a team. These experiences have helped me grow, not only as a student, but as a future engineer.

Alec Crispino — Westfield, New Jersey

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to help combat the climate change crisis through direct work in renewables or adjacent careers. I am particularly interested in developing solutions that make cleaner energy technologies more efficient, reliable, and accessible at scale.

Course Comment: This course has provided me with practical experience working on a large-scale project involving problem solving, system testing, and system integration. These experiences have strengthened the technical and collaborative skills that will help me become a valuable engineer in the future.

Anderson Crouse — Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire to develop my expertise in the power and energy systems field while contributing to innovative and sustainable electrical infrastructure solutions. I plan to continue growing as an engineer by contributing to meaningful projects and gaining hands-on industry experience.

Course Comment: This course provided my teammates and I with valuable real-world engineeirng experience by allowing us to apply our technical knowledge to a comprehensive, team-based project. It strengthened my problem-solving, communication and project management skills while preparing me for professional engineering work.

Charles Elliott — Arlington, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to grow my experience within the national security and defense industry by applying my background in electronics and cybersecurity. My goal is to contribute to secure, critical systems that demand precision, reliability, and technical excellence.

Course Comment: This course has strengthened my ability to translate engineering theory into a real world application. Through collaborative problem solving, system integrating, and design, I developed a deeper understanding of technical documentation and delivering solutions under practical constraints.

Solar Powered Offshore Oyster Nursery

Team: Charles Elliott, Joshua Grubb, Alec Crispino, Nicholas Burant, Anderson Crouse, Anthony Concessi
Team Mentor: Dr. Adams | **SME:** Dr. Feng | **Customer:** Annapolis Aquaculture

Background

- Oyster nurseries are controlled environments where oyster seedlings grow until they are large and resilient enough to be transferred to farms.
- Nurseries typically grow seedlings from 2mm to about ½"-¾" in diameter.
- Water containing nutrients and oxygen continuously circulates through silos to promote growth.
- Oyster waste and biofouling rapidly accumulate, requiring daily maintenance and cleaning.
- Offshore nurseries are of particular interest due to their potential for lower energy use and reduced environmental impact.

Fig. 1: Commercial implementation of oyster nursery

Objectives

- Design an autonomous solar powered offshore oyster nursery capable of reliably growing seedlings to the desired diameter with no grid dependence.
- Ensure any non-autonomous maintenance can be easily performed by a non-technical expert.
- Create a sustainable system that can run all loads for a minimum of 6 hours continuously, regardless of solar panel output.

Fig. 2: Prototype testing setup and implementation

High Level Design

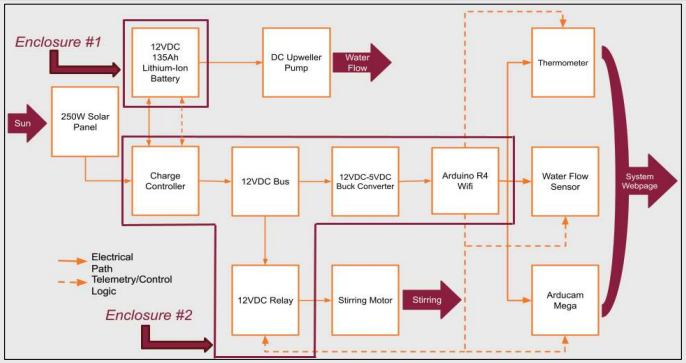


Fig. 3: High level design diagram of system

Power Stage: 250W Solar Panel supplies energy to the charge controller. The charge controller has the governing logic which prevents overloading of the battery and controls whether the batteries are charging or discharging.
Loads: DC upweller water pump runs continuously. DC stirring motor runs periodically. Bus voltage stepped down to 5V using a buck converter to supply the Arduino. The Arduino supplies power to the peripheral sensors.
Arduino Server: The Arduino server can be accessed remotely through connection to the local Wi-Fi network. The server broadcasts read data from the temperature sensor, the flow rate sensor, and the Arducam camera module. The data can be refreshed on command through the server at the user's discretion.

Software

- The autonomous tasks of the oyster nursery are run via an Arduino R4, powered by a 12V to 5V buck converter.
- The Arduino's local server serves an HTML page and displays the flow rate, silo temperature, stirring motor status, and camera status/image.
- An internal timer signals when the motor relay should switch states, turning the stirring motor on and off.

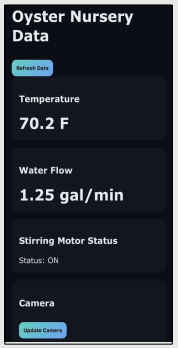


Fig. 4: Arduino web page

Results

- Various tests were conducted to visualize weather impact on battery charge over time.
- Sunny, night, and overcast conditions were tested.

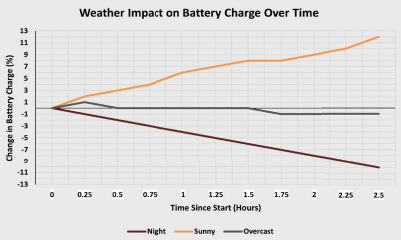


Fig. 5: Visualization of weather impact on battery charge over time

Conclusion

Our solution provides Annapolis Aquaculture with a self-sustainable oyster nursery that can grow 5-10 thousand oyster seedlings to be grown for an oyster farm with minimal human intervention required. This project serves as a scalable blueprint for the oyster farming community to help farmers begin nursing their own oysters to reduce reliance on current land-based systems.

Looking Forward

- There remains plenty of potential for expansion with a project like this since it is a first of its kind.
- Our project would benefit from being implemented onto the main GUI that the customer's oyster farm will be on.
- The oyster sorting process is a highly labor-intensive step in oyster farming that has yet to be automated.

Acknowledgements

We as a team extend our deepest gratitude to Dr. Adams and Dr. Feng for their invaluable guidance and mentorship throughout our Major Design Experience here at Virginia Tech. Utilizing their extensive experience and expertise in both Electrical/Computer Engineering and Biological Systems has not only enlightened us but also deeply inspired our understanding in both fields.

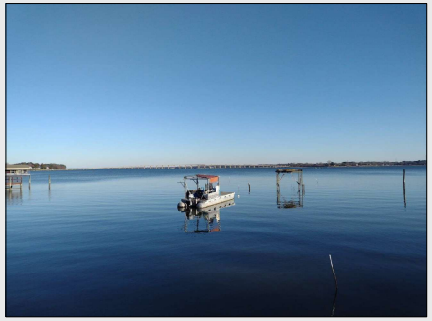


Fig. 6: System's future location in Chesapeake Bay

Project Contributor Acknowledgements

We want to acknowledge and thank the many people who contributed to this program:

Dr. Rose Hu
for her vision and continued unyielding support to prepare our students for the future.

Joe Adams, Kelley Andrews, Daniel Connors, Ken Schulz and Shelley Stover
for mentoring the teams and making the course and all involved with it better.

Mary Brewer, Susan Broniak, Nicole Gholston, Kimberly Johnston, Alicia Sutherland, Minerva Sanabria-Padilla, Virgilio Centano, Scott Dunning, Paul Plassmann and Laura Villada
for watching over and advising each and every ECE student through the many challenges on the rocky road to becoming an engineer.

Dr. William Baumann and Toby Meadows
for allowing us complete access to the design studio and conference room and providing assistance to students in need.

Afroze Mohammed
for being our partner and diligently working to nurture our industry relationships and to secure those critical sponsorships.

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for speaking to the students about graduate school.

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for ordering our materials, helping us solve supplier issues and managing conference rooms.

Christine Absher and Melanie Gilmore
for tirelessly providing financial guidance and support.

The SMEs
for providing technical expertise in guiding the teams.

Niki Hazuda and Nathaniel Cranfield
for helping to share the amazing message of our students' successes and for great support on our website.

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for solving our IT and building facility issues.

Bianca Norton and Virginia Tech Inn Staff
for helping plan, cater and secure all arrangements to make the Major Design Experience Expo so great.

Muntasir Mahdi, Ibrahim Eshera, Mohammedreza Saghafi and Prajwal Keshava Murthy
for being great teaching assistants in support of these MDE students.

Eric Louis Bagtas, Joshua Nafziger, Vivian Wright and Otniel Nguehou
for helping run tracks and registration at the day of the Expo.

The MDE Expo Judges
for judging the MDE presentations and posters.

Best in Course Recognition for Base Course Performance

Fall 2025

ECE 1004–Introduction to ECE Concepts

- Jianming (Jeremy) Chen
- Parasi Goswami
- Blake Powers

ECE 2024–Circuits and Devices

- Rishi Choubey
- Zachary LaCava
- Sam Troy
- Nathaniel Werns

ECE 2214–Physical Electronics

- Joshua Dugan

ECE 2514–Computational Engineering

- Hussein Al Blooshi
- Mohammed Al Hilali
- Xiao Qu

ECE 2544–Fundamentals of Digital Systems

- Isla Carlson
- Blake Morris
- Shelby Owed
- Sam Troy

ECE 2564–Embedded Systems

- Phillip Mellusi

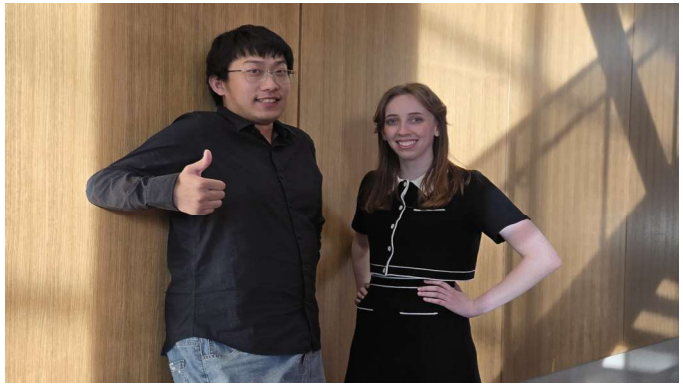
ECE 2714–Signals and Systems

- Evan Cedar

ECE 2804–Integrated Design Project

- Ryan Jastrzembski
- Quinlan Justice
- Collin Rice
- Keira Shaw
- Edward Wang
- Haoxuan Yang

Personal Smart Locker



LEFT to RIGHT: Haoxuan Yang, Keira Shaw

CHALLENGE

This project required designing a standalone, battery-powered smart locker using an ATmega328P microcontroller with secure 4-digit keypad access. The system needed non-volatile password storage via EEPROM, servo-driven locking with automatic obstruction detection, and an intuitive LED-based user interface. A key technical challenge was achieving long-term battery life through ultra-low-power sleep modes while maintaining stable voltage during high-current servo operation. The project demanded careful integration of hardware and software to deliver a reliable, secure, and energy-efficient device.

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VIRGINIA TECH

Keira Shaw Springfield, Virginia

Bachelor of Science in Computer Engineering
Networking and Cybersecurity

Aspirations: I aim to apply my background in networking and cybersecurity to design and implement secure, scalable technical systems as a Solutions Architect.

Course Comment: IDP provided hands-on experience integrating hardware and software with security-first principles, which is essential for designing resilient and optimized systems.

Haoxuan Yang Nanjing, China

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I want to build giant robots.

Course Comment: This course deepened my understanding of micro-controller programming and low power optimization for embedded systems, and I'm grateful for the collaboration with Keira and the guidance from Ji Wu.

Personal Smart Locker

Team: Keira Shaw & Haoxuan Yang
Instructor: Ji Wu Hong
Bradley Dept. of Electrical & Computer Engineering

Objective

Design and build a standalone, battery-powered personal smart locker controlled by an ATmega328P microcontroller. The system provides secure, keypad-based access with password encryption, servo-driven locking, user interface, automatic block detection, and ultra-low-power sleep mode for extended battery life.

System Architecture

The system consists of three core modules integrated through a finite state machine:

- **Actuator Module** — Servo motor with PMOS power switching and PWM control via 16-bit timer for precise angular positioning
- **User Interface** — Resistor-ladder keypad (7 keys → 1 ADC pin), 4 green + 1 red status LEDs with animated feedback patterns
- **Control Circuit** — ATmega328P processing keypad input, managing servo, LED output, password verification via EEPROM, and sleep/wake transitions

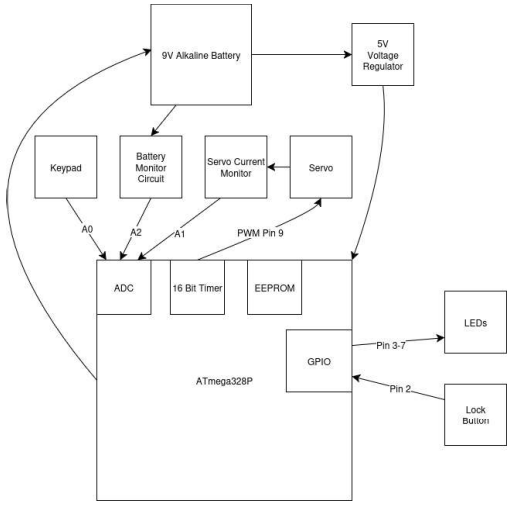


Fig. 1: System block diagram showing ATmega328P peripherals and external components

Design Requirements

- Secure 4-digit password entry via keypad with EEPROM storage
- Servo-controlled locking with automatic block detection
- Battery-powered standalone operation (9V alkaline)
- Low battery detection and user warning via LED
- Low-power sleep mode for long battery life
- Non-volatile password storage surviving power loss
- Intuitive LED status indication for all system states

Key Design Features

Battery Power System

9V alkaline battery regulated to 5V via MCP1702. Voltage divider with PMOS/NMOS switching enables ADC-based battery monitoring while drawing zero current during idle. Dual decoupling capacitors (100 μF + 1 μF) suppress voltage spikes during servo operation, keeping V_{CC} within the ATmega's safe operating range.

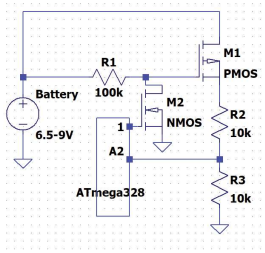


Fig. 2: Battery monitor circuit with PMOS/NMOS switching

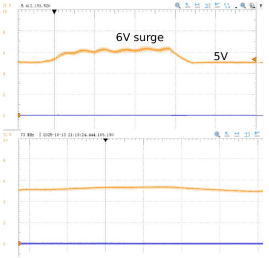


Fig. 3: V_{CC} with (bottom) and without (top) decoupling caps

Servo Control & Block Detection

Phase-correct PWM at 50 Hz generated by the 16-bit timer drives the servo through precise angular positions. A 1 Ohm resistor in series enables real-time current monitoring via ADC. When current exceeds threshold for >50 ms, the system detects a physical blockage and automatically reverts to the previous lock state. A 750 ms debounce timer prevents oscillation between states.

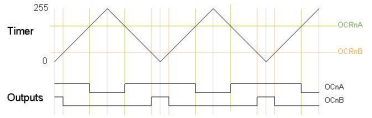


Fig. 4: Phase-correct PWM mode — timer counts up/down, OCRnA/B thresholds set duty cycle

Keypad Input & Password Security

A resistor-ladder network maps 12 keys to unique analog voltages read by a single ADC pin, reducing wiring from 7 pins to 1. Passwords are protected using a salt-and-pepper obfuscation scheme. A hard-coded pepper combined with a randomly generated salt produces an obfuscated result stored in EEPROM — the raw password is never stored.

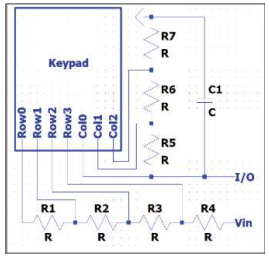


Fig. 5: Resistor-ladder keypad network schematic

```
void passwordSet_Obfuscated(int* arr) {
  long newSalt = analogRead(); // Use an UNUSED analog pin
  delay();
  newSalt += analogRead() << 10;
  delay();
  newSalt ^= analogRead();

  Serial.println("Generating new salt...");

  Serial.println("Calculating obfuscated result...");
  long result = calculateObfuscation(arr, newSalt);

  Serial.println("Saving salt...");
  EEPROM_writeLong(SALT_ADDRESS, newSalt);

  Serial.println("Saving result...");
  EEPROM_writeLong(RESULT_ADDRESS, result);

  EEPROM.write(SETUP_FLAG_ADDRESS, SETUP_MAGIC_NUMBER);
}

bool passwordCheck_Obfuscated(int* arr) {
  long storedSalt = EEPROM_readLong(SALT_ADDRESS);

  long storedResult = EEPROM_readLong(RESULT_ADDRESS);

  long calculatedResult = calculateObfuscation(arr, storedSalt);

  if (calculatedResult == storedResult) {
    return true; // Match!
  } else {
    return false; // No match.
  }
}
```

Fig. 6: Salt-and-pepper password obfuscation flow

Results

Battery Life Performance

- **2.4 μA** sleep current **22.8 yr** battery life
- **32.5 mA** avg. active current
- **2,439** full lock/unlock cycles per battery
- **5.16 yr** estimated life at 1 open/day
- **3.88** orders of magnitude: sleep vs. active

Finite State Machine

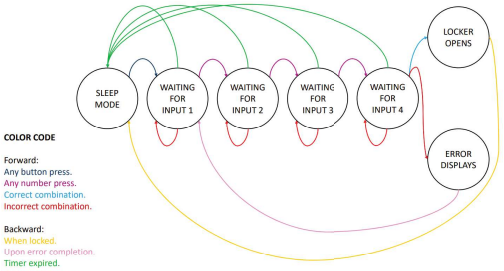


Fig. 7: System FSM — states include sleep, locked, password input, and locker open

Constructed System

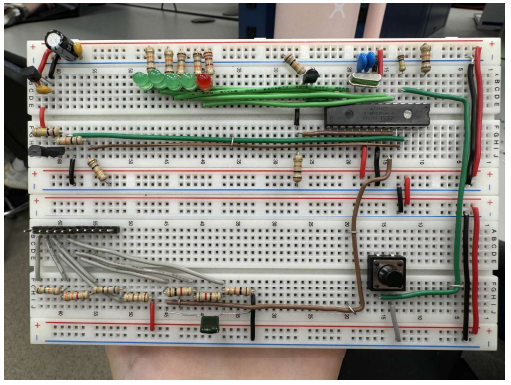


Fig. 8: Completed circuit — ATmega328P, signal pins for servo and keypad, LEDs, and battery monitor

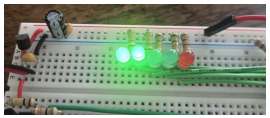


Fig. 9: Green LEDs — password input state

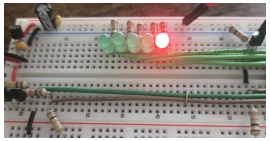
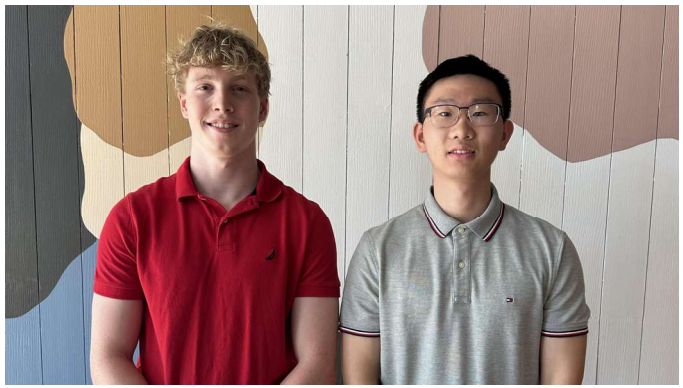


Fig. 10: Red LED — low battery warning

Infrared Radio Teletype



LEFT to RIGHT: Ryan Jastrzembski, Edward Wang

CHALLENGE

This project involved designing and building an infrared radioteletype (RTTY) system capable of transmitting digital data using frequency-shift keying. The main challenge was achieving reliable communication over several feet while operating under strict power constraints. Signal attenuation and ambient noise required careful design of amplification, filtering, and modulation stages.

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Ryan Jastrzembski Ashburn, Virginia

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: I plan to follow my passions and make my family proud.

Edward Wang Oakville, Canada

Bachelor of Science in Electrical Engineering
Applied Electromagnetics

Aspirations: I intend to pursue a master's degree in electrical engineering and work in the communication industry.

Course Comment: The course was a great way to integrate and apply knowledge from previous classes. This course emphasized practical skills and real-world problem solving that are not typically developed through just reading textbooks and taking exams.

INFRARED RADIO TELETYPE

Team: Ryan Jastrzembski and Edward Wang
Instructor: William Shuxiang Yu

VIRGINIA TECH

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BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH.

Background

Radioteletype (RTTY) is an early communication technology that transmits text by encoding characters into binary signals represented by two distinct frequencies, historically used in radio-based long-distance communication systems. This project explores how an IR-based RTTY system can reliably transmit and recover digital information while overcoming instrument practical limitations

Figure 1: Classical Radio Teletype

Objective

Design, build, and validate an infrared RTTY system

- Transmit ASCII data using frequency-shift keying (2125 Hz and 2295 Hz)
- Achieve reliable end-to-end communication from inches to at least 5 feet
- Operate under strict transmitter power constraints
- Optimize signal integrity through amplification, filtering, and sampling techniques.

Constraints

- Only parts from standard parts kit may be used in the solution
- Current through the infrared emitter must be limited to 0.4mA
- The frequency states must be 2295Hz and 2125Hz with a baud rate of 45.45
- No optical devices shall be used to enhance the range of the system

Design

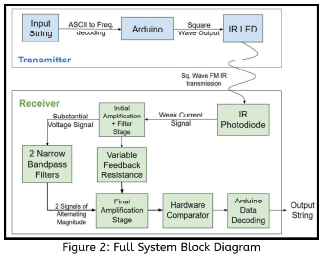

Figure 2: Full System Block Diagram

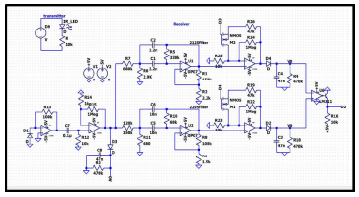

Figure 3: Full System Schematic

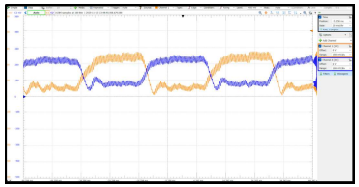

Figure 4: Transmitter Signal at 5 ft

The core of our design employs two parallel, narrow bandpass filters tuned to 2125 Hz and 2295 Hz to distinguish between the two tones. The outputs of these filters are rectified to extract their peak amplitudes, which are then compared to determine the transmitted frequency and produce a corresponding digital output.

Variable Gain

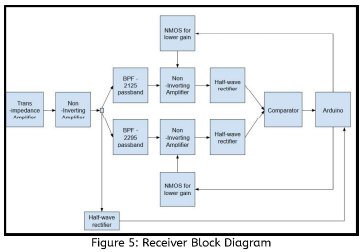

Figure 5: Receiver Block Diagram

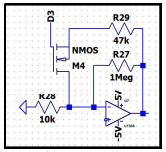

Figure 6: Variable Gain Implementation

- Amplifies the signals for the comparator
- Switches gain value based on analog input from initial amplification output

Receiver Circuit

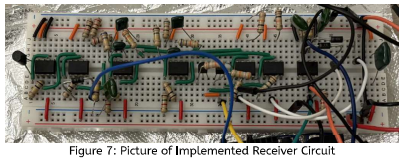

Figure 7: Picture of Implemented Receiver Circuit

Software Structure

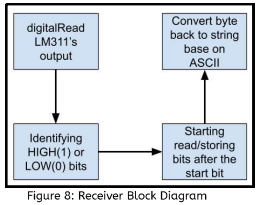

Figure 8: Receiver Block Diagram

Results and Validation

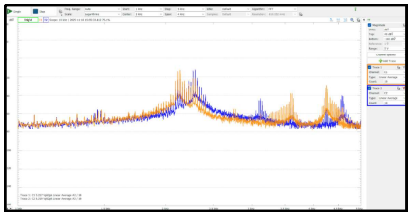

Figure 9: Spectrum Analysis at 5ft.

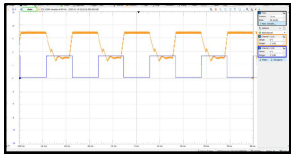

Figure 10: Digital result at 6 inches

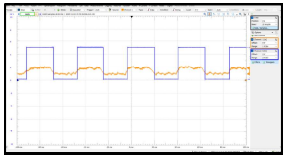

Figure 11: Digital result at 6.5 ft

Blue is comparator output
and orange is one input

- Achieved reliable and accurate communication from 6 inches to ~6.5 feet.
- Transmitter generated required frequencies; 2125 Hz and 2295 Hz.
- Receiver successfully distinguished frequencies using band-pass filtering and comparator detection.
- Spectrum analysis showed clear signal peaks above the noise floor.

Conclusion and Improvements

- Successfully designed and implemented an IR-based RTTY communication system.
- Achieve reliable transmission beyond the required 5ft (6.5ft)
- Variable gain approach improved performance across a wide range of transmission distances

- Gaussian Frequency transitions message transmission
- Higher Order filtering
- Full bridge Rectifiers
- PCB Design to replace breadboard
- Enhance system robustness against ambient light interference

Challenges
Conclusion
Future Work

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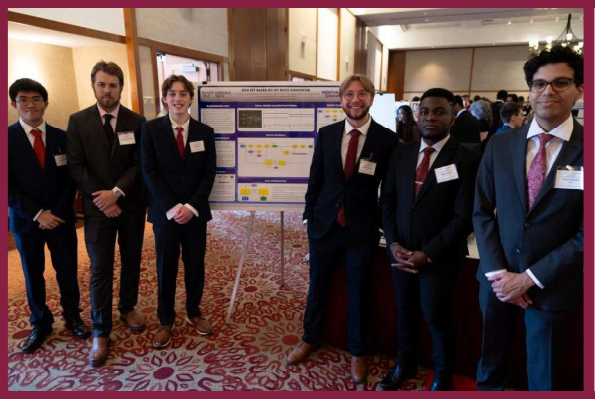

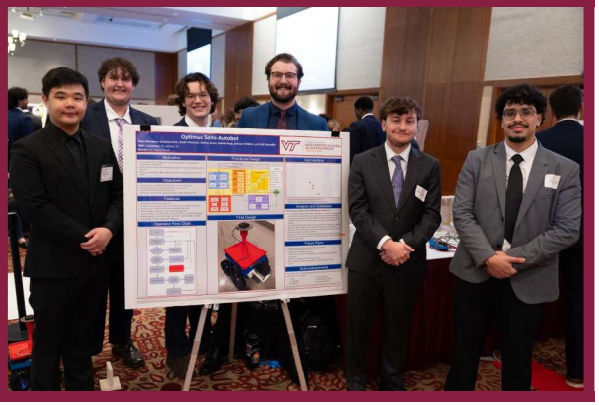

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Best in Track

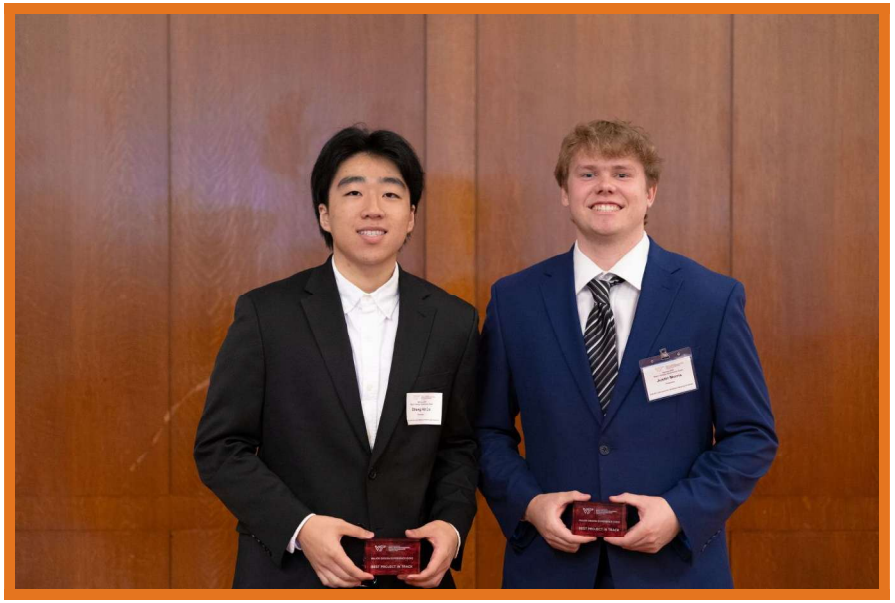
Track 1: Germanium NSFETs With Ferroelectric Materials for Use in High-Speed, Ultra-Low-Power Applications

Track 2: Rendezvous, Proximity Operations, and Docking (RPOD): Charging and Docking Bots

Track 3: Multi-Protocol Launchpad Integration SCADA for Virginia Spaceport Authority

Track 4: Sensor System for LoRaWAN

Track 5: Low-Cost Newborn Hearing Screener Using Auditory Brainstem Response



Best by Popular Vote and Best Overall

8-Element X-Band Digital Phased Array with RFSoC

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