ECE

MAJOR DESIGN EXPERIENCE EXPO

April 17, 2024

The Inn at Virginia Tech

COLLEGE OF ENGINEERING

BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

VIRGINIA TECH

Agenda

Registration	9:30–10:15am
Welcome	10:15am
Tracks	10:45am–12:45pm
Posters and Pizza	1:00–3:00pm
Awards	3:00–3:30pm

Presentation Tracks

Welcome to our Spring 2024 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 199 students, each working and learning together as a member of a design team finishing their second semester of work on their teams' unique projects.

Today, 42 exciting projects, each is a unique, open-ended, technical challenge defined by our industry partners; and 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've 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.

Congratulations to each of the students; their dedication and diligence are evidenced in these 42 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.

Luke Lester
Roanoke Electric Steel Professor and Department Head
Bradley Department of Electrical and Computer Engineering

Sponsors

We greatly appreciate their support.

BAE SYSTEMS

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BioDesign Research Group

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MARION DUPONT SCOTT
EQUINE MEDICAL CENTER

NATIONAL SECURITY INSTITUTE
VIRGINIA TECH

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	**Smart Cooling Loop for a Data Rack of the Future**	Scot Ransbottom
AFRL SDR University Challenge Dayton, Ohio	Louis Beex	**Counteracting Doppler Using OTFS Zak Transform**	Louis Beex
Analog Devices Greensboro, North Carolina	Jeff Chambliss, Sam Ringwood and Michael Jones	**X-band Hybrid Beamforming to Minimize Phased Array Grating Lobes**	Jeff Walling
Anduril Costa Mesa, California	Jonathan Ballagh	**LLM Powered Room Perception From Autonomous Aircraft**	Cameron Patterson
Army DEVCOM/ASPIRE	Justin Wright	**Field Guide Vision App: Arabic to English Road Sign Translation for US Soldiers**	Creed Jones
Army DEVCOM/ASPIRE	Sarah Jensen	**FPGA Implementation of a Radar System**	Jeff Walling
BAE Systems Manchester, New Hampshire	Jeremy Reeves	**Parallelized Photonic Compute Techniques**	Linbo Shao Zin Lin Yizheng Zhu
Biodesign	Jonas Hauptman	**Bamboo Canes: Omnidirectional Imaging and 3D Reconstruction**	Creed Jones
Biodesign	Jonas Hauptman	**Dual Input 3D Scanner for Bamboo Canes**	Creed Jones
Boeing Blacksburg, Virginia	Stephen Moyer	**IEEE Robotic Competition Hardware Team**	Arthur Ball
Boeing Blacksburg, Virginia	Robert Smith, John D. Williams and Michael Mitchell	**Early Failure Detection of Lithium-Ion Batteries Using Gas Sensing**	Khai Ngo
FoxGuard Solutions Christiansburg, Virginia	Michael Baker	**Digital Inventory as a Software Bill of Materials**	Daniel Connors

Sponsor	Customer	Project	Subject Matter Expert (SME)
FoxGuard Solutions Christiansburg, Virginia	Michael Baker	**Decision Tree Graphical Editor and Execution for Cybersecurity Vulnerabilities**	Alkan Soysal
Framatome	Heshan Gunawardane and Bob Furter	**Manual Control Brushless DC Motor Two-Axis Control Box**	Khai Ngo
G3 Technologies Mount Airy, Maryland	Juliet Anderson	**Low-Cost Portable Antenna Range**	Carl Dietrich
General Dynamics Mission Systems Fairfax, Virginia	Scott Patterson a nd Ethan Brooks	**Car Engine Audio Classifier**	Sook Ha
General Dynamics Mission Systems Fairfax, Virginia	Andrew Kolarits and Ethan Brooks	**Image Recognition AUTOmation**	Nektaria Tryfona
General Dynamics Mission Systems Fairfax, Virginia	Ethan Brooks	**AR Headset Object Identification**	Alkan Soysal
General Dynamics Mission Systems Fairfax, Virginia	Ethan Brooks	**Natural Language Interpreter**	Kristie Cooper Al Cooper
Kryptowire Arlington, Virginia	James Sugrim and Angelos Stavrou	**Cyberchase Tabletop Board Game**	Joe Adams
Marion duPont Scott Equine Medical Center	Almuatazbellah Boker	**Equine Vital Tracking: Real-Time Automated Health Monitoring**	Almuatazbellah Boker
MICRON	Marius Orlowski	**Simulation of Thermal Transport in Resistive Memory Arrays**	Amrita Chakraborty Aaron DeFilippo
Micron and ADSEL	Mantu Hudait	**Germanium Based Multi-Gate FETs for Ultra-Fast, Low-Power CMOS Computing**	Rutwik Joshi
Micron and ADSEL	Mantu Hudait	**A Germanium Laser for Future Quantum Technologies: Design and Implementation**	Rutwik Joshi
NASA and SSAI	Jackie Kendall	**Astrochemical Sensor Integration**	Scott Bailey
NASA and SSAI	Jackie Kendall	**B.U.R.S. : Balloon Ultraviolet Radiation Sensor**	Scott Bailey
NASA/VT ECE	Elena Lind	**Cimel Data Relay and Storage Unit**	Shelley Stover

Sponsor	Customer	Project	Subject Matter Expert (SME)
NAVAIR FRC East, MCAS Cherry Point, North Carolina	Dylan Gooch	**Aircraft Data Acquisition Device**	Peter Han
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Ya Li	**Verification of Microelectronics Protection Technology**	Jason Thweatt
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Matthew Erik Mills and Christopher Lillard	**Mobile Digital High Frequency Ionosonde**	Zach Leffke
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Bill Smith	**Far-Field Antenna Pattern Reconstruction From Probe Data in the Planar Near-Field of an Antenna**	Brad Davis
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Bill Smith	**Instrument and Control for a Near Field Planar Scanner**	Brad Davis
Naval Surface Warfare Center, Dahlgren Division (NSWCDD)	Alan Overby	**Signals of Distress: Detecting UAS Damage in High-Powered Microwave Environments**	Daniel Connors
NAWCAD, NAS Patuxent River, Maryland	Israel Jordan and Andrian Jordan	**IEEE Robotic Competition Software Team**	Arthur Ball
Virginia Spaceport Authority Norfolk, Virginia	Sidnee McGee	**SCADA System Development for Oversight of all MARS Facilities**	Joe Adams
Virginia Tech, ECE Blacksburg, Virginia	Luke Lester	**Automated Coin Detection**	Creed Jones
Virginia Tech, ECE Blacksburg, Virginia	Luke Lester	**Lester Labs Automated Grading Service: Saint-Gaudens Double Eagle**	Creed Jones
Virginia Tech, ECE Blacksburg, Virginia	Wenjie Xiong	**Optimization and Hosting of Embedded Systems Chatbot**	Wenjie Xiong
Virginia Tech, ECE Blacksburg, Virginia	Scott Dunning	**Open ERCOT: Open Source Grid Modeling**	Scott Dunning
Virginia Tech, National Security Institute Blacksburg, Virginia	Alan Michaels	**Account Interaction System**	Alan Michaels
Wiley Wilson Lynchburd, Virginia	Dan Morton, Chuck Niedermayer, Mark Atkinson and Gary Li	**Campus-Wide Deployment of Solar Lighting**	Kelley Andrews
Zeta Associates Fairfax, Virginia	Nic Rohr, Michael Drescher and Jared Desai	**Personal Locator Beacon Range Extender and Transceiver Network**	Tim Talty


BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH
MAJOR DESIGN EXPERIENCE EXPO
BEST OVERALL PROJECT


Partnership with
ANDURIL

Project Teams and Posters

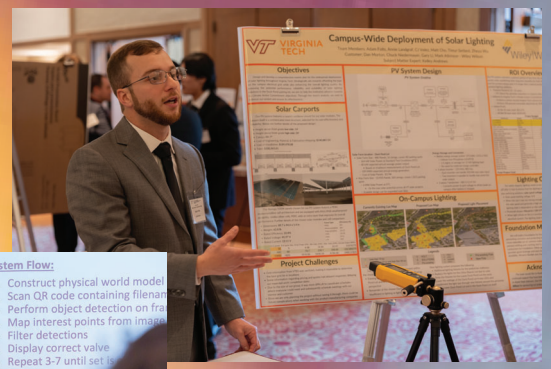
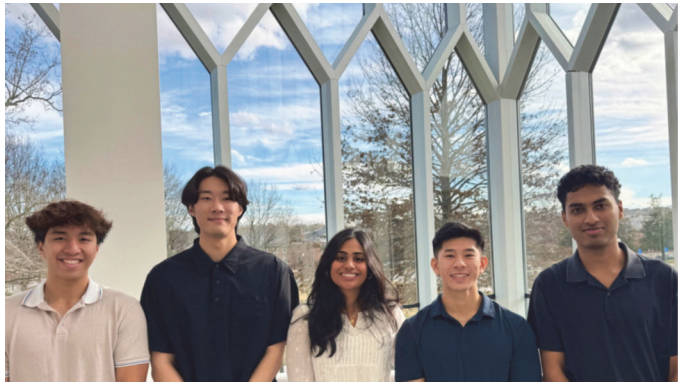


Image Recognition AUTOmation



LEFT TO RIGHT: Alex Nguyen, Andy Lee, Ramya Aluri, Dan Nguyen, Arya Naren

CHALLENGE

Create an offline Artificial Intelligence tool that uses image recognition to identify a cars make, model, and year in real-time which then displays the top 3 predictions onto a Graphical User Interface. This project can be applied to areas within the Navy, a GDMS partner, to aid a sailor's task regarding underwater object detection.

GENERAL DYNAMICS
Mission Systems

SME: Nektaria Tryfona

Customers: Ethan Brooks and Andrew Kolarits

Ramya Aluri Glen Allen, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: Having pursued a degree specializing in Autonomy, I hope to develop software for the advancement of autonomous systems and vehicles. I am excited to usher in the next generation of transportation technology making goods and services more accessible. Post graduation, I will be relocating to Seattle, WA to work as a Software Developer at the Boeing Company.

Course Comment: This class has given a practical application of the theoretical principles we learned in our other coursework. It has given me instrumental skills to excel in the workplace including collaboration, problem-solving, and cross-tool integration. I had the perfect team to push me and rise to the challenge to meet our customer's goals, and for that I am grateful. Additionally, I am very appreciative of GDMS for challenging us and setting high expectations knowing we would work hard to meet our goals.

Andy Lee Vienna, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My career goal is to become a leader in the computer engineering field and to expand my knowledge of software development. Following graduation, I will be working for Northrop Grumman as an Associate Software Engineer.

Course Comment: This course has given me the opportunity in gaining valuable hands-on experience in planning, designing and managing an engineering project.

Arya Naren Fairfax, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: As a machine learning major with a passion for fintech, I aspire to leverage my skills to drive innovation at the intersection of technology and finance, contributing to the evolution of ML-powered solutions within the fintech industry. Following graduation, I will be moving to San Francisco to work at Visa as an Associate Product Manager on Visa's AI/ML team.

Course Comment: This class has been instrumental in developing my skills, from customer interaction to effective teamwork under tight deadlines. I'm grateful for my incredible teammates and would like to thank our SME and mentor for providing the support for our success, as well as our customer GDMS for giving us a challenging yet rewarding project.

Alexander Nguyen Alexandria, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: As a machine learning engineer, my career goal is to contribute to future technological advances, specifically, the integration of artificial intelligence into blockchain technology.

Course Comment: I appreciate learning about the design and implementation process of the project as I believe that it is essential to our careers. I also enjoyed working with my team to develop a successful and note-worthy project.

Dan Nguyen Lorton, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My career goal is to develop software for the Department of Defense and eventually move up into a Senior Manager role. My plan for Summer 2024 is to intern as a Software Engineering intern for General Dynamics Mission Systems.

Course Comment: I have enjoyed learning about the logistical non-technical aspects of running a project through the different assignments such as the Preliminary Design Review and Critical Design Review.

Popular Vote

Image Recognition AUTOmation

Team: Ramya Aluri, Andy Lee, Arya Naren, Alex Nguyen, Dan Nguyen
Customer: Andrew Kolarits & Ethan Brooks - General Dynamics Mission Systems
Subject Matter Expert: Dr. Nektaria Tryfona | **Mentor:** Dr. Daniel Connors

VIRGINIA TECH

GENERAL DYNAMICS Mission Systems

Problem Statement

- Create an Artificial Intelligence tool that uses **image recognition** to define whether a vehicle is a **car or a truck and its make and model, and year (MMY)**
- Have the capability to do this in a field of multiple cars **in real time**
- This project can be applied to areas within the Navy, a GDMS partner, to aid a sailor's task regarding underwater object detection.

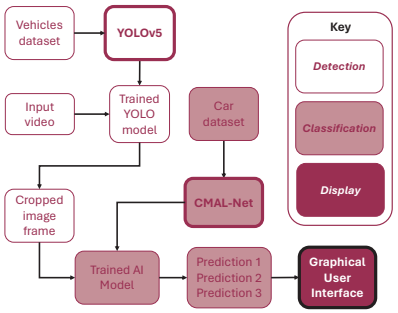
Constraints

- Focused on top 10 models (2010-2020)
- Restricted to offline functionality
- System must operate continuously without interruption
- Must achieve high confidence in target recognition before capturing the car
- Utilize internal database for MMY identification
- Consider only 2-axle vehicles as cars

Requirements

- ≥ 85% accuracy
- Return top three predictions and display on GUI
- Stretch goal: Identify cars partially in frame (40%-80%)

System Design



1. YOLOv5 trained on vehicle dataset
2. Video fed into trained YOLO model and cropped into frames
3. CMAL-Net trains on car dataset
4. Trained model predicts each cropped frame
5. GUI displays top 3 predictions

YOLOv5

- State-of-the-art object detection model
- Offers improved architecture and various model sizes for different requirements
- Implemented in PyTorch, featuring built-in data augmentation and training pipeline for enhanced ease of use
- Use case: detecting when a car or truck is in frame

CMAL-Net

- Cross-layer mutual attention learning network (image classification)
- Utilizes convolutional neural network layers as "experts" to capture varying levels of detail
- Employs attention regions predicted by each expert to identify distinctive features
- Use case: make, model, & year prediction

Results

85%
accuracy achieved

demo

Test videos included live video feed via campus and pre recorded B-roll footage

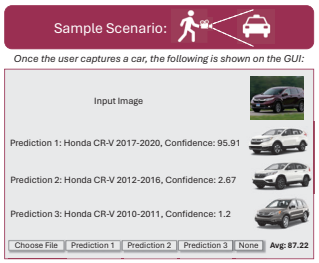
Future Implementations

- Add more car models and train on a larger dataset
- Color, trim, and estimated value capability
- Damage prediction (as a %), given a vehicle

Challenges

- Hardware restrictions
  - Trained on NVIDIA GeForce RTX 2060
- Long training time
  - 15 hours to train 2100 images (35 classes, 60 images per class)
- Weak initial dataset

User End



Acknowledgements

We would like to extend a special thank you to the following for supporting us:

- **Dr. Nektaria Tryfona** for assisting with technical matters
- **Dr. Daniel Connors** for mentoring us and providing areas of resource
- **Andrew Kolarits & Ethan Brooks (GDMS)** for a fun project!

AR Headset Object Identification

Track 1 Winner

LEFT TO RIGHT: Samuel Park, Andrew Salzmann, Tad DiDio, Liam Bushway, Varin Nakka

CHALLENGE

Our challenge was to develop an Augmented Reality (AR) system using the Magic Leap 2 headset to guide a worker through the process of performing maintanence on a plumbing system. Our system will provide instruction by clearly highlighting components in the real world that require user interaction in the correct order. This project aims to minimize human error in maintenance through an intuitive, user-friendly interface, enhancing efficiency and safety.

GENERAL DYNAMICS
Mission Systems

SME: Alkan Soysal

Customers: Ethan Brooks and Jordan Trcka

Liam Bushway Norfolk, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I want to apply what I learned in my academic career to help innovate the next generation of technology.

Course Comment: This course was a great experience to learn how development works in the real world.

Tad DiDio Westminster, Maryland

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I am continuing on to obtain my master's degree and afterwards I would like to solve cutting edge problems in research and development.

Course Comment: This was an amazing course because it presented our team with a real world problem and gave us experience in producing a solution that would have a beneficial impact.

Varin Nakka Ashburn, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Pursue a master's degree in engineering.

Course Comment: As a computer engineer focusing on networking and cybersecurity, my goal is to enhance digital security at a leading tech firm. My time at VT and work at GDMS has exposed me to pressing cybersecurity challenges, sharpening my skills in protecting information systems. Pursuing further studies in grad school, I aim to deepen my expertise and contribute significantly to the field of cybersecurity, striving to make a meaningful impact on network security and resilience.

Samuel Park Sacheon, Korea

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: My research of interest is object detection that would enhance in identifying object for autonomous driving. I would love to see full automatic vehicle one day!

Course Comment: I loved everthing about this course. It helped me develop communication skills and how to work as a team.

Andrew Salzmann Ashburn, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: Pursue a master's degree in engineering with a focus in Secure Information Systems and Networks.

Course Comment: This course taught me many lessons that I know I will need to apply in a real work environment such as organization, communication, and problem solving. I enjoyed my time in this course and working with my team.

Track 1 Winner

Augmented Reality Object Identification

VIRGINIA TECH
GENERAL DYNAMICS Mission Systems

Members: Tad DiDio, Andrew Salzmann, Samuel Park, Liam Bushway, Varin Nakka
Mentor: Dr. Daniel Connors
Subject Matter Expert: Dr. Alkan Soysal

Sponsor: General Dynamics Mission Systems
Customers: Ethan Brooks, Jordan Trcka

Problem Statement

Facing the challenge of error-prone maintenance in systems with complex plumbing configurations, General Dynamics Mission Systems (GDMS) proposes an innovative solution: an Augmented Reality application using the Magic Leap 2 Headset. This technology aims to guide users through a set of instructions by precisely identifying, localizing, and displaying the correct operations that need to be performed.

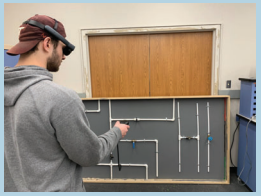


Figure 1: User Operating Headset

Objectives

- Develop an AR headset application to assist a user in performing maintenance on a complex plumbing system.
- Utilize Magic Leap 2 AR headset to automatically identify which valves need to be operated on.
- Use QR codes to easily and unambiguously select an instruction set.
- Ensure the system operates in a standalone state with pre-built libraries and without internet connectivity.
- Guide maintenance on a plumbing system by finding and displaying which valve should be operated on and how.

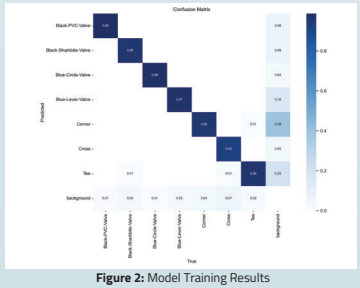


Figure 2: Model Training Results

High Level Application Design

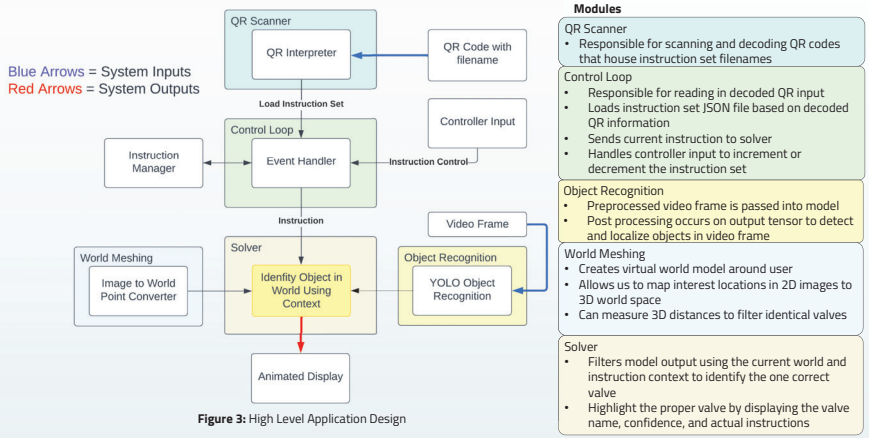


Figure 3: High Level Application Design

Results

Algorithm Performance
- Enhanced object identification algorithm for valve detection and world space localization
- Inference runs at approximately 5Hz
- Inference calculated across multiple render frames to avoid lowering frame rate.
- Object detection model operates at 97% mAP (mean average precision)

World Meshing
- We construct a model of the physical world around the user
- This allows us to place objects in the world and measure accurate world space distances to within 1% margin of error

System Reliability and Functionality
- System is able to operate completely standalone.
- No need for internet connection or external databases.
- Proven consistent identification and highlighting of mechanical components.

User Experience and Interface
- Developed a user-friendly GUI, enabling easy navigation and interaction within the AR environment.
- Implemented intuitive control mechanisms for the Magic Leap 2 headset.

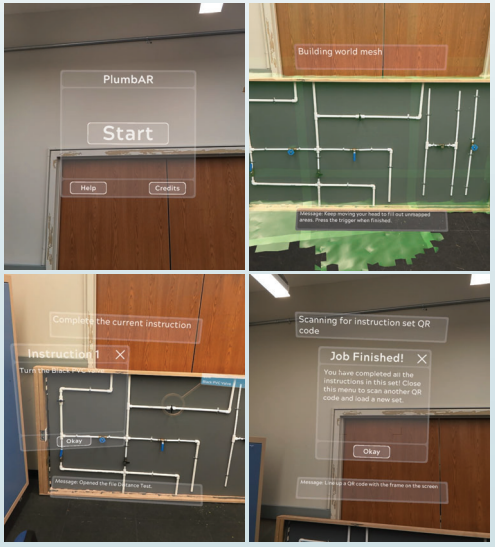


Figure 4: GUI Screens

Challenges

- **Model Optimization**
  - Running an object detection model to process live video is computationally intensive, making it difficult to run the application efficiently.
- **Offline Application**
  - Creating the application for offline use made deploying the model from internet servers impossible.
- **Model Inference**
  - Understanding how to interpret and process the output tensors from inference was a challenge.
- **Documentation**
  - Little documentation available about the APIs and systems we used.
- **Application Instability**
  - Complex actions in the software would cause crashing to occur.
- **Time**
  - The team faced many setbacks, which lead to loss of time.

Conclusion

Through innovative integration of AR technology and machine learning, our project has made great progress in the field of pipe system maintenance. By achieving precise real-time object identification on pipe valves, we've laid the groundwork for future developments in AI assisted maintenance systems. Our success demonstrates not only the feasibility but also the potential of AR in industrial application, setting a new benchmark for safety, efficiency, and user interaction in complex maintenance tasks.

Lessons Learned:
- Importance of robust algorithm development and real-world testing for AR application success.
- Technical details of convolutional neural networks and inference post processing.
- Effective team collaboration and iterative design was crucial for navigating the complexities of integrating AR with real-time data processing and machine learning.

Future Plans

- Hand tracking and speech recognition for instruction control
- In-application instruction set generator
- Validation of distances using pathfinding to trace pipes between valves and connectors
- Offload object detection to a local server to improve speed and battery life
- Store instruction set files on a local server for ease of use

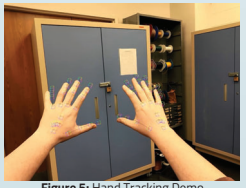


Figure 5: Hand Tracking Demo

Acknowledgements

The Augmented Reality Object Identification team would like to thank:
- Dr. Daniel Connors, our mentor
- Dr. Alkan Soysal, our SME
- Ethans Brooks and Jordan Trcka, our customers

Natural Language Interpreter

LEFT TO RIGHT: Samuel Abraham, Claire Doody, Luis Vazquez, Burak Taha Topo, Noah Bardenstein

CHALLENGE

Design and develop a standalone, natural language processing tool similar to ChatGPT, which leverages a pre-downloaded library of PDF's created by the user for any specific use case. This system must interpret human input, efficiently retrieve relevant information from the documentation, and display the findings in a readable format using a generative model, all while operating independently of an internet connection.

GENERAL DYNAMICS
Mission Systems

SME: Al Cooper and Kristie Cooper

Customers: Thomas Arbeiter and Ethan Brooks

Samuel Abraham Kuwait City, Kuwait

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I wish to be at the cutting edge of new technologies that can make an impact on people's lives. Natural Language processing and Generative AI is a nascent field that has immense potential, of which I hope to be part of.

Course Comment: This course has provided me with design experiencing in terms of working with a team, customer, SME and mentor. Senior Design showcases the engineering process in its fullest and forces you to make design decisions in terms of requirements and constraints.

Noah Bardenstein Ashburn, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I want to work on the forefront of machine learning technologies and make meaningful contributions in the field. I aspire to help engineer solutions to real world problems using software systems.

Course Comment: This course provided a unqiue experience to work on a complex project with practical applications. I believe I am more prepared for my professional career and will extensively use the skills I have developed during the course.

Claire Doody Great Falls, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: Following graduation I will be staying at Virginia Tech to pursue a Master's in Computer Science. After this I hope to work in industry working with embedded systems.

Course Comment: I am grateful MDE gave me the opportunity to work together with a team and industry partners to create a final product. I feel as though my communication and teamwork skills have been enhanced through this experience.

Burak Taha Topo Herndon, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I am dedicated to creating innovative and well-designed solutions to our problems, aiming to leave the world a better place than I found it, by leveraging the resources, knowledge, and experience I gained from Virginia Tech.

Course Comment: The MDE provided an excellent opportunity to explore real-world software development challenges, improving my coding and problem-solving skills. Through close collaboration with industry professionals, I gained valuable insights about agile methodology and project management, preparing me for a smooth transfer from academia to the tech industry.

Luis Vazquez Culpeper, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to work in a job that helps make a positive impact to people

Course Comment: The course taught me how to work with others to help develop a large software project

Natural Language Interpreter

Claire Doody, Samuel Abraham, Noah Bardenstein,
Luis Vazquez Morales, Burak Taha Topo
Sponsor: Thomas Arbeiter, Ethan Brooks - General Dynamics Mission Systems
Subject Matter Experts: Dr. Kristie Cooper, Al Cooper – Virginia Tech

Background

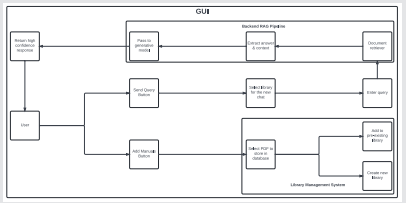
- **Natural language processing** (NLP) is an approach aimed to connect human communication with computer understanding. Generative models, like ChatGPT, drives productivity but faces issues like high costs, outdated knowledge, and security risks.
- **Retrieval Augmented Generation** (RAG) is a novel solution that addresses these limitations by incorporating an information retrieval component to augment the generative model's responses with user-provided data.
- **General Dynamics Mission Systems** has tasked us with creating an offline NLP system that answers questions using a user-uploaded document store.

Objectives

- **Natural Language Query Processing**: Understands and processes queries in natural language, allowing users to ask questions as they would normally speak or type.
- **Subject-Specific Knowledge Library:** Manuals as PDFs from various fields can be deployed separately and queried.
- **User-Friendly GUI**: Information is presented in a clean, readable format, enhancing user experience and understanding.
- **Offline Functionality**: Operates in a standalone state without the need for internet connectivity, ensuring data security.

System Overview

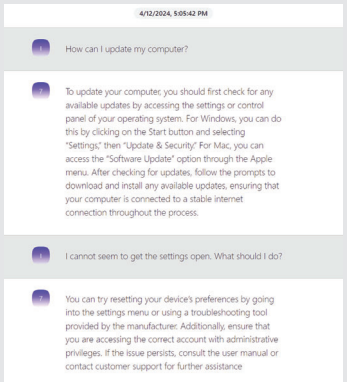
The system utilizes Serge for the chat interface on the frontend and a RAG-based pipeline on the backend that processes documents into searchable vectors, ensuring efficient, prompt question-answering capabilities. The information is extracted from relevant documents to provide a contextually accurate and confident response to the query.



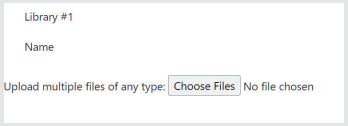
High level system overview block diagram

Frontend

- Accepts and passes queries to the backend
- Turns JSON objects from API call into readable format
- Allows manuals to be added to the database
- Able to create multiple different chats with any specified library



New chat with query & response

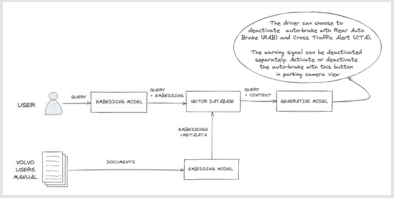


Add Manuals page to store PDF's

Backend

Specifications:

- Retriever: BM25 Retriever
- Document store: InMemoryDocumentStore
- Database: MongoDB
- Model: Mistral 7B with llama.cpp
- Framework: Haystack



Retrieval Augmented Generation (RAG) architecture

RAG Example:

- Documents/library: Volvo XC60 User Manual PDF
- Query: "How do I turn off the automatic reverse breaking on the Volvo XC60"
- Response: "The driver can choose to deactivate auto-brake with Rear Auto Brake (RAB)…"

Additional Processing:

- Pre-processing PDF's before converting to text to remove non-ascii related characters and fix whitespace issues.
- Post-processing LLM response to determine clear start and stop of response.

Analysis

Time Analysis in seconds

- Dataset used: Feature extraction for robust physical activity recognition.
- 5 different queries were provided and the average time for each query was calculated.
- The local machine utilized a 16GB AMD Ryzen 4700u with Radeon Graphics

Query	Local machine	Nvidia V100	A100
Q1	62.01	5.42	4.32
Q2	61.97	5.67	6.86
Q3	41.23	4.37	4.41
Q4	38.95	5.32	7.00
Q5	15.91	8.01	4.17
Avg. All queries	44.01	5.76	5.35

Challenges

- Insufficient GPU resources on local machines
- Large Model size and load times
- All aspects of the project had to be downloaded onto the local disk for development
- Using different Development Environments:
  - Colab Pro vs Local

Future Optimizations

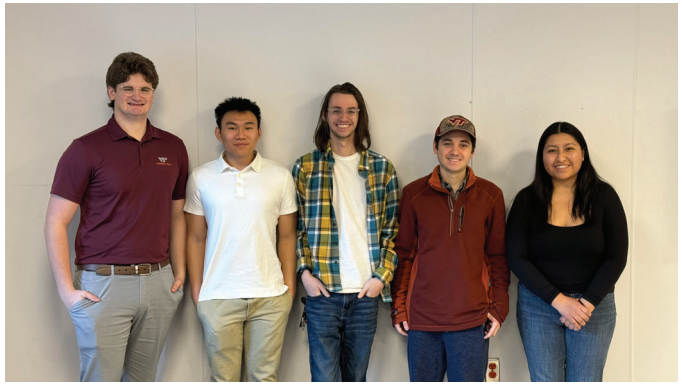
- Ability to recognize out of domain question
- Chat persistence
- Library persistence
- GPU and RAM optimization for specific local configuration
- More robust document pre-processing
- Store more than only PDF files
- Keep images, tables and context together
- Finetuning hyperparameters for optimization
- Better context retrieval

Acknowledgements

The team would like to give special thanks to the following for their support:

- Dr. Daniel Connors (Mentor)
- Dr. Kristie Cooper and Al Cooper (Subject Matter Experts)
- Thomas Arbeiter (Main Contact)
- Ethan Brooks (Customer)

Car Engine Audio Classifier



LEFT TO RIGHT: Rayden Dodd, Ryan Hua, Austin Hall, Dylan Green, Valeria Pozo

CHALLENGE

For our project, we developed an offline engine detection program that is triggered by engine idling. Using machine learning techniques, the program identifies the engineâ€™s brand within a 5-minute timeframe and displays the three closest matches.

GENERAL DYNAMICS
Mission Systems

SME: Sook Ha

Customers: Ethan Brooks and Scott Patterson

Rayden Dodd Vienna, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My aspiration is to become a pioneering figure in autonomous vehicle technology, utilizing machine learning and computer vision to develop innovative solutions that redefine transportation safety and efficiency.

Course Comment: Partnering with GDMS was an invaluable experience, offering practical insights into the world of machine learning. It not only enhanced my understanding of the field but also provided hands-on learning opportunities that will undoubtedly benefit my future career.

Dylan Green Norfolk, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My aspiration is to become a machine learning engineer and develop software that will help make everyday life safer and more enjoyable for everyone. I will also pursue a master's degree and continue my hobby in electronics.

Course Comment: This course taught me a lot about working on a long-term project as a team. Specifically, the need for frequent communication and good planning.

Austin Hall Centerville, Ohio

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to use my knowledge of robotics along with my passion for circuits to help create electronics that improve people's daily lives.

Course Comment: I am extremely grateful for the opportunity to use all the knowledge and skills I have gained up to this point and work with a company to create a product, similar to a real-world engineering experience.

Ryan Hua Lorton, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I want to pursue a career in software engineering, specializing in machine learning. I want to focus my efforts on developing applications for AI speech recognition and audio processing to help connect people with different languages.

Course Comment: This course has provided me with real experience on how to work with a team and be challenged by the different aspects of the engineering design process.

Valeria Pozo Springfield, Illinois

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: With the skills I have gained these past four years, I aim to be a part of innovative AI and ML projects that have a lasting positive impact on daily life.

Course Comment: This class gave me the necessary skills and experience to work on long-term projects in the real world.

Car Engine Audio Classifier

Team Members: Rayden Dodd, Ryan Hua, Valeria Pozo, Dylan Green, Austin Hall
Mentor: Dr. Daniel Connors | **Sponsors:** Scott Patterson, Ethan Brooks
SME: Dr. Sook Shin Ha

Overview

- Proof of Concept
- Can an engine's make be identified from its sound?
- Applications in signal/audio processing
- Will be used in military applications
- Detecting submarines while underwater

Objectives

A US Navy submarine's mission is to remain as silent as possible to complete their objectives. Sailors must continuously measure sound output within the submarine. Using computer assistance for this task would greatly benefit the boat's safety. The goal is to apply machine learning techniques to identify car engines as a proof of concept.

Requirements

- Program has minimum accuracy of 80%
- Constantly listens to its environment
- System only activates when engine sound is detected
- Uses machine learning techniques to determine car brand
- Displays top 3 predicted car brands in GUI
- Engine identification is complete within 5 minutes
- Program must run completely offline

Acknowledgements

Our team would like to thank the following people for their support throughout the project:
- Dr. Daniel Connors
- Dr. Sook Shin Ha
- Scott Patterson
- Ethan Brooks

Solution

- Engine classifier program written in Python
- Can record audio from microphone or read from file
- Mel Frequency Cepstral Coefficients (MFCCs) extracted from audio
- MFCCs fed into to binary classifier for engine detection
- Deep Neural Network used to classify audio
- Top 3 predicted car brands shown in GUI

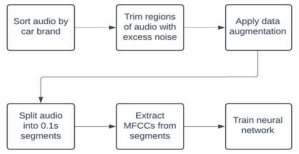


Fig. 1: Neural network training process

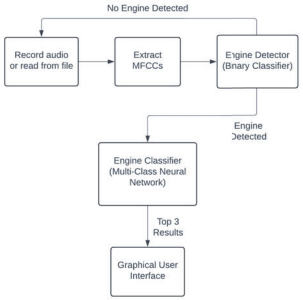


Fig. 2: Software flowchart

Results

- System runs completely offline
- Neural network classifies audio with 96% accuracy
- System activates only when engine is detected
- Average time per engine identification: 8.5s

Fig. 3: Program GUI

Predicted Brand

Actual Brand	BMW	Ford	GMC	Honda	Hyundai	Jeep	Kia	Nissan	Subaru	Toyota
BMW	91	0	0	0	0	1	1	0	0	2
Ford	0	69	0	0	0	0	0	0	0	1
GMC	0	0	102	1	0	0	0	0	2	5
Honda	0	0	1	122	1	0	1	0	0	0
Hyundai	1	0	0	1	84	0	4	0	0	0
Jeep	0	0	0	1	0	84	1	1	0	3
Kia	1	0	0	0	0	0	89	0	0	0
Nissan	1	0	0	1	0	0	1	107	0	0
Subaru	1	0	1	0	0	1	0	0	107	0
Toyota	0	0	0	5	2	0	1	0	0	222

Fig. 4: Engine classifier confusion matrix

Lessons Learned

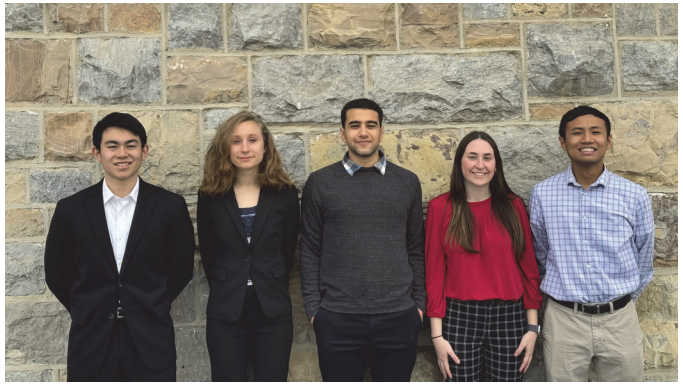
1. Data collection
   a. Very difficult to find usable car engine audio online
   b. Balanced dataset is difficult to obtain
2. Machine learning model performance
   a. Prone to overfitting
   b. Longer audio segments leads to high input dimensionality
   c. Distance from microphone affects classification accuracy
3. Model preparation
   a. Tuning of model parameters is very time consuming
   b. Difficult to work with large audio datasets
   c. Data augmentation greatly improved performance

Future Plans

1. Dataset
   a. Balance total audio length between brands
   b. Add class for engines that are not cars (motorcycles, planes, etc.)
2. Machine learning model
   a. Add ability to determine car model in addition to brand
   b. Test different neural network architectures
   c. Test effects of microphone distance on classification accuracy

Fig. 5: Audio recording setup

Field Guide Vision App: Arabic to English Road Sign Translation for US Soldiers



LEFT TO RIGHT: Kyle Takeuchi, Freya Archuleta, Omar Nweashe, Jessica Beltz, Nathaniel Sianipar

SME: Creed Jones

Customer: Justin Wright

CHALLENGE

Our objective is to develop an iOS and Android application for US Army soldiers overseas that translates text extracted from images of Arabic road signs to English. Modern translation solutions commonly cannot detect discrepancies between literal translations and native pronunciation. The goal of our app is to limit the need for human translators and provide higher accurate translations considering these discrepancies.

Freya Archuleta Ellicott City, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I will pursue many forms of design work using my creativity and resourcefulness to create community and togetherness.

Course Comment: I developed the skills to managing a project over two semesters which requires effective planning, organization, and time management. Our team struggled at first but then we found great synergy that brought us far.

Jessica Beltz Coopersburg, Pennsylvania

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: In my future career, I aspire to work with a power utility company where I can use hands-on experiences to help solve problems and improve the power grid. My aim is to help create a greener future.

Course Comment: The experience of working with an industry sponsor as well as on an engineering team has helped show me the practice of working in industry and overcoming the challenges that come along with it.

Omar Nweashe Fairfax, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aspire to leverage the skills I've learned to make a positive impact through innovative products that benefit the people and communities around me.

Course Comment: Thankful for the opportunity to work with an industry sponsor, and the insights from our subject matter experts and mentors.

Nathaniel Sianipar Lorton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to take what I have learned throughout my time at Virginia Tech and use it in the Cybersecurity field.

Course Comment: The course helped give me hands-on experience with APIs.The course also helped me learn how to work on a long term engineering project in a team.

Kyle Takeuchi San Ramon, California

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My aspiration is to leverage data and work with machine learning models to provide significant value to companies.

Course Comment: Engaging in this experience has given me a better understanding of the practical elements of product development, significantly enhancing my communication and teamwork skills.

Field Guide Vision: Arabic to English Road Sign Translation for US Soldiers

Team Members: Freya Archuleta, Jessica Beltz, Omar Nweashe, Nathaniel Sianipar, Kyle Takeuchi

Sponsor: Justin Wright, US Army DEVCOM C5ISR **Subject Matter Expert**: Dr. Creed Jones, Virginia Tech

Background

To assist abroad U.S. soldiers, Field Guide Vision provides Arabic-to-English online translation of text in National Standard Road and Street Sign images.

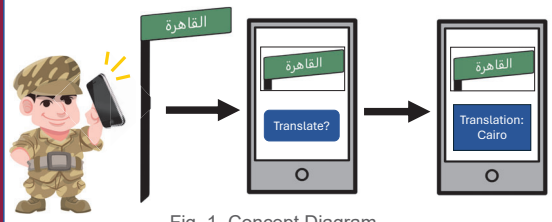
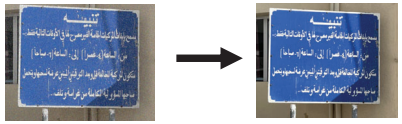


Fig. 1. Concept Diagram

Image Enhancement Subsystem

The success rate of extracting Arabic text from an image is increased with image enhancement. We developed manual and automatic adjustments to improve clarity of text in the image. Manually, the user can alter the contrast and brightness, while automatic adjustments include:

- Median (noise) filtering



- Sharpening filter

- Histogram equalization

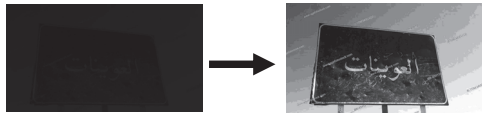


Fig. 4-6. Images Before and After Adjustment

Top-Level Diagram

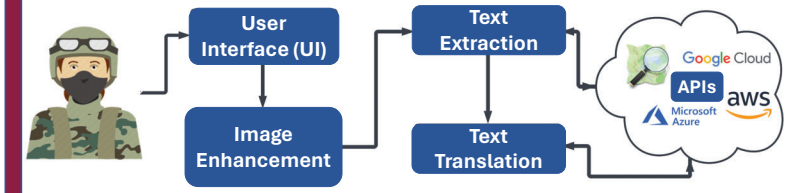


Fig. 2. Field Guide Vision's Top Level Block Diagram

Text Translation Subsystem

Differentiating Field Guide Vision from current translation tools held significant importance to our team. One approach our final design utilized was employing redundance and multiple translation services to translate the text for the user. The translations together could either show corroboration or multiple possible translations, satisfying our requirements FR-10, FR-11, and FR-12.

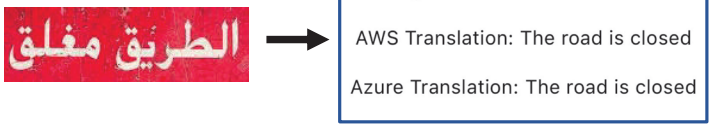


Fig. 7. Translation Results in App

In addition, we leveraged a geocoding service to determine if the sign contains a location name in Arabic. If the translation services return a literal translation, then our geocoding functionality will provide the user an idiomatic translation.

Fig. 8. Translation and Geocoding Results in App

UI Subsystem

We developed our User Interface (UI) for ease of use so that any user could immediately begin translating with the app. In the case of any ambiguity, we also include an instructions page.

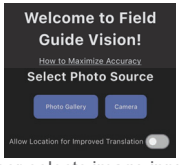


Fig. 3. User selects image input source

Conclusion

Our final product:

- Has a complete application loop by allowing users to continuously upload images for translation.
- Successfully implemented tools for increased accuracy compared to industry-standards, including automatic and manual image enhancement as well as geocoding.
- Defaults to Google Translate API's translation after it was determined to have higher accuracy through research and testing.

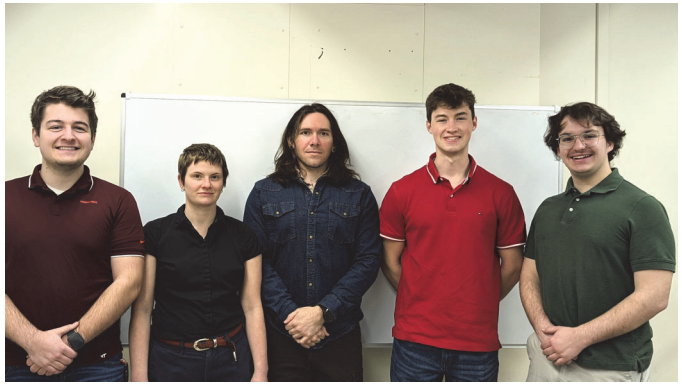
Fig. 9. Field Guide Vision Logo

Acknowledgements

For their expertise, guidance, and support in making Field Guide Vision possible, we would like to give our gratitude to:

- Justin Wright
- Dr. Creed Jones

FPGA Implementation of a Radar System



LEFT TO RIGHT: Tommy Skidmore, Allison Pitzl, Vincent Snell, Paul Broome, Elliott Kroll

CHALLENGE

The goal of this project is to use a software-defined radio (SDR) to implement a real-time radar system. By using an SDR, radio components that are conventionally implemented using analog hardware can instead be implemented in the digital domain with software. This enables the creation of systems that have higher portability, lower cost, and greater reconfigurability. With these benefits in mind, our challenge is to use an SDR to bring these improvements to the radar world.

DEVCOM C5ISR CENTER

ASPIRE CAPSTONE

SME: Jeff Walling

Customer: Sarah Jensen

Paul Broome Oakton, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to complete my master's degree in electrical engineering here at Virginia Tech. Beyond that I hope to pursue a career in industry that keeps me challenged, motivated, and happy.

Course Comment: This course provides a unique experience for students to gain hands on team experience in a simulated job environment. I am very thankful to have been able to work with the team, our mentor, and our customer.

Elliott Kroll Roanoke, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I want to apply engineering principles and decision making to policy making for industry/governments. Easier said than done of course, but thats the goal!

Course Comment: its really hard to learn when you don't know what exactly you're trying to learn. but other than finding materials and focusing, at the end of the day completeing a project from start to finish (wherever those two points may be) is more or less the same.

Allison Pitzl Duncan, Oklahoma

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I'm pursuing a MS with thesis here at VT and am going to be doing research with the SuperDARN radar array. In general I want to work with cool RF/space/comms systems and I don't want to do the same thing every day!

Course Comment: This was certainly a learning how to learn experience.

Tommy Skidmore Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: As I still am early in my career, my career aspirations are not specific. However, I want to constantly challenge myself, learn and become a valuable leader. As a result of this experience, my interest in applications of FPGA systems has grown into my current focus. I hope to continue my academic career with a master's degree from Virginia Tech or begin my fulltime career with an entry-level computer hardware position.

Course Comment: The biggest lesson from this course is you cannot start early enough. Project management is a constant challenge especially when this is not our full time job, being a full time student means we all have different schedules and coursework. However, this course has certainly been a learning experience and has opened my eyes to the potential of FPGAs.

Vincent Snell Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My aspirations are to live a well rounded and fulfilling life that provides the opportunities to help others in direct and meaningful ways and to grow closer to the people I care about.

Course Comment: As with all things in life, it's best to take the positive experiences into the future and to use the negative to grow from. I can say I have some experiences I will take from this course and some to grow from.

FPGA Implementation of a RADAR System

Team Members: Allison Pitzl, Elliott Kroll, Paul Broome, Tommy Skidmore, Vincent Snell
Sponsor: Dr. Sarah Jensen Subject Matter Expert: Dr. Jeffrey Walling

Background and Motivation

- Software defined radio (SDR) is a method of designing and operating a radio primarily with software.
- Field Programmable Gate Array (FPGA) is hardware that can be changed with software.
- Using both these technologies together allows for rapid testing and changes.
- FPGA and SDR systems are a quickly growing and in demand technology. By developing on early-access equipment such as our development board we endeavor to provide advancements in capabilities.

Fig 1. Xilinx Zynq UltraScale+ RFSoC DFE ZCU670

Objective

- Develop a stationary software-defined RADAR system working in the C band (around 5 GHz).

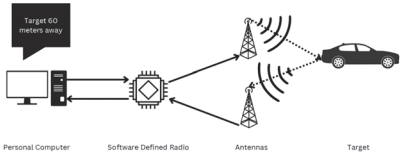


Fig 2. High-level visualization of project objective

Methodology

- Our approach was to create a Frequency Modulated Continuous Wave (FMCW) system. FMCW is more feasible than pulse radar for close range applications.
- Consists of transmitting a signal linearly increasing in frequency (chirp signal) and receiving the time delayed copy after reflecting off the target. The delay between TX and RX signal gives distance information.
- **Digital implementation:**
  1. Transmit a chirp signal through our digital to analog converter (DAC)
  2. Sample output of analog to digital converter (ADC)
  3. Compute FFT to determine frequency difference (beat frequency)
  4. Convert measured frequency to corresponding distance

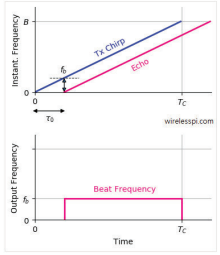


Fig 3: FMCW Theory
wirelesspi.com/fmcw-radar-part-1-ranging/

Design

- Use MATLAB to create testbench data
- Use Simulink to model system
- Convert Simulink flowgraph to HDL using HDL Coder tool
- Upload HDL code to board as custom IP block in Vivado
- Validate system on board

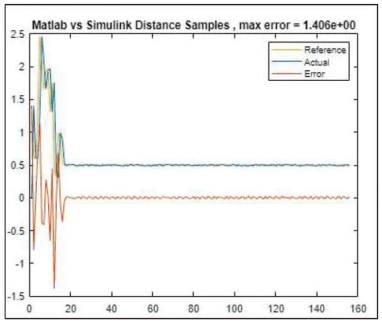


Fig 4. Error measurements (distance vs. sample)

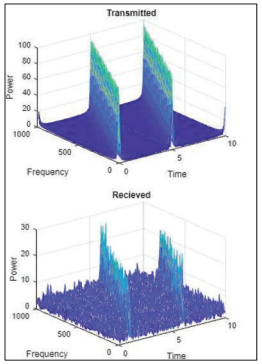


Fig 5. 3D representation of chirp

Results

- Transmit and receive a chirp signal simultaneously on the same board
- Simulink radar processing model and simulation

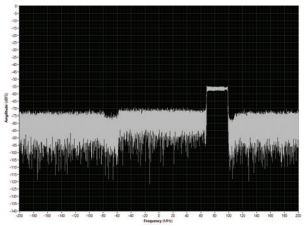


Fig 6. Transmitted chirp signal (dBFS vs MHz)

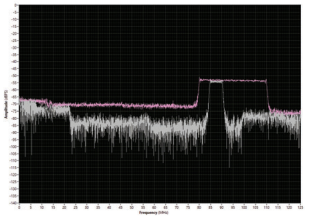


Fig 7. Received signal with maxhold value (pink line)

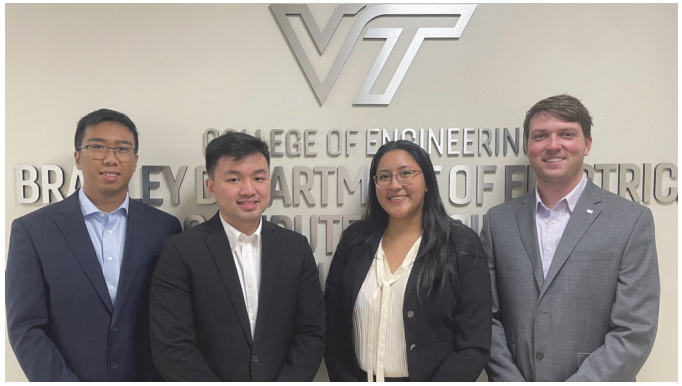
Future Work

- Integrate Simulink processing model onto our ZCU670 RFSoC.
- Integrate doppler shift processing to calculate distance to moving targets.
- Transition from omnidirectional system to a more advanced beamformed system to focus transmitted signal on targets more effectively.
- Fully incorporate hardware to create a self-contained system to enable field testing and deployment.

Acknowledgements

- Dr. Sarah Jenson, Customer
- Dr Jeffery Walling, SME
- Dr. Scot Ransbottom, Mentor
- Dr. Timothy Talty, Technical Consultant
- Cathal McCabe, Xilinx Representative

Decision Tree Graphical Editor and Execution for Cybersecurity Vulnerabilities



LEFT TO RIGHT: Jerico Manalang, Joseph Long, Nathalie Chambi, Benjamin Goetz

CHALLENGE

Design a graphical editor for generating new decision trees or modifying existing ones. These decision trees, which include inputs, decision points, and potential outcomes, are structured and stored in a database. The main focus for the decision tree is to serve as a cybersecurity tool, detailing how to prioritize patching vulnerabilities for each asset defined by the user.

foxguard

SME: Alkan Soysal

Customer: Michael Baker

Nathalie Chambi Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am seeking to advance my expertise in Cybersecurity and secure a Technical Consultant position within a forward-thinking company.

Course Comment: This course has given me valuable skills for real-world work where I learned teamwork essentials like time management and communication, preparing me for my future career.

Benjamin Goetz Bristow, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My career goal is to become a Cybersecurity analyst for a defence contracting company and work my way to becoming a Chief Security Officer for a company.

Course Comment: This course has given me valuable insight into how an industry project functions, such as meeting deadlines throughout the project and updating the project manager throughout the process. These skills will be very beneficial after graduation.

Joseph Long Woodbridge, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Over the course of my career, I desire to seek positions within the Federal Government with emphasis on software development and cybersecurity.

Course Comment: The Major Design Experience has brought many perceptions on how to collaborate on a team-based project for a sponsor. These perceptions include but not limited to time management, communication, and meeting requirements.

Jerico Manalang Fairfax, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aim to start my career in the cybersecurity field with a reputable company and then broaden my expertise to include networking or cloud computing.

Course Comment: In this course, I've not only applied skills acquired from my previous classes but also gained valuable insights into the dynamics of a real-world work environment, which has been instrumental in preparing me for my future professional endeavors.

Decision Tree Graphical Editor and Execution for Cybersecurity Vulnerabilities

Team: Benjamin Goetz, Joseph Long, Nathalie Chambi, Jerico Manalang
Sponsor: Mr. Michael Baker, Foxguard Solutions **Subject Matter Expert:** Dr. Alkan Soysal

Problem Statement

FoxGuard Solutions seeks a comprehensive solution to create, edit, version-control, and manage these decision trees effectively, along with the ability to perform interactive and regression testing. Design a web-based graphical editor for decision trees, placing emphasis on prioritizing cyber vulnerabilities within the customer's Operational Technology (OT) system.

Background

In modern cybersecurity, promptly addressing vulnerabilities is vital. However, organizations struggle with resource allocation due to the abundance of vulnerabilities. While some evaluation tools exist, they offer generalized suggestions rather than tailored criteria for prioritizing vulnerabilities with specificity.

Objectives

- Interactive mode
  - Enable users to create custom decision trees for vulnerability prioritization.
- Autonomous mode
  - Implement an autonomous prioritization system based on asset and CVE attributes.
- Document Saving
  - Enable users to save decision trees as PDF documents with accompanying result details.

Top-Level Diagram

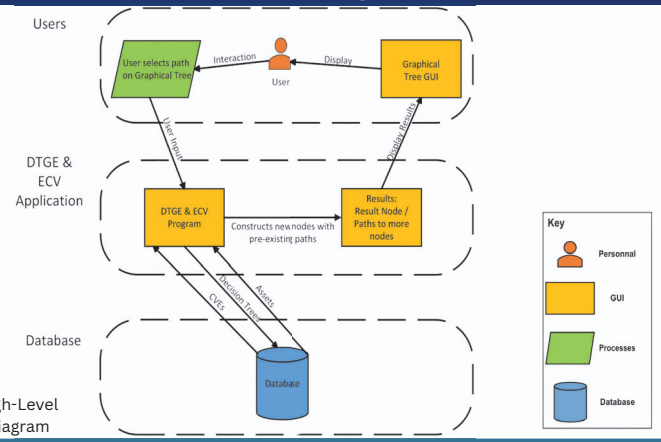


Figure 1: High-Level Concept Diagram

Design Implementation

Graphical User Interface (GUI)

- Provide an intuitive platform for users
- Include drag-and-drop functionality
- Support decision tree visualization
- Enable printing of PDFs for record-keeping

Decision Tree Application

- Implement a decision-making algorithm
- Define outcomes for user-defined paths
- Allow users to customize nodes and connections

Database

- Ensure data consistency across the application
- Support scalability for growing data needs
- Enable secure and easy data access for trusted users

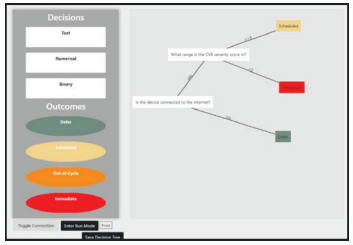


Figure 2: GUI display of Edit Mode

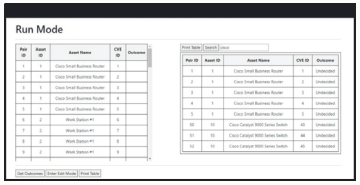


Figure 3: GUI display of Run Mode

Final Product

- A personalized tool to prioritize vulnerabilities in a large-scale environment.
- A Web-based Graphical Interface for utilization of the tool.
- Database interaction to store and retrieve products of the tool.
- Exports the decided outcomes to storage in the database.

Future Work

- Include additional relevant details regarding the attributes associated with the company's assets.
- Ensure that the CVE data remains current with the NVD.
- Improve the GUI to make it more appealing to the user.

Challenges

- Accessing and retrieving data from the SQL database
- Interpreting an SQL database
- Learning a new language (C#, JavaScript, HTML, CSS, SQL)
- Acquiring proficiency in ASP.NET MVC

Acknowledgment

The team would like to express our gratitude to our Mentor, Dr. Joe Adams, Subject Matter Expert, Dr. Soysal Alkan, and our Sponsor, Mr. Michael Baker for their support and guidance.

Digital Inventory as a Software Bill of Materials

LEFT TO RIGHT: Johann Ruiz, Nathan Dhanasekaran, Robert Oertel, Nicholas Hillengas, William Ivey

SME: Daniel Connors

CHALLENGE

Keeping track of software installed on all machines in an organization can be time-consuming for even the best System Administrators. Keeping a history of these software lists and tracking changes can be even more difficult and impossible without automation. The goal of this project is to design and implement software that acts as a comprehensive toolset for identifying applications from Windows and Linux operating system back-up files. Additionally, this tool must be able to extract identified application files directly from those back-up files for further analysis. This software allows for easy viewing of change reports and extraction of all programs in a back-up file from any point in time, enabling for security-focused analysis of back-up files.

foxguard

Customers: Michael Baker and Steven Wirt

Nathan Dhanasekaran Aldie, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My career goal is to contribute as a computer engineer at a company specializing in embedded systems. To that end, I will be working with G3 Technologies after I graduate as an Embedded Firmware engineer.

Course Comment: This course gave me experience in working with a product-development team that develops according to a specification provided by a customer. I also learned about the process of working with a team and how to successfully develop a project in a collaborative environment that emulates the real world.

Nicholas Hillengas Albany, New York

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My aspirations for the future are deeply rooted in harnessing and expanding my expertise in network infrastructure and cybersecurity, with the ultimate goal of progressing to the position of a network administrator.

Course Comment: This project has been pivotal to sharpening my frontend development skills, like learning C#, in addition to introducing me to SQL servers and management of said servers. More generally, it showed me how to implement a software project with a team in a way that is more closely related to industry standards.

William Ivey Fairfax, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: While I've spent much of my coursework learning Cybersecurity strategies and software development to hone my passion for security as a whole, I aspire to develop ways to further secure existing hardware and push performance in an effort to reduce e-waste and to conserve resources.

Course Comment: While taking this course, I gained more experience working as a part of a team on a larger project and of the critical design decisions necessary for a project to work. My role allowed me to enhance my pre-existing knowledge of the Windows operating system's inner-workings.

Robert Oertel Burlington, North Carolina

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My aspirations are to grow my knowledge about the cyber space to be an effective cyber security engineer with the goal of becoming part of a red team or pen tester.

Course Comment: This course gave me experience in frontend development, interactions with SQL servers, and on the development of security tools. Leading to a deeper look into the design choices that make secure tools and where the vulnerabilities could be hidden.

Johann Ruiz Midlothian, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: After I graduate, I will be working full-time with Collins Aerospace as a Software/DevOps engineer working on simulation tools for the military. I will also be a part-time student working toward my Master of Engineering in Computer Science through Virginia Tech. My career aspirations is to become a Full-Stack Software Engineer, knowing the full process of writing code to deploying it into production.

Course Comment: This course gave me skills in frontend development, learning C#, and SQL database interaction. In addition, it gave me practical experience with learning what type of documents are created in industry and designing a project with a team.

Digital Inventory as a Software Bill of Materials

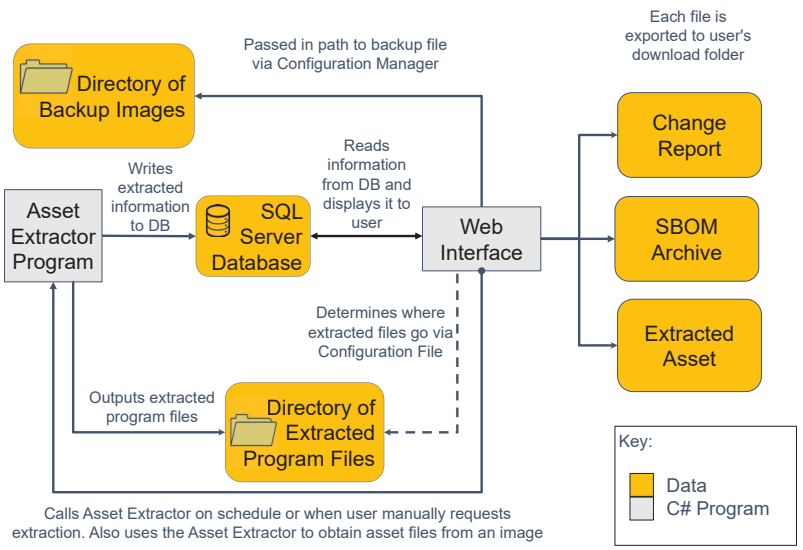
Team Members: Nathan Dhanasekaran, Nicholas Hillengas, William Ivey, Robert Oertel, and Johann Ruiz
Customer: Steven Wirt **Subject Matter Expert:** Dr. Daniel Connors

Background

Foxguard has tasked us with creating a client product that consists of the following parts:

- A C# program that reads a backup image of any Windows or Linux computer and outputs a list of all installed software on the machine into a SQL Database
- A C# program capable of taking a backup image and extracting a specified program and all associated libraries from it
- A Blazor web application that displays content generated from SQL Database and calls to C# program for SBOM generation and Asset Extraction

System Diagram



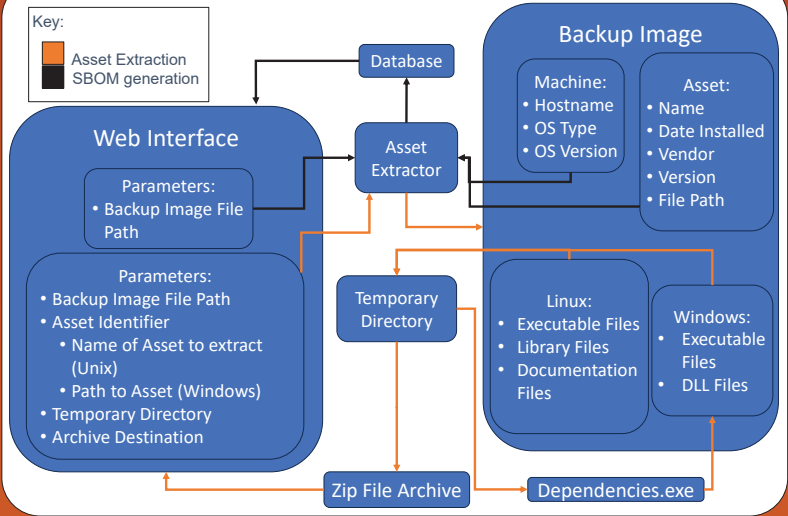
Future Work

- Export database into SBOM formats (SPDX)
- Support extraction for additional Linux distributions (RPM/YUM)
- Add additional features to Blazor application, like User Management Page and loading screens
- Add support for assets that aren't registered within the backup's OS

Acknowledgements

We would like to thank our sponsor: Foxguard, our customer: Steven Wirt, our mentor: Dr Joe Adams, and our SME: Dr Daniel Connors.

Asset Extractor Flow

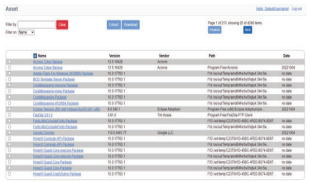


Impact

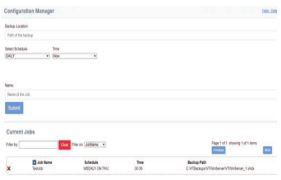
- Development of a cybersecurity tool for cataloguing the installed applications on a fleet of computers.
- This makes it easier to analyze the installed packages over time for the fleet
- This tool is for a system administrator's toolkit to ensure they know what's installed on the systems they manage

Blazor Pages

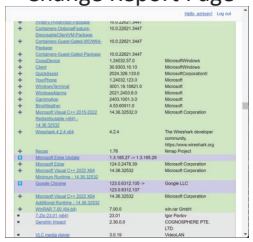
View of Asset Page



Configuration Manager

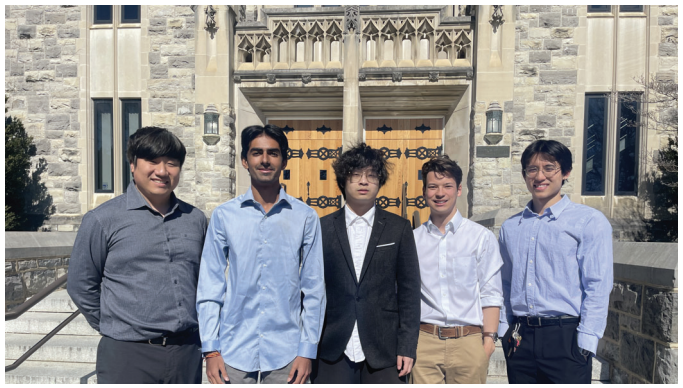


Change Report Page



Scan me to see demos!

Automated Coin Detection



LEFT TO RIGHT: Sungwon Jung, Ayush Shah, Richard Liu, Mark Carroll, Hunter Ellis

CHALLENGE

To design and build a coin detection application. Using computer vision and machine learning techniques, images of groups of wheat cents can be identified simultaneously by date and mint mark. The output will be provided to the user through the application and allow the coins of interest to be extracted. The value of this project is to increase the throughput and accuracy of checking for significant coin dates and mint marks.

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VIRGINIA TECH

SME: Creed Jones

Customer: Luke Lester

Mark Carroll Columbus, Ohio

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My goal as an computer engineer is to contribute to a company specializing in developing new and innovative AI models using deep learning. I wish to be able to contribute in the development of new advancmensts in the field of AI.

Course Comment: This course helped me exeprience the design process involved in generating an application focused on using machine learning to process large amounts of data at once.

Hunter Ellis Herndon, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: As an electrical and computer engineer my goal is to develop innovative hardware and software, solve complex controls problems, and design autonomous systems

Course Comment: This course gave me hands-on experience with computer vision methods and IOS application development.

Sungwon Jung Busan, South Korea

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My aspiration as an electrical engineer is to leverage my technical expertise to create innovative solutions that positively impact society.

Course Comment: Through this course, I've learned how to collaborate with team members and have gained a deeper understanding of machine learning.

Richard Liu Beijing, China

Bachelor of Science in Computer Engineering
Machine Learning

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: My overall goal is to develop the skills necessary to apply advanced data science technologies to real-world industrial challenges and contribute meaningfully to Industry 4.0 transformation.

Course Comment: This course gave me the opportunity to participate in the integration of ML deep learning models and front-end applications, and gave me experience in actual project.

Ayush Shah Chesapeake, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: My overall goal is to aspire to gain more knowledge and apply the fundamentals of signal processing and artificial intelligence, as well as the overlap between them.

Course Comment: This course allowed me to improve and learn useful skills that are important for the work field, such as teamwork, communication, and innovation.

Automated Coin Detection

Team: Mark Carroll, Hunter Ellis, Sungwon Jung, Richard Liu, Ayush Shah
Customer: Dr. Luke Lester
Subject Matter Expert: Dr. Creed Jones

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BRADLEY DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
VIRGINIA TECH

Objective

- Coin collectors often sift through thousands of coins to find specific rare types of coins.
- Simplify the process of finding rare coins among Wheat Cent Pennies by determining the date and mint mark on batches of coins automatically.
- Reduce the cost of human time and labor

Specifications

Requirement	Marginal	Ideal	Actual
Application	IOS	IOS	IOS
Accuracy (%)	80	95	98
Time (sec)	300	5	15
Coins	10	25	∞*

* Accuracy of 98% found on 37 coins

System Overview

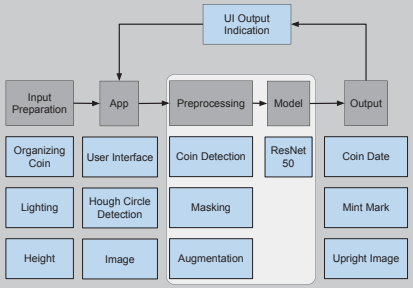

Fig 1. Architecture of Application Process

Application Wireframe

Screens

- Home
  - Choose to capture or upload image
- Camera/Gallery
  - Capture or select image to use
- Preview
  - Auto detect coins
- Results Overview
  - Coin predictions
- Individual Results
  - Oriented Coin
  - Top 3 Dates + Mint

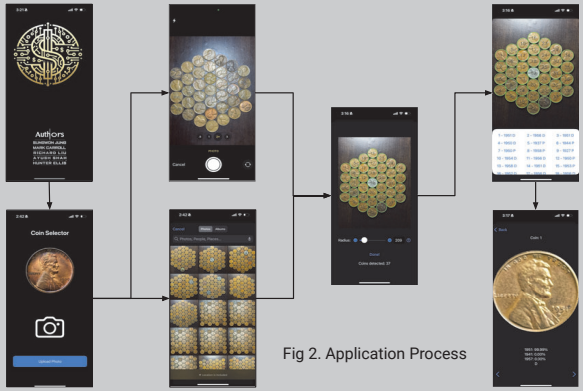

Fig 2. Application Process

Coin Detection

- Hough Circle Detection
  - Parameters: Radius (min, max) and Distance between circles
- Automatic detection
  - Sample radius at steps of 25
  - Check for max circles detected
  - End if max circles > 1 and max circles hasn't changed in two steps
  - Redo at step size 5 and 1 on reduced range (w/o early stopping)

Fig 3. Image of coins after Auto Detection

Dataset

- ~8000 Coin images used in dataset
  - ~4000 Images obtained from David Lawrence database online
  - ~4000 Images taken by our team from a variety of condition levels
- Images in each year are duplicated to reach 1000 images per year to prevent favoring specific years
- Augmentations to images such as noise, rotation, and contrast are added to help generalization

Fig 4. David Lawrence Image Left, Team Image Right

Features

- Automatic Coin Detection
  - Coins in the image are detected automatically
  - User can modify detection size manually after automatic detection is complete
- Individual image view
  - Each image can be viewed individually along with the top 3 dates and their corresponding probabilities
- Image Orientation
  - Each individual coin is rotated to be fully upright
- Convolutional Neural Network (CNN)
  - Outputs year and mint of each coin
  - Trained on ~8000 images with a small batch size and early stopping to prevent over and under fitting

Future Work

- Model Expansion
  - More years
  - Different types of coins
  - Special coins (error coins, etc.)
- Indicate coins of interest
  - Highlight valuable date + mint
- Recognition of coin backs

Acknowledgments

Dr. Luke Lester
Dr. Creed Jones
Dr. Scot Ransbottom

Lester Labs Automated Grading Service: Saint-Gaudens Double Eagle

LEFT TO RIGHT: Tanmay Dogra, Asim Dahal, Eric Ngo, Mohammad Alam, Jean-Paul Talavera

CHALLENGE

Develop a machine learning algorithm capable of accurately grading Saint-Gaudens Double Eagle coins using image processing techniques, with the goal of challenging human-level accuracy on the Sheldon Scale. The machine learning algorithm will be trained using a curated database of coins that can be uploaded on a web page to receive immediate, detailed grading feedback.

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SME: Creed Jones

Customer: Luke Lester

Mohammad Alam Lorton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My career goal is to refine my skills as a software/computer engineer in different areas such as Artificial Intelligence and make proper contributions to the field.

Course Comment: This course helped me gain experience with working with a group for a long-term project in an industry setting. I have gained increased confidence and enhanced my current set of abilities.

Asim Dahal Chantilly, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to have a career in software where I use the skills I have learned throughout my classes and projects.

Course Comment: This course has given me hands-on experience working on a team over a long period. It has given me valuable experience that I can translate to work I do in the future.

Tanmay Dogra Doha, Qatar

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My career goal is to learn and improve my knowledge of Machine Learning to develop intelligent solutions and to become a machine learning engineer that leverages powerful tech to tackle real-world problems.

Course Comment: This course is one of a kind, and I wholeheartedly appreciate it along with the valuable lessons I have learned through it. It really changes pace from a typical college class to a real-world project completion class, which helps you become a well-polished engineer.

Eric Ngo Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I hope to further develop my computer engineering skills and gain new experiences as I enter the workforce.

Course Comment: This course offered tangible, experiential learning by addressing real-world engineering issues, equipping me with problem-solving abilities and teamwork skills for future challenges.

Jean-Paul Talavera Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I hope to continue to develop my software engineering skills and to solve technical problems of this world. Specifically, I hope to encourage critical thinking and conscientiousness to help others reason through tomorrow's problems.

Course Comment: This course gave me a solid foundation on how working on a team may look in industry. It also provided an interesting problem to work on throughout the year.

Lester Labs Automated Grading Service: Saint-Gaudens Double Eagle

Eric Ngo, Tanmay Dogra, Jean-Paul Talavera, Mohammad Alam, Asim Dahal

Customer: Dr. Luke Lester Subject Matter Expert: Dr. Creed Jones, Jianzhu Chen

VIRGINIA TECH

COLLEGE OF ENGINEERING
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VIRGINIA TECH

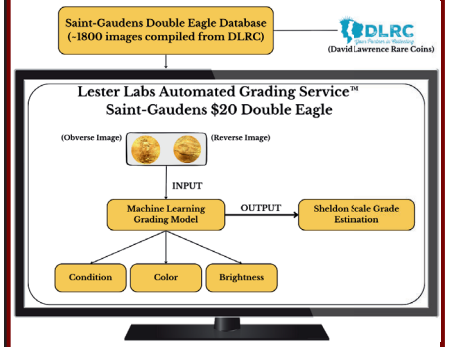
Background

The Saint-Gaudens Double Eagle gold coin is a highly valued collectible coin with prices that will start from a few thousand dollars and can cost up to millions. These coins were minted from 1907 to 1933 and are considered by many to be among the most beautiful U.S. coins ever produced.

Since these coins are manually graded by humans at grading services, they rely on human judgement and bias, which can lead to **inconsistency** in results. These services charge a fee and can take months to produce a grade.

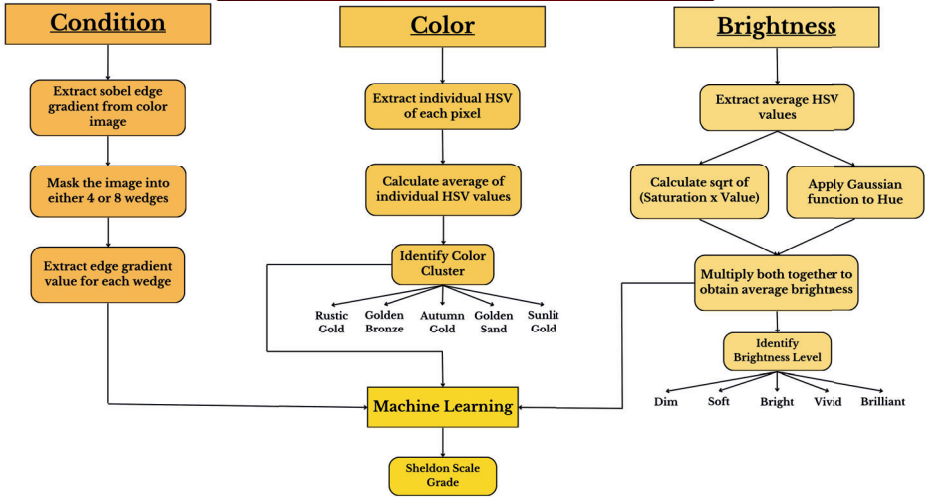
Our goal is to create an automated grading service that aims to reduce human bias and challenge human-level accuracy.

Objectives



- Curate a database of graded Saint-Gaudens coins from professional grading services
- Define a fixed set of subsystems for a Machine Learning model to be trained on
  - **Condition, Color, Brightness**
- Achieve **99% accuracy** with ±5 tolerance on the Sheldon Coin Grading Scale.
  - 70-point numerical grading scale
- Create a GUI on a server that will allow users to upload coin images to the grading model
- Provide instant grading feedback in **under 10 seconds**

Machine Learning Model



Our grading model is divided into 3 subsystems: **Condition, Color, and Brightness.** These components are compiled into a dataframe for our model to train using an Artificial Neural Network (ANN) training process. The ANN, a type of deep learning model, uses the data to learn to correlate the specific attributes of condition, color, and brightness with the corresponding grades of the coins.

The **Condition** subsystem focuses on the edge gradient analysis to determine the level of wear and tear on the coin's edges, utilizes a 4 and 8 slice mask to increase the learning data points for the model.
The **Color** subsystem accesses the specific color of the coin by extracting its HSV values and assigning it as one of the following color cluster groups: Rustic Gold, Golden Bronze, Autumn Gold, Golden Sand, Sunlit Gold (Figure 2).
The **Brightness** subsystem also uses HSV information to determine the luster of the coin and assigns it to one of the following brightness levels: Dim, Soft, Bright, Vivid, Brilliant.

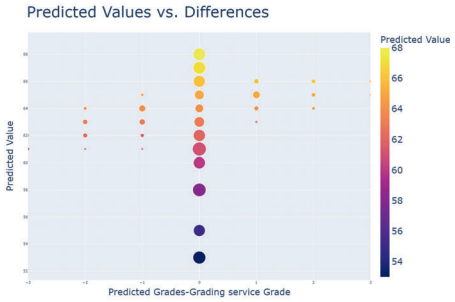
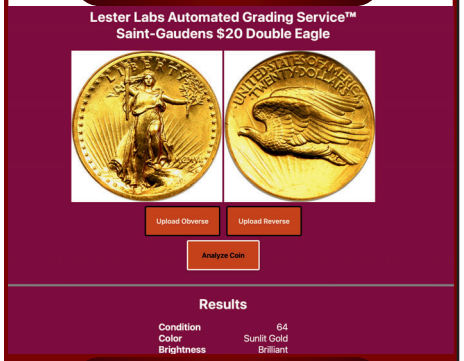


Figure 1: This plot compares the predicted Sheldon Scale grade from our model versus the professional grading service grades from our database.

Figure 2: This color palette represents the 5 color cluster groups that are assigned to the coin inputs of the model.

Web Interface



Results

Exceeds original goal of 99% with ±5 tolerance
- 86% without tolerance
- 95% with ±1 tolerance
- 98% with ±2 tolerance
- **99% with ±3 tolerance**

Exceeds original goal of feedback in under 10 seconds
- Coin analysis completed in **2 seconds**

Conclusions

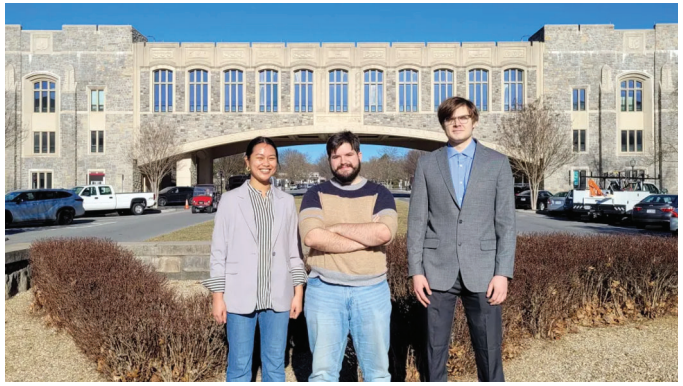
- Model trains on coins graded between 50-68
- Imbalanced dataset:
  - Contains too many coins graded 62-66
- Conservative grading model
  - Tends to predict lower grades than the grading service's grades
- Grades 60-66 are most affected by inconsistencies in human bias
  - Coins with grades below 60 and above 66 are predicted with nearly 99% accuracy

Acknowledgements

We would like to thank the following people for their guidance and contribution to this project:
- Dr. Luke Lester - Customer
- Jianzhu Chen - Graduate Teaching Assistant
- Dr. Scot Ransbottom - Mentor
- Dr. Creed Jones - Subject Matter Expert

Bamboo Canes: Omnidirectional Imaging and 3D Reconstruction

Track 2 Winner



LEFT TO RIGHT: Regan Meana, Jack Timmins, Jonathan Hurley

CHALLENGE

Design a lightweight software system that can interface with an existing bamboo scanning apparatus, while being extensible to future hardware, in order to produce a 3D model of a bamboo cane. Photographs of the bamboo, taken at 15-degree intervals around its perimeter, are used to compute the bamboo's structure. Additionally, the system is tasked with identifying the existence and location of the cane's nodes (significant deviations along the cane's length).

BioDesign Research Group

SME: Creed Jones

Customer: Jonas Hauptman

Jonathan Hurley Spotsylvania, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My goal is to make life on earth more fulfilling, by having more foresight than the engineers that came before me.

Course Comment: This course taught me a lot about how to manage a project's schedule

Regan Meana Vienna, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I aspire to use my skills and technical background to responsibly create innovative solutions.

Course Comment: This course has deepened my understanding of the project planning process and has given me the opportunity to build upon teamwork and communication skills.

Jack Timmins Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: To have engineers continue the tradition of Ut prosim while asking Cui prodest?

Course Comment: This course did a great job preparing me for the future.

Track 2 Winner

Bamboo Canes: Omnidirectional Imaging and 3D Reconstruction

Jonathan Hurley, Jack Timmins, Regan Meana

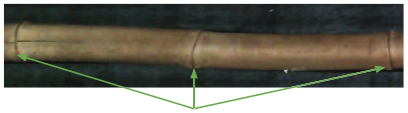
Sponsor: Dr. Jonas Hauptman, Subject Matter Expert: Dr. Creed Jones

VIRGINIA TECH

BioDesign Research Group

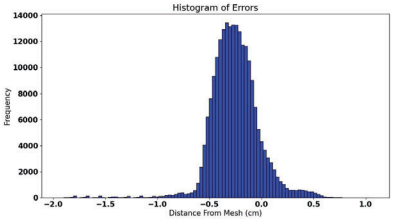
Background

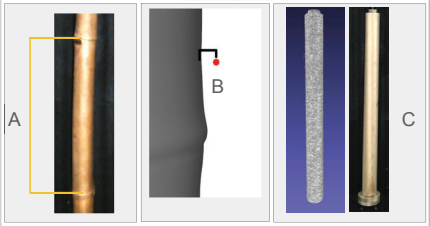
- Bamboo Canes are cheaper than wood
- Bamboo Canes can be scanned with a robotic probe
  - 20 minute scan time
  - $10k robot
- 3D Scan needed for precision machining



Results

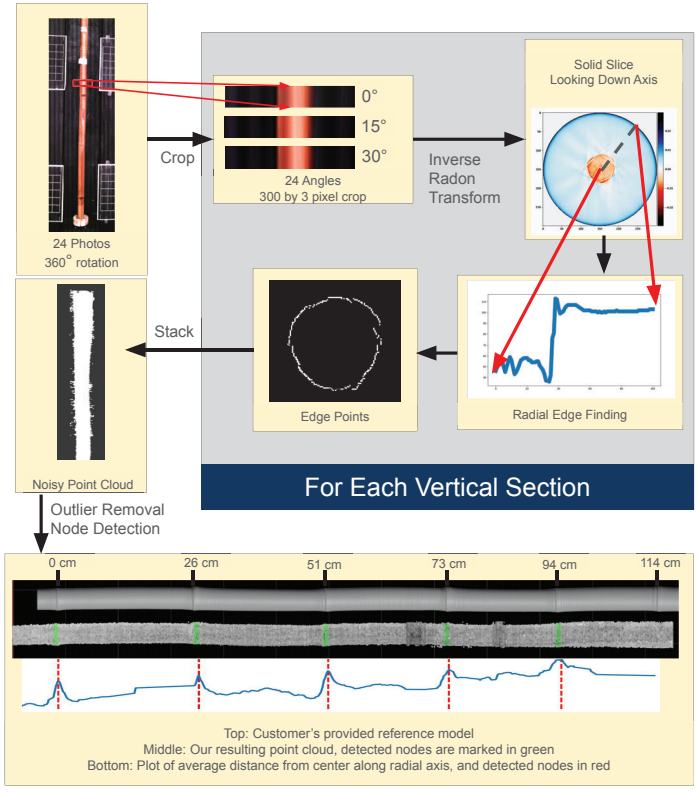
Measurement	Max Error	Avg Error
Internodal Distance (A)	6mm	4mm
Point Distance to Mesh (B)	6mm	3mm
Cylinder Radius (C)	3mm	3mm





Partially Met Met

Top Level Signal Chain



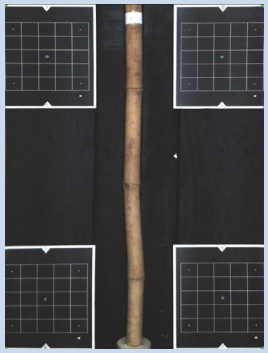
Top: Customer's provided reference model
Middle: Our resulting point cloud, detected nodes are marked in green
Bottom: Plot of average distance from center along radial axis, and detected nodes in red

Lessons Learned

- Define scope before starting work
- Make requirements as specific as possible
- Explicitly delineate responsibilities and deadlines as early as possible

Future Research

- Analyze bamboo to determine its usability in construction
- Design prototype based on our MVP
- Testing with more bamboo canes



Photographic Scanning Rig

Requirements

Measurement	Result	Required Value
Processing Time	3 Minutes	< 5 minutes
Reproducible Results	✓	✓
Stability	24 Hour Uptime	24 Hour Uptime

Challenges

- Non uniformly colored background
- Misaligned cameras
- Lens distortion artifacts in the image
- 1GB RAM constraint

Acknowledgements

We thank Dr. Jonas Hauptman and Dr. Creed Jones for their collective technical expertise and support. We also thank Dr. Scot Ransbottom for his impassioned feedback and mentorship.

Dual Input 3D Scanner for Bamboo Canes

LEFT TO RIGHT: Corey Casiano, Brendan Love, Nikith Kadambi

CHALLENGE

The objective of this project is to develop and refine a low-cost electrical control and image capture system to rotate a bamboo cane and capture data from it in several different modalities: imagery and mechanical probe. The canes are up to 9 feet long. Motion of the cane and sensors are controlled by stepper motors. The canes are to be used in countries with greater access to bamboo than lumber as a structural application. The data will be sent to a software system designed to generate a 3D model from these scans.

BioDesign Research Group

SME: Creed Jones

Customer: Jonas Hauptman

Corey Casiano Long Island, New York

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: United States Air Force Helicopter Pilot.

Course Comment: This course has provided me the opportunity to solve real world problems and an opportunity to effect the lives of those who can benefit from this technology. The course is designed for you to make mistakes, learn from them, and gain confidence solving these complex issues.

Nikith Kadambi Fairfax, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to be a cybersecurity professional so that I help keep the world more secure.

Course Comment: This course has taught me how to go through the entire engneering process with a team and the responsibilities a professional engineer has.

Brendan Love Richmond, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: My career goal is to step into the world of oceanic robotics to combine my love of aquatic ecosystems and technological solutions in an effort to give back to the world.

Course Comment: This opportunity showed me areas of the engineering process that I had not been exposed to in a typical course. By applying the knowledge of engineering design experienced during this course, I will be a much greater asset to my employer.

Dual Input 3D Scanner for Bamboo Canes

Corey Casiano, Nikith Kadambi, Brendan Love
Customer: Jonas Hauptman SME: Dr. Creed Jones

VIRGINIA TECH

BioDesign Research Group

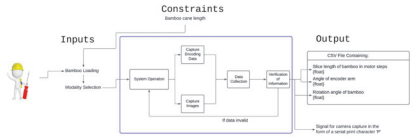
Motivations and Background

- Bamboo is a widely used resource for structural applications
- Unpredictable node locations makes processing difficult
  - 60% of biomass lost during processing
- Creation of an open-source 3D model library would allow for efficient processing of bamboo
- Our system is to autonomously gather the geometric data and image files to be translated into models, which is the first step in population of the model library.

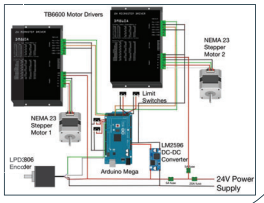
System Requirements

- Generate measurement **data < 2 mm of the true surface**
- **Ideally $500 Budget**
  - CNC machines can accomplish the scan for thousands of dollars
- Accommodate **3-9 foot bamboo canes**
- Materials **must be available** in target countries

Architecture

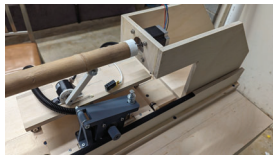


- Autonomous operation with 2 methods of data collection
  - Geometric data
  - Image capture
- Horizontal mechanical design to handle 9 foot canes
- Output tuple is easy to interpret information for model generation
- CNC based hardware and software



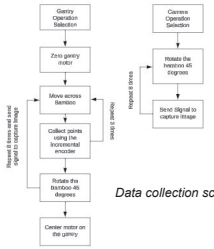
The Scanning Machine

Control System



Capabilities

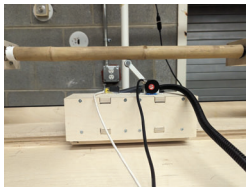
- Bamboo length accuracy within ±0.1799 mm
- 45° bamboo rotations within ±1°
- Speed of 0.1 m/s
- Max time: ~14 minutes for 9 foot cane



Data collection scheme

Data Collection

- Incremental encoder measures the angle of fixed probing arm
- A tuple is sent over a UART connection
- Python script formats data into a CSV file
  - Contains distance along cane, averaged radius value at each positional slice along bamboo, and angle of rotation.
  - Data density of 1 geometric point every 2.35 mm along bamboo

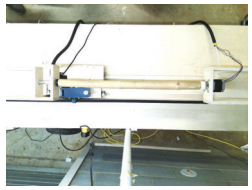


- Four 8MP Cameras installed one meter above bamboo axis of rotation
- The system sends a capture signal, the character 'P', over UART for the python script to recognize and trigger the cameras to fire.
- Data handling software receives the UART signal and takes images with each of the cameras.
- Images are stored with the name of the camera that took the image and the timestamp of the image in a .PNG file.

Results & Conclusions

X Position	Angle	Radius
1.5	0	11.41704
3.299	0	11.61861
5.098	0	11.41704
6.897	0	11.41704
8.696001	0	11.41704
10.495	0	11.41704
12.294	0	11.41704
14.093	0	11.21591
15.892	0	11.21591
17.691	0	11.21591
19.49	0	11.21591
21.289	0	11.21591
23.088	0	11.01524
24.887	0	11.01524

Geometric Capture



Test Image Gathered

3D Model made using Geometric Output

- Cameras can capture images of 3280 x 2464 pixels. This equates to **~0.1 square millimeters per pixel with 0.3485mm sides.** It would take 6 pixels to exceed 2mm face error.
- Sensor carriage can determine bamboo length accurately to **< 1 mm of error.**
- Encoder can find radius within **2mm of error**.
- We worked with Nepal, England and the Phillipines to ensure materials used in our system are available in those countries.
- Final cost: **$482.44-$549.22** dependent on target country.
- This data is within the radial face tolerance and thus can be used to form the library of bamboo species to increase the capacity of bamboo research around the world.

Acknowledgements

We would like to thank our customers,
Jonas Hauptman and Seyed Ali Derazgisoo, and our SME, Dr. Creed Jones, for their help and guidance in completing this project.

We would also like to extend our gratitude to Nicholas Bedard and Ramtin Haghnazar Kouchaksaraei for their help in topics outside of our team's fields.

B.U.R.S. : Balloon Ultraviolet Radiation Sensor

Track 3 Winner

LEFT TO RIGHT: Gabe Mills, Aaron Johnson, Zachary Schmidt, Shabir Hossain

CHALLENGE

The team has been tasked with the goal of designing a low-cost, rugged, and reusable instrument for measuring UV radiation from a high-altitude balloon. The device must be able to reliably measure Type A, B, and C ultraviolet radiation at different heights of the atmosphere to create vertical profiles from the stratosphere to the Earth's surface. This project will be used to educate pre-college STEM programs on the topic of atmospheric composition, variation of UV radiation throughout the atmosphere, and how instruments are designed to meet scientific requirements.

SME: Scott Bailey

Customers: Matthew Deland, Jackie Kendall and Frank Peri

Shabir Hossain Indianapolis, Indiana

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I have a passion for anything with space. I am looking forward to getting my degree in ECRA and using my skills to advance the use of AI in the space industry.

Course Comment: This was an amazing experience to use all the skills that I learned in the past years and applying it to a real project. It was extremely valuable to me to work with my classmates and collaborate with the customers and our mentors.

Aaron Johnson Powhatan, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I will be working for Dominion Energy upon graduation. I plan to continue a career in the energy sector improving and maintaining infrastructure.

Course Comment: It has been a pleasure to have the opportunity, to work on a project with a tangible goal and solution. I have enjoyed affirming and building on my embedded systems skills throughout this development process.

Gabe Mills Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I am planning to start my masters at VT in Fall 2024. After that, I intend to pursue a career in the space industry.

Course Comment: I have particularly enjoyed working with SSAI on this project and learning more specific design techniques used on space hardware.

Zach Schmidt Culpeper, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: Next fall I will be returning as a graduate student for my masters degree. After that, I may work in the space communications industry for a few years, but I hope to eventually return to get my PhD and become a professor.

Course Comment: This course was a valuble experience in being able to learn about cooperationg with fellow students, mentors, superviosrs, and gave me a lot of valuble experience in projct design. Thank you for everyone who made this possible.

B.U.R.S.: Balloon Ultraviolet Radiation Sensor

Team Members: Shabir Hossain, Aaron Johnson, Gabe Mills, Zachary Schmidt
Customer: Jacqueline Kendall, SSAI **SME:** Dr. Scott Bailey **Mentor:** Professor Shelley Stover

Track 3 Winner

Motivation

The team has been tasked with the goal of designing a low-cost, rugged, and reusable instrument for measuring UV radiation from a high-altitude balloon. The device must be able to reliably measure Type A, B, and C ultraviolet radiation at different heights of the atmosphere in order to create vertical profiles from the stratosphere to the Earth's surface.

Objectives

- Durable sensor package for multi-flight useability
- Off the shelf parts wherever possible
- Record UV-A, UV-B, and UV-C adiation
- Design and build a custom UVC sensor
- Relate UV measurements to altitude and time
- Record and control internal temperature of package
- Record external temperature

Concept of Operation

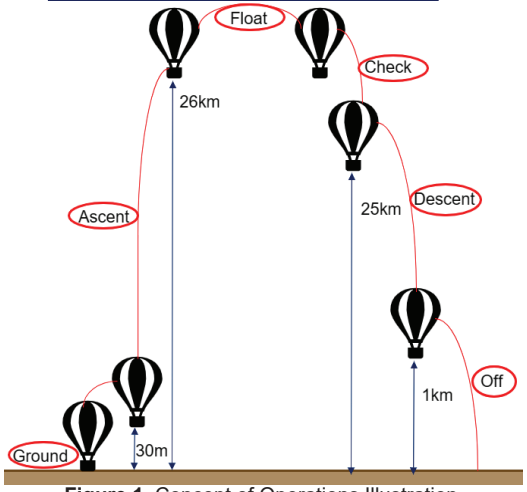


Figure 1. Concept of Operations Illustration

- Ground: 1Hz sample rate
- Ascent: 4Hz sample rate
- Float: 1Hz sample rate
- Check: No sampling (Descent decision timer)
- Descent: 16Hz sample rate
- Off: No sampling (flight time check)

UV-C Sensor Design

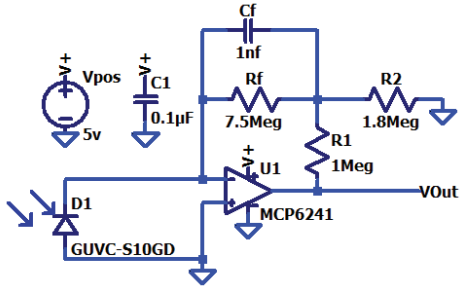


Figure 2. UV-C Sensor Circuit

GUVC-S10GD

- Photodiode with spectral range of 220-280nm
- Outputs current based on UV-C radiation

Amplifier Circuit

- Converts current to voltage signal
- Amplifies signal for use with analog to digital converter

Data Format

SCI.csv Format				
Time (ms)	Altitude (m)	UV-A (counts)	UV-B (counts)	UV-C (voltage)

HOUSE.csv Format		
Time (ms)	Temp Internal (°C)	Temp External (voltage)

Figure 3. Data File Formats

- Data sampled at varying frequencies through flight
- At the end of every sample data is save permanently to a micro-SD Card

Off the Shelf Components

UV-A Sensor	Adafruit LTR390
UV-B Sensor	Mikroe UV-B Click
Altimeter	Adafruit DPS310
Real Time Clock/Internal Thermistor	Adafruit DS3231
External Thermistor	MCP 9700-E TO
Microcontroller	Arduino Uno
SD Writer	Adafruit micro-SD

Conclusion

Figure 4. Sensor Package

- Capable of measuring UV-A, UV-B, and UV-C
- Files created: scientific data and engineering data
- Scientific: time , altitude, UV-A, UV-B, UV-C
- Engineering: time, internal temp, external temp
- Stores files externally on a micro-SD card
- Controls sample rate based on altitude
- Controls internal temperature
- Packaged in size efficient 2u CubeSat

Challenges

- Arduino Uno flash memory limitations required reduction of standard libraries used in the software
- Clean wiring practices in small 2u CubeSat

Future Plans

Future opportunities to improve device functionality include:

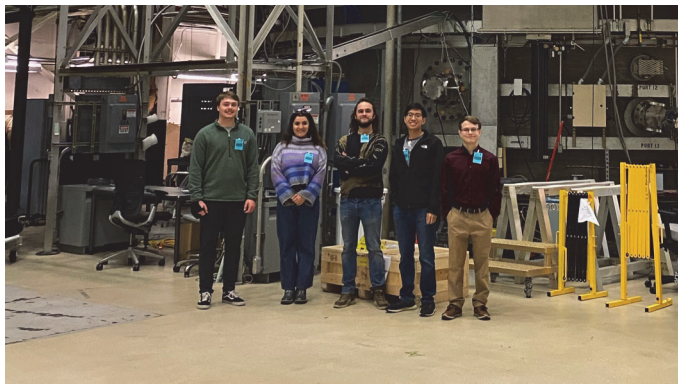
- Use SparkFun AS7331 UV sensor which houses 3 separate photodiodes for each spectral range
- Improve mount designs to create a more compact 1u CubeSat package
- Using a microcontroller with increased storage would allow for additional sensing capabilities
- Additional sensors such as an accelerometer and hygrometer for better atmospheric data collection

Acknowledgements

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

- Customers: Jackie Kendall, Frank Peri, Matthew Deland
- SME: Dr. Scott Bailey
- Mentor: Professor Shelley Stover
- Lab TA: Sowmya Muthurangan

Astrochemical Sensor Integration



LEFT TO RIGHT: Taylor Kennedy, Hannaneh Shadabi, Kian Pierce, Tuan-Minh Nguyen, Brian Bauer

SME: Scott Bailey

CHALLENGE

The project's goal is to miniaturize and complement the instrument electronics to operate a multifunctional sensor platform that was developed by researchers at the NASA Goddard Space Flight Center. The sensor platform should be able to provide autonomous detection of methane and other trace gases that are important to the search of life throughout the solar system. The goal was to make the instrument electronics more compact and suitable for deployment as a drone payload.

Customers: Scott Coste, Christopher Green, Jackie Kendall and Mahmooda Sultana

Brian Bauer Venetia, Pennsylvania

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to find a workplace that I both feel like I am accomplishing something in and enjoying what I do. I have very much enjoyed working on embedded systems in the development of measuring components in past workspaces, so I hope to find myself there in the future.

Course Comment: This course has proved to be both difficult and rewarding, and it has challenged me in many ways that I did not expect. Not only that, but the challenge provided within the course has instilled in me a sense of pride both in my team and in my own work, due to how hard all of us have worked to achieve our goals over the past two semesters.

Taylor Kennedy Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I hope to contribute toward revolutionizing the global energy landscape. With a drive to address the challenges of sustainable energy production and distribution, my goal is to leverage my technical expertise to pioneer innovative solutions that propel us towards a greener future.

Course Comment: This course provided me with an enriching experience that honed my problem-solving and critical thinking skills. It was undeniably rewarding, leading to a sense of accomplishment as I saw my ideas come to life. Through hands-on experience, I grew both personally and professionlly, while working with a team.

Tuan-Minh Nguyen Gainesville, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to be able to make a meaningful impact on the technology industry through my strong skills as an engineer. I want to significantly contribute and be a part of the cutting-edge innovation of computer engineering.

Course Comment: This course has challenged me through its deadlines and real-world isues that myself and the team have encountered and resolved with a high-quality solution. I'm grateful of the lessons learned throughout this course.

Hannaneh Shadabi Falls Church, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: As a space fanatic, I hope to leverage my expertise to drive impactful advancements in space-related technologies. With aspirations to excel as an electrical engineer and serve as a role model, I hope to cultivate a culture of innovation that fosters groundbreaking developments in the field, paving the way for future breakthroughs.

Course Comment: This course has provided me with the opportunity to acquire new skill sets by tackling complex real-world problems, employing trial-and-error learning methods to find solutions. These invaluable lessons will undoubtedly accompany me throughout my professional journey.

Kian Pierce Chesterfield, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: Ultimately, I aspire to have a career where Im equally as excited to go to work in year 30 as I was on day one. In my career, I want to be as involved as possible in every area of the development and design process. I plan to continue my education as far as I can to hone my skills and expertise. I want to be on the frontline of designing new age, cutting-edge technology which leaves an impact on the world.

Course Comment: Our team project in this class has revealed to me where my passion lies in the widely varying field of Electrical Engineering. I have loved every aspect of the project, from drawing up diagrams, to wiring and testing systems, to programming and debugging. This has been the exact kind of challenge I love to solve. The experience of working in a team in a professional setting will be invaluable as I go into the workforce. This class showed me what I want to look for in a career and how to excel in that field.

Astrochemical Sensor Integration

Team Members: Brian Bauer, Taylor Kennedy, Tuan-Minh Nguyen, Kian Pierce, Hannah Shadabi
SME: Dr. Scott Bailey **Customer:** Jackie Kendall – SSAI, Dr. Scott Coste – NASA, Chris Green – NASA, Dr. Mahmooda Sultana – NASA **Mentor:** Shelley Stover

VIRGINIA TECH

SSAI
Science Systems and Applications, Inc.

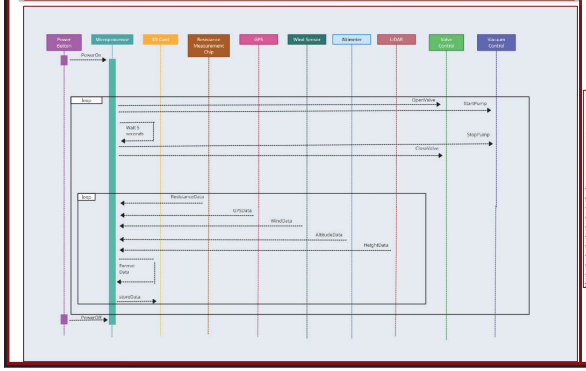
Background

A multifunctional sensor platform was developed by researchers at NASA Goddard Space Flight Center and can provide **autonomous detection** of methane and other trace gases that are **important to the search of life** in the solar system. Advancing the technology towards space deployment involves field demonstrations. To move to this step, the **miniaturization of the sensor platform** is needed to allow for the deployment on a drone for field demonstration.

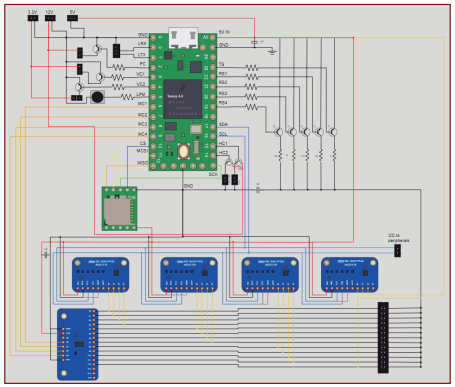
Requirements

- Ability to **automatically range** between the sensors on the chip
- **Continuously record** sensor data and relevant peripheral data (such as GPS location, altimeter reading) onto an SD card
- Sensor measurements must include trace gas readings, GPS location, altimeter reading, wind speed, and distance to ground via LiDAR
- Be able to maintain operations and record data for the **entire drone flight duration** of two hours
- Develop a **lightweight platform** that is less than 2 kilograms and smaller than an 8 x 8 x 8-inch space
- Utilize the power supplied by the drone during flight operations

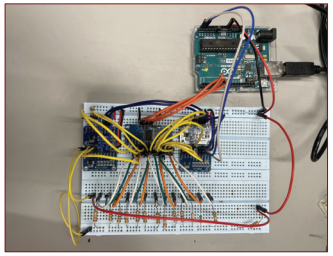
Software Flow

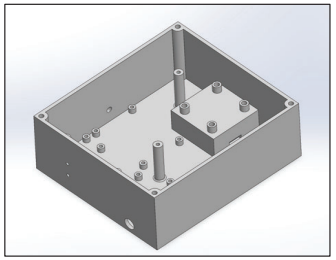


Detailed System Diagram



Development





Test Results

	A	B	C	D	E	F	G	H	I	J	K
1	Time(ms)	Longitude	Latitude	Altitude(G	AirFlow	Temp(Win	AirConsur	Pressure(	Altitude(A	Temperati	LIDAR(mm)
2	9167	-80.4264	37.2296	2040	0	26.5	0	950.74	621.79	23.06	X.
3	17327	-80.4264	37.2296	2040	0	26.5	0	950.75	621.791	23.06	X.
4	25390	-80.4264	37.2296	2040	0	26.8	0	950.76	621.792	23.06	X.
5	33349	-80.4264	37.2296	2040	0	26.5	0	950.76	621.792	23.06	X.
6	41405	-80.4264	37.2296	2040	0	26.5	0	950.72	621.794	23.06	X.
7	49362	-80.4264	37.2296	2040	0	26.4	0	950.75	621.792	23.06	X.
8	57420	-80.4264	37.2296	2040	0	26.5	0	950.72	621.792	23.06	X.
9	65378	-80.4264	37.2296	2040	0	26.7	0	950.78	621.792	23.06	X.
10	73335	-80.4264	37.2296	2040	0	26.8	0	950.74	621.792	23.06	X.
11	81395	-80.4264	37.2296	2040	0	27	0	950.73	621.792	23	X.
12	89354	-80.4264	37.2296	2040	0	26.8	0	950.78	621.792	23	X.
13	97412	-80.4264	37.2296	2040	0	26.5	0	950.72	621.792	23	X.
14	105370	-80.4264	37.2296	2040	0	26.5	0	950.75	621.792	23	X.
15	113330	-80.4264	37.2296	2040	0	27	0	950.75	621.792	23	204
16	120390	-80.4264	37.2296	2040	0	27.3	0	950.78	621.792	23	207
17	127348	-80.4264	37.2296	2040	0	27.7	0	950.8	621.792	23	168
18	134411	-80.4264	37.2296	2040	0	27.8	0	950.76	621.792	23	1053
19	141373	-80.4264	37.2296	2040	0	28.1	0	950.77	621.792	23	X.
20	149334	-80.4264	37.2296	2040	0	28	0	950.76	621.792	23	X.

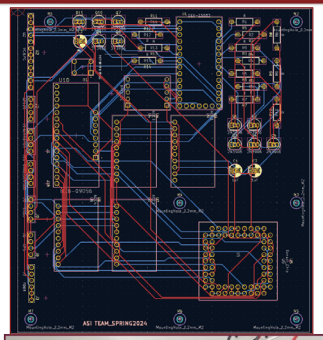
R1: 1000.00	R2: 81.66	Actual: 82	%err: 0.78%
R1: 1000.00	R2: 217.41	Actual: 217	%err: -0.19%
R1: 1000.00	R2: 384.52	Actual: 386	%err: 0.38%
R1: 1000.00	R2: 556.90	Actual: 559	%err: 0.38%
R1: 1000.00	R2: 815.60	Actual: 819	%err: 0.41%
R1: 1000.00	R2: 2197.51	Actual: 2200	%err: 0.11%
R1: 1000.00	R2: 3862.49	Actual: 3870	%err: 0.19%
R1: 1000.00	R2: 5536.07	Actual: 5550	%err: 0.25%
R1: 1000.00	R2: 8145.57	Actual: 8180	%err: 0.42%
R1: 1000.00	R2: 21661.82	Actual: 21700	%err: 0.18%

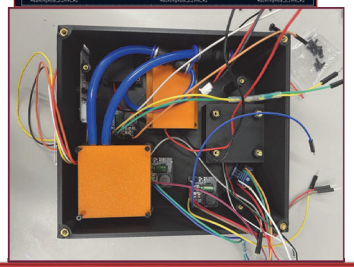
R1: 1000.00	R2: 38811.74	Actual: 38800	%err: -0.03%
R1: 1000.00	R2: 55334.09	Actual: 55700	%err: 0.66%
R1: 1000.00	R2: 82028.26	Actual: 81600	%err: -0.52%

Challenges

- **Initial wiring issues** due to packaging of off-the-shelf components
- **Nuances of sensor chip**, such as ESD requirements, had to be considered
- Issues with **targeting precision requirements** due to transistors
- Fabrication and printing of the enclosure was **inconsistent and slow**

Final Implementation





Future Plans

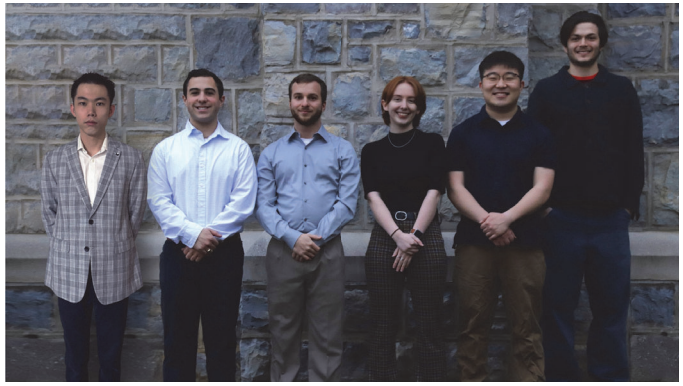
- Handoff all project files and code to NASA for further development
- Test the sensor platform on the drone for field demonstrations in Alaska
- Develop a platform that is certified for space flight
- Deploy the sensor platform across a variety of spacecraft for deployment to the Moon, Mars, and other planets

Acknowledgements

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

- Richard Gibbons for PCB review and guidance
- Jackie Kendall of SSAI for the opportunity and support throughout the project

Campus-Wide Deployment of Solar Lighting



LEFT TO RIGHT: Zheyu Wu, Carlos Velez, Adam Folts, Annie Landgraf, Matthew Cho, Timur Serbest

SME: Kelley Andrews

CHALLENGE

To design a solar-powered lighting system master plan that would provide green energy to VT, helping to meet current Climate Action Commitment goals while providing improved lighting to campus.

Wiley|Wilson®

Customers: Mark Atkinson, Gary Li, Dan Morton and Chuck Niedermayer

Matthew Cho Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: My career goal is to deepen my general knowledge in electrical engineering so that I will be able to apply myself no matter which workplace I am at. Even though I may be graduating soon, that does not mean that I still have a lot to learn.

Course Comment: Being able to tackle a large engineering problem with a group of gifted and smart individuals I believe has helped me peek into the world out there and collaborate critically. My teamwork skills have definitely improved thanks to this course.

Adam Folts Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: With my degree, I hope to help teach others how to design and maintain their own renewable energy systems in order to foster electrical independence and individual confidence in their electrical systems.

Course Comment: This course has taught me how to take my knowledge of small-scale systems and apply them to commercial and industrial projects of much greater magnitude.

Annie Landgraf Southern, Maryland

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I hope to continue my education towards a PhD focused on research with renewable energy and desalination.

Course Comment: This course allowed me to better collaborate with a team as well as understand more long term research.

Timur Serbest Conshohocken, Pennsylvania

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My career goals are to be involved in an engaging work environment where I can enhance my electrical design engineering skills. I hope to contribute positively to society through engineering while continuously expanding my abilities as an EE.

Course Comment: Throughout the length of this project, I have gained confidence in my ability to effectively communicate with professional construction companies. Learning the technical details and system components relevant to a project of this scale helped expand my knowledge of how real applications are developed.

Carlos Velez Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I hope to use my degree to work in an environment where I am learning more about electrical engineering and working toward a better future while being surrounded by individuals who are also passionate about their jobs.

Course Comment: This project has provided me with the opportunity to apply the knowledge I have gained thus far in a hands on method and in a more real world environment. I have also been able to utilize and improve my data analysis and presentation skills.

Zheyu Wu Nanjing, China

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: My career goal is to become a circuit designer or verifier in the chip industry, and I also hope to acquire more comprehensive knowledge.

Course Comment: This project is the first complete engineering project I have participated in. Although I have actively participated in some engineering projects before, this experience has given me a deeper understanding of the complete project process and developing a solution. At the same time, the relevant experiences I have in energy gave me a more detailed understanding of the entire electronic engineering industry. I believe this has an important positive impact on my future study and work experience.

Campus-Wide Deployment of Solar Lighting

Team Members: Adam Folts, Annie Landgraf, CJ Velez, Matt Cho, Timur Serbest, Zheyu Wu
Customer: Dan Morton, Chuck Niedermayer, Gary Li, Mark Atkinson - Wiley Wilson
Subject Matter Expert: Kelley Andrews

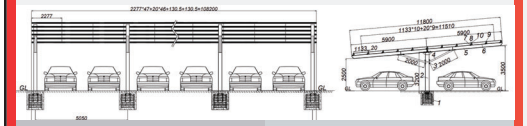
Objectives

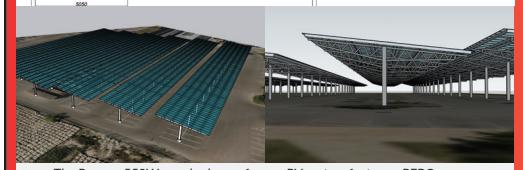
Design and develop a comprehensive master plan for the widespread deployment of solar lighting throughout Virginia Tech. Strategically aim towards offsetting the load on the campus electrical grid while also enhancing the overall lighting quality. By assessing the potential performance, reliability, and suitability of solar lighting solutions in the Duck Pond parking lot, we aim to help the institution advance towards its Climate Action Commitment objectives. Through the team's analysis, we seek to optimize our system and ensure its effectiveness.

Solar Carports

Our PV system features a carport cantilever mount for our solar modules. The carport itself is a prefabricated steel structure, selected for its cost-effectiveness and reliability. Below are further details of the proposed design:

- Height above finish grade **low side: 14'**
- Height above finish grade **high side: 20'**
- Canopy **tilt: 7°**
- Cost of Engineering, Material, & Fabrication+Shipping: **$140,887.53**
- Cost of Installation: **$189,478.08**
- Total: **$330,365.61**





The Renogy 550W panels chosen for our PV system feature a PERC monocrystalline cell architecture and are equipped with IP65/IP68 weatherproof durability. Unlike other cells, PERC adds an extra layer that improves its overall performance. Further details of the chosen solar modules and cell comparison:

- Dimensions: **89.7 x 44.6 x 1.4 in**
- Weight: **62.8 lb**
- Rated Efficiency: **22.8%**
- Rated Voltage: **41.97 V**
- Rated Current: **13.11 V**

Panel Type	Efficiency (%)
PERC	25+
Monocrystalline	20+
Polycrystalline	15-17
CIGS	13-15
CdTe	9-11
a-Si	6-8

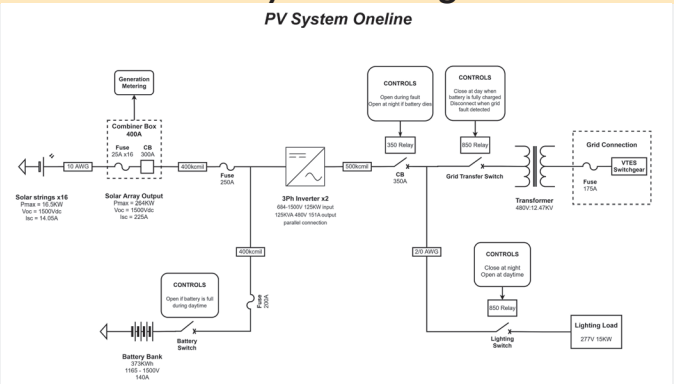
	# of panels	# of spots	Max. Array Power (KW)	Min.Daily (KWh)	Max. Daily (KWh)	Annual Output (MWh)
Expected Array Output	30	5	4.98	14.94	22.41	6.816375
	480	80	79.7	239.1	358.65	109.089375
	10950	1825	1818.68	5456.04	8184.06	2489.31825

Project Challenges

- Grid information from VTES was sanitized, making it impossible to determine the best grid tie-in locations
- Some information regarding pricing and quotes had delayed responses, delaying our expected work completion dates
- Due to the size of our group, it was more difficult to coordinate schedules where everyone could meet and subsequently schedule meetings with our mentor and customer
- Since we are only planning the project without seeing it through, there could be future complications when working with the product manufacturing companies

PV System Design

PV System Oneline



Solar Farm location - ***Duck Pond Lot***

- Solar Farm Size - 480 Panels, 16 strings, covers 80 parking spots
  - 264 kW Solar Power at Standard Test Conditions (STC)
  - 80 kW expected annual average power output
    - Based on irradiance measurements at Duck Pond Lot
  - 109 MWh expected annual energy generation
  - Cost of Solar Panels - $174k
- Max Farm Size - 10,950 Panels, 365 strings, covers 1,825 parking spots
  - 6 MW Solar Power at STC
    - ~3x the max solar potential across all VT solar projects
  - Scalable design can be expanded over time

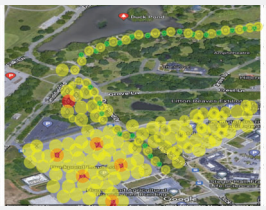
Energy Storage and Conversion

- *Battery energy storage system*- 373 kWh, 1331.2 VDC
  - Lithium Iron Phosphate (LiFePO4)
  - 1.5 nights of storage for 15 kW lighting load
  - No need for external charge controller
- *3-phase Inverter* - 125 kVA, 480 Vac
  - Each inverter can handle 250 kW max solar input
  - Two inverters in parallel to handle max potential solar output
- *3-phase Transformer* - 480 V:12.47 kV
  - Converts power to grid voltage to offset loads on campus after battery is charged

On-Campus Lighting

Currently Existing Lux Map

Proposed Lux Map



Proposed Light Placement

Legends

- Less than 10 lux
- Greater than 10 lux and less than 50 lux
- Greater than 50 lux

- ▽ VOLT
- ☆ SOLUTIONS
- ◇ Pre-existing

- × FALC
- □ LITA
- ✳ QUASAR
- ○ OKAY

- Pre-existing Pole
- New Pole

Lux testing conducted on the lights present within the chosen Duck Pond area demonstrated the following:

- Existing lighting was sufficient in the Lower Duck Pond Lot and in the Litton Reaves Lot from a lux perspective
- Remainder of the chosen Duck Pond area was either insufficient in lighting or lighting was too bright

New lighting system proposes the following:

- Additional lighting fixtures for the pedestrian walkways
- Replace the lights for the Litton Reaves Lot due to color
- Keep the fixtures for the Lower Duck Pond Lot the same
- Lower the wattage of the Duck Pond Lot 4-way LEDs and supplement the light lost through new fixtures around the perimeter of the Lower Duck Pond Lot and in the Duck Pond Lot itself

ROI Overview

Our PV system maintains a payback period of less than the expected lifespan of the solar panels while establishing other long-term benefits for both the current exterior lighting and the current campus grid. It is longer than a typical payback period for solar due to our updated lighting additions.

- Payback Period of 23 - 24 years
  - ITC Direct Pay provides reductions to improve this number
- Adheres to Virginia Tech's Climate Action Commitment Goals
  - Achieve a carbon-neutral Virginia Tech campus by 2030
  - Achieve 100 percent renewable electricity by 2030
- Added Profit:
  - At the 25-year mark: $25,571
  - At the 50-year mark: $324130

Project Budget

Part/Service	Vendor	Unit Price Estimate	Quantity of Units	Total Price
Lumen Meter #1	Dr. Meter	*$34.99*	1	*$34.99*
Lumen Meter #2	Klein Tools	*$84.97*	1	*$84.97*
Irradiance Meter	Fluke	*$404.00*	1	*$366.16*
550W Solar Panels	Renogy	*$362.50*	480	*$174,000.00*
Cantilever Support Materials and Construction	Solar Carports	*$2,368.49*	80	*$189,478.08*
Solar Combiner Box	Power Assemblies	*$2,094.50*	1	*$2,094.50*
Battery Energy Storage System	Symtech Solar	*$78,732.00*	1	*$78,732.00*
125KW 3PH Inverter	SMA	*$15,500.00*	2	*$31,000.00*
Lighting materials and construction	Various (See attached sh	*$37,100.33*	1	*$30,680.33*
Generation Monitoring	Voltacon	*$151.00*	1	*$151.00*
Wiring - 10AWG 1000ft	Southwire	*$302.44*	8.8	*$2,661.47*
Wiring - 400kcmil 1000ft	Southwire	*$10,225.27*	0.15	*$1,533.79*
Wiring - 500kcmil 1000ft	Southwire	*$12,920.40*	1	*$12,920.40*
Wiring - 2/0 AWG 1000ft	Southwire	*$3,506.75*	12	*$42,081.00*
480:12.47KV Transformer	Eaton	*$20,000.00*	1	*$20,000.00*
Automatic Transfer Switch	Generac	*$2,439.00*	1	*$2,439.00*
Current Transformers	ISE and Ram Meter Inc.	*$138.59*	1	*$138.59*
Potential Transformers	Phoenix Phase Converter	*$881.60*	3	*$2,644.80*
200A Fuse	Bussman	*$553.00*	1	*$553.00*
250A Fuse	Mersen	*$740.00*	1	*$740.00*
Circuit Breaker	Square D	*$19,140.00*	1	*$19,140.00*
Multilin 350 Relay	GE Vernova	*$2,000.00*	1	*$2,000.00*
Multilin 850 Relay	GE Vernova	*$4,000.00*	2	*$8,000.00*
Total Project Cost				***$621,474.10***

Lighting Controls

For safety reasons, lighting needs to be turned on before the sun sets, and turned off after it rises to ensure that the lighting covers the entire dark time. We provide two switching solutions: **solar panel voltage reading** and **photocells.**

- Solar panel starting voltage: **5 V**
- When the sun's rays are strong enough, photons hit the semiconductor material of the solar panel and generate a high enough voltage to turn on the solar panel. The lighting state is dependent on the voltage of the solar panel.
- Photocell chosen: **Macarrie's 120-277 V photocells**
- When light shines on the p-n junction, carriers are generated, thereby generating electrical current. The lighting state is dependent on the intensity of this current.

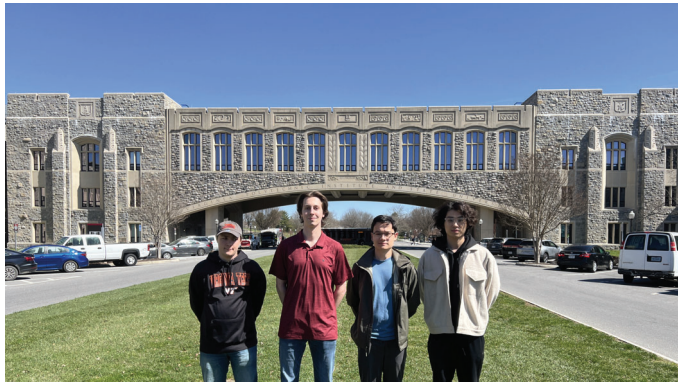
Foundation Material Selection

We will build a foundation for the entire system. The system will be stable, preventing corrosion and protecting land. Selecting materials for the foundation, we chose **concrete** out of common materials. Concrete can store large devices and prevent shifting and cracking, but it comes at a high cost and requires licensed contractors for installation. Other options are **gravel**, **geotextiles**, and **wood**. Gravel provides good drainage and easy installation. Geotextiles are cheap with the same durability. Wood is flexible and cheap, but not suitable for heavy devices.

Acknowledgments

The team would like to thank **Kelley Andrews** for her invaluable advice and continued support that have been pivotal throughout this project. We would also like to thank Mark Atkinson, Dan Morton, Chuck Niedermayer, and Gary Li with **Wiley Wilson** for sponsoring our project along with their guidance.

X-band Hybrid Beamforming to Minimize Phased Array Grating Lobes



LEFT TO RIGHT: Daniel Fox, Kyle Walsh, Connor Winters, Xuanmin Zheng

CHALLENGE

Develop a hybrid beamforming method to minimize phased array grating lobes using the Analog Devices X-Band Phased Array Development Platform. Grating lobes are unwanted artifacts in the radiation patterns of phased arrays, occurring when the spacing between elements is more than half a wavelength.

ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

SME: Jeff Walling

Customers: Jeff Chambliss, Michael Jones, Brandon Lopez and Sam Ringwood

Daniel Fox Frederick, Maryland

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: I am excited to contribute in a team to engineering projects that impact the world. I hope to work in the communications industry or work on DSP projects. I hope to eventually become a senior engineer and provide expertise.

Course Comment: This class allowed me to work on solidifying my teamwork skills. It has also allowed me to develop in the theory of phased arrays.

Kyle Walsh Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: My career goal is to work in the developing field of chip-scale photonics and help to research and develop systems for communications spectroscopy and biological applications.

Course Comment: I appreciate being partnered with an industry sponsor and exposed to novel engineering problems faced today. The systems engineering skills I have learned have already proven to be valuable outside this course.

Connor Winters Herndon, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: After graduating I will be starting a PhD in ECE at Carnegie Mellon University in Pittsburgh, Pennsylvania. My research will focus on analog/RF ICs for next-generation wireless communications. Ultimately I want to join the industry as a chip designer working on developing high-speed communications chips.

Course Comment: This course was my first experience working on an open-ended engineering problem over an extended period. In addition to developing my technical and problem-solving skills I learned valuable lessons about teamwork.

Xuanmin Zheng Qingdao, China

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: My career goal is to work as a digital chip designer for a chip company. I hope to devote myself to CPU or GPU related development work.

Course Comment: This course gave me a certain understanding of the radar field and RF field. Industry sponsors and my team members have given me a lot of professional help in this regard.

X-band Beamforming to Minimize Phased Array Grating Lobes

Team: Daniel Fox, Kyle Walsh, Connor Winters, Xuanmin Zheng
Sponsors: Jeff Chambliss, Michael Jones, Brandon Lopez, Sam Ringwood
SME: Dr. Jeffrey Walling

VIRGINIA TECH

ANALOG DEVICES
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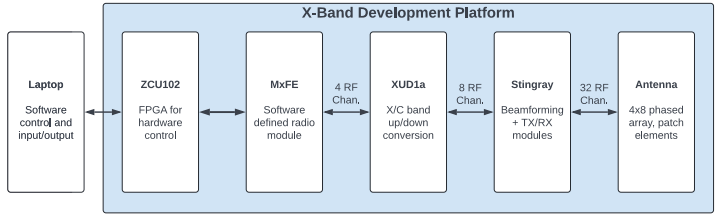
Hardware

Analog Devices' X-Band Development Platform is a complete system solution for a hybrid beamforming phased array radar

System Diagram



Applications

- ***Electronic Warfare***
- ***Ground-Based SATCOM***
- ***Weather Forecasting***
- ***Space Exploration and Research***
- ***Automotive Radar***
- ***Telecommunications***

Problem

Goal: Minimize or eliminate *grating lobes* without significantly impacting other signal parameters.

Grating lobes:

- Occur with inter-element spacing over half a wavelength.
- Closely resemble the main, in unwanted directions
- They reduce the directivity of the array and main beam power

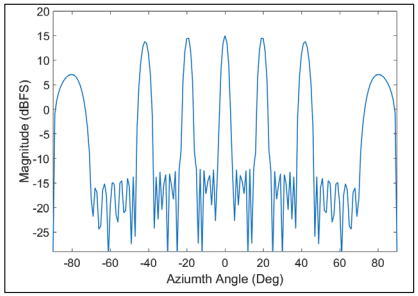
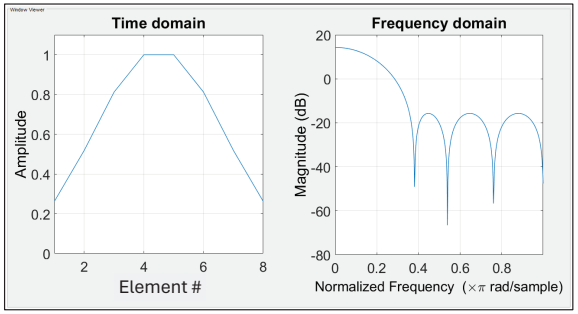


Figure: Radiation pattern of a phased array showing grating lobes

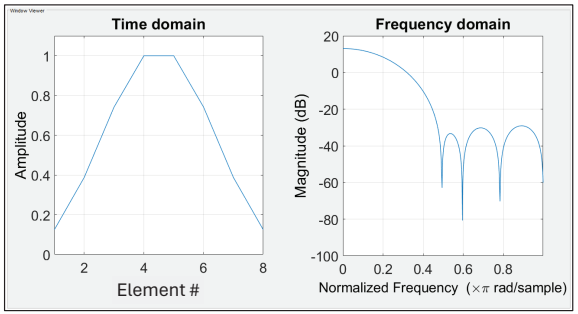
Solution

Antenna Element Amplitude Tapers:

- **Chebyshev:** Yields the narrowest main lobe for a given sidelobe level (α):

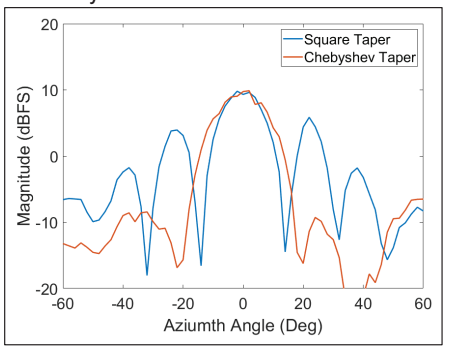


- **Ultraspherical:** Sidelobe pattern controlled with parameters x_0 and μ:

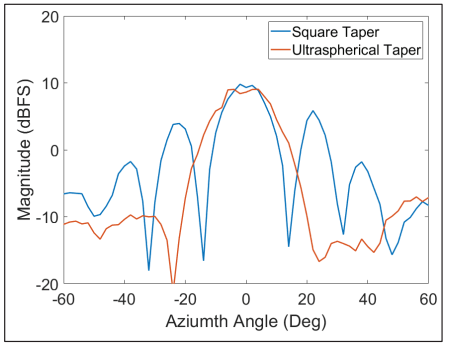


Test Results

- Chebyshev:



- Ultraspherical:



Parallelized Photonic Compute Techniques

LEFT TO RIGHT: Ian Seabrooke, John Gagnon, Kristopher DeGray, Will Park

CHALLENGE

To analyze the current and future feasibility of optical computing based on the Mach-Zehnder Interferometer (MZI). Additionally we looked at a Silicon-Nitride implementation, a new material with lower losses and higher bandwidth. To accomplish this, we researched network designs, peripheral components, and the photonic computing performance compared to traditional computing methods.

BAE SYSTEMS

SME: Zin Lin, Linbo Shao and Yizheng Zhu

Customer: Jeremy Reeves

Kris DeGray Deerfield, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I'm going directly into a Master's degree program. After that I'm hoping to find a career in designing cutting edge processors and ASICs.

Course Comment: This course has given me a lot of insights into project development, timeline, and execution. Other classes can teach concepts and design, but this one give the hands on experience of execution.

John Gagnon South Chesterfield, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: My goal is to become a VLSI/design engineer in the semiconductor industry. I want to push the boundaries of high-performance computing.

Course Comment: This course made me appreciate the time and effort that goes into research projects.

Will Park Fredericksburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to get my master's degree and eventually work as an electrical engineer at a company that contributes to making an impact to people's lives.

Course Comment: This course has shown me insight into how industry works and how important it is to work and communicate with your team, mentor, and customer to enusre a successful project.

Ian Seabrooke Front Royal, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I hope to be a networking engineer or security specialist.

Course Comment: This course has prepared me better than any other for future employment.

Parallelized Photonic Compute Techniques

BAE SYSTEMS

Sponsor: Jeremy Reeves (BAE) **Subject Matter Experts:** Linbo Shao, Yizheng Zhu
Team: John Gagnon, Kristopher DeGray, Will Park, Ian Seabrooke
Mentor: Kenneth Schulz

VIRGINIA TECH

IS THE FUTURE OF COMPUTING OPTICAL?

Machine learning and A.I. have exploded in popularity in recent years. Many of these are household names:

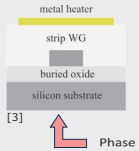
alexa ChatGPT Hey Siri TESLA

These tasks take millions to **TRILLIONS** of multiplications. For example, here is a matrix vector multiplication:

That is 9 multiplications and 6 additions for a small 3x3 example.

Let's multiply at the speed of light!

What is an MZI?



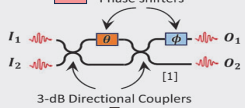
[3]

The Mach-Zehnder Interferometer (MZI) is an optical device that can perform any rotation in special unitary group of degree two, i.e., SU(2) on a 2x1 input vector with values represented by real and complex optical magnitudes. Each MZI uses two voltage-controlled modulators to create interference that produces the rotated output.

$$[D_{MZI}] = \begin{pmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \end{pmatrix} = je^{j\left(\frac{\theta}{2}\right)} \begin{pmatrix} e^{j\phi}\sin\left(\frac{\theta}{2}\right) & e^{j\phi}\cos\left(\frac{\theta}{2}\right) \\ \cos\left(\frac{\theta}{2}\right) & -\sin\left(\frac{\theta}{2}\right) \end{pmatrix}$$

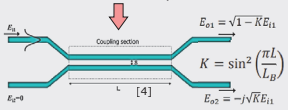
SU(2)

Phase shifters



[1]

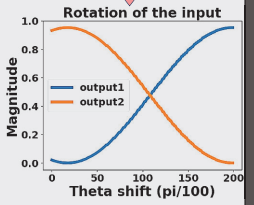
3-dB Directional Couplers



[4]

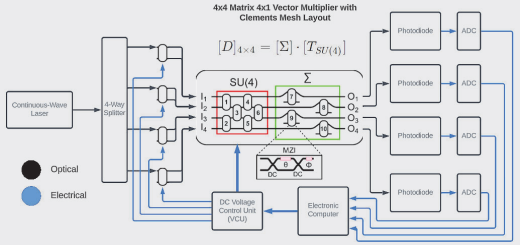
A practical demonstration of an MZI using mirrors and beamsplitters

Rotation of the input



Recommendations

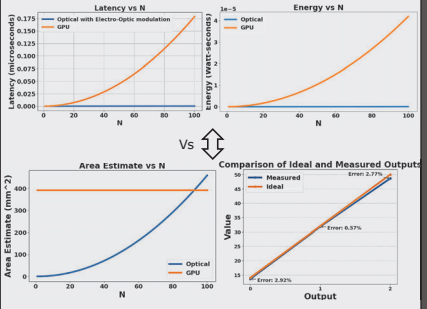
A Possible 4x4 MVM system is shown below with all peripheral devices. A single laser is divided, and each input is intensity-modulated to represent values in the vector. It then passes through the mesh and the result is converted to an electrical output that can be interpreted by a separate electronic computer.



Partially derived from [2]

Performance Potential

Optical Matrix-Vector Multiplication (MVM) lets us trade accuracy and size for Speed and energy efficiency.



Keep in Mind

- Optical accuracy loss
- Range loss is potentially acceptable for machine learning applications

	Traditional Float	Optical Range
Typical Max Value	3E38	1
Typical Min Values	1E-38	1.9E-3
Bit Equivalent	32bit	9bit in/24bit out

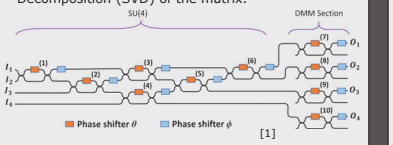
Building a Network

$$[D]_{4\times4} = [\Sigma] \cdot [T_{SU(4)}]$$

$$= \begin{pmatrix} u_{11}^{(7)} & 0 & 0 & 0 \\ 0 & u_{11}^{(8)} & 0 & 0 \\ 0 & 0 & u_{11}^{(9)} & 0 \\ 0 & 0 & 0 & u_{11}^{(10)} \end{pmatrix} \cdot \begin{pmatrix} U_{11} & U_{12} & U_{13} & U_{14} \\ U_{21} & U_{22} & U_{23} & U_{24} \\ U_{31} & U_{32} & U_{33} & U_{34} \\ U_{41} & U_{42} & U_{43} & U_{44} \end{pmatrix},$$

[1]

Multiple MZIs can be combined to form a mesh that perform a MVM of N order through Singular Value Decomposition (SVD) of the matrix.



[1]

Network Performance

Latency is determined by the input speed.

- Network size does not slow the multiplication
- Network size has minimal effect on accuracy

Each input N adds 2*N phase shifters in the network

N	Phase Shifter Count
2	6
3	12
4	20

Each phase shifter adds

- Power
- Size

5x5 MVM Case Study - Future Potential

An Application Specific Integrated circuit (ASIC), is a circuit made to do a specific task. Here we compare a CMOS ASIC with an optical equivalent.

Findings:
Current shortcomings make an Optical MVM difficult to recommend.

Optical Advantages

- Linear increase in delay as N increases

Optical Shortcomings

- Bit precision is limited to peripherals
- Exponential increase in area and power as N increases

Results:
The Good

- 25us latency
- High-performance scaling potential

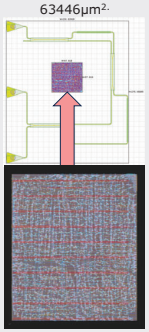
The Bad

- Area of optical MVM is 228x the size
- Average power of 448mW
- Comparably expensive

Future Potential:

- Photonic memory improvement would enable greater throughput, area savings, and power reduction
- Modulator / On-Chip Laser / Photodiode improvements would decrease area and cost

A 5x5 MVM CMOS ASIC within single MZI diagram shown to scale
63446μm².



Enlarged view of the ASIC
3342μm²
(optical is 228x size = .762mm)

Conclusion

Though difficult to recommend in the present, photonic computing could have a bright future.

Realistic Improvements:

- Faster phase modulators to increase I/O limitations
- Better On-chip laser sources to reduce implementation complexity

Needed Breakthroughs:

- New types of photonic memory to reduce the need for conversion between electrical/optical
- Reduction in cost: Photonic components are large, requiring higher chip space compared to CMOS and making for an expensive product

Acknowledgements and References

Our team would like to thank Jeremy Reeves (Sponsor BAE), Linbo Shao (Subject Matter Expert), Yizheng Zhu (Subject Matter Expert), and Kenneth Schulz (Mentor) for their insight, advice, and time throughout this project.

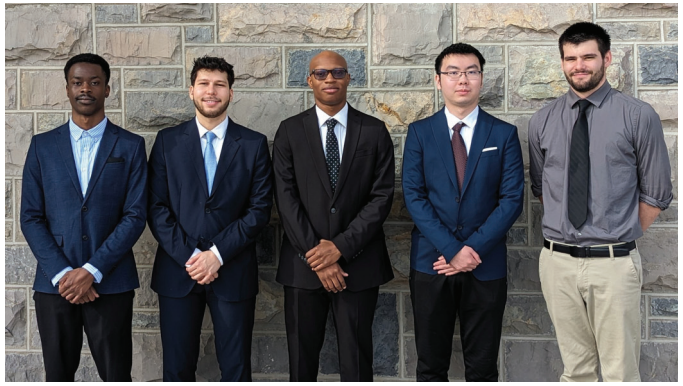
[1]https://www.researchgate.net/publication/339031190_Theoretical_and_Experimental_Analysis_of_a_44_Reconfigurable_MZI-Based_Linear_Optical_Processor

[2]https://www.researchgate.net/publication/353016983_Photonic_Integrated_Reconfigurable_Linear_Processors_as_Neural_Network_Accelerators

[3] https://www.researchgate.net/figure/Cross-sections-of-different-kinds-of-TOPS-a-TOPS-based-on-strip-waveguide-with-a-metal_fig1_359903063

[4] https://riunet.upv.es/bitstream/handle/10251/174345/Santome%20-%20Diseno%20de%20un%20acoplador%20direccional%20asimetrico%20combinando%20silicio%20y%20nitruro%20de%20silicio.pdf

Smart Cooling Loop for a Data Rack of the Future



LEFT TO RIGHT: Rick Ejizu, Juan Diego Castrellón, Oral Dale Walker Jr., ChenHao Qiu, Westin Erwin

CHALLENGE

To develop a solution to expand the cooling capacity of a data rack. This is in preparation of an increasing heat demand due to the rise of advanced research, artificial intelligence, and cloud computing.

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

SME: Scot Ransbottom

Customer: Jeff McWhirt

Juan Diego Castrellón Panama City, Panama

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan on pursuing a career in the power industry. My interests are in the automotive and the solar energy industries.

Course Comment: This course taught me the importance of planning ahead, making conscious design decisions and how to operate in a professional team setting.

Rick Ejizu Houghton, New York

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to actively engage in the evolution of software technology within a prominent software company, using the skills I have acquired through the VT CPE program to make meaningful contributions. I recognize that there are numerous software challenges on the horizon, and I am eager to tackle them head-on.

Course Comment: I am immensely grateful for the opportunities provided by the ECE MDE program for myself and my team. This program has been instrumental in enhancing my engineering proficiency and refining my customer interaction skills, an aspect that sets it apart from other courses at Virginia Tech.

Westin Erwin Virginia Beach, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: After graduation I will be working as an electrical design consultant with the short-term goal of registering as an engineer in training and the long-term goal of becoming a licensed professional engineer.

Course Comment: This project has been an in-depth culmination of many of the skills I've learned over the past few years. I also had a great time touring several data centers and talking to industry experts.

ChenHao Qiu ShangHai, China

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aspire to leverage the knowledge gained from my coursework to secure a position in Electrical Engineering. Additionally, I am open to the possibility of pursuing graduate studies to further deepen my understanding of this field.

Course Comment: The MDE course has been instrumental in providing me with practical experience, allowing me to engage in real-life projects and learn how to initiate a project from inception. Moreover, it has equipped me with essential collaboration skills, enabling me to effectively work with team members' competency that I recognize as invaluable for my future career endeavors.

Oral Dale Walker Jr. Warrenton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goals as an engineer are to expand my knowledge and experiences by applying my skills to many different jobs and opportunities. I'm more then willing to jump right in to projects that are new to me and figure out how I can make an impact. I eventually want to continue my schooling and get a masters degree.

Course Comment: The Major Design Experience has given me valuable experience in an engineering team environment. My biggest take away was learning how to interact with senior engineers, SMEs, advisors, and customers.

SMART COOLING LOOP FOR A DATA RACK OF THE FUTURE

Juan Diego Castrellón, Rick Ejizu, Westin Erwin, ChenHao Qiu, Oral Dale Walker Jr.
Sponsor: Jeff McWhirt, Digital Realty
Subject Matter Expert: Scot Ransbottom, Virginia Tech
Project Advisor: Joe Adams, Virginia Tech

7x24 Exchange Washington, D.C. The end-to-end reliability forum.

VIRGINIA TECH

Background

Expecting power usage of data racks to as much as triple over the next few years, the 7x24 Exchange, a consortium of data center operators, inquired about methods to increase their ability to regulate heat within a rack. In conversations with data center professionals, we found that a recent product was a rack wide cooling loop which pushed water evenly across each node. In an effort to optimize coolant transmission, the team developed a system capable of manipulating flow rates to match the dynamic heat loads as server usage rises.

Figure 1: Lenovo's Neptune Cooling Loop In Virginia Tech's Steger Hall

Objectives

As a proof of concept for the smart cooling loop, a small-scale PVC model was constructed with the goal of:

- Understand sensor requirement and usage.
- Recognize cooling necessities for heat loads.
- Coolant flow control.
- Comprehensive and friendly graphical user interface.
- Accurate electronic valve and flow control

Figure 2: Deliverable and Demonstration Video

System Design

Users can replicate a server in high power usage by blowing a heat gun on a branch's radiator. Flowing water will transport the heat away and a GUI will show the coolant flow and temperature changes as well as the loops modification.

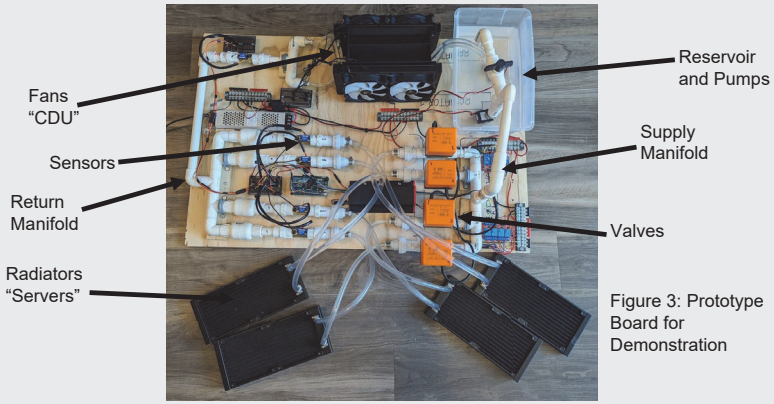


Figure 3: Prototype Board for Demonstration

User Interface and Controls

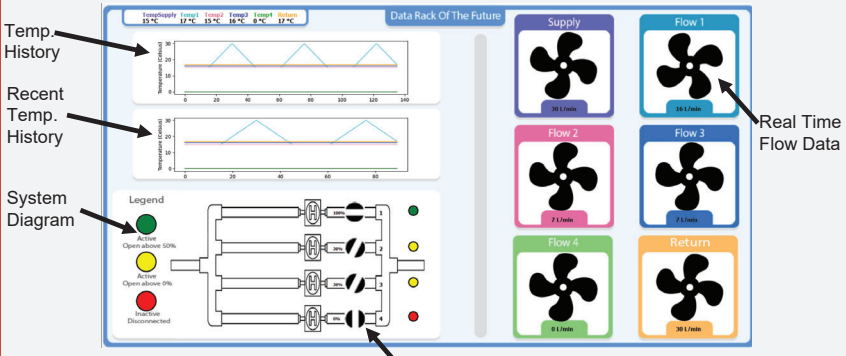


Figure 4: Screenshot of GUI

Conclusion

- Power usage and heat dissipation will be an issue for any data center over the next few decades.
- Data centers with CRAC systems or chilled water infrastructure can easily install direct-to-chip cooling loop system
- Usable floor space in data centers will decrease due to Coolant Distribution Unit (CDU) placement (1 CDU : ~6 Racks)
- Modularity should be an important design consideration for ease of use.

Figure 5: Steger Hall's first coolant distribution unit

Moving Forward

Future work includes:

- Scaling design to make it capable of dealing with more nodes and higher power.
- Replicating CDU to increase cooling beyond two radiators to maximize efficiency.
- Improve the GUI to allow operator more control, access to information, and diagnostics

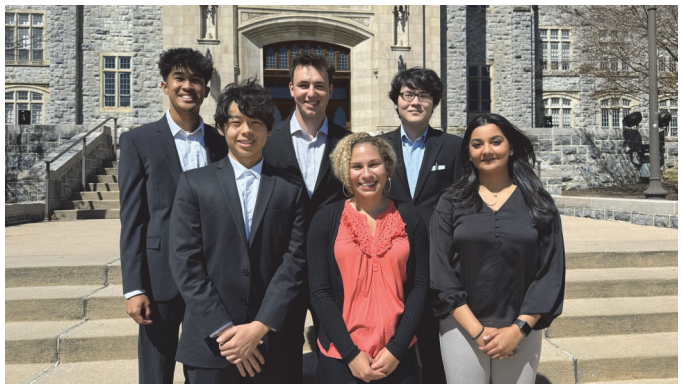
Acknowledgement

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

Industry Partners:
7x24 Exchange
Digital Realty
VT Data Center Staff:
Mr. Mike Moyer
Mr. Miles Gentry

VT ECE:
Dr. Joe Adams
Dr. Scot Ransbottom
Customer Representative:
Mr. Jeff McWhirt

Account Interaction System



LEFT TO RIGHT: (Front): Charles Zhao, Kyla Coles, Simran Kumari, (Back): AJ Valencia, Jack Kolenbrander, Haochen Zhang

SME: Alan Michaels

CHALLENGE

Design, build, and test a system that extends the work of the VT National Security Institute's ongoing project, which involves analyzing messages (emails, sms, and voicemails) exchanged between dummy users (fake identities) and second-party organizations to investigate the propagation of personal information through the internet.

NATIONAL SECURITY INSTITUTE
VIRGINIA TECH

Customers: Madison Boswell and Alan Michaels

Kyla Coles Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to use my skills and knowledge in the cyber-field doing valuable work that protects and helps others.

Course Comment: This course has significantly prepared me for my engineering career. I was able to get hands-on industry-like experience working with a team and a customer.

Jack Kolenbrander Ashburn, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to apply my current knowledge as well as continue learning in order to address and solve cyber challenges.

Course Comment: This course provides a hands-on, applicable experience to prepare you for your career.

Simran Kumari Centreville, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to continue to learn from others and challenge myself throughout my career as well as use what I have learned to help others.

Course Comment: This course emphasizes the importance of teamwork and prepares you for the industry.

AJ Valencia Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to apply my skills to better understand work in the cyber-discipline to help those vulnerable to arising challenges

Course Comment: This course has prepared me to work with peers with similar goals and aspirations improving my technical and social skills

Haochen Zhang Guangzhou, China

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to use my knowledge and skills to better people's lives and bring a positive impact to the world, one small step at a time.

Course Comment: Major Design Experience is an opportunity for aspiring engineering students to work through a full cycle design project, collaborate with real customers and experts, and find pride in overcoming a challenge with a team of fellow students. This course has given me more insight into my role within a team and collaboration of a longer term project.

Charles Zhao Los Angeles, California

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to never stop learning and to live a fulfilling life by serving others wherever I go.

Course Comment: The senior design course is a good opportunity for students to get a taste of what it's like to work on a project for a company.

Account Interaction System

Team: Kyla Coles, Jack Kolenbrander, Simran Kumari, AJ Valencia, Haochen Zhang, Charles Zhao
Customer: Madison Boswell, Virginia Tech National Security Institute
Subject Matter Expert: Dr. Alan Michaels, Virginia Tech National Security Institute

Background & Motivation

Personal Information (PI) is targeted, leaked, and used by second parties for financial gain or malicious intent. At Virginia Tech's National Security Institute (NSI), a research team aims to understand **how real-time PI is transferred** between targeted organizations around the internet. NSI needs an **efficient system that can interact with second party responses and report data analytic findings derived from the various interactions.**

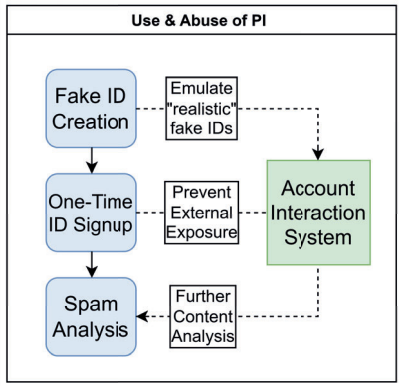


Figure 1. Use & Abuse Project Simplified Overview

Key Objectives

- Ingest and preprocess data from input content database.
- Utilize a large language model to generate human-like responses using e-mail content and behavior profiles as inputs .
- Implement an anti-virus scanning system to inspect attachments and URLs received for malicious content.
- Web scrape all links received for each communication and generate reports with findings.
- Generate detailed logs for each interaction and create a UI to display logs and results.

Design & Approach

Account Interaction System is split into **six** subsystems:

- Each subsystem is isolated with a **LXC system container**.
- Subsystems operate **asynchronously**.
- **File I/O** used to pass information between subsystems.

Control System
Query and preprocess input from content database, select a behavioral profile based on input, then assign tasks to other subsystems.

Interaction Engine
Stand up temporary Windows-based virtual environment to perform content interaction using **Proxmox Virtual Environment**.

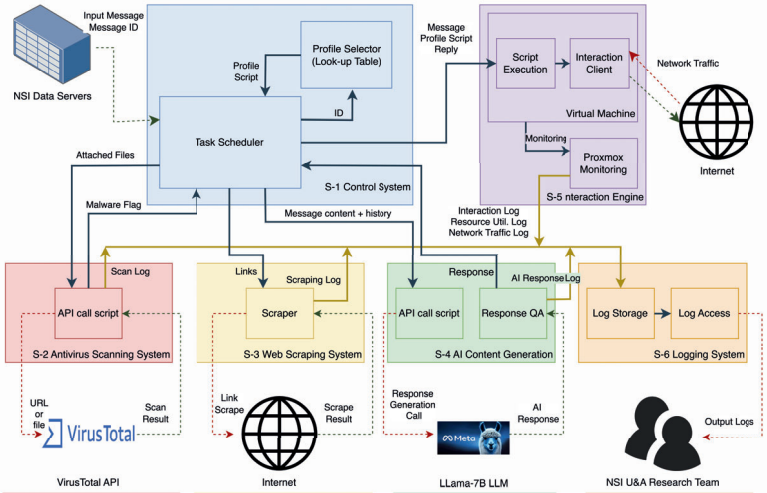


Figure 2. Account Interaction System

Antivirus Scanning System
Perform malware detection queries using input attachments via **VirusTotal API** and report findings.

Web Scraping System
Perform customizable web scraping using input email URLs and log scraped content to logging system.

AI Content Generation
Craft an email response to input content using a locally hosted large language model (**Llama 2**).

Logging System
Aggregate and store task results and logs from all other subsystems into a **MongoDB** database for future queries.

Conclusion

Together, the team created a system that performs the following tasks:

1. Query and process input emails from a processed email database.
2. Categorize email into a behavior profile.
3. Extract attachments to perform malware detection.
4. Extract URL to perform contextual web scraping.
5. Standup virtual environment to perform interaction.
6. Log subsystem performance and interaction forensics for future research analytics.

Future Work

Potential future system improvement:

- Implement full system automation to run tasks continuously without human input.
- Expand interaction design and profiles to include SMS *and Voi*cemail.
- Adapt alternative virtualization technology to move system beyond Proxmox Virtual Environment's limitations, especially the lack of Docker support.
- Apply higher fidelity LLM to generate more "realistic" responses.
- Reduce per-task operation time by optimizing VM standup time, removing a major time bottleneck.

Acknowledgements

The team would like to give a special thanks to the following people who helped make this project possible.

- **Dr. Alan Michaels** (Subject Matter Expert)
- **Madison Boswell** (Customer)
- **Elliott Rheault** (VT NSI Engineer)

Counteracting Doppler Using OTFS Zak Transform

Track 4 Winner

LEFT TO RIGHT: From Nathan Scollar, Andrew Hermansen, Ethan Costello, Danielle Felder

SME: Louis Beex

CHALLENGE

Our project is to demonstrate that Orthogonal Time Frequency Space (OTFS) can be used to handle signal transmission through harsh conditions of doppler and multipath. Our project aims to prove that OTFS is applicable in industry and to validate the effectiveness of the Zak Transform. OTFS does this by transmitting data within the delay doppler domain, where the signal remains invariant.

Customer: Louis Beex

Ethan Costello Wake Forest, North Carolina

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: After University I plan on becoming an industrial network engineer. I will start my career working on implementing process control networks for different factories and plants.

Course Comment: This course has been challenging, especially as it is not a field I am very familiar with. I had to learn to be uncomfortable and become more flexible to all kinds of different failures and experiences. Mostly I learned the importance of breaking down problems and conquering small milestones.

Danielle Felder Locust Grove, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My career goal is to continually enhance my skills in Electrical Engineering, contributing positively to projects and leaving a lasting mark wherever my professional journey leads.

Course Comment: This course has taught me the importance of effective communication, adaptability, and collaboration, providing invaluable experience that will be beneficial in future projects.

Andrew Hermansen Mullica Hill, New Jersey

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I strive to be in a career where I can embrace the motto of not all hero's wear capes. I want to protect people on their digital platforms. This includes civilians and military personnel while fortifying current network infrastructure.

Course Comment: Although the course was beneficial in many ways, including meeting mentors, and working on an industry leading problem, I would like to see more support from the community of professionals in my field. The support from my mentors and subject matter expert exceeded all my expectations though and I really appreciated having them as a part of my team.

Nathan Scollar Columbia, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am still figuring out my career goals, although I am currently planning to go to graduate school to get a Master's degree in Data Science. At this point, all that I know is that I want to work somewhere where I can make a real impact in the world.

Course Comment: I think this course has been a valuable experience. I have really enjoyed learning new technical skills, embracing the design process, and building leadership and communication skills that will be useful for my future.

Track 4 Winner

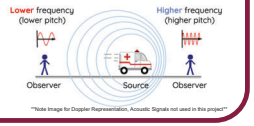
Counteracting Doppler Using OTFS and Zak Transform

Students: Ethan Costello, Danielle Felder, Andrew Hermansen, Nathan Scollar

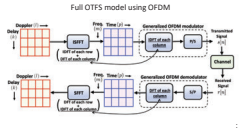
Mentor: Dr. Daniel Connors; Subject Matter Expert/Customer: Dr. Louis Beex

Project Statement

- Orthogonal Time Frequency Space Modulation (OTFS)
- Counteract doppler and delay
- Prove justification of simplified OTFS, Zak Transform

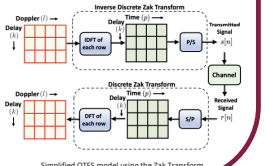


OTFS Models



- IDFT of each row takes a 1D complex IFFT of each row in the matrix
- P/S appends the input matrix by column into a serialized array of values
- S/P takes the received array and rebuilds the matrix by column
- DFT of each row takes a 1D complex FFT of each row in the matrix

- The DFT of each column and IDFT of each column on the transmitter side cancel out
- The DFT of each column and IDFT of each column on the receiver side cancel out
- These cancellations form the simplified OTFS model using the Zak Transform



Simplified OTFS model using the Zak Transform

Modulation Schemes

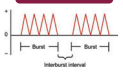
QPSK

Quadrature Phase-Shift Keying. Data Modulation based on phase of the signal

QAM

Quadrature Amplitude Modulation. Data Modulation based on amplitude of the signal and phase of the signal.

Burst



Appending interburst interval "dead space" into the signal to find signal, aided with use of pilot signals.

Simulations

Matlab (Fig 1 - 6) and LabVIEW (Fig 7) Simulations: Implementing the Simplified OTFS model using the Zak Transform

Fig. 1: Initial 30 x 50 Complex matrix

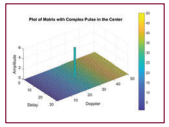


Fig. 2: After the IFFT of the single pulse

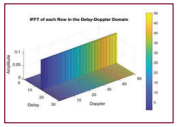


Fig. 3: Serialized IFFT values before the Channel

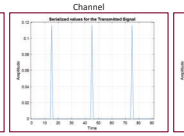
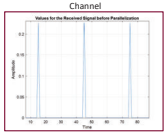


Fig. 4: Received values after the Channel



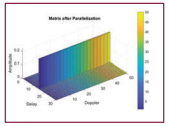


Fig. 5: Parallelized values before the FFT

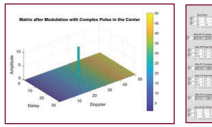
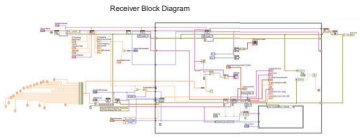
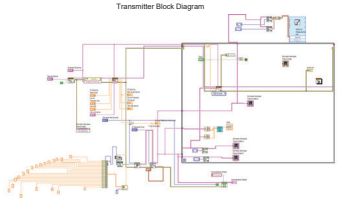


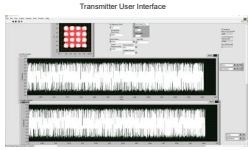
Fig. 6: Final 30 x 50 matrix after the FFT

Fig. 7: Front Panel Indicators for Simulated OTFS Model

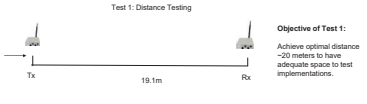
System Implementation







Testing



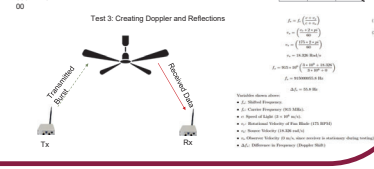
Objective of Test 1:

Achieve optimal distance ~20 meters to have adequate space to test implementations.

Objective of Test 2:

Transmit a pilot signal into a burst QAM signal and create the delay and doppler Matrix.

	8E-10	8E-10
2.18	-7	8E-10
3.12	3.08	



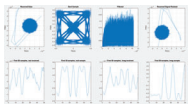
Objective of Test 3:

With an aluminum reflector, transmit the signal to a moving object (fan blade) generating doppler.

Results

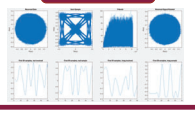
Received data is greatly down - sampled, causing low correlation of received sample.

Distance



Loopback

Received data is an exact match to our sent signal, with slight rotation.



Reflection

Received data mixing with noise. No correlation.

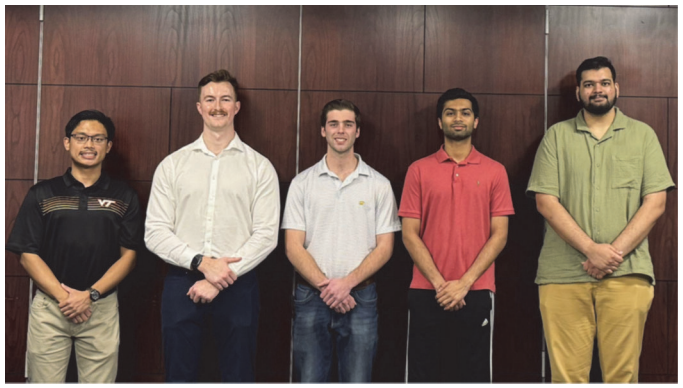
Future Work

- Signal range increase (Physical Distance).
- Improve signal clarity (Stronger signal).
- Further optimizations for signal processing.
- Increase scalability of testing.

2024 Spring Major Design Experience

Sponsors: Air Force Research Lab
Wright Brothers Institute

SCADA System Development for Oversight of all MARS Facilities



LEFT TO RIGHT: Patrick Aguda, Ryan Clarke, Thomas Langley, Nithin Kumar, Sagar Ranga

CHALLENGE

Design and implement a SCADA system to integrate all MARS launch pad facilities, providing a unified, secured, reliable, redundant and scalable interface that efficiently collects sensor and relay device data to the central serverâ€™s database and GUI.

SME: Joe Adams

Customers: Brian Bishop, Nick Counts, Sidnee McGee, John Phillips and Walter Taraila

Patrick Aguda Vienna, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspiration is to explore the various opportunities within the field of computer engineering. I aim to discover my ideal career path through hands-on experience and trends from emerging technologies.

Course Comment: Throughout this course, I have gained valuable insight with the engineering design process and field of control systems engineering. Additionally, I have been able to foster my teamwork and professional skills.

Ryan Clarke Portsmouth, Rhode Island

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to make people's lives easier using innovative technology and software solutions.

Course Comment: This course gave me the opportunity to learn from and work with a great group of students, mentors, and engineers while sharpening my technical and personal skills in a real-world environment.

Nithin Kumar Glen Allen, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My career goal is to be able to create programs to enhance security and ensure that any malicious attempts are stopped before issues arise.

Course Comment: I appreciate being able to get a hands-on experience with circuits such as Arduino's and Raspberry Pi's as well as technical experience with SQL and VM's. These skills will help me move forward in my career and improve my entire skillset.

Thomas Langley Mendon, New York

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I hope to explore varying areas of the computer engineering field and develop new products and technologies for various industries.

Course Comment: This course has provided me with an immense amount of exposure to different niche, and not so niche, areas of networking and computer engineering.

Sagar Ranga Mumbai, India

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to work on next generation technologies like VR/AR and create clever solutions to complex problems.

Course Comment: I have worked with more documentation that I ever imagined and learnt a lot about Controls Engineering. The opportunity to learn from engineers at VSA has taught me a lot about how to become a professional.

SCADA System Development for Oversight of all MARS Facilities

Nithin Kumar, Patrick Aguda, Thomas Langley, Ryan Clarke, Sagar Ranga
Customers: Sidnee McGee, Walter Taraila, Brian Bishop, Nick Counts, John Phillips
Subject Matter Expert & Mentor: Dr. Joe Adams

Background

The Virginia Spaceport Authority (VSA) would like to upgrade their existing launch pad control system to a Supervisory Control and Data Acquisition (SCADA) design for use on all Mid-Atlantic Regional Spaceport (MARS) launchpad sites owned and operated by VSA.

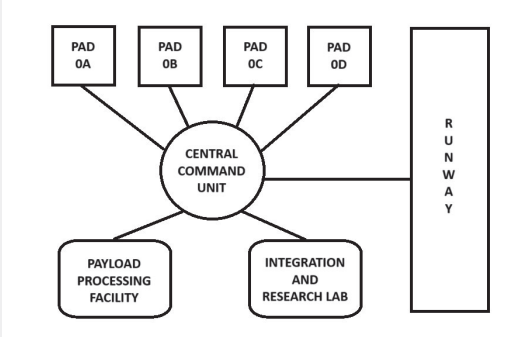


Figure 1. Mock Representation of MARS Facilities Layout

Objectives

Design and implement a SCADA prototype to integrate all MARS launch pad facilities.

- Provide a unified, secured, reliable, redundant and scalable interface.
- Efficiently collects sensor and relay device data to the central server's database and GUI.
- Has a security interface that only allows for authorized personnel to access data and modify processes.

Prototype Design

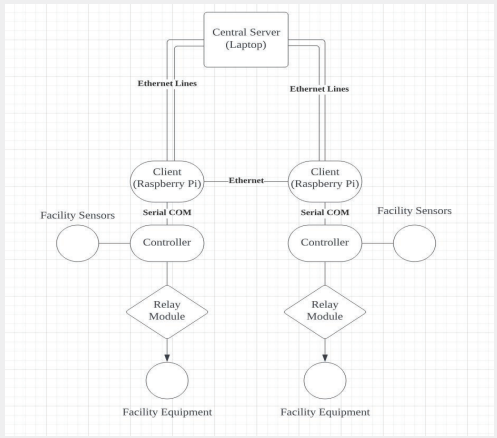


Figure 2. Top-Level Design

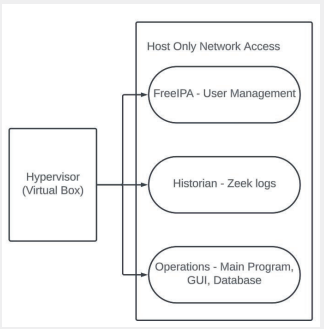


Figure 3. Virtual Machine Diagram

Prototype Breakdown

There are four key aspects of our design:

- Server
  - Virtual Machines
    - FreeIPA - User management
    - Historian - Zeek logs
    - Operations - Main programs, GUI, database
  - SQL Database
- Client
  - GUI - Data display
  - SQL Database Copy
- Controller
  - Relay Module
  - Sensors - Temp/humidity, pressure, infrared
  - Devices - Fan, water pump, linear actuator
- Security & Protocols
  - ITAR Category 15, NIST SP 800-171/800-172
  - Zeek Network Security Monitor
  - Air-gapped Architecture

Validation

- VM Snapshot
  - Automated script for daily snapshot
- Arduino Response Time
  - Every 5 seconds
- Redundancy
  - FreeIPA redundant server
- Security
  - Air-gapped

Conclusion

The SCADA concept allows for efficient data communication between pads while full mesh network connections create a redundant, fail-safe system. The addition of Zeek and FreeIPA allow for user tracking, and overall network security.

Moving Forward

To transition our prototype for implementation to MARS facilities, software aspects of our project can be put into a container such as Docker and a GitHub repository can be shared. Hardware aspects can be modified to better represent facility equipment at specified launchpads.

Acknowledgment

We would like to thank all VSA members who have supported us in developing this project, as well as our mentor and subject matter expert Dr. Adams for his guidance.

LLM Powered Room Perception From Autonomous Aircraft

LEFT TO RIGHT: Henry Forsyth, Gabriel Abernathy, Matthew Rajan, Kurtis St.Thomas, Layan Kutbi

SME: Cameron Patterson

CHALLENGE

Desgin an autonomous system that can navigate a room, gather room dimensions and images, and return that data textually with the help of an LLM

ANDURIL

Customer: Jonathan Ballagh

Gabriel Abernathy Paeonian Springs, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: My carrer goal is to find innovative solutions to hardware and software problems faced in the defence community today.

Course Comment: This course gave me more experience hands on experience working on a small team, working together to solve problems we didn't anticipate while meeting our goals.

R. Henry Forsyth Jr Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I want to develop tools and products that promote innovation. A good product should reduce the intellectual barrier to entry, bring with it power, not create their own hurtles.

Course Comment: I enjoyed working working with a proper team again. As a young engineer, I often find myself on personal-growth, individual projects. It beings me joy to succeed at such a complex problem with a team I can trust to get the work done.

Layan Kutbi Jeddah, Saudi Arabia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to use my software skills and my knowledge of event management and hospitality to create better technology solutions for events, making them more engaging and enjoyable for everyone.

Course Comment: In this senior design course, I applied all the knowledge I've gained throughout my studies to this project. The class also taught me valuable workplace skills, such as teamwork and time management.

Matthew K Rajan Chicago, Illinois

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My goal is to find unique opportunities where AI/ML can help describe a problem and its surrounding context, with the aim of leveraging models to guide and inform decision-making processes.

Course Comment: The Senior Design Experience has given me a fantastic opportunity to engage in a highly interesting project, enabling me to research and implement state-of-the-art models and algorithms. In addition to the technical development, this project has taught me a great deal about system design, project management, and system deployment, all of which are essential skills in industry.

Kurtis St. Thomas Springfield, Virginia

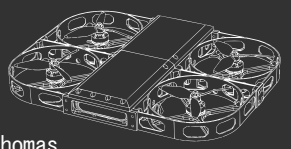
Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My career goal is to become a software architect that designs solutions that can make a meaningful impacts on people's lives.

Course Comment: This course gave me a great oppotunity to scope, design, and implement solutions to real problems. It has given me the most useful hands-on exeperiences of the classes I've taken here.

LLM Powered Room Perception From Autonomous Aircraft

By: Henry Forsyth, Matthew Rajan, Gabriel Abernathy, Layan Kutbi, Kurtis St. Thomas
Dr. Joe Adams (Mentor), Dr. Cameron Patterson (SME)



Created in Partnership with: VT ANDURIL

Special Thanks to the company sponsor!

Problem and Objective

Problem:
Create a safe, unique hardware/software solution that can analyze a room using mobile visual sensors and produce a textual output describing the environment

Objectives:
- System must perform indoor object recognition
- System must be intuitive and safe
- System must leverage an LLM after CV data collect

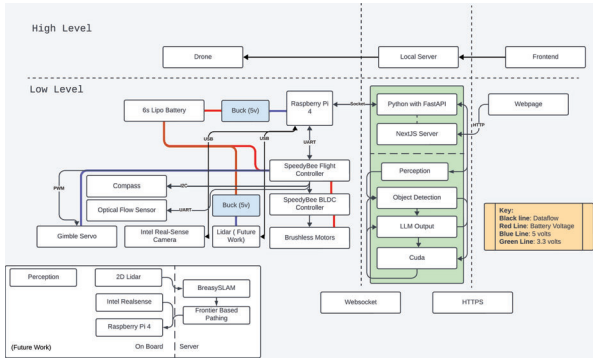
Issues Encountered

- Maintaining the identity of objects that went out-of-view
- Hardware changes after discovering intergation limitations (Raspberry Pi especialy)
- Planned SLAM algorithm ran behind schedule due to hardware limitations, so was eventually simplified
- Dronekit was initially proposed as Mavlink solution, but instead we went with PyMavLink

Solution At A Glance

Custom Drone

Custom GUI
- Video Stream
- Teleop Control
- Control Params
- Easy Controls
- LLM-Assisted Responses



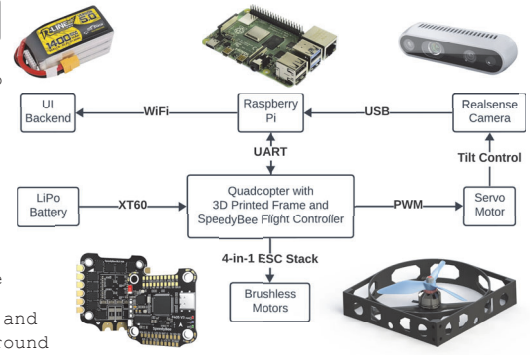
Core Frameworks

FastAPI — Firmware, Backend
ARDUPILOT — Firmware
NEXT.JS — Frontend
Backend, Firmware
Ubuntu 22.04 Jammy Jellyfish

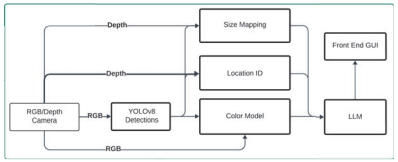
Docker builts all our images for x86 and ARM architectures

Hardware Solution

- Custom 3D printed frame to mount components
- Raspberry Pi to pilot the drone autonomously and execute mission commands
- Realsense Camera provides object detection, recognition, and avoidance
- Servo Motors level camera and maneuver vehicle on the ground



Software Solution



- Implements YOLOv8 for real-time, accurate object detections and extracts metadata from detected objects
- Applies K-means clustering to find the most prominent RGB value and matches it to the closest color name using a KD Tree
- Input objects and their metadata into LLama2-7b with quantized weights locally for enhanced security and hardware compatibility
- Live depth and color streams from Intel RealSense, current drone heading, and TELE-OP control displayed via the GUI during flight, and allows users to prompt the LLM for insights about the room and its objects post-mission

Conclusion

- Drone design takes careful planning and a focus on system integration. We made sure to not neglect industry standard CI/CD
- We could not account for everything at the outset of the project. Pivoting effectively is what shows the merit of an engineer
- Having a large selection of frameworks (FastAPI, NextJS, PyMavLink, DroneKit, etc) made project deliverables more attainable
- The team achieved great success in object detection, local LLM, drone hardware design, and software integration

Aircraft Data Acquisition Device

LEFT TO RIGHT: Clayton Ulrey, Caroline Larsen, Christopher Boerner, Andrew Weber, Mostafa Gaafar

CHALLENGE

To design and construct a data acquisition device that can measure temperature, humidity, vibration, and sound from multiple locations in an aircraft, wirelessly transmit the measurement data to a handheld device, and display the data in real time. This device will allow aircraft technicians and mechanics to remotely inspect conditions in hard-to-reach locations on an aircraft.

SME: Peter Han

Customer: Dylan Gooch

Christopher Boerner Falls Church, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am pursuing a master's degree at Virginia Tech to continue my passion for the hardware-software relationship and the field of embedded systems. I hope to apply my skills to cutting-edge technology for the betterment of people's lives.

Course Comment: This course has helped me understand the engineering process from identifying a problem to developing a working prototype. This has enabled me to enhance my teamwork and ECE skills in all aspects.

Mostafa Gaafar Radford, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I aim to pursue a PhD in the future, alongside obtaining a Professional Engineer license. Additionally, I aspire to establish my own engineering firm specializing in both technology/defense and in the health sector.

Course Comment: This project has enabled me to apply my past career skills while collaborating with very talented electrical and computer engineers on the project team. I've especially valued delving into PCB design and coordinating integration with team members, which has significantly aided in transitioning old skills into the future role.

Caroline Larsen Blacksburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I hope to contribute to the field of power grid communications and control.

Course Comment: This course has taught me a great deal about the practical side of engineering projects. This project in particular has been valuable because it integrates many hardware and software components, so team members have learned to collaborate closely and share their skills.

Clayton Ulrey Grantville, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: My goal is to use my knowledge of computer networking to enhance the lives of people. I believe technology can better people's lives socially, materially, and spiritually.

Course Comment: Man oh man has this course been frustrating at times but so rewarding that makes it well worth it. I have enjoyed working with my great team and learning how to tackle a real world problem.

Andrew Weber Chantilly, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to pursue a career in embedded software and to work on projects that help to expand my engineering knowledge. Through my experiences, I want to learn all sides of computer engineering and computer science to work on my own personal projects outside of my career.

Course Comment: This course has given me a chance to experience the engineering process within a team to design a product for a customer. It has also allowed me to explore different approaches and evaluate the best plan of action to produce the best design.

Aircraft Data Acquisition Device

Sponsor: Dylan Gooch, NAVAIR Fleet Readiness Center East
Subject Matter Expert: Peter Han, Virginia Tech ECE
Team Members: Christopher Boerner, Mostafa Gaafar, Caroline Larsen, Clayton Ulrey, Andrew Weber

Introduction

- Current data acquisition (DAQ) technology for aircraft testing is cumbersome and dangerous
- A new DAQ system would allow remote monitoring of points in aircraft
- Our system includes detachable sensors, long distance wireless transmission, and an easy-to-read GUI

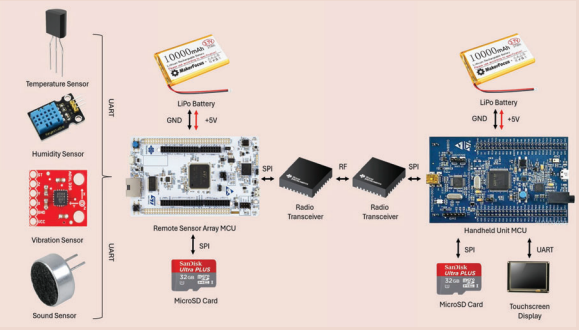
System Overview

Three major subsystems make up the Aircraft Data Acquisition Device:

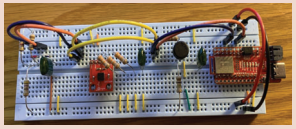
1.Sensor Nodes
- 8 detachable sensors
- Four types: Vibration, Temperature, Humidity, Sound
- Read and calculate data from real world

2.Remote Sensor Array (RSA)
- Receives data from sensor node via current loop
- Transmit data to handheld device via radio frequency

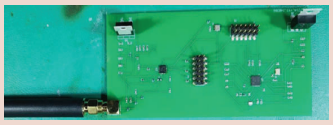
3.Handheld device
- Receives and displays real time data for user



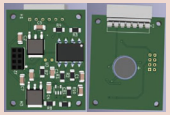
Hardware Solution



Circuits for temperature sensor, vibration sensor, and humidity sensor are connected to the sensor node SparkFun Artemis MCU



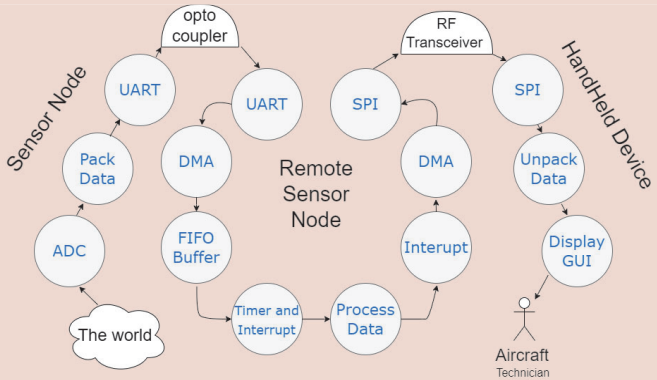
Wireless Radio Frequency transceiver board



Sensor node design

Current loop communication between sensor node and RSA

Software Solution

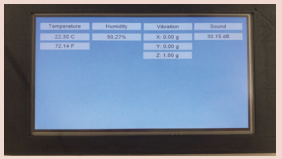


Packet Structure:

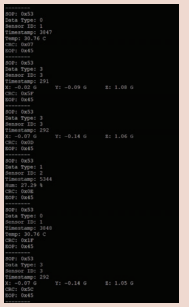
1 BYTE SOP	1 BYTE DATA TYPE	1 BYTE SENSOR ID	4 BYTES TIMESTAMP	8 BYTES DATA (4 x 14 BIT ADC SAMPLES)	1 BYTE CRC	1 BYTE EOP

Final Product

Data Packet being sent over a 60ft Twisted Pair Cable



Handheld Unit Showing Basic Display of Sensor Data



Output from Serial Monitor on Handheld receiving end

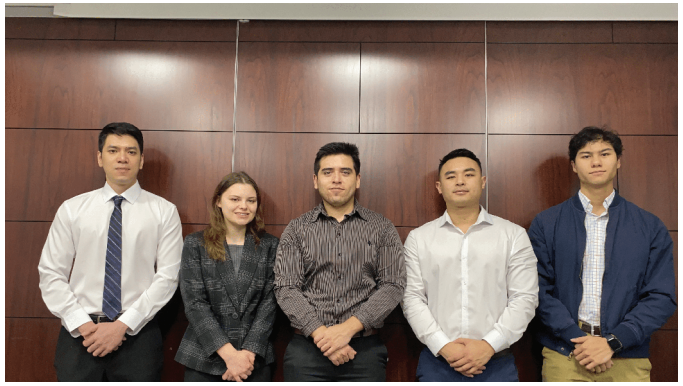
Results

- Sensor node data can transmit to RSA through current loop sampling at 54kHz
- Multiple sensor nodes can be connected to RSA simultaneously
- RSA data can transmit to Handheld Unit through SPI
- Handheld Unit displays received sensor data

Acknowledgements

- Peter Han of Virginia Tech ECE Department as our Subject Matter Expert
- Dylan Gooch and Sarika Khanal of Fleet Readiness Center-East (NAVAIR) as our primary point of contact

Equine Vital Tracking: Real-Time Automated Health Monitoring



LEFT TO RIGHT: Quoc Tien Le, Kylie Angel, Mario Montano, Vu Mai, Ian Page

CHALLENGE

The Marion duPont Scott Equine Medical Center receives roughly 100 foals during the January to June seasonâ€‹. Their veterinarians do manual vital checks on foals consistently while they are in intensive careâ€‹. Our goal is to help the veterinarians save time, effort, and immediately alert them to abnormal vital readingsâ€‹. Our device monitors heart rate and respiratory rate, which are vitals that need to be checked often. It also monitors activity level.

VIRGINIA TECH.
MARION DUPONT SCOTT
EQUINE MEDICAL CENTER

SME: Almuatazbellah Boker

Customers: Almuatazbellah Boker, Krista Estell, Megan Marchitello and Patrick Wolak

Kylie Angel Fincastle, Virginia

Bachelor of Science in Electrical Engineering
Communications & Networking

Aspirations: I aspire to use my engineering skills to contribute to projects that influence others in a positive way.

Course Comment: This course gave me hands-on experience in many areas such as circuit design, system design, research, power budget considerations, and digital signal processing. It also gave me valuable experience with formal presentations, which has greatly prepared me for professional presentations in the future.

Tien Le Sterling, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I want to learn and explore new technology, especially the prospect of developing systems that can autonomously work.

Course Comment: This course provided me with the opportunity to collaborate with teammates and develop a system capable of autonomous operation. I have acquired numerous skills that I believe are essential in the real world, particularly in industry, including research, circuit design and testing, teamwork, and time management.

Vu Mai Chantilly, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to use my engineering experience gained at Virginia Tech to innovate for conservation efforts, applying advanced technologies to protect and restore our natural environments.

Course Comment: This Senior Design course provided me with hands on experience in working with and designing a product for a real company, teaching me the essentials of teamwork, time management, and the aquisition of new skills throughout the process.

Mario Montano Sterling, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I want to work on projects that i am passionate about that help develop technology in our world.

Course Comment: This course has helped me understand the importance of research and development within projects. It has also shown me how to be able to compile projects with partners and formulate a final design that fits the criteria set by a customer.

Ian Page Arlington, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I seek the betterment of the world and people's lives in it. Learning new skills to help the quality of life for everything is what I'd love to do in the future.

Course Comment: Senior Design has allowed myself and my teammates to work within a small group throughout the past several months to develop a project given to us with little information about it. This opportunity is an amazing chance to understand what it's truly like in the industry and get us prepared for the real-world. I have enjoyed these classes much more than the typical class and wish they continue this for years to come.

Equine Vital Tracking: Real-Time Automated Health Monitoring

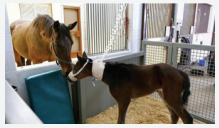
Kylie Angel, Mario Montano, Ian Page, Tien Le, Vu Mai
Sponsor: Marion duPont Scott Equine Medical Center
Subject Matter Experts: Almuatazbellah Boker, William Baumann

VIRGINIA TECH

VIRGINIA TECH
MARION DUPONT SCOTT
EQUINE MEDICAL CENTER

Background

The Marion duPont Scott Equine Medical Center faces the challenge of **manually monitoring vital signs of 100+ foals** during the Spring and Fall, consuming considerable time and effort. To address this issue, we present a detailed design for a monitoring device aimed at increasing efficiency and aiding in the recovery process.



Device is designed to...
- Be Comfortable
- Be Non-invasive
- Be Accurate
- Have Wireless Communication
- Have a battery life of 24 hours minimum
- Have a graphical User Interface (GUI) availability on PC/mobile devices
- Have Real-Time and continuous data sending
- Be a monitor for heart rate, activity level, and respiratory rate.

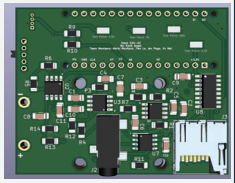
Power Systems & Battery Monitoring

A decision matrix was conducted for deciding what type of battery to use.
Chose a 9V rechargeable lithium-ion battery:
- high charge capacity
- substantial energy density
- Built-in recharging capabilities and overcharge protection

Software contains battery monitoring detection that alerts the user that the battery needs recharging

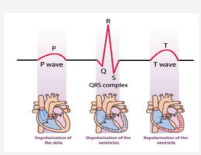
"Main" PCB

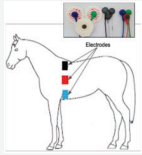
Front


Back

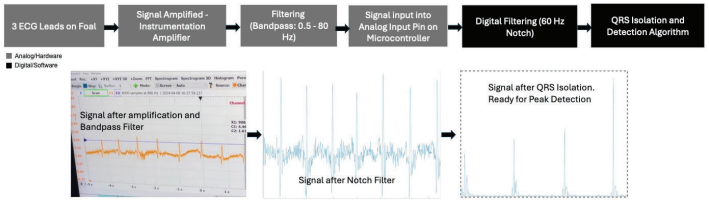
Heart Rate Monitor

- The heart produces electrical signals that can be picked up on the skin using electrodes
- Calculation of Beats Per Minute (BPM) needs R-wave interval
- Goal: software identifies the QRS complex
- Noise should be eliminated as much as possible before QRS detection through filtering.
- Test verification was performed on a human (BPM is different for human but HR components are the same)





Overall Process

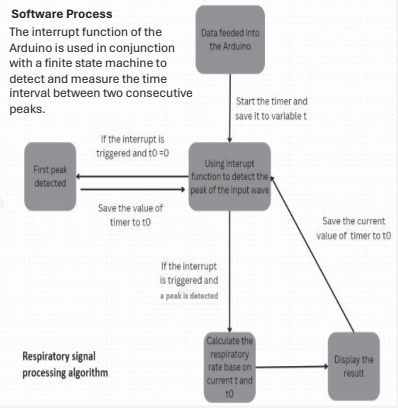


QRS Isolation/Detection Algorithm

Respiratory Rate Monitor

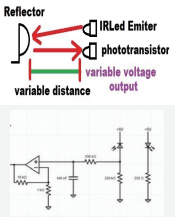
Software Process

The interrupt function of the Arduino is used in conjunction with a finite state machine to detect and measure the time interval between two consecutive peaks.



- A stretchy belt is wrapped around the abdomen
- As the abdomen expands during breathing, the belt that houses the sensor stretches
- An IR LED is pointed at a reflector and a photodiode to detect the intensity of light
- The light intensity changes with distance and this is used to measure breaths per minute (bpm)
- An active lowpass filter with the gain of 10 and the cutoff frequency at 5Hz to refines the input signal to the Arduino
- Testing was performed on a human and compared to manual measurements using a stopwatch

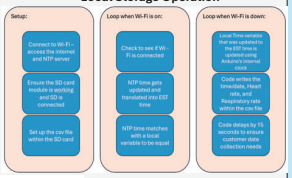
PCB for Respiratory Belt

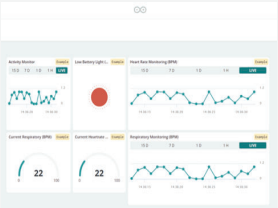


Communications, GUI, and Local Storage

- Wifi is used to transmit data
- We are using an Arduino with built-in Wifi capabilities
- Automatic data backup via micro-SD card when the Wi-Fi goes down

Local Storage Operation





- Our project uses the Arduino Cloud Dashboard
  - Integrated live data in the GUI
  - Can be accessed on PC and mobile devices

Activity Monitor

- The Arduino RP2040 has a built-in IMU sensor
- The magnitude of the IMU axis (x, y, and z) is taken to determine movement

Conclusion & Future Work

Our project marks a significant leap in equine health care by leveraging IoT technology to monitor vital signs of foals and their mothers. The innovative system enables real-time, remote health tracking, promising a bright future for equine well-being.

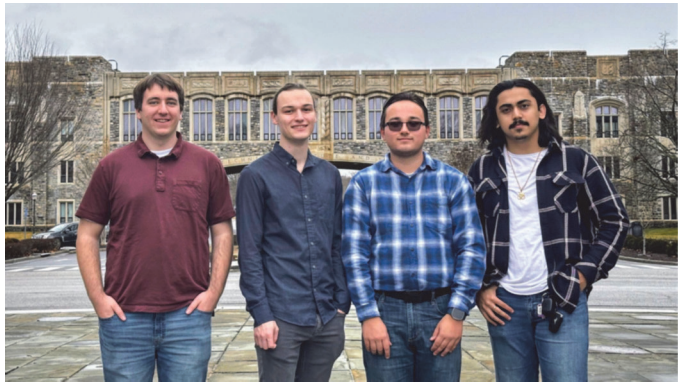
In the future, we would add a muscle sensor to aid in reducing ECG noise from muscle movement.

Acknowledgement

Joe Adams
William Baumann
Krista Estell

Almuatazbellah Boker
Patrick Wolak
Megan Marchitello

Personal Locator Beacon Range Extender and Transceiver Network



LEFT TO RIGHT: Caleb Grohs, Patrick Stock, Matthew Urquhart, Vivaan Jaiswal

SME: Tim Talty

CHALLENGE

This project aims to build upon personal locator beacons (PLB) built previously by another MDE Team. The PLB uses a protocol called LoRa, which is a low-power method of wireless communication. The locator beacons achieve around a mile of range for connecting with the base station, and send only GPS coordinates and a distress signal. This is a problem because most locator beacons are used in rural and spread-out areas, which a device with such limited range does not support, and limited information could make it difficult to locate somebody in an enclosed space. The customer has asked us to work on these issues and improve the system to increase its practicality.

ZETA ASSOCIATES

Customers: Jared Desai and Michael Drescher

Caleb Grohs Bedford, Virginia

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I plan to further my study in computer engineering in graduate school with emphasis in Controls, Robotics, Autonomy, Networking, and Cybersecurity.

Course Comment: The Major Design Experience allowed me to put classroom concepts to action. It also provided insight into the business and management side of the engineering occupation that is often missed in classroom assignments.

Vivaan Jaiswal Delhi, India

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: A personal goal of mine is to work on the electronic systems in performance vehicles. I want to use my skills as an electrical engineer and combine that with my passion for cars.

Course Comment: I enjoyed working with our customers. It provided us with an industry like experience and helped introduce us to the change we are about to experience going from college to industry

Patrick Stock Midlothian, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I plan to become a software engineer and earn a master's degree in computer engineering.

Course Comment: I enjoyed seeing my code and efforts accomplish a larger goal within our team. I enjoyed working with my team to complete a task that would have been otherwise impossible without them.

Matthew Urquhart Jacksonville, Florida

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I plan to pursue a career in cellular network engineering or software engineering. Before that, I plan to continue studying for my master's degree at Virginia Tech.

Course Comment: This course provided me with the experience needed to start on projects in a design team in the workforce. I developed a lot of team management and interpersonal skills which are invaluable in the workplace. I highly recommend taking this course seriously to all prospective engineers.

PLB Range Extender & Transceiver Network

Matthew Urquhart, Caleb Grohs, Patrick Stock, & Vivaan Jaiswal
Virginia Tech Electrical & Computer Engineering
In Partnership with Zeta Associates

Background

- Personal Locator Beacon (PLB) Device was Designed by a prior MDE Team.
- Range is limited. The environment in which locator beacons are typically used requires great range.
- Very little data currently transmitted.
- Our goal is to improve on both shortcomings.

Use Cases

- Hikers and Skiers
- Firefighters & First Responders
- Construction Workers
- Other Workers in Dangerous Environments

Project Requirements

- Less than 20 Cubic Inches
- Less than 0.5 pounds
- Four hours or more in battery life
- 100m range extension
- Less than 1 minute round trip time

Top-Level Design

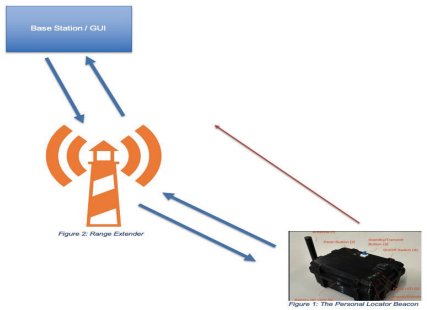
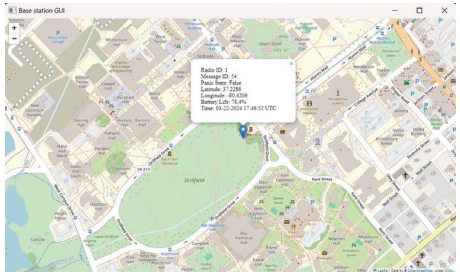


Figure 2: Range Extender

Figure 1: The Personal Locator Beacon

Base Station GUI

- Base station GUI runs HTML in a QT window
- HTML uses Leaflet to display a map with PLB markers
- Back end written in Python
- Separate thread decodes packets from GNU Radio over TCP socket
- GUI sends acknowledgements after receiving packets



Range Extender - Software

- Range Extender constantly "listens" for packets.
- Differentiates received packets between acknowledgements and data based on length.
- If a data packet is received, it is stored in an array.
- If an acknowledgement is received, any packets with the corresponding radio & message ID are deleted from the array, preventing retransmission.
- Packets waiting to be retransmitted are sent with a one second interval. First in, last out methodology

Data Packet

	Radio ID	Panic State	Message ID	GPS Latitude	GPS Longitude	Battery Life	Coordinated Universal Time	Total
Number of Bits	16	1	7	32	32	8	32	128

Personal Locator Beacon (PLB)

Software:

- The PLB Software has been updated from the prototype
- Properly encodes information in a byte array
- Puts radio module to sleep when in standby mode
- In active mode, transmits a packet every ~10 seconds
- Updated packet structure
- Added Message ID to packet in order to differentiate multiple messages from same PLB

Hardware:

- Arduino Feather M0 with RFM95 LoRa Radio
- BE–880 GPS Receiver Module
- 3.7v LiPo Battery
- Green Power LED
- Yellow Active LED
- Red Panic LED
- 915Mhz LoRa Antenna
- Power and Panic Switches
- Active/Standby Switch

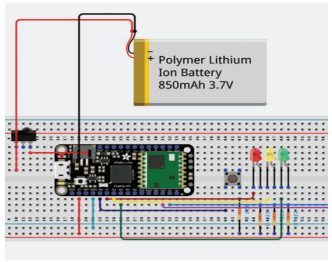
Acknowledgements

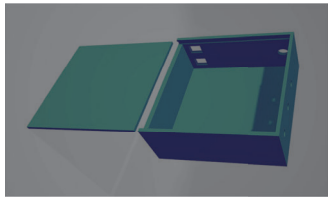
Customer - Michael Dresher & Jared Desai
Subject Matter Expert - Dr. Tim Talty
Mentor - Dr. David Connors

Acknowledgement Packet

	Radio ID	Panic State	Message ID	Total
Number of Bits	16	1	7	24

Range Extender – Hardware





Loosely based off the PLB design.

- Arduino Feather M0 with RFM95 LoRa Radio
- 3.7v LiPo Battery
- Green Power LED
- Yellow Battery LED
- Red Transmit LED
- 915MHz Lora Antenna

- The case design was changed from last year
- Added sliding panel for easier accessibility of hardware
- Increased volume to 40mmx80mmx100mm (~19.5 cubic inches) to help organize hardware
- Holes created for peripheral parts
- 2 square switches, 3 Status LEDs, Antenna

Challenges

- Reading Data into Base Station GUI using TCP Port
- Redesigning the Packet Structure
- Sending Acknowledgements
- Preventing/Deleting Duplicate Packets
- Range Testing
- Obtaining information from previous MDE Team

Validation/Results

- Our design meets ALL project requirements.

Far-Field Antenna Pattern Reconstruction From Probe Data in the Planar Near-Field of an Antenna

LEFT TO RIGHT: Christopher Barrett, Aidan Graffam, Nicholas Martin

CHALLENGE

To implement an algorithm to collect antenna near-field data and transform it into its far-field. This allows for the collection of highly useful data without having to set up a complex and expensive far-field measurement range.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

SME: Brad Davis

Customer: Bill Smith

Christopher Barrett Centreville, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I hope to pursue a Master's degree in electrical engineering.

Course Comment: I learned a great deal about a topic that I had no prior experience with.

Aidan Graffam Falls Church, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: To become the best version of myself

Course Comment: Thankful for good project support staff

Nick Martin Warrenton, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: Advance the field of electrical engineering and see something I worked on help humanity for the better.

Course Comment: This course allowed me to delve deeper into a topic of interest and learn so much about RF, antennas, and myself.

Far-Field Antenna Pattern Reconstruction From Probe Data in the Planar Near-Field of an Antenna

Nick Martin, Aidan Graffam, Christopher Barrett

Sponsor: Mr. Bill Smith, NSWC, Dahlgren **SME:** Dr. Brad Davis, VT NSI **Mentor:** Dr. Daniel Connors

Motivation

- Design and develop an algorithm to take data from a probe measured in the radiative planar near-field of an antenna or antenna array.
- Transform that data to retrieve the approximate far-field characteristics.

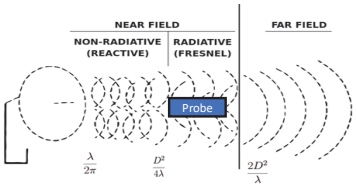


Fig 1. Antenna Radiation Zones

- Performing antenna tests in a laboratory environment is often more expeditious and cost effective than testing on an open range.
- This reliable method for reconstructing far-field antenna patterns serves as an important steppingstone towards enhancing the pragmatic application of antenna testing in a laboratory environment.

Objectives

- Definition of mathematical transformations and development of code for reconstruction of far-field patterns from near-field measurements.
- Development of command code to assist with measurement techniques, such as positioning of probes and coordination between the probe and network analyzer.
- Collection of data in the near-field using a probe and associated measurement techniques.
  - Probe correction ignored for the purposes of this project
- Collection of far-field data to validate the results using standard gain horn antennas.

Theory of Operations

- Receive data in near-field from measurement probe.
- Perform data conditioning.
- Perform mathematical transform upon near-field data to acquire far-field data.
- Plot far-field data.
- Compare to measured far-field data of NSI near-field scanner.

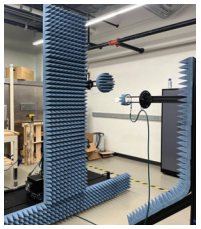


Fig 2. NSI Near-Field Scanner

System Diagram

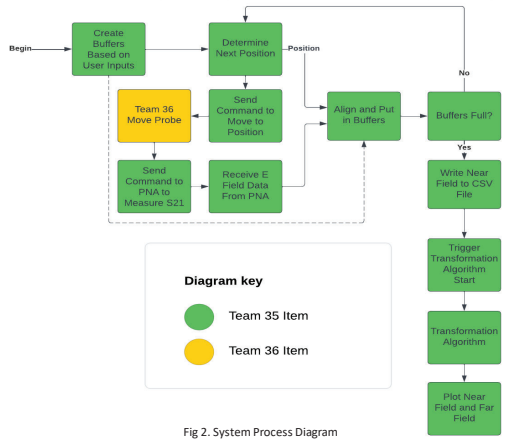


Fig 2. System Process Diagram

Test Results

Measurements taken of a X-Band standard gain horn operating at 10 GHz:

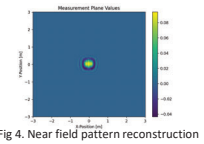


Fig 4. Near field pattern reconstruction on the measurement plane.

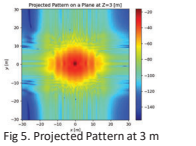


Fig 5. Projected Pattern at 3 m away from the antenna source.

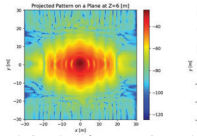


Fig 6. Projected Pattern at 6 m away from the antenna source.

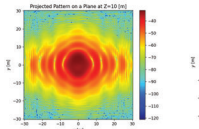


Fig 7. Projected Pattern at 10 m away from the antenna source.

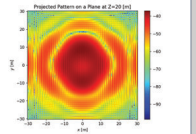


Fig 8. Projected Pattern at 20 m away from the antenna source.

Measurements taken of a X-Band 8 elem. OEW array operating at 8.5 GHz:

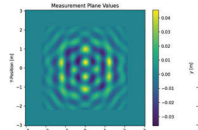


Fig 9. Near field pattern reconstruction on the meas. plane.

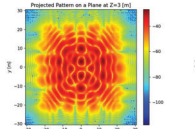


Fig 10. Projected Pattern at 3 m away from the antenna source.

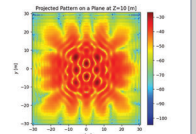


Fig 11. Projected Pattern at 10 m away from the antenna source.

Analysis and Conclusion

- The near field to far field transformation algorithm is far more efficient and cost effective than acquiring and utilizing a far-field antenna range.
- Our results showed it is possible to achieve a reasonably high degree of fidelity when comparing the far-field patterns of this system with the NSI scanner far-field.
- Once measurements are taken, the absence of probe correction in our system can introduce significant error in the near field measurements.
- We created a way of analyzing the data that shows the patterns in a projected plane that can be easily measured on a traditional x-y grid while most scanners give the pattern as a function of elevation and azimuth thus making it hard to examine if a measurement at a specified distance is required.

NSI Scanner Far-Field Projection VS. **Mathematical Far-Field Projection**

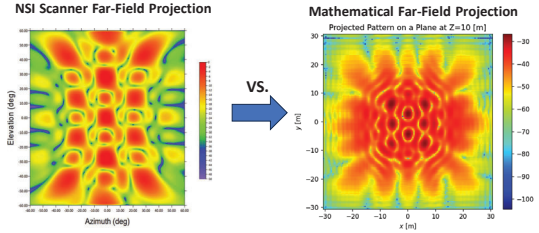


Fig 12. Comparison of NSI scanner output and our algorithm output

Future Plans

- Implement time gating to minimize multipath.
- Use in newly constructed anechoic chamber.
- Implement probe correction factors for higher fidelity scans.
- Implement the algorithm with a full rail movement mechanism.
- Scale up system and algorithm to accept larger data sets to accommodate large scale arrays and antennas.

Acknowledgements

We would like to thank the following people for their assistance and support

- Mr. Bill Smith, NSWC, Dahlgren (Customer)
- Dr. Brad Davis, VT NSI (Subject Matter Expert)
- Dr. Daniel Connors (Mentor)

Instrument and Control for a Near Field Planar Scanner

LEFT TO RIGHT: Nick Merton, Mashnoor Kabir, Joe Esser, Chuck Krzyzewski

CHALLENGE

To design and build the motor control system for a near field planar scanner to measure antennas operating in the X-band. To ensure positional accuracy, a 60GHz radar system was used.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

SME: Brad Davis

Customer: Bill Smith

Joseph Esser Poolesville, Maryland

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: I hope to contribute to the field of radio frequency enginnering so that wireless communication services continue to improve while also supporting an ever increasing number of users.

Course Comment: It is vital to establish team communication early as it is far easier to resolve conflicts in style or approach early on as opposed to when you are doing serious engineering work.

Mashnoor Kabir Blacksburg, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: My goal has always been to contribute to the digital semiconductor industry. As humanity continues to push the boundaries of transistor technology from FinFETs to GAAFETS and from 7nm to 5nm to 3nm: I want to be part of a team that continues to push these technologies to their limits a limit a future engineer breaks later on.

Course Comment: If you haven't learned how to schedule and keep track of your deliverables and assignments (i.e. haven't learned to make a todo list) you should probably learn that now.

Chuck Krzyzewski Naperville, Illinois

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: Space exploration and aviation has always been a keen interest of mine and I have found through different projects, experiences, and teams that avionics and power systems pique my interest the most. I intend to be one of the people to help further our exploration of not just our nearby solar system but space as a whole.

Course Comment: Being proactive and brainstorming potential solutions to your project early on will benefit you greatly in the second semester of the course.

Nick Merton Chesapeake Beach, Maryland

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: As an electrical engineering student specializing in control systems and hardware devices, I hope to contribute to the continuing innovations involving controller systems in the medical or robotics fields. I want to work to produce and create accurate controller devices that can help the everyday lives of people all over the world.

Course Comment: The senior design course provided an invaluable hands-on experience, allowing me to apply my knowledge of motor and control systems to solve real-world engineering challenges. It was a transformative journey that not only sharpened my technical skills but also instilled in me a deep sense of confidence as I enter the professional realm.

Instrument and Control for a Near Field Planar Scanner

Nick Merton, Mashnoor Kabir, Joe Esser, Charles Krzyzewski

Sponsors: Bill Smith, Naval Warfare Center Dahlgreen Division

Subject Matter Expert: Dr. Brad Davis

Objectives

- Create a commercial antenna scanner using off-the-shelf parts while maintaining accuracy against professional systems
- Design a control system to move the probe on a 3mm scale
- Use a 60GHz radar system to accurately measure the distance between the probe and antenna allowing for post-correction to acquire more accurate results

Requirements

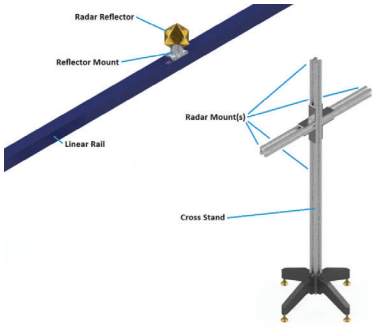
- Achieve a probe step size of at most 3mm
- Assure accurate distance measurement between the antenna and probe using a 60GHz radar system
- Develop software and user interface to successfully integrate with a separate team's far-field approximation using our data

Results

- Radar has not proven viable in measuring sub-millimeter position outside of lower frequency bands when pursuing non-planar shapes
- Motor system is incredibly accurate: should look into position acquisition through motor system

Motor Control

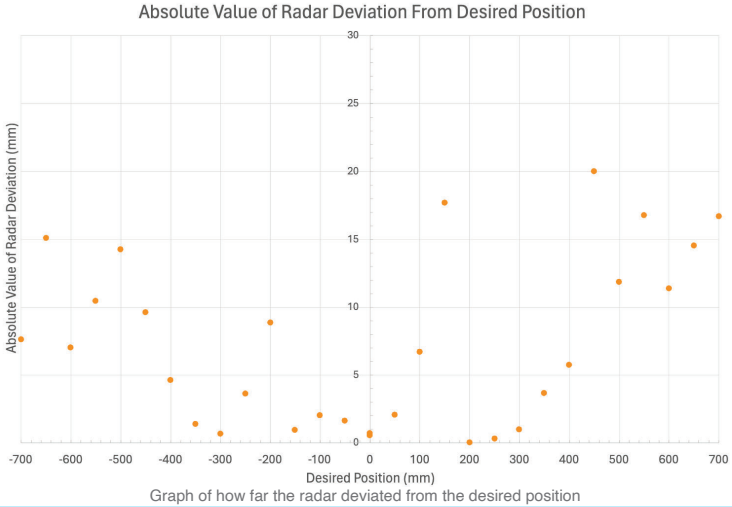
- Gearbox motors
- Uses PID tuning algorithms
- Can move in 1mm steps
- Command sets to move motors



Depiction of radar system

Radar Control

- Acconeer XC120 was used for the radars
- 4 radars were used concurrently to ensure accurate measurement
- Radar system was used to measure discrepancies and calibrate them out
- Position acquired through bilateration
- Accurate to the centimeter



Graph of how far the radar deviated from the desired position

Testing Process

- Probe attached to motor system to read approx. zero (reducing noise readings)
- Motor and radar calibrated as zero at the center of the rail to establish a common zero
- Moved motor in 10mm steps up to ±750mm
- Measured
  - Command position
  - Readout position
  - Motor position
- Moved again in 1mm steps up to ±10mm

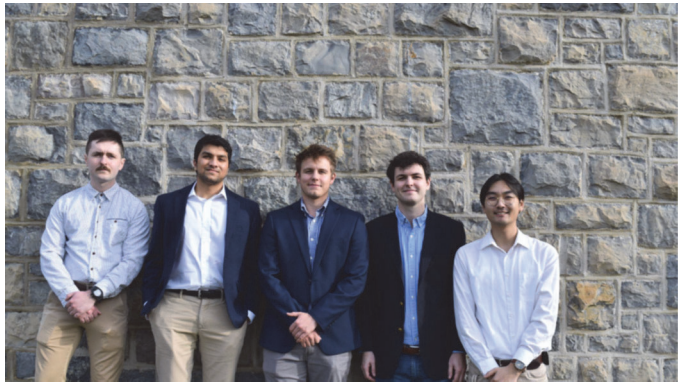
Future Plans

- Integrate motor and VNA control GUI into system
- Test motor accuracy at sub-mm positions
- Modify radar configuration to increase accuracy
- Complete a full near field scan

Acknowledgements

- The Hume Center
- Dr. Brad Davis
- Dr. Daniel Connors
- Bill Smith
- Emerson Dove

Signals of Distress: Detecting UAS Damage in High-Powered Microwave Environments



LEFT TO RIGHT: Jackson Burns, Jai Deshmukh, Michell Kuhns, Joseph Glennon, Logan Um

SME: Daniel Connors

CHALLENGE

The Naval Surface Warfare Center Dahlgren Division (NSWCDD) utilizes High Powered Microwaves to test their UAS devices to ensure they are battle ready. Utilizing parabolic microphones and signal processing software, the NSWCDD tasked us with determining any differences within a UAS hit by HPMs.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

Customers: Logan Bradbury, Alan Overby and Corey Vyhlidal

Jackson Burns Appomattox, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I intend to commission in the US Army as an aircraft maintenance officer. After gaining experience in the military, I hope to use my degree in an engineering capacity in the private sector.

Course Comment: This course provided an avenue to acquire new skills as well as test out various different skills that I have acquired through out my time in university.

Jai Deshmukh Charlotte, North Carolina

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am passionate about aircraft simulations and machine learning, due to their expanding contribution to the public. My aim is to actively contribute to the advancement of these technologies for the betterment of the public.

Course Comment: I am grateful for the opportunity to create an effective product and work alongside like-minded individuals. This course has not only provided valuable connections and resources, but set an invaluable stepping stone for my career.

Joseph Glennon Atlanta, Georgia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: After college I hope to work in the biomedical field with prosthetics. Later in my career I hope to work on project development and innovation.

Course Comment: The Senior Design Experience is a course that gives students the opportunity to participate in a long term project. I liked how each student was required to find a way to add something to their project, and how the mentors instructed the course.

Michell Kuhns Warrenton, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aim to start as a Systems Software Engineer, then transition into a managerial role blending engineering and business insights. Finally, I hope to return to education to teach and share my knowledge.

Course Comment: This senior design class was invaluable, fostering collaboration and practical skills essential for real-world projects. Grateful for the guidance and meaningful experiences.

Logan Um Ellicott City, Maryland

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: Work in the private sector to learn and innovate on new technology. Inparticular I would like to work on innovations that will postively effect as many people as possible.

Course Comment: This course has opened my eyes to how the industry works. The lessons I learned here will be invaluable to my future as an engineer.

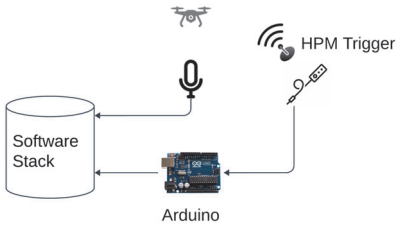
Signals of Distress: Detecting UAS Damage in High-Powered Microwave Environments

Jackson Burns, Jai Deshmukh, Joseph Glennon, Mitchell Kuhns, Logan Um

Problem Statement

- NSWCDD utilizes High Powered Microwaves (HPMs) to test UAS readiness.
- Employ parabolic microphones and signal processing to detect differences in HPM-affected UAS.
- Ensure UAS effectiveness and resilience in combat conditions.

System Diagram



- Microphone records audio data from the High Power Microwave (HPM).
- Arduino waits for the high-powered microwave trigger via the BNC connection.
- Damage is assessed based on the received data.

Acknowledgments

This work would not have been possible without the following individuals:
Dr. Joe Adams, Dr. Daniel Connors, Mr. Logan Bradbury, Mr. Corey Vyhlidal, Mr. Alan Overby

Damage Classification

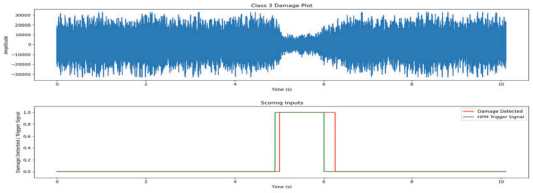
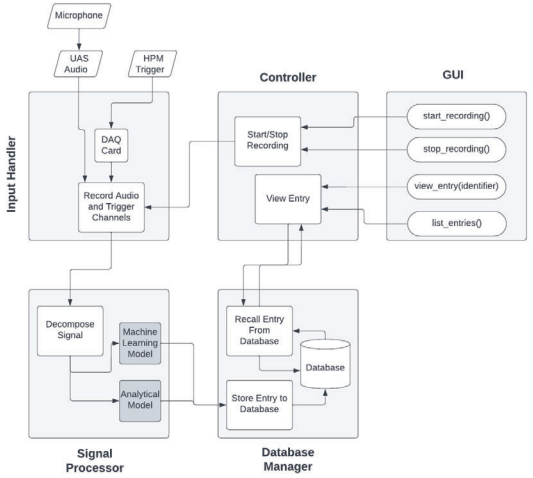


Fig. 1
Amplitude vs. Time graph of data provided by NSWCDD. This data illustrates a **class 3** level of damage.

Fig. 2
Trigger Signal (green) overlayed with the **duration of damage detected** (red) on the data provided in figure 1. Duration of damage was determined via our signal processing algorithm.

- **Class 0**: No damage detected AND trigger is in 'off' state
- **Class 1**: Trigger is in 'on' state AND no damage is detected
- **Class 2**: Damage is detected while the trigger is 'on' but ceases once the trigger returns to the 'off' state
- **Class 3**: Damage is detected while the trigger is 'on' and persists for 5 seconds or less beyond the point when trigger transitions to 'off'
- **Class 4**: Damage is detected while the trigger is 'on' and persists for longer than 5 seconds beyond the point when trigger transitions to 'off'
- **Class 5**: Damage is detected while the trigger is 'on' and persists for longer than when the test is completed

Software Stack



Machine learning Model

- The model is an image classification model that classifies audio through images of their spectrograms.
- The model utilizes a supervised TensorFlow framework for training and testing evaluation.
- The model is trained using open-source drone data and NWSCDD-provided drone data.
- The results indicate approximately 10-20% accuracy due to current data and model limitations.

Signal Processing:

- Damage detection algorithm monitors changes in wave amplitude from audio data.
- Flags the binary damage array as high when amplitude deviates from expected values.
- Binary damage array is sent to a damage scoring function.
- Damage scoring function compares it with the HPM trigger array for scoring.

Conclusion

- Detects damage based on amplitude of UAS audio
- Classifies damage based on high-powered microwave trigger and duration of damage

Future Work

Improve detection capabilities through better hardware and software.

- Can improve detection range, detect moving UASs, and detect
- Better hardware such as microphone and data acquisition devices can improve sound quality/range
- Improved ML model/signal processor can improve detection accuracy up to higher ranges.

Verification of Microelectronics Protection Technology

LEFT TO RIGHT: Nicholas Longest, Sean Cordrey, Christopher DiGiorgio, Hunter Frederick, Ben Updike

CHALLENGE

The client has developed a protection technology for microelectronics. This project aims to design and implement a test to determine whether modifications made to a microelectronic device can be detected, based on its performance before and after alteration.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

SME: Jason Thweatt

Customers: Wayne Churaman, Kathleen Coleman and Ya Li

Sean Cordrey Mechanicsville, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I'd like to continue developing and working on testing/verification techniques and approaches, especially those involving FPGAs.

Course Comment: I appreciate the opportunity this course presented to collaborate with real-world engineers with a diverse background of skills and education, working together to produce a unique solution to a problem.

Christopher DiGiorgio Red Bank, New Jersey

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My career goals are to experience many different fields within Electrical Engineering and find which suits me best.

Course Comment: I believe this course is vital experience for any engineer, it gives an idea for what real life engineering projects are and is especially important for students who do not experience an internship.

Hunter Frederick Blacksburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to develop software for network security applications. I also desire to further my education with a Master's after working in industry for a few years.

Course Comment: I enjoyed the opportunity to work with the Naval Surface Warfare Center Dahlgren Division and DEVCOM Army Research Laboratory. I got to meet very intelligent engineers and researchers through customer meetings.

Nicholas Longest Aldie, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I want to be able to explore the field of ECE outside of college, where I think I will be able to better establish which field I would like to end up in.

Course Comment: This course is the only course where we are able to work with established engineers in order to deliver a product, which I think is a very useful opportunity.

Ben Updike Falls Church, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: After graduation I am pursuing a masters degree in Electrical Engineering, with the goal of working as an analog circuit designer.

Course Comment: This course has given me experience working with a team on an engineering project.

Verification of Microelectronics Protection Technology

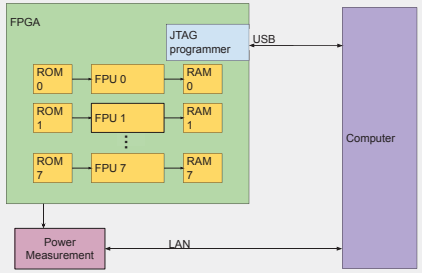
Ben Updike, Christopher DiGiorgio, Nicholas Longest, Hunter Frederick, Sean Cordrey
Customer: Dr. Ya Li, ONR
Advisors from DoD: Dr. Wayne Churaman, Dr. Kathleen Coleman, ARL
Subject Matter Expert: Prof. Jason Thweatt

Objective

To detect any change in performance of an FPGA after implementation of protection technology

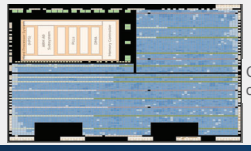
We sought to create an automated benchmark of FPGA performance with the goal of detecting any changes in performance caused by the protection technology.

Top Level Diagram



Approach

- An automated test to measure the performance of the Field Programmable Gate Array(FPGA).
- The test is designed to be run on the FPGAs before and after modification to test if there is a measurable difference in the performance.
- Data recorded:
  - Sequential circuit outputs
  - FPGA board power consumption.
- Both metrics are recorded for various FPGA clock speeds.
- The maximum clock speed can by found by checking the highest frequency at which the FPGAs outputs are correct.
- If the modification to the FPGA reduces its performance then the maximum clock frequency of the circuit will be reduced and the circuit outputs will fail at a lower frequency than the unmodified baseline.
- If the modification causes the FPGA to consume more power, this will be shown in the power consumption measurement.

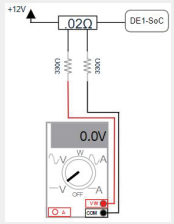


Chip planner view of application.

Design Elements

Power Measurement

- Externally collect power measurement using a shunt resistor spliced into positive power cord
- Transmit reading from multimeter to computer via Standard Commands for Programmable Instruments with Python
- Collects measurements for each clock frequency to allow comparison to pre/post modified boards.

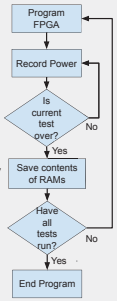


FPGA Application

- The hardware design is shown left in the top level diagram.
  - The board is filled with floating point arithmetic units and memory.
- The design uses a large amount of board resources to maximize load on the FPGA and increase chances of finding a fault or performance difference.
  - 71% of Adaptive Logic Modules.
  - 71% of total memory
  - 92% of Digital Signal Processing Blocks

TCL/Python script

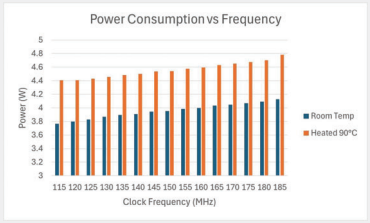
- Programs the FPGA with different clock frequencies using PLLs (Phase-Locked Loop) to change between desired frequencies
- Records power measurement data over a two minute period for each different clock frequency in a CSV
- Writes contents from the RAMs on the FPGA into .mif files (ASCII Text Files)
- Stores data from each run of the script in separate folders labeled by the data and time the test was run in order to keep data from previous tests



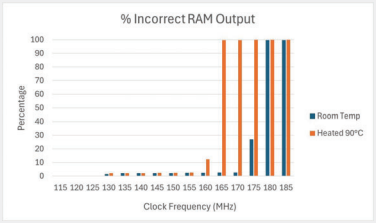
Simulated Change

- Unexpected delays prevented the return of the modified boards before expo.
- Under the hypothesis that the temperature of the FPGA during operation would increase post-modification we decided to raise the temperature of the FPGA manually
- A FPGA was placed in a heated chamber and held at 90° C for the duration of the test.
- While this experiment is a not an exact reproduction for a modified board it allows us to see if the benchmark can detect changes in the operating condition of the FPGA.

Results



Power Consumption for temperature controlled board



Error rate for temperature controlled board

Conclusions

- We successfully ran the benchmark on 5 unmodified boards and sent them to the customer for modification.
- As the post modification tests have not been run, we simulated a condition that we hypothesized would affect FPGA performance to see if our test could measure the impact.
- Our simulated modification results demonstrate that our test is capable of measuring changes in FPGA performance. By placing a FPGA in a chamber heated to 90° C we measured an average of 13.3% increase in power consumption and causes the boards to completely fail at 165 MHz, 10 MHz lower than the same board when run at room temperature(21° C).

Future Work

LogicLock

Logic lock is a feature in Quartus that would allow us to specify what regions on the chip each part of the application is instantiated on. This would allow faults in circuit outputs to be traced to specific parts of the chip. Logic lock is only accessible in the premium version Quartus

Xilinx Board

Switching to a Xilinx FPGA such as a Artix-7 would allow us to use on die voltage supply and temperature sensors that are not available on Altera FPGAs. This would allow us to record more test data to increase the chance of detecting a difference post modification.

Acknowledgements

Our team would like to extend our thanks to:

- The Naval Surface Warfare Center Dahlgren Division for sponsoring our project.
- The DEVCOM Army Research Laboratory team members for their time, technical expertise, and consultation including but not limited to
  - Dr. Wayne Churaman
  - Dr. Kathleen Coleman
  - Katherine Mumm
  - Brett Cranston
- Our Subject Matter Expert, Prof. Jason Thweatt, for their guidance and patience on all aspects of our project throughout
- And Dr. Scot Ransbottom, for mentoring us on this project, providing insight on technical communications.

Mobile Digital High Frequency Ionosonde

Track 5 Winner

LEFT TO RIGHT: Smail El oumari, Nicholas Hoang, Ehite Anteneh, Tommy Trinh, John Larus III

SME: Zach Leffke

CHALLENGE

Develop a small form factor ionosonde transmitter that can refract high frequency radio waves off of the ionosphere to gather information on current ionospheric conditions. These conditions are affected by weather changes, time of day, sunspot position, etc. This was achieved using commercial-off-the-shelf components and the utilization of an open source software repository to process and create visualizations of the data.

NAVSEA
NAVAL SEA SYSTEMS COMMAND

Customers: Christopher Lillard and Matthew Erik Mills

Ehite Anteneh Alexandria, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I will be working in a rotational program post graduation at Caterpillar. After finishing the program I plan to return to school to get a masters degree. I aspire to get into more managerial roles after buidling my expertise through gradaute school and real world experience.

Course Comment: This project has given me great exposure to the relationship between hardware and software in a radio frequency context. I have also developed skills such as interpreting code of other engineers and working alongside other engineers to complete a long-term goal with specifications, budgets, a customer, etc.

Smail El oumari Alexandria, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to use my expertise in FPGA and digital circuit design to revolutionize electronics and computing. My goal is to harness FPGA technology to enhance high-speed computing, signal processing, and embedded systems, thereby advancing digital solutions.

Course Comment: I have learned a lot about project management and how RF systems operate for signal detection and coordinate registration. Although RF is outside my scope of study, I have learned a lot about signal gain, attenuation, as well as power transmission and link budgeting and this has helped me expand my skills as an engineer.

Tommy Trinh Springfield, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I aspire in working with electrical circuits and utilities in either the public or private sector. Additionally, I would like to work in maintaining and improving large scale machinery in order to reduce downtimes, improve production quality, and reduce costs.

Course Comment: I have learned a lot about project management and RF from working on this project. Although RF is outside my scope of study, I believe a good engineer should be able to adapt and learn more about concepts outside of their skillsets. I have learned a lot about how important project management is especially involving money and why certain protolcols are in place such that well-informed decisions are made to reduce delays and risks.

Nicholas Hoang Stafford, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering
Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I hope to learn more about radar and aerospace at a graduate level post-Navy. I aspire to learn as many skills and explore as many fields as possible, to have the ability to work on any project and bring innovation that is only possible with a interdisciplinary perspective.

Course Comment: This project has provided high level of hands on exposure to RF systems and how they are used for communications and detection. This experience has grown my interest in RF significantly, prompting me to take a class in satellite communications and pursue working on RF and space systems as a career.

John Larus III Richmond, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I hope to contribute to bringing nuclear energy to the forefront and improving the utilization of renewable energy sources. Additionally, I hope to spend time working in system protection and fault analysis in order to reduce downtime and improve grid reliability and resiliency.

Course Comment: I have gained much experience as a result of working outside my primary field of study. I have grown passionate about RF through this project and I have gained invaluable experience in handling customer relations and professionalism at multiple levels.

Track 5 Winner

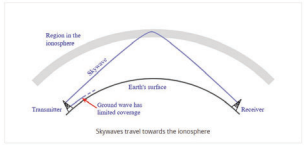
MOBILE DIGITAL HIGH-FREQUENCY IONOSONDE

CUSTOMER: Matthew Erik Mills & Chris Lillard, NSWCDD
SUBJECT MATTER EXPERT: Zach Leffke & Carson Horne, VT NSI
TEAM MEMBERS: Ehite Anteneh, Smail El oumari, Nicholas Hoang, Tommy Trinh, John Larus III
MENTOR: Dr. Scot Ransbottom

NAVSEA WARFARE CENTERS DAHLGREN
NATIONAL SECURITY INSTITUTE VIRGINIA TECH
VIRGINIA TECH

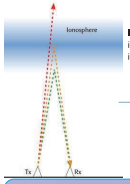
BACKGROUND

- Solar radiation ionizes certain molecules in Earth's atmosphere from 50-1000km, forming a layer known as the ionosphere
- This layer **refracts** high frequency (HF) signals directed at it back towards Earth. This presents an opportunity for communication and radar detection beyond line-of-sight, a concept known as Over-The-Horizon Radar (OTHR).
- OTHR systems have had limited reliability due to the ionosphere's dynamic nature, varying based on time of day, season, solar cycle, etc. However, if these systems can receive feedback on ionospheric conditions, they can adapt their operating characteristics to improve transmission and reception.

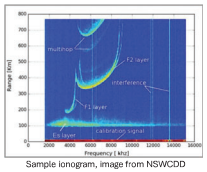


OTHR function

- An ionosonde (a pulsed HF radar), is used to probe the ionosphere and generate such feedback. From returned pulses transmitted at a certain frequency, the signal strength and time of flight can be determined.
- Sweeping frequencies generates an ionogram, which shows refraction altitude and signal strength at each frequency across a range of interest. Typically, the maximum usable frequency of the ionosphere lies between 1-12 MHz dependent on its current state.



Ionosonde interaction with ionosphere



Sample ionogram, image from NSWCDD

OBJECTIVE

- Historically, vertical incidence (signal angled directly upwards) ionosondes are large, bulky, and high-power.
- The Naval Surface Warfare Center Dahlgren Division's goal is to **mobilize and modernize** these systems for flexible, precise ionospheric data collection to enhance OTHR system models while using less transmit power, and a software-defined radio.

KEY REQUIREMENTS

- **Frequency Range**: 2-8MHz
- **Operating Altitude**: 60-500km
- **Voltage Standing Wave Ratio**: 1.5
- **Transmit Power**: <10W
- **Instantaneous Bandwidth**: 50kHz
- **Sweep Time**: <10 minutes
- **Utilize Software Defined Radio**

Wallops Island VIPIR hardware


Bulky analog hardware compared to small, digital hardware. **The farthest right image is the receiver that was pre-existing at the Hume Center**

DESIGN OVERVIEW

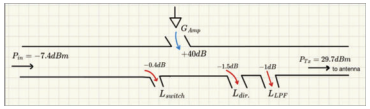
The basis of this design stems from an open-source software repository developed by Dr. Juha Vierinen of the University of Tromsø, Norway. This software performs all necessary operation and calculations for the system and produces ionograms, range-doppler plots, and range-power plots. Deep analysis of this software was necessary to understand how it functions and how to properly configure it for our use case. From here, research into HF propagation was necessary to develop an estimated **link budget** for our use case. This design utilizes **Software Defined Radio (SDR)** to perform signal generation and sampling. An SDR combines traditionally independent, complex to configure, analog components to a digital implementation that can be easily configured in software for general purpose design flexibility. For this project, the Ettus Research USRP N210 served as the transmit and receive SDR. GPS Disciplined Oscillators are used on transmit and receive to synchronize measurements to a rising edge pulse-per-second signal.

LINK ANALYSIS

The **link analysis** is the determination of all sources of loss in the path of the signal from leaving the transmit SDR to reaching the receiver after propagating through cables, antenna, and free space. Losses are accrued at every step, but these losses can be estimated and summed. The chart below shows the maximum, typical, and minimum estimated losses through the atmosphere.

Minimum (dB)	Typical (dB)	Maximum (dB)
68.03	127.79	157.55

Hardware components each have additional loss factors called **insertion loss**. The Sankey diagrams below visualize estimates of these losses as in and outflows, with the inflows being positive gains from signal amplification. Atmospheric losses are named.



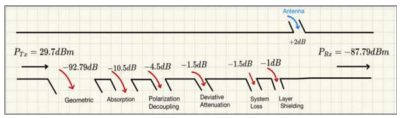
Gains and losses of the transmitter hardware. The necessary power to the antenna is approximately 1W.

$$P_{Tx} = P_{in} + \sum Amplifier\ Gain - \sum Component\ Losses$$

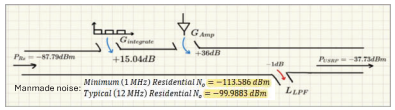
$$P_{Rx} = P_{Tx} - \sum Total\ Atmospheric\ Losses$$

Power returning to USRP:

$$P_{USRP} = P_{Rx} + \sum Integrated\ Gain + \sum Amplifier\ Gain - \sum Component\ Loss$$



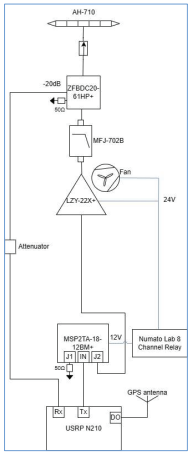
Various atmospheric losses with the addition of antenna gain.



Gain due to sending pulses of the same signal. Received power is approximately 0.0002mW. Under highest typical noise conditions, the system has a positive SNR of 12.1983 dB.

TRANSMITTER

Shown below is a hardware schematic of the transmitter. Powered hardware components are controlled via an Ethernet relay to remove voltage when not in operation or during sudden hazardous operating conditions.



Hardware schematic of transmit chain.

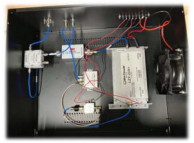
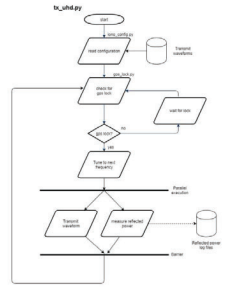
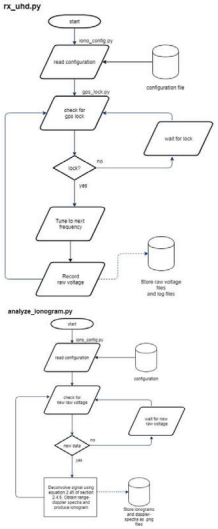


Fig. 1 Transmit hardware enclosure setup. The most current revision does not include the pre-amplifier at the bottom of the image.

SOFTWARE





Figures credited to Markus Floer

ANALYSIS AND RESULTS

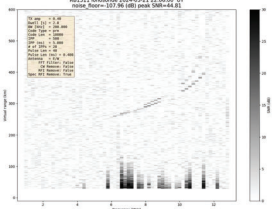


Fig. 2 Experimental ionogram from 0-12MHz, March 21, 2024, 5:06pm. **Darker color indicates higher received signal correlation with the transmitted signal.**

The results of our system testing indicate strong ionospheric signal returns from 5.5-12.5MHz. The lower frequency range of our system showed minimal returns. This is possibly due to the **inefficiency** of our transmit antenna at lower frequency, or a large presence of interference at this range. Furthermore, the colocation of the transmitter and receiver has a very strong correlation at altitudes lower than the ionosphere due to a **direct path** between the pair. This data can be omitted for graphical representation to remove SNR skew, but the signal is still physically present. The system cannot currently produce an ionogram accurately with a waveform bandwidth below 100kHz.

KEY RESULTS

- **Frequency Range**: 5.5-12.5MHz
- **Operating Altitude**: 225-500km
- **Voltage Standing Wave Ratio**: <1.5
- **Transmit Power**: 2.1W
- **Instantaneous Bandwidth**: 200kHz
- **Sweep Time**: 2 minutes
- **Utilized Software Defined Radio**

CONCLUSION

The project demonstrates the capability of a mobile small form factor, low power digital ionosonde to transmit sufficient power vertically to probe the ionosphere and maintain both successful reception and correlation at a receiving ground station.

FUTURE WORK

There are several areas of improvement or extension for this project:

- Development of new, standalone receiver to join transmitter, emphasis on low noise reception, receiver hardware blanking to remove direct path, an efficient antenna, and a small form factor
- Design of new transmit antenna or development of antenna tuner to improve low frequency range efficiency
- Cascade array of receivers along a path of interest
- Separate transmit antenna and receive antenna for quasi-vertical or oblique sounding
- Investigate various software configurations for improved performance using other waveform types

ACKNOWLEDGEMENTS

The team would like to thank the project sponsors Matthew Erik Mills and Chris Lillard from the NSWCDD for their support. Additionally, we would like to thank Hume Center Research Associates Zach Leffke and Carson Horne for providing the team with guidance on every milestone of our project; including technical expertise, assembly, and test setup in the lab workbench. We are also grateful to our mentor Dr. Scot Ransbottom for his assistance in providing us with industrial standards and expectations. Lastly, we would like to thank our families for their tireless support.

Manual Control Brushless DC Motor Two-Axis Control Box

LEFT TO RIGHT: Luis Morillo Jr, Del Christy, Benjamin Gallini, Benjamin Barber, Austin Burke

SME: Khai Ngo

CHALLENGE

When performing NDE (Non-Destructive Evaluation) inspections at nuclear power plants our customer typically has a NDE tool with 2 BLDC (brushless DC motors with hall sensors) connected by cables to a control box that is then connected to a remote computer. During the equipment set up phase of an outage it is typical for a tooling technician to have the NDE tool set up, ready to be function checked, prior to having LAN communication established to the remote computer, and prior to having a computer operator available to help with the tool functional checks. Our manual control box will be used to test the NDE device's motors before a remote computer is set up.

framatome

Customers: Bob Furter and Heshan Gunawardane

Ben Barber Lynchburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to work in a high demand environment where I can apply my programming and electrical engineering skills while always being pushed to learn from novel aspects of the projects.

Course Comment: This course gave me experience with motor controllers, PCB design, and consolidating electrical systems into a working product based on customer requirements.

Austin Burke Aliso Viejo, California

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: A career that challenges me, that I enjoy, that allows for me to provide for a family someday

Course Comment: This course provided me with experience leading a design team on a project from the ground up.

Del Christy Paintsville, Kentucky

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: To visit that glowing dot on the horizon

Course Comment: This course provided me experience with experience working on a large-scale multi-month long project

Ben Gallini Richmond, Virginia

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: I want to have a career that keeps me interested and challenged.

Course Comment: This course gave me experience designing and delivering a project for a customer and working with motors, motor controllers, and control systems.

Luis Morillo Jr Williamsburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My carrer goal is ultmatly assist in the net zero emission effort by working with renewables or in the power industry.

Course Comment: This course gave me a peek into what goes into a major engineering project.

Manual Control Brushless DC Motor Two-Axis Control Box

Team members: Ben Barber, Benjamin Gallini, Luis Morillo Jr, Del Christy, Austin Burke
Customers: Bob Furter, Ken Ritchey, Nghiep Du
Subject Matter Expert: Khai Ngo **Mentor:** Kelley Andrews

VIRGINIA TECH framatome

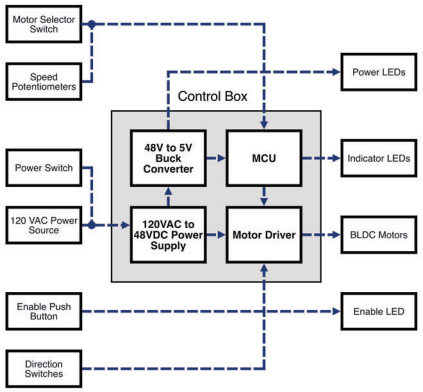
Objective

- Create small and user friendly manually operated 48V BLDC motor control box.
- Variable speed and direction controls for two interlocked motors.
- Must interface with existing non destructive examination (NDE) tool

Faulhaber Motor 4490
- Rated speed of 10930 rpm
- Avg. power of 232 W

Faulhaber Motor 3564
- Rated speed of 10800 rpm
- Avg. power of 126 W

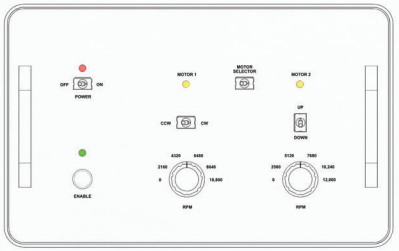
System Architecture

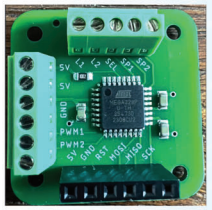


Design Approach

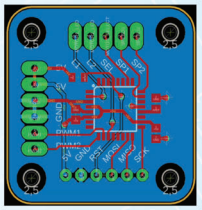
User Interface

- Power switch with power LED indicator
- Enable Push Button to run motors when held with an indicator light
- Speed potentiometers for variable speed
- Direction switches for variable direction
- Motor selector switch with indicator LEDs for switching which motor is running and being controlled





Final PCB



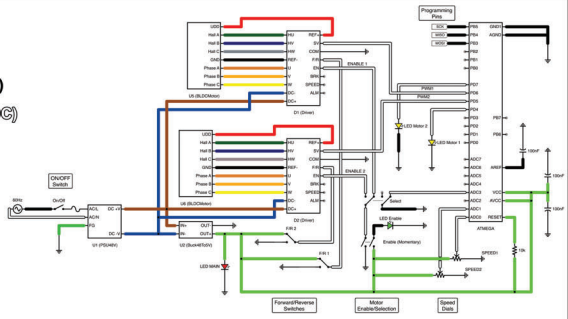
Board View

Printed Circuit Board

- Uses ADC to read potentiometer voltages
- Turns ADC readings into duty cycles for PWM speed control
- Interlocks motors and powers the LED indicators based on motor select input
- Ground plane lowers inductance and EMI
- Capacitors close to processor power pins to lower inductance

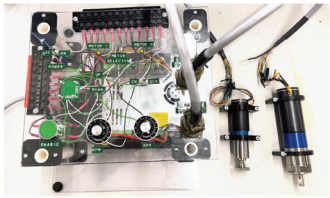
Wiring Diagram

Live (120VAC) / Ground (5VDC)
Neutral (120VAC) / Signal (5VDC)
Ground
DC 48 Volt **DC -48 Volt**
UDD (Pos Ref 5V)
DC 5 Volt
Phase A **Phase B** **Phase C**
Hall A **Hall B** **Hall C**



Conclusions

- Provides manual control and operation
- All functionality achieved within natively allowing for use without need to connect to external software
- Can interface with existing adapter used by customer, no additional wiring needed



Future Work

- As a safety feature, add a delay between switching motor directions to stop jolts
- The prototype will be put into a durable box with a NEMA rating for use in the field

Acknowledgments

- Prof. Kelley Andrews for being our mentor and guiding us throughout the entire project, as well as reviewing our work
- Dr. Khai Ngo for his technical advice on the operation of BLDC motors and understanding about the principles of Hall Effect sensors
- Framatome for sponsoring our project and providing the necessary components

Cyberchase Tabletop Board Game

Track 6 Winner

LEFT TO RIGHT: Jiawen Bao, Matthew Vandeveire, Alex Saura, Matt Zarnowsky, Kojo Poku

SME: Joe Adams

CHALLENGE

To create a tabletop board game that simulated a cybersecurity exercise to educate novice users and entertain professionals in the field. This included the educational cybersecurity concepts of network analysis, host configuration, and exploit testing, all intertwined with entertaining game aspects to spread awareness of cybersecurity concepts and procedures.

kryptowire labs

Customers: Angelos Stavrou and James Sugrim

Jiawen Bao Xi'an, China

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to become a Computer Engineer involved in the Internet Industry.

Course Comment: This program was very meaningful to me and I was able to practice a lot of knowledge about cybersecurity.

Kojo Poku Haymarket, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to become a Software Engineer

Course Comment: This project gave me real insight on working within the Cybersecurity field in industry. I am very thankful for the experience.

Alex Saura Raleigh, North Carolina

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to become a Computer Engineer involved in the Robotics Industry.

Course Comment: This project was very entertaining and rewarding, since it allowed to learn about a cyber security, which is a field I would not have learned about,if not for this project. This project had its difficulties but was very rewarding once the hardship were overcome. It also gave us the opportunity and experience of working with a customer, which is something I am very grateful for.

Matthew Vandeveire Springfield, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to become a Computer Engineer involved with AI generation

Course Comment: This project has pushed me to be more well rounded in computer networking security which is not a field I wouldve neccesarily developed on my own. Additionally I got more experience with AI image generation and furthered my understanding and comfortability with it for game design and implementation.

Matt Zarnowsky Philadelphia, Pennsylvania

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to become a Cyber Security Engineer working on Vulnerability Research and Penetration Testing, to partner with being an Engineer Officer in the U.S Army.

Course Comment: I really enjoyed working with Kryptowire Labs and getting the chance to be a part of an entertaining yet rewarding Cyber Security Project.

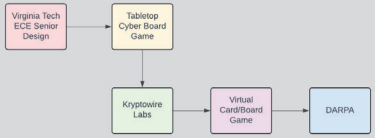
Track 6 Winner

Cyber Chase: Tabletop Board Game

Matthew Zarnowsky, Matthew Vandeveire, Alex Saura, Kojo Poku, Jiawen Bao
Sponsor: Mr. James Sugrim, Kryptowire Labs
Subject Matter Expert: Dr. Joe Adams, Virginia Tech

Background

Kryptowire Labs is a cybersecurity company focused on providing secure wireless communications over 5G.They are developing a full-stack 5G network emulation framework and a cybersecurity video game for DARPA.

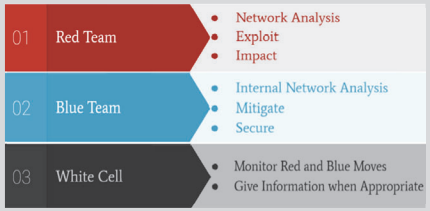


Our development of this tabletop game will assist Kryptowire Labs in developing a video game version by providing tests and suggestions on possible game mechanics, cybersecurity procedures, and improvements for the game.

Objectives

Create an educational and entertaining board game to bring in consumers of all skill levels, from novices to professionals in the field of cybersecurity.

- Perform network analysis on a network to understand how to determine a network layout and learn the "lay of the land."
- Perform a software inventory on a provided virtual machine and use Nessus to determine possible exploits and known vulnerabilities within the device.
- Perform exploit testing on the CASTLE Emulated Network provided by Kryptowire to test known exploits to gain the probability of their success and time delay for initialization.
- Incorporate all of the previous objectives into an entertaining game design incorporating game aspects including; card play, dice rolling, board construction, and player vs. player capabilities.



Educational Game Aspects

Component	Points	Color
Switch	100	
IDS	200	
Workstation/Client	300	
Database	400	
Server	500	
Router	600	
Firewall	700	
DNS Server	800	

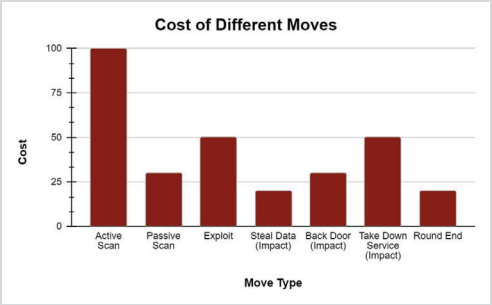
Our game incorporates a red vs. blue cyber dynamic involving a white cell to provide the feeling of a hands-on cyber exercise.

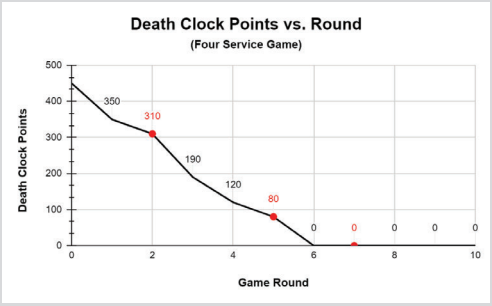
- Network Analysis for Red's identification of network components and Blue's analysis of malicious intent within the network.
- Host configuration for Blue to identify known vulnerabilities in their network and design the layout according to their best interest using realistic and crucial network components.
- Exploit and mitigation testing to provide realistic success probabilities for Red's exploitation of known network services.

Game Design

The educational concepts were tied together using entertaining game aspects including cardplay, dice rolls, board design, and strategy.

- **Cardplay:** Red and blue team card decks resulting from network analysis tools, exploits, mitigation strategies, and ways of impacting a service.
- **Dice rolls:** Success values to initiate exploits, mitigations, and network analysis tools are directly related to their success in real-life implementation within the testing environment.
- **Board Design:** The blue team builds their network layout using game pieces representing crucial network components (i.e. firewall, workstation/client, router).
- **Strategy:** Death clock implementation to represent red's time to live within the network, and how the more noise made in the network, the greater the chance they are identified.





Conclusion

- Provides a physical representation of a cybersecurity board game for Kryptowire to study for their digital version.
- Provides an engaging simulation of real-world applications for exploit and mitigation strategies.
- Incorporates network analysis, host configuration, exploit testing, and game design mechanics in an entertaining and educating manner.

Moving Forward

Future work includes:

- Run tests through full rounds of the game with different groups of people to gauge the game's level of engagement.
- Work side by side with Kryptowire Labs to enhance the software version of the game, based on the strengths of the tabletop version.
- Develop a new version of the tabletop game with the knowledge gained from the test runs.
- Digital version of the board game including; electronic boards for network design, shared scoring metrics, and death clock information.

Acknowledgement

Our team extends our gratitude and appreciation to our sponsor and subject matter expert. Thank you, Kryptowire Labs, for overseeing this project and allowing us to work on such a fun and rewarding challenge. Thank you, James Sugrim and Dr. Joe Adams, for the advice, guidance, and support we received during the development of our project.

Cimel Data Relay and Storage Unit

LEFT TO RIGHT: David Zhang, SeongSoo Jeong, Will Bonner, Pranav Sukumaran, Alan Wang

SME: Shelley Stover

Customer: Elena Lind

CHALLENGE

To design and build a low-power device to collect data from photometers in remote locations around the world and upload data to a server hosted by NASA using WiFi or cellular reliably. The data collected creates a public domain database for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases.

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

Will Bonner Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My goal is to work as an embdedded software engineer developing low level code for a multitude of devices. In the future I would like to see firmware that I developed used in everyday systems.

Course Comment: This course has provided experience in planning an upgrade to an existing large scale firmware architecture. These skills will be applicable to my desired job field.

Seong Soo Jeong Goyang, South Korea

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: My goal is to work as a machine learning engineer specialized in computer vision / image processing.

Course Comment: The learning experience from the course has taught me how real-world projects make progress through an year - from recognizing the requirements to building a fully-functional device through various testings.

Pranav Sukumaran Sterling, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I want to work on FPGA engineering or digital circuit design.

Course Comment: Over the course of the project I've learnt how an often vague set of requirements gets translated to a functional product through thorough planning, diagramming, and finally implementation and testing.

Zepeng Wang Shenzhen City, China

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My goal is to work in software design.

Course Comment: This class taught me how to combine programming and circuits to complete a large project.

David Zhang San Jose, California

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to work on robots specifically developing control algorithms. I would like to see automation become more prevalent in real life down the line.

Course Comment: This course has provided me with experience in planning and executing a large-scale project, which lines up very well with working with robots.

Cimel Data Relay and Storage Unit

Team Members: Will Bonner, Seong Soo Jeong, Pranav Sukumaran, Zepeng Wang, David Zhang

Customer: Dr. Elena Lind, NASA **SME:** Dr. Shelley Stover **Mentor:** Dr. Shelley Stover

Motivation

To design a system to remotely collect and upload data to contribute to a public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases.

Fig 1. Map of AERONET photometers

Objectives

1. Develop a low power device to collect and store sun photometer data
2. Transfer sun photometer data to NASA AERONET servers using a cellular modem
3. Design the device to be robust from power failure, connection losses, or any other failures

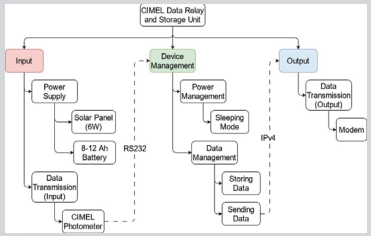


Fig 2. Summary of system functions

Theory of Operations

The device is powered on, this involves making sure every interface is connected together between subsystems. As soon as power is connected, the device will turn on and automatically launch the C-Script. The user can be connected to the device via SSH to monitor the status during startup. The C-Script will open the COM port and look for a CIMEL device, logging a message on failure and trying again in a minute. This is so the user could plug in the CIMEL device in case they did not earlier. The C-Script will now enter it's main loop of collecting data, trying to upload to the AERONET server, and waiting for the next data collection.

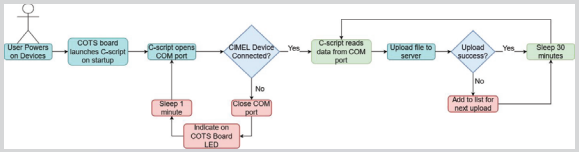


Fig 3. Concept of Operations for the Data Relay and Storage Unit

Architecture

The architecture of our design includes 3 main subsystems.

- Computation subsystem communicates with photometer and server
- Power subsystem charges system batteries with solar power and provides backup power
- Housing subsystem protects other subsystems

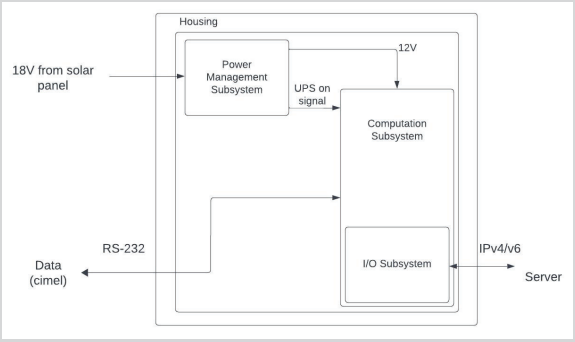


Fig 4. Data Relay and Storage Unit High Level Architecture

Experimental Setup

- We tested the power subsystem to determine the voltage that triggers the power failure mode.
- The following equipment and conditions are used:
  - Tektronix DMM4050 6-12 Digital Precision Multimeter
  - Tektronix PWS4323 Power Supply (0-13VDC, 1A)
- The power supply voltage is decremented until the UPS switches to alternate power source (battery)

Fig 5. Testing Setup

Challenges

While implementing our solution, we realized that our modem was dead and that we required a new one. The modem we select will have a large impact on power consumption. We are currently using a modem lent to us for testing purposes.

Analysis and Conclusion

Analysis

- The device successfully collects and transmits simulated data with low power usage, ensuring operational reliability in remote areas.
- The power subsystem performs source transition under certain conditions, which helps to maintain continuous data collection in case of power failure.
- The computation subsystem will perform simulated data transmission to the server due to modem failure.

Conclusion

The Cimel Data Relay and Storage Unit significantly advances aerosol research by providing a robust, efficient tool for environmental monitoring. Its innovative design ensures reliable data collection and transmission, contributing valuable insights into aerosol properties and their environmental impact.

Future Plans

Future opportunities to improve the functionality of the device include:

- Utilizing a modem that supports low power mode to increase power efficiency when the system is not in operation.
- Implementing a finite state machine for the Computation subsystem to handle various types of connection errors with the modem by sending AT commands and checking the responses.

Acknowledgements

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

- Dr. Elena Lind (Customer Contact)
- Ilya Slutsker (Customer Contact)
- Kim Medley (Parts Ordering)
- Dimitri Dessources (Test Equipment)

Low-Cost Portable Antenna Range

LEFT TO RIGHT: Anna Sullivan, Tyler Rodgers, Jivitesh Kukreja

CHALLENGE

To enhance a low-cost portable antenna range based on a design developed by VT ECE graduate Christian Hearn and his fellow faculty at Weber State University by investigating signal processing to remove reflected signals and multipath that distort antenna pattern measurements through FPGA time-gating approach.

G3 Technologies, Inc.
PROVIDING NEXT GENERATION WIRELESS SOLUTIONS

SME: Carl Dietrich

Customer: Juliet Anderson

Jivitesh Kukreja New Delhi, India

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I plan to pursue a master's or a Ph.D. in electromagnetics to add my contribution to this field that hopefully others could benefit from. Afterward I plan to become part of this industry.

Course Comment: I liked being partnered with an industry sponsor and I feel this has prepared me for the industry even though it may be a while before I become part of the industry. The soft and technical skills I have learned throughout this course have helped me progress in my journey.

Tyler Rodgers Charlottesville, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: My aspiration is to work as a computer engineer to develop technology that protects people, specifically in the defense and intelligence community.

Course Comment: I found this major design experience to be very captivating, providing me with a platform to refine and cultivate new skills.

Anna Sullivan Vienna, Virginia

Bachelor of Science in Electrical Engineering
Radio Frequency & Microwave

Aspirations: My aspiration is to graduate and work in the RF field as an antenna engineer, and hopefully design solutions to complex real-world problems

Course Comment: This course was very interesting since it provided experience with solving problems without textbook solutions, it also provided the industry-like experience of having to coordinate with many stakeholders.

LOW COST PORTABLE ANTENNA RANGE

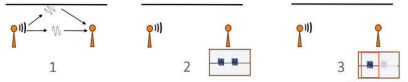
Team - Anna Sullivan, Tyler Rodgers, and Jivitesh Kukreja
SME - Dr Carl Dietrich
Customer - Juliet Anderson/ G3 Technologies

VIRGINIA TECH

G3 Technologies, Inc.
PROVIDING NEXT GENERATION WIRELESS SOLUTIONS

BACKGROUND

Indoor antenna ranges such as anechoic chambers are used for antenna pattern measurements. They are expensive, require a lot of space, and are fixed to one location. Echoic antenna ranges fix these problems with the anechoic chambers; however, it is prone to multipath, which causes pattern distortion. This project conducts a novel investigation into a digital signal processing (DSP) technique called time-gating to remove this distortion.



OBJECTIVES & PHASES

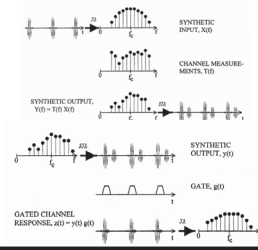
This project aims to enhance a low-cost portable antenna range based on a design developed by VT ECE graduate Christian Hearn and his fellow faculty at Weber State University. The design team will accomplish this by investigating the DSP technique, time-gating, as a method to remove reflected signals and multipath that distort antenna pattern measurements. The team will then optimize the antenna range using an FPGA implementation. Finally, the design team will test the results of our enhancement with simple antennas.
These objectives are avchieved in three phases:

- PHASE 0: Proof validation of signal processing in MATLAB
- PHASE 1: DSP time-gating in Python on legacy system
- PHASE 2: FPGA Implementation of DSP algorithm

THEORY OF OPERATION

Time-gating uses the principle that signals that are reflected off the environment will take longer to arrive than line of sight (LOS) components. We used this idea along with DSP of continuous wave (CW) signals to optimize the measurements and remove reflections. The steps are as follows:

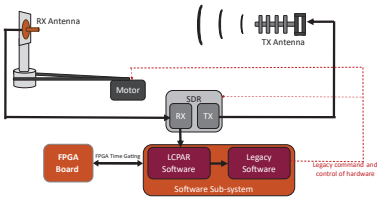
1) Create synthetic pulses
2) Take CW measurements of the antenna under test (AUT)
3) Create a synthetic output by multiplying them together in the frequency domain
4) Convert to the time domain using an IFFT
5) Create an appropriate gate
6) Multiply them together in the time domain to get a gated channel response

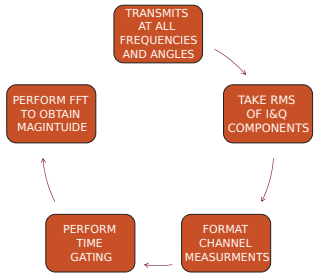


[1]

SYSTEM INTEGRATION

Our DSP software and FPGA time gating are implemented with the legacy software that transmits and receives from the SDR and controls the position of the AUT.



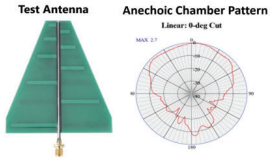


RESULTS

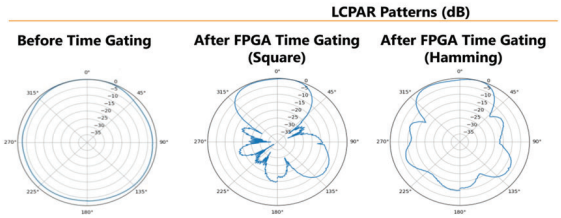
A Log periodic antenna was used for testing. The antenna was tested in an anechoic chamber and in the low-cost portable antenna range with our DSP time-gating implementation.

RMS Error Imporvement:

Time Gate	RMSE in dB	RMSE in linear units
No Gate	11.81	0.4500
Square	9.915	0.1939
Hamming	7.183	0.1856

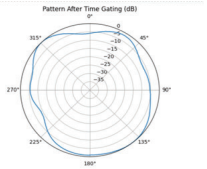


LCPAR Patterns (dB)



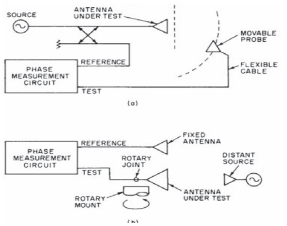
CONCLUSIONS

Overall, we have had promising results in this original technique to improve pattern measurements. With evident improvements being seen at select discrete frequencies when we perform a measurement. However, more work can be done to examine why our measurements might be inconsistent and improve the reliability of this technique. If this issue is solved, experimentation with optimizing the synthetic pulses should lead to better results. Moreover, this project was meant to utilize FPGA time gating instead of time gating on the range computer; however, using FPGA to just time gate does not yield much benefit of using an FPGA. If the whole algorithm, including synthetic pulse generation, IFFF, FFT, etc. is implemented on an FPGA then an FPGA would be beneficial.



FUTURE WORK

1) Use Gain-Transfer Method to get absolute gain of antennas
2) Use more accurate phase measurements by calibrating out losses in system.
3) Speed up measurement process and integrate FPGA directly
4) Experiment with synthetic input tapering and pulse width



[2]

ACKNOWLEDGMENT & SOURCES

The Team would like to thank the following for their support and assistance
•Juliet Anderson (G3 Technologies)
•Prof Stover (Virginia Tech)
•Dr Dietrich (Virginia Tech)
•Dr Hearn (Weber State)
•Dr Manteghi (Virginia Tech)
•PHD student, Shashank Chinnakkagari (Virginia Tech)
•Dr Polys (Virginia Tech)

SOURCES:

[1]Andrew M. Predoehl, "Time Domain Antenna Pattern Measurements," MS Thesis, College of Engineering, Virginia Tech, Blacksburg, VA, 1996.
[2]"IEEE Standard Test Procedures for Antennas," in ANSI/IEEE Std 149-1979 , vol., no., pp.1-144, 30 Nov. 1979, doi: 10.1109/IEEESTD.1979.120310.

Optimization and Hosting of Embedded Systems Chatbot

LEFT TO RIGHT: Sherric Nelson Jr., Jaydahn Belnavis, Elhyanah Desir, Jordahn Belnavis, Chenglong Liao

SME: Wenjie Xiong

CHALLENGE

The customer desires to create a platform in which her students in the Embedded Systems course can access the chatbot and receive timely responses to their inquiries. Our team is tasked with deploying the chatbot application on a stable and reliable hosting (web) server.

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

Customer: Wenjie Xiong

Jaydahn Belnavis Dumfries, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to play a role in technological advancements that impact the world in a positive way.

Course Comment: This course, above all else, has taught me how to lead in different aspects of the project development cycle. I have gained valuable skills not only as a leader but also as an engineer. I got to explore and learn new technologies and work cohesively with a team.

Jordahn Belnavis Dumfries, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to use my knowledge and skills for the betterment of the world and mankind as a whole.

Course Comment: This course taught me the value of communication and upholding a positive team dynamic. It provided me with an opportunity to both lead and be led and gave me a fundamental understanding of the project development cycle.

Elhyanah Desir Elmont, New York

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to use my skills in engineering to improve education and advance technology in third and second world countries.

Course Comment: This course showed me how much communication is an essential part of working on a long-term project. I also obtained new technical and soft skills.

Chenglong Liao JiangXi, China

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I want to use my knowledge to make the cyberspace safer.

Course Comment: This course showed me that communication is necessary not only between the members in the group, but also all other people related to the project. Also, I had a better understanding of the different tools and methods for the server.

Sherric Nelson Jr. Waxhaw, North Carolina

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I want to use my degree to make a difference in the world and continue to improve my skills as an engineer.

Course Comment: This course gave me valuable experience in working with an engineering team on a long-term project. I have a better understanding of the project process and how to manage it.

Optimization and Hosting of Embedded Systems Chatbot

Team Members: Sherric Nelson, Jaydahn Belnavis, Jordahn Belnavis, Elhyanah Desir, Chenglong Liao
Subject Matter Expert / Customer: Dr. Wenjie Xiong
Mentor: Dr. Adams

Motivation

The customer has developed a chatbot which they desire to deploy on a platform that their students can access and receive timely responses from. We were entrusted with optimizing the security and developing the hosting server aspects. This project positively impacts students, professors, and teaching assistants.

Objectives

- Obtain a secure host website
- Provide an adequate security system
- Ensure chatbot application is fully functional on the web server
- Restrict chatbot access to VT students
- Implement feedback feature
- Implement message history system
- Design user interface

Results

- ✓ Successful transition from Streamlit to Flask framework.
- ✓ Successful integration of message history system.
- ✓ Successful integration of feedback feature.
- ✓ Created a fully functional user interface.
- ✓ Hosted the application on a web server.
- ✓ Obtained SSL certificate.

Conclusion

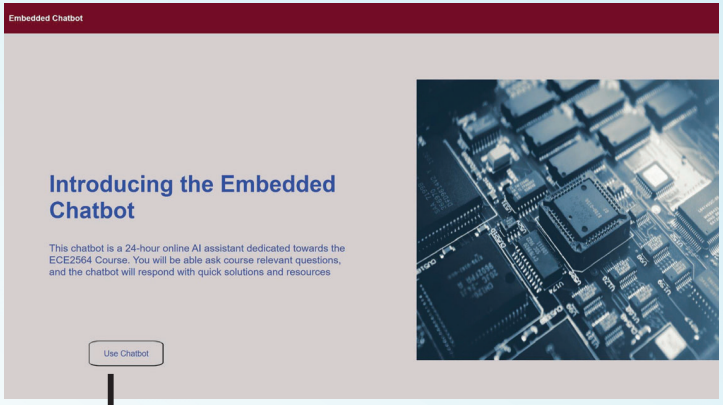
Upon completion of the project, the team has successfully hosted the python application of a web server that is accessible to students.

Once the application is fully secure, students will be able to start asking questions and receiving answers which the chatbot team will use to further optimize the bot.

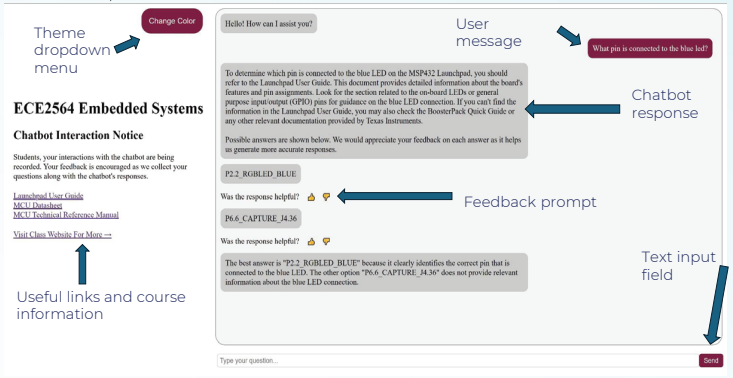
Future Work

- Continue working with IT to
  - Apply VT SSO to docker container
  - Directly apply SSL to Apache terminal
- Update the user interface for a more modernized look after chatbot has been optimized.

User Interface



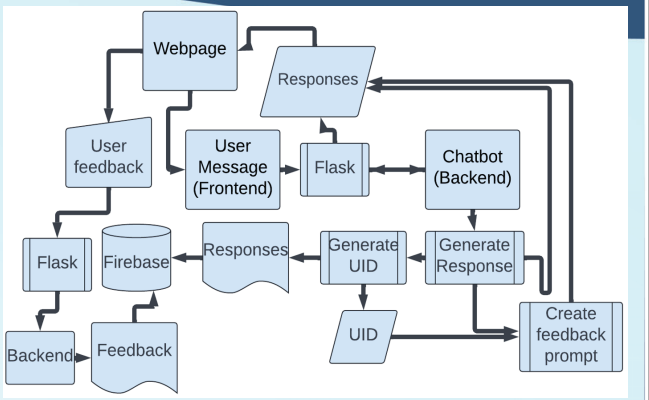
The "Use Chatbot" button within the introduction page is used to direct students to the docker containerized chatbot



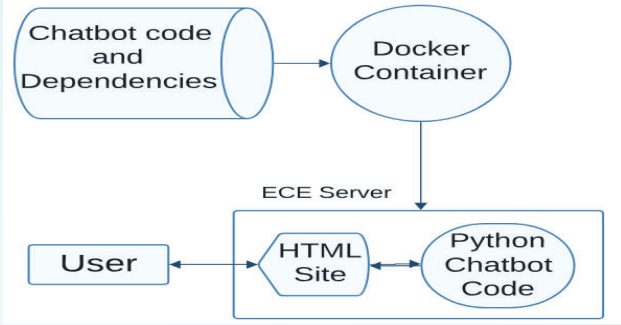
Security Approach

To improve security, we obtained an SSL and applied for SSO integration through Virginia Tech. Additionally, we applied an inbound firewall rule to the Docker container.

Message History System



Hosting Approach

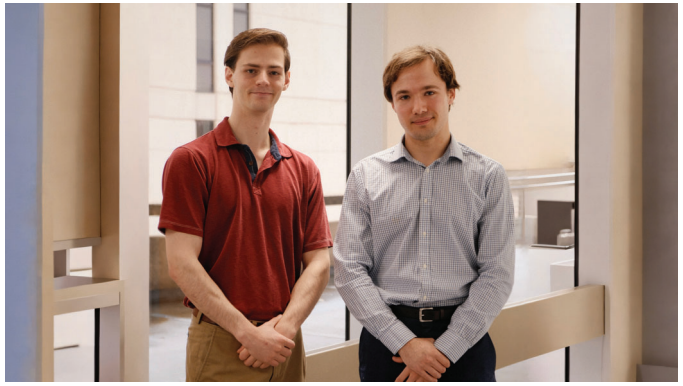


- For a more robust system , we switched web application frameworks from Streamlit to Flask.
- We used Docker to containerize the Flask application then uploaded it onto an Apache Server.
- Using HTML/CSS and JavaScript, we created a dynamic chatbot window and added an introduction page so users can access it.

Acknowledgment

Thank you to Dr. Adams, Dr. Wenjie Xiong, IT team, and Rong and the chatbot team.

Open ERCOT: Open Source Grid Modeling



LEFT TO RIGHT: Hayden Gray, Malcolm Moss

CHALLENGE

To design an open-source model for the Texas grid that is capable of simulating a variety of conditions and use it to analyze various configurations and scenarios. This model can be used to view the impact of renewable energy sources on the grid and give concrete answers on where we should begin adding batteries.

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

SME: Scott Dunning

Customer: Scott Dunning

Hayden Gray Roanoke, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My goal is to build high-performance software that is a joy to use and also fast under the hood.

Course Comment: This course was an engaging conclusion to my degree that allowed me to put many of the skills I had learned in the past four years to use.

Malcolm Moss Arlington, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to combine an engineering mindset with an understanding of markets to solve problems applicable to the energy transition.

Course Comment: This project gave me a way to combine skills learned through my coursework with experiences outside of the classroom to create a powerful model with real world applications.

openERCOT → Open-Source Grid Modeling

Malcolm Moss, Hayden Gray

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

Background

As renewables become more important to our grid, batteries have become an increasingly valuable component that improve the responsiveness of dispatchable generation. As a result, we aim to view the impact that these batteries have on the grid from a variety of perspectives.

Objectives

- Create a model capable of simulating ERCOT for at least a year
- Simulate ERCOT with and without batteries
- Identify key impacts that batteries have on the grid
- Open-Source the model, enabling future contribution with no strings attached

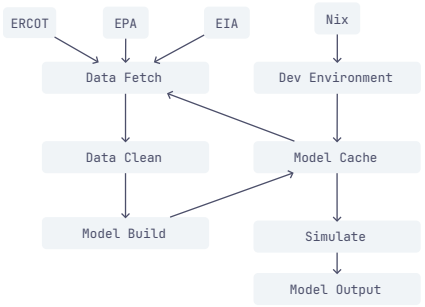
Model Assumptions

- Batteries optimize for maximum profit, making them purely economically driven
- Batteries act as fully independent market participants, decoupled from renewables
- Grid is based on ERCOT weather zones which reduces transmission granularity
- Lossless transmission links which could impact overall generation demand
- Fixed marginal cost depending on generation technology and fuel cost
- Uncommon plants costed around the price of natural gas
- Battery round-trip efficiency based on on EIA data

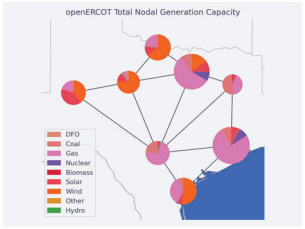
Challenges

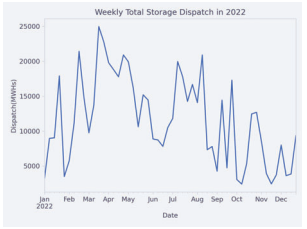
- Difficulty obtaining transmission data
- Long simulation times when using more complex modeling techniques
- Finding the assumptions to make
- Dependency management when using a large number of conflicting Python libraries
- Fine-tuning model parameters to increase model accuracy

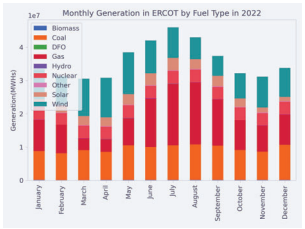
Data Pipeline

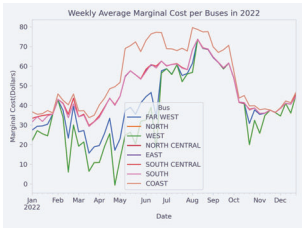


Model Outputs

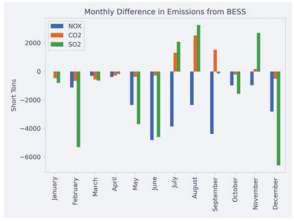


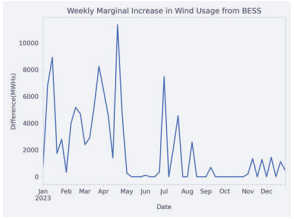






Analysis





Conclusions

From our work we think this model has lots of potential applications and room for growth. Making modeling simpler allows for more experiments and refinement. We believe this model can be grown to give both policy makers and industry veterans important knowledge about our electrical system. In addition to this specific mode, it is clear that for any economic dispatch system, a similar approach can be taken to build a high level model.

Project Links

openERCOT GitHub

Determinate Systems Nix Installer

IEEE Robotic Competition Hardware Team

LEFT TO RIGHT: Top Row: Kyle Hayslett, Gaurav Kharel, Maria Zakhem, Muhammad Tahir; Bottom row: Joshua Vigil, Terrence Brown, and Maria Baig

SME: Arthur Ball

CHALLENGE

To design and build a robot to compete in the IEEE SoutheastCon 2024 Hardware Competition to be held in Atlanta, Georgia.

Customer: Stephen Moyer

Maria Baig Woodbridge, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspiration is to work on interesting and upcoming ideas in computer and electrical engineering.

Course Comment: This course was exciting, challenging, a very memorable experience. I loved the uniqueness and competitiveness of our project, and had an amazing team to work with while learning so much.

Terrence Brown Monkton, Maryland

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Aspirations: I aspire to advance my knowledge in robotics for practical applications for the future.

Course Comment: This course allowed me to exemplify classroom techniques while embracing creativity in an open ended competition setting.

Kyle Hayslett Troutville, Virginia

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: My aspiration is to build robots for the military.

Course Comment: This course challenges you in ways you don't expect.

Gaurav Kharel Manassas, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspirations include learning how to solve engineering challenges across disciplines.

Course Comment: I enjoyed getting to take this course as it opened my eyes to new experiences, opportunities, and advancements within our engineering fields.

Muhammad Tahir Riyadh, Saudi Arabia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: The next steps for me include starting my career as an engineer in the industry and pursuing oppurtunities in order to gain different experiences.

Course Comment: This course has honed my teamwork, communication, and technical abilities, offering invaluable insight into engineering design experiences.

Joshua Vigil Chesapeake, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: To work towards new technology for the future.

Course Comment: This course allowed me to work towards soft skills with large group projects.

Maria Zakhem Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: My aspiration is to work across various fields within electrical engineering, contributing new technological advancements and achievements to this growing industry.

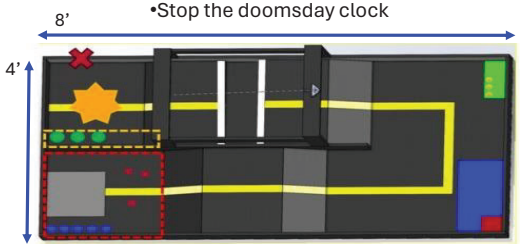
Course Comment: I thoroughly enjoyed my senior design course, appreciating the opportunity to work interdisciplinary and the ability to gain a hands-on learning experience that allowed me to tackle complex engineering challenges.

ECE Robotics Competition Hardware Team

Customer: Stephen Moyer
Subject Matter Expert: Arthur Ball
Team members: Maria Baig, Andrew Brown, Kyle Hayslett, Gaurav Kharel, Abdullah Tahir, Joshua Vigil, Maria Zakhem

Competition Overview

•Autonomous start
•Acquire and deliver different sized packages
•Acquire and assemble thruster fuel tanks onto boosters
•Traverse gap
•Stop the doomsday clock

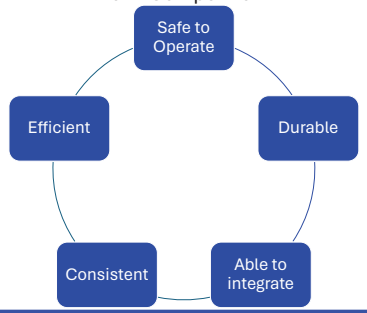


Key Requirements

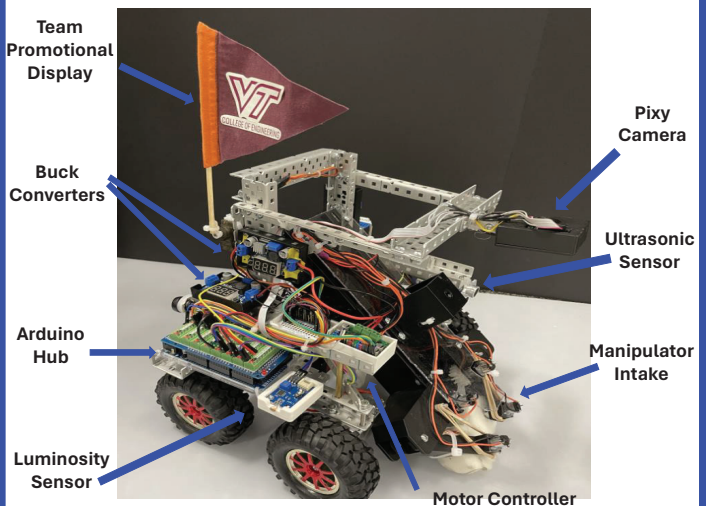
- Fully autonomous
- Must be within 12"x12"x12"
- Must complete all competition tasks in 105 seconds
- Weigh less than 25 pounds
- Activate upon flashing green LED
- Hit red button to signify the end of the round

Objective:

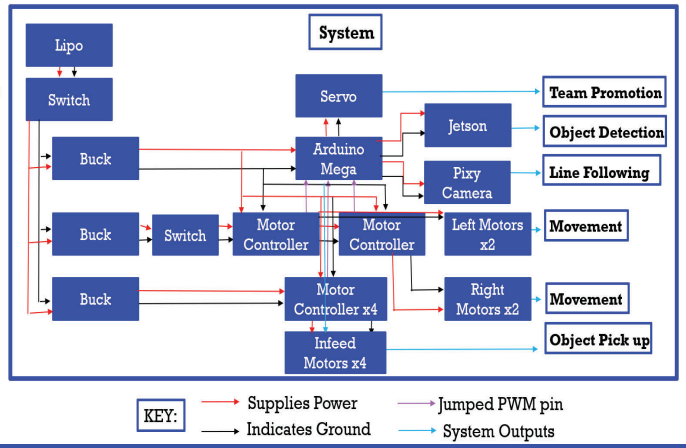
Create and develop a fully autonomous robot to compete and score maximum points in the IEEE SoutheastCon 2024 Competition



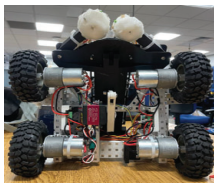
Full Robot



Electrical Design



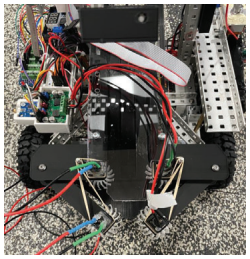
Drivetrain



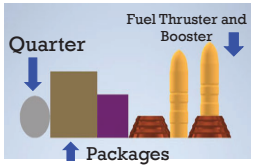
4 RC car wheels
-Maneuverability

4 37D 24V Motors
- High speed
- Ample torque for traversing course

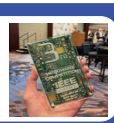
Manipulator



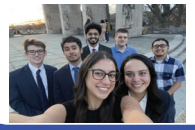
- Manipulator has a dual purpose to collect all game elements
  - Fuel tanks are separated from packages in storage system for alternate deposit
- Second set of wheels separate large packages to alleviate main rollers
- Packages are dispensed by reversing intake while fuel thrusters are dispensed from the rear
- Manipulator can pivot 90 degrees for traversing the course and dispensing fuel thrusters



Results: Our team placed **3rd** in the main competition amongst 42 other teams in the Southeast region!



Acknowledgments: The hardware team would like to express their gratitude to the following individuals: Dr. Arthur Ball, Professor Daniel Connors, Stephen Moyer and the IEEE Organization and volunteers



IEEE Robotic Competition Software Team

LEFT TO RIGHT: Peter Poth, Rahul Menon, Jordan Boyle, Zhiling Liu, Governor Clark

CHALLENGE

Our task was to develop a fully autonomous robot for the IEEE SoutheastCon 2024 Student Hardware Competition. The competition simulates a crisis scenario where robots must prevent asteroid collisions with Earth by deploying cargo containers and rocket thruster fuel tanks. Robots navigate a challenging obstacle course within a set time, delivering essential components. Objectives include retrieving and transporting cargo containers, ferrying rocket fuel tanks across a chasm, and positioning them accurately. The challenge concludes with the robot reaching the course's end and activating a button.

SME: Arthur Ball

Customers: Israel Jordan and Andrian Jordan

Jordan Boyle Spartanburg, South Carolina

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: I want to work on Machine Learning Systems

Course Comment: This course has given me the oppurtinity to get hands on experience with solving a real world engineering problem in my desired focus area.

Governor Clark Fredericksburg, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My career objective is to contribute and learn as a Computer Engineer at a company specializing in controls, robotics, and/or autonomy.

Course Comment: This course has given me the oppurtinity to get hands on experience with solving a real world engineering problem in my desired focus area.

Zhiling Liu Luzhou, China

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: My career objective is to find a good job that will allow me to live comfortably

Course Comment: Very nice. I like this course a lot. I like our SME and instructors. They helped a lot. I also like our sponsors. They gave us a lot of money.

Rahul Menon Dubai, United Arab Emirates

Bachelor of Science in Computer Engineering
Controls, Robotics & Autonomy

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I want to continue working on autonomous systems that would help improve our standard of living and quality of life.

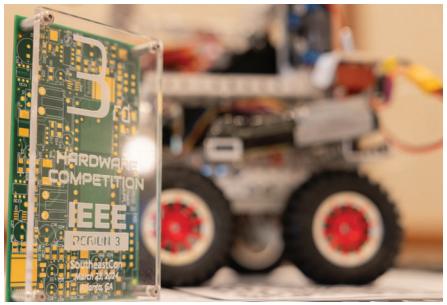
Course Comment: I loved working on this project due to its room for creativity and its real world applications.

Peter Poth Bloomingdale, New Jersey

Bachelor of Science in Electrical Engineering
Controls, Robotics & Autonomy

Aspirations: I want to learn as much as possible and improve or create various control systems for complex systems.

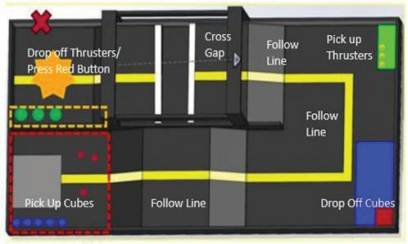
Course Comment: This course has given me valuable experience and insight into various problems that can come up while working in a large group.



ECE Robotics Competition Software Team

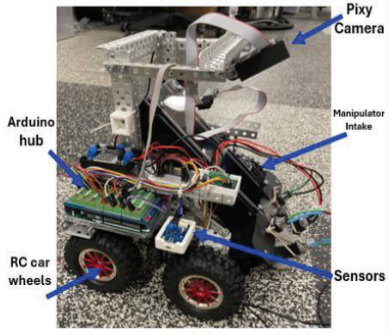
Customers: Andrian Jordan, Israel Jordan, Azam Shoaib
Subject Matter Experts: Arthur Ball, Stephen Moyer
Team Members: Rahul Menon, Peter Poth, Jordan Boyle, Governor Clark, Zhiling Liu

Competition Outline



- Robot Starts in Grey Zone
- Acquires cube shaped packages of various sizes
- Delivers package in correct zone
- Collect and deposit fuel tanks
- Cross the gap and hit the stop button

Robot Specifications



- Size: 12"x12"x12"
- Weight: < 25 pounds
- Fully autonomous and starts at the presence of a green light
- Has an intake system called a manipulator to move game objects
- Utilizes RC car wheels
- Powered by an Arduino Mega

Project Objective

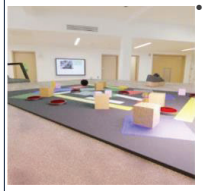
- Create a fully autonomous robot encompassing both hardware and software elements.
- Develop a robot that scores the maximum points possible at IEEE Southeast con 2024 while adhering to health and safety requirements.

Automated Start

- For an autonomous green light start we used the LM393 Luminosity sensor with the Arduino Mega.
- The mega read the output of the sensor through the analog pin.
- If the sensor dropped below the threshold the robot starts.

Object Detection

- We attempted to implement a computer vision system for navigation.
- This system utilized a YOLOv8-Seg model combined with an Intel RealSense camera and controlled by a Nvidia Jetson Nano.
- We used Blender to generate and annotate the entire dataset.

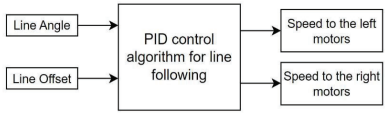


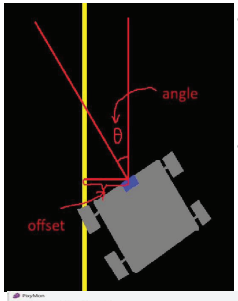
- We used Meta's Segment Anything Model (SAM) to convert object detection datasets into instance segmentation datasets.

- Finally, we implemented depth detection for objects by averaging depth values across significant pixels in the detected object.

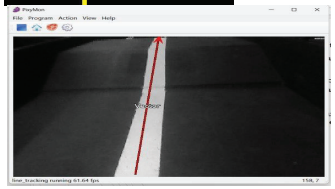
Line Following Algorithm

- We used the Pixy camera's line detection function for line following.
- The camera returned an offset and an angle to the yellow line on the board.





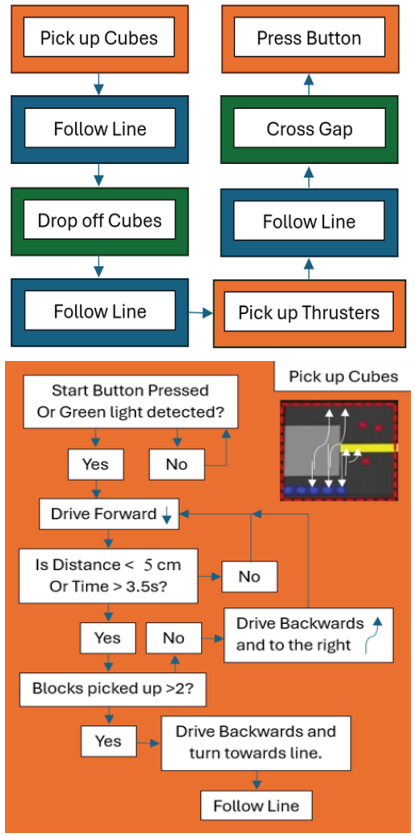
- The line had to be in the camera view to work.
- The Pixy camera had to be far enough away to detect the line.



Fail-Safe Mechanisms

- If green light start doesn't work, there is an emergency start push button.
- During the large block pick up, the forward movement ends with the ultrasonic or the end of the timer.
- Dead times are intentionally added between movements to make sure everything is in the right state before continuing.

Main Drive Train Algorithm



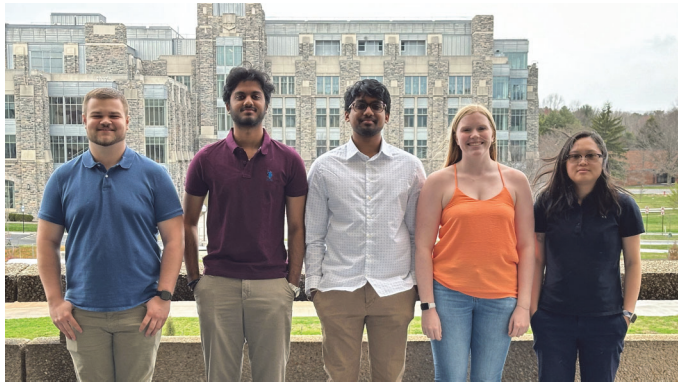
Acknowledgements

The team would like to express their gratitude to the following individuals for their unparalleled support on this project:

- Dr. Arthur Ball, and Stephen Moyer
- NAVAIR team: Andrian Jordan, Israel Jordan, Azam Shoaib
- Dr. Daniel Connors

Early Failure Detection of Lithium-Ion Batteries Using Gas Sensing

Track 7 Winner



LEFT TO RIGHT: Triston Seaford, Sai Mukkollu, Siddhu Gogineni, Rachael Sherbo, Jenny Li

SME: Khai Ngo

CHALLENGE

Lithium-Ion Batteries pose a risk of failure and combustion during transportation and intensive use applications. We have developed an early failure detection system using a BME688 gas and environment sensor and a bluetooth capable microcontroller. Using a trained ai model the system is able to detect the unique gas composition released by a failing lithium ion battery in its early stages of failure and issue a warning to a connected parent system. The developed system is small and portable for multiple applications.

BOEING

Customers: Michael Mitchell, Robert Smith, John Williams and John D. Williams

Siddhu Gogineni Richmond, Virginia

Bachelor of Science in Computer Engineering
Networking & Cybersecurity

Aspirations: I aspire to be a good engineer that can help others in need

Course Comment: This class helped me gain a hands on experience regarding customer needs and requirements.

Jenny Li Chesapeake, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I hope to transition into working in a project management role after a few years in the industry.

Course Comment: This course allowed me to interact with professionals in the industry at lower stakes.

Sai Tarun Mukkollu Vijayawada, India

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I aspire to be an engineer who brings positive impacts to society with the skills I have harnessed.

Course Comment: This course helped me understand teamwork and professional customer interaction.

Triston Seaford Yorktown, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I want to be a software engineer, developing systems to benefit the public

Course Comment: This course provided my first experience working with industry professionals

Rachael Sherbo Austin, Texas

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aim to work with embedded technologies, developing software at a core and operating systems level.

Course Comment: This course allowed me to develop my teamwork skills under stress.

Track 7 Winner

Early Failure Detection of Lithium-Ion Batteries Using Gas Sensing

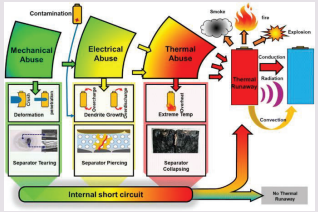
Team: Jenny Li, Rachael Sherbo, Sai Tarun Mukkollu, Triston Seaford, Siddhu Gogineni
Subject Matter Expert: Dr. Khai Ngo Mentor: Prof. Kelley Andrews
Sponsors: Dr. Michael Mitchell, Dr. John D. Williams, Dr. Robert Smith, The Boeing Company

Motivation

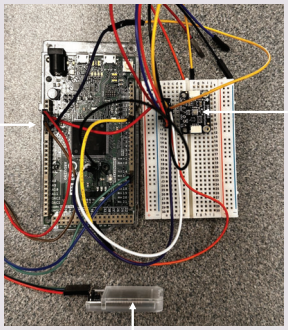
- The use and sale of Lithium-Ion batteries has increased in almost every major device ranging anywhere from phones to cars. Lithium-Ion batteries have a propensity to experience thermal runaway when exposed to conditions of low pressure, high temperature, and jarring movement.
- These conditions are often found in transportation, such as traveling in the cargo of an airplane or the body of an electric car. Thus, demonstrating the evident need for a system that can detect failing Lithium-ion batteries early.
- Currently Lithium-ion batteries are transported using special boxes that can contain thermal runaway. Our proposed solution is a small integrable system that can detect Lithium-Ion battery failure with a gas sensor.

Thermal Runaway

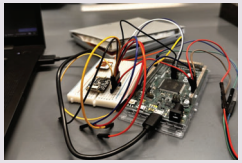
- Low pressure lowers the maximum surface temperature of Lithium-Ion batteries.
- Thermal runaway has two main stages; first venting and combustion. The first venting stage lasts several minutes releases the most gases and is the target of our system.



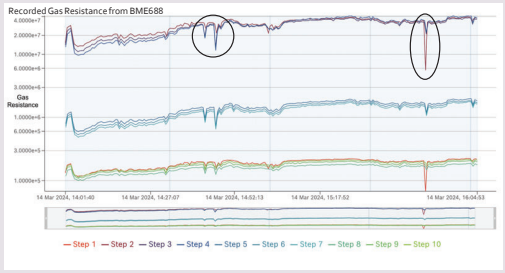
Prototype System



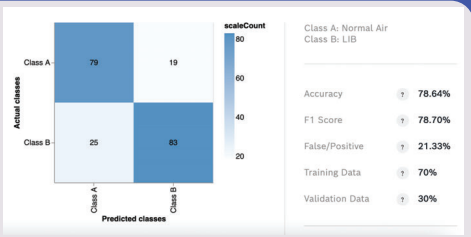
Methodology



- Failing Lithium-Ion Batteries release CO, CO_2, and several VOCs.
- These gases can be detected by a gas sensors.
- Data was collected of regular air and the leaking gases of a bloated Lithium-Ion battery in a fume hood.
- Safety concerns and lack of resources required the use of a bloated battery instead of one actively failing.



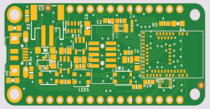
- A metal oxide (MOx) gas sensor is able to collect a "fingerprint" of the unique composition of gases because of their unique reactions with the sensor's metal at different temperatures.



- Collected data from the MOx gas sensor can be used to train Bosch's BSEC2 AI algorithm for detection.
- Since we use the BME688, it is compatible with this software.
- Pictured above is the training results for this algorithm.

Further Development

- Extensive data collection and testing will need to be done with several types of Lithium-Ion batteries undergoing thermal runaway, as well as several different plain air environments.
- Custom palm sized board with BLE capability and the BME688 sensor is a necessary future extension.



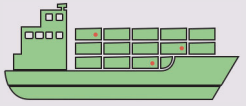
Flowchart

Thermal runaway in Li-on battery → Resistance of sensor drops → Lithium-ion battery failure is recognized → System Sends alert signal

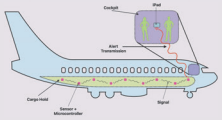
- Chemical sniffer - Arduino Due, Adafruit BME 688 sensor, and HC-06 Bluetooth.
- Thermal runaway/resistance drop is recognized by our AI module.
- Alert signal is sent via HC-06 Bluetooth and over serial.

Applications

- Use in an electric vehicle to detect battery failure before combustion, can alert user to stop and get out of the car.



- Can be used inside current cargo hold Lithium-Ion battery boxes to set an indicator to alert personnel that a battery failed and released toxic gases before opening the container.



- Use in the cargo hold of an airplane to detect failure and subsequently employ prevention and mitigation methods against combustion and toxic gases.

A Germanium Laser for Future Quantum Technologies: Design and Implementation

LEFT TO RIGHT: Purv Bavishi, Ben Westcott, Joshua Seplak, Zibing He, Rebecca Rainhart

SME: Rutwik Joshi

CHALLENGE

Beyond classical computing, quantum computers can achieve supremacy provided their building blocks can be scaled and manufactured on-chip leveraging the existing semiconductor fabrication infrastructure. This project aims to design a Germanium quantum well laser and optimize the various physical parameters to make the laser suitable for applications in quantum technologies while understanding the various design intricacies, metrics, and trade-offs. The students will use prototype laser devices to provide analytical retrospect on their functionality, merits, improvements, and applications.

Customer: Mantu Hudait

Purv Bavishi Baroda, India

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: My aspiration is to find something I am really passionate about that forces me to think outside the box. I want to research more in the field of semiconductors as they are cutting edge technology.

Course Comment: The senior design experience has been one of the most challenging and fun classes. It has been one of the few classes where I was excited on what I was going to do and what new things I am going to learn every single week. I also learnt about team building skills and how to communicate professionally.

Zibing He Inner Mongolia, China

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I hope to continue my graduate studies in digital and analog IC. After completing my graduate degree, I hope I can work in a well-known semiconductor or chip company.

Course Comment: This class gave me a lot of experience in teamwork and communication. Let me truly understand the process of a project from design to output. Also for our project, I learned more about the physics and materials of quantum wells and lasers

Rebecca Rainhart Oakton, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: In my career I want to contribute as an electrical engineer to a company focused on technology in the aerospace industry. I am excited opportunities that involve learning from an interdisciplinary team with work that could contribute to the future of projects in space.

Course Comment: This course gave me valuable backgound in semiconductor physics and fabrication that I wouldn't have gotten from any course offering. I now feel more prepared to go into industry after graduation with a mindset open to learning new skills to complete challenging design tasks.

Joshua Seplak Chesapeake, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I would like to see myself working hands on in the field as much as possible, bridging the gap between theory and application. A work environment where I am applying my skills to see a physical and long-standing result would be ideal

Course Comment: Before this course, I was fairly unfamiliar with how semiconductors truly functioned; however, this course has diversified my knowledge of a field within electrical engineering that I was previously wary to study in a very engaging way.

Ben Westcott Winston-Salem, North Carolina

Bachelor of Science in Electrical Engineering
Energy & Power Electronics Systems

Aspirations: My aspirations after I graduate college is to find a career that I enjoy and challenges me to learn new things

Course Comment: This senior design course gave valuable insights not only into semiconductors and the physics behind them, but also how to work in a team effectively and efficiently

A Germanium Laser for Future Quantum Technologies: Design and Implementation

Team Members: Rebecca Rainhart, Purv Bavishi, Ben Westcott, Zibing He, Joshua Seplak

Customer: Dr. Mantu Hudait of ADSEL at Virginia Tech **SME:** Rutwik Joshi

Best Overall

Background

Introduction

Beyond classical technologies, quantum computers and quantum technologies can achieve extensive benefits provided their building blocks can be scaled and manufactured on-chip leveraging the existing semiconductor fabrication infrastructure. A tunable coherent light source which covers a vast range of these classical and quantum technologies is an ongoing search and Ge is a potential candidate. This project focused on the design of a Germanium quantum well laser to optimize the various physical parameters and make the laser suitable for applications in quantum technologies, while understanding the various design intricacies, metrics, and trade-offs.

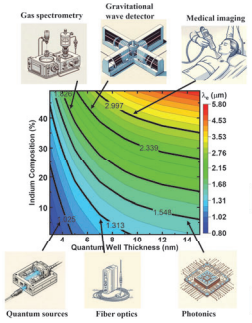
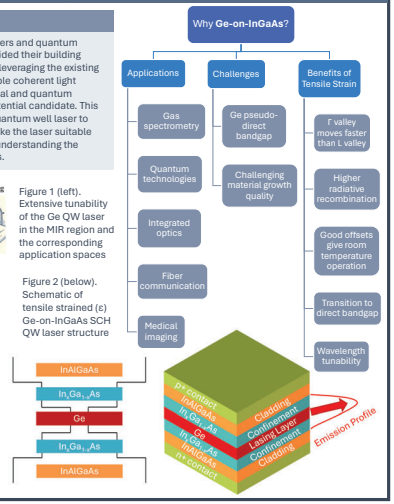


Figure 1 (left). Extensive tunability of the Ge QW laser in the MIR region and the corresponding application spaces

Figure 2 (below). Schematic of tensile strained (ε) Ge-on-InGaAs SCH QW laser structure



Design of a Ge QW Laser

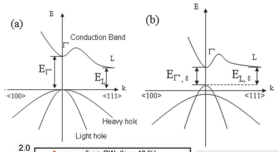


Figure 8. (a) band structure of Ge without strain, (b) and with 1.4% biaxial strain [2]. Notice lowering of the Γ valley and separation of the LH and HH bands with the transition to direct bandgap

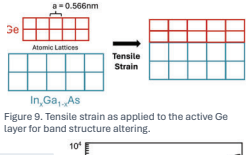


Figure 9. Tensile strain as applied to the active Ge layer for band structure altering.

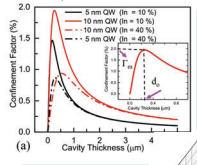
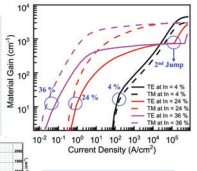


Figure 10 (left). Design of optimum SCH Ge/InGaAs QW cavity, showing maximized confinement factor over sensible cavity thicknesses. Γ_m is considered over the range of tensile strain. [3]

Figure 11 (right). Material gain of the QW as a function of injected current density, with increased In%, there is decreased saturation point of the material gain.



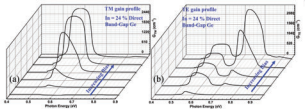


Figure 12 (right). Gain spectrum of QW with increasing bias for both TE and TM modes of operation.

Gain spectrum shows saturation of the QW with increasing bias dependent upon photon energy

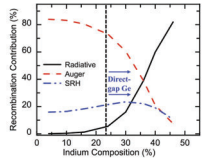


Figure 13. Effect of In composition on contributions of radiative vs non-radiative Ge transitions, as Ge becomes pseudo direct gap.

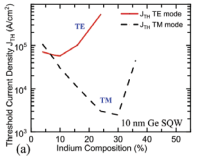


Figure 14. In the TM guided mode, lasing conditions can occur around 2 kA/cm^2, where biaxial tensile strain is sufficient to make Ge pseudo-direct bandgap

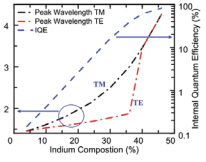
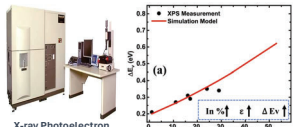


Figure 15. IQE vs In%. TM dominant scales In% with emission wavelength over a much broader range. Increasing strain increases efficiency of recombination

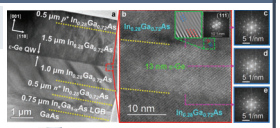
Materials and Device Characterization

Experimental data for band offsets, PCD lifetime, structural models, and 30x30 k.p utilizing TEM and XPS were provided to calibrate electrical parameters in TCAD



X-ray Photoelectron Spectroscopy

Figure 3 (above). XPS band alignment measurement. Higher In% increases band offsets [3].



Transmission Electron Microscopy

Figure 4 (above). TEM micrographs of a 1.95% ε-Ge QW laser structure on GaAs with InGaAs barrier layer [1], show good growth quality.

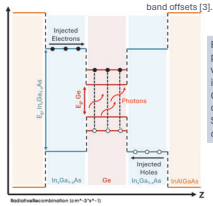
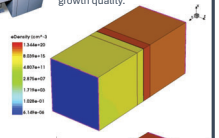
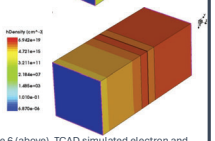


Figure 5 (left). The emission of photons in the QW can occur when the quasi-fermi separation is greater than the bandgap. The QW confines electron to the order of its wavelength, and the SCH confines the photon to the order of its wavelength.





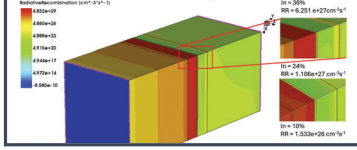


Figure 6 (above). TCAD simulated electron and hole densities in a 10 nm QW with In = 24%

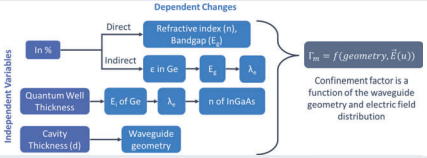
Figure 7 (left). TCAD simulated radiative recombination rates in the active region for varying In%. Shows increasing radiative recombination with higher strain by Indium

Design Optimization and Results

What is Adaptive Design?

Indium composition, QW thickness, and cavity thickness (d_c) have compounding effects on electrical field distribution

An adaptive design (AD) methodology **optimizes** the **optimal confinement** factor considering the relationship between **tensile strain** from In% and the QW **geometry**



$\Gamma_m = f(geometry, \vec{E}(u))$

Confinement factor is a function of the waveguide geometry and electric field distribution

$$\Gamma_{opt} = \frac{\int_{cavity} |E(x,z)|^2 \, dz}{\int_{total} |E(x,z)|^2 \, dz} = \frac{1 + (2\gamma d_{opt})/V^2)}{1 + (2/\gamma d_{opt})}$$

$$\Gamma_m = \max_d(\Gamma_{opt}) = \Gamma_{opt}(d_m)$$

Performance Metrics

Threshold Current Density (J_{TH})

J_{TH} quantifies the injection of carriers required to overcome mirror losses (α_m) and free carrier absorption loss (α_{FCA})

Material Loss

$$\alpha_{net} = \frac{\alpha_{tot}}{\Gamma_m}$$

Modal Loss

$$\alpha_{tot} = \alpha_{FCA}\Gamma_m + \alpha_m$$

Material Gain

$$G = \sum DOS \cdot A \cdot (f_c - f_v)$$

Modal Gain

$$g = G\,\Gamma_m$$

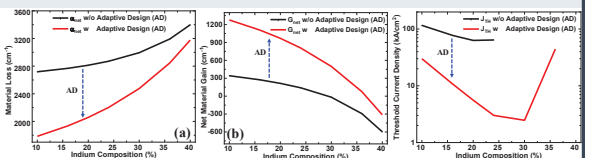


Figure 16. Improvement in the lasing performance due to the AD as seen through (a) reduced net material loss and consequently (b) increased net material gain.

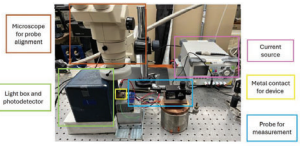
Figure 17. Drastic improvement in J_{TH} indicating the importance of the AD methodology for the Ge QW laser. When In > 24%, an unoptimized ε-Ge/$In_xGa_{1-x}As$ QW laser structure leads to a J_{TH} that is not quantifiable

An adaptive design methodology is essential to ensure efficient performance improvement of the ε-Ge QW laser in the MIR region due to widespread spectral tunability

- 30% decrease in material loss
- Additional net modal gain of ~10 cm⁻¹
- > 1 order of magnitude decrease in threshold current density (J_{TH})

Prototype Device Characterization

- Functional fabricated Q-dot devices were utilized for practice characterizing MIR devices
  - Optical test bench utilized to apply current to the device and capture light emission
    - Photodetector measures generated light and translates to current
  - Measurements taken for devices of varying active layer thicknesses
  - Temperature dependent electrical characterization for CV measurement provided device metrics



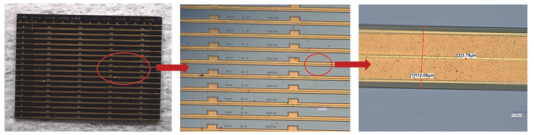
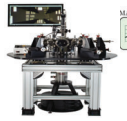


Figure 18-20 (above). Magnification of the p-contacts on the measured Q-dot device



Temperature Dependent Electrical Characterization

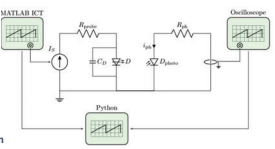
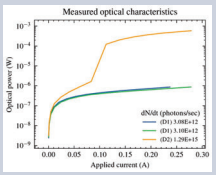


Figure 21 (left). Schematic of measurement system used for optical power measurement and processing to determine photon emission



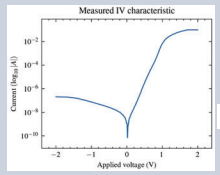
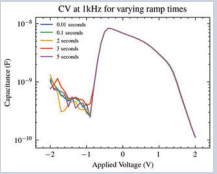


Figure 22-23. Optical power indicates number of photons emitted per second with applied current, IV curve indicates the current threshold for light emission

$$P_{opt}(I_S) = i_{ph}(I_S)/K_{ph}$$

$$\frac{dN}{dt} = \frac{P_{opt}}{E_{photon}}$$



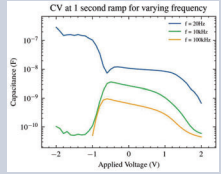


Figure 24-25. CV characteristics with applied voltage indicate minority carrier response, Varying frequency across applied voltage indicates pulsed application characteristics

Conclusions

- Tensile strained Ge-on-InGaAs QW lasers are promising for varying wavelength applications in the MIR region for integrated photonics
- Adaptative design reveals an efficient approach for implementation of a tunable tensile strained Ge laser for Si photonics.
- Device characterization allows for calculation of photon emission contributing to the assessment of the performance of MIR devices in varying application spaces.

References and Acknowledgements

[1] M. K. Hudait, et. al., "ACS Applied Electronic Materials" vol. 3, no. 10, p. 4255-4656, 2021. DOI: 10.1021/acsaelm.1c00660.

[2] R. Joshi, S. Karthikeyan, and M. K. Hudait, "Monolithically cointegrated tensile strained germanium and InxGa1-xAs FinFETs for tunable CMOS logic," IEEE Trans. Electron Devices, vol. 69, no. 8, pp. 4175–4182, Aug. 2022, doi: 10.1109/TED.2022.3181112.

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Thank you to Rutwik Joshi, Dr. Hudait, and Dr. Lester for their continued support of this project and the team's success!

Germanium Based Multi-Gate FETs for Ultra-Fast, Low-Power CMOS Computing

LEFT TO RIGHT: Eli Levi, Atif Alam, Rebecca Schuette, Nada Mohamed, Anson Trapani, Runbo Deng

SME: Rutwik Joshi

CHALLENGE

Over the past 60 years, the semiconductor industry has made technological leaps unlike any other using scaled silicon technology. Unfortunately, the benefits of scaling Silicon transistors have been diminishing for the past decade and further scaling will soon reach a dead-end. This project aims to design a germanium-based, multi-gate CMOS transistor and optimize the various physical parameters to boost its performance beyond its Si-counterparts, while understanding the various design intricacies, metrics, and trade-offs.

Customer: Mantu Hudait

Atif Alam Midlothian, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I would like to research in and work on emerging quantum technologies after graduate school.

Course Comment: This course has showed me the process for solving real life engineering problems and how to effectively do so in a team. In addition, it has taught me how to effectively communicate about the design process in technical and non-technical ways.

Runbo Deng Suzhou, China

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Aspirations: I would like to engage in semiconductor and chip-design industries after I graduate.

Course Comment: Through this course, I learned turning theories into practical experience and developed my teamworking skills that will helpful to my future career.

Eli Levi Clifton, Virginia

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I would like to research and innovate in the semiconductor industry.

Course Comment: The course has allowed me to learn many technical, interpersonal and problem solving skills that I will carry through my future.

Nada Mohamed Khartoum, Sudan

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I would like to be working on solving problems in electrical circuits and power electronics.

Course Comment: This course gave me the opportunity to collaborate in a diverse environment and improve my technical skills which will help me in my future career.

Rebecca Schuette McLean, Virginia

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: In the future, I want to design circuits for space applications.

Course Comment: This course has exposed me to technical areas I would not otherwise have been involved. In addition, it allowed me to expand my problem solving and team work skills.

Anson Trapani Alexandria, Virginia

Bachelor of Science in Electrical Engineering
Micro/Nano Systems

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I would like to work on cutting-edge semiconductor devices at the chip level after obtaining my Masters degree.

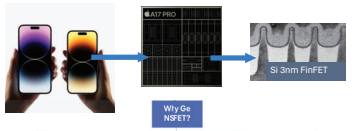
Course Comment: This course has really demonstrated to me the inner workings of the engineering-design process, and how industry-standard tools and procedures are integrated into the workflow to accomplish the objectives outlined in the problem statement.

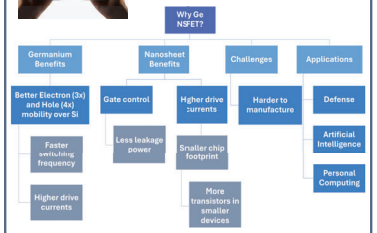
Germanium Based Multi-Gate FETs for Ultra-Fast, Low-Power CMOS Computing

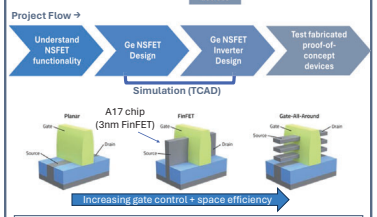
Customer: Dr. Mantu K. Hudait, Advanced Devices & Sustainable Energy Laboratory (ADSEL) at Virginia Tech
SME: Rutwik Joshi, Virginia Tech ECE
Team Members: Rebecca Schuette, Atif Alam, Anson Trapani, Eli Levi, Nada Mohamed, Runbo Deng

Background

The average person owns hundreds of billions of silicon transistors – in your phone, computer, watch, car and more. Over the past 60 years, the semiconductor industry has made technological leaps unlike any other using scaled silicon technology. Unfortunately, the benefits of scaling silicon transistors have been diminishing for the past decade and further scaling will soon reach a dead-end. This project aims to design a germanium-based, multi-gate CMOS transistor and optimize the various physical parameters to boost its performance beyond its Si-counterparts, while understanding the various design intricacies, metrics, and trade-offs.







- The Ge channels are grown heteroepitaxially on GaAs with intermediate AlAs. **Lattice matched** Ge/AlAs heterostructures provide a **defect-free** interface and channel for nanosheet transistor configurations [1].
- The Ge/AlAs stack is cut to form a fin, and STI (shallow trench isolation) is applied.
- A dummy gate and spacers to hold the Ge channel layers are added. Then the source and drain.
- The AlAs layers are removed using a dry-etching process. Then the final gate and oxide layers can be placed.

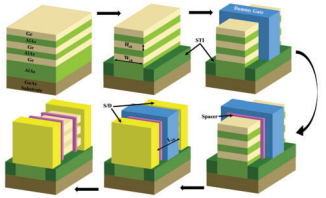


Figure 1. Proposed Ge/AlAs process flow for NSFET fabrication.

Ge NSFET Design

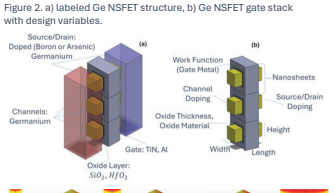


Figure 2. a) labeled Ge NSFET structure, b) Ge NSFET gate stack with design variables.

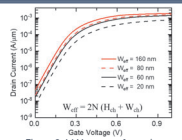


Figure 3. Id-Vg curves for various effective widths by N scaling.

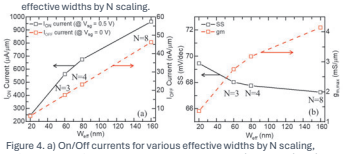


Figure 4. a) On/Off currents for various effective widths by N scaling, b) Subthreshold Slope and transconductance for various effective widths.

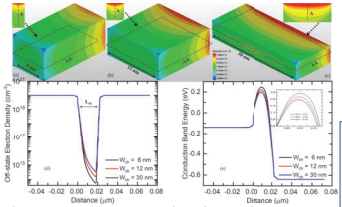


Figure 5. a-c) Off state electron density profiles for various channel widths, d) Electron density, e) Conduction band energy.

- While increasing W_{eff} by scaling N improves SS, Increasing W_{eff} by scaling W degrades SS.
- This is can explained through the channel electron density contours in the off state which are a consequence of the electrostatic potential variation across the 3D channel (Fig. 5 a-c).
- Lower conduction band energy (Fig. 5 e) in wider NSFETs corresponds, and leads to, higher electron density in wider NSFETs (Fig. 5 d).

What is TCAD?

A 3D simulator that uses solid-state physical theories to model semiconductor structures. As it has incredible predictive power, TCAD is widely used in industrial and academic research to improve current solid-state devices and develop brand-new semiconductor technologies.

- The **N scaling** (# of nanosheets) is a preferable choice for **boosting on current**, and other performance metrics, when there is an **area constraint** on the device design.
- Greater W_{eff} (effective width) increases on and off currents (Fig. 4a). This implies **fast switching** speeds due to increased load capacitance charging/discharging rates. The trade off is larger static power dissipation via I_{OFF}.
- Greater W_{eff} increases $g_{m,max}$, leading to better amplification capabilities in analog circuitry applications.
- Lower subthreshold slope (SS) comes with increasing W_{eff}. Implying **increased gate control** over the channel during transitions from on to off states and vice versa.
- SS, I_{ON}, and $g_{m,max}$, trends indicate that as N scaling increases, the rate at which performance improves diminishes due to increased parasitic capacitance and resistor networks.

Ge Inverter Design

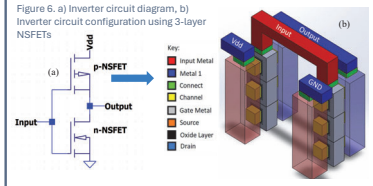


Figure 6. a) Inverter circuit diagram, b) Inverter circuit configuration using 3-layer NSFETs

	n-NSFET	p-NSFET
Length (nm)	12	12
Width (nm)	6	6
Height (nm)	5	5
Oxide Thickness (nm)	1	1
Source/Drain Doping (cm^{-3})	10^{20}	10^{20}
Channel Doping (cm^{-3})	10^{15}	10^{15}
Gate Metal	Aluminum	Titanium Nitride
Work Function	4.28	4.45

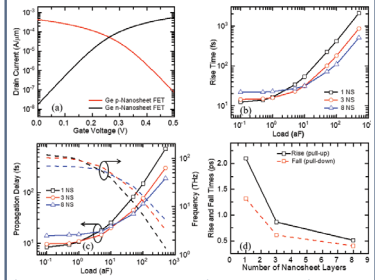
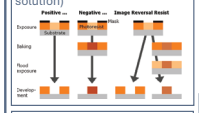


Figure 7. a) Id-Vg crossovers, b) Load capacitance and nanosheet impacts on rise time, c) Load capacitance and nanosheet impacts on propagation delay and frequency, d) Rise and Fall transitions with increasing nanosheets at 500aF.

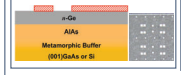
- CMOS inverters are fundamental components of all digital logic circuitry.
- **Matched ON currents** and **threshold voltages** for n-NSFET and p-NSFET are required for CMOS inverters. To simplify potential fabrication processes, the dimensions of both NSFETs were made the same.
- Ge NSFET CMOS inverters were simulated using TCAD. Transient simulations were done to determine delays and operating frequencies of inverters with various load sizes and number of nanosheets (Fig. 7).
- While driving bigger loads, delays (rise time (Fig. 7b), fall time (Fig. 7d), propagation delay (Fig. 7c)) are shorter and operating frequency (Fig. 7c) is greater for inverters with more nanosheets.
- While driving smaller loads, delays are shorter and operating frequency is greater for inverters with fewer nanosheets.
- Therefore, using Ge NSFET CMOS inverters, it's better to use **more nanosheets** for circuits where inverter is connected to many outputs that require **lots of power** and **less nanosheets** for circuits where inverter is connected to a few outputs that require less power and **faster switching**.

Clean Room Fabrication

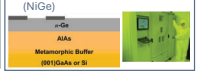
Lithography (Litho) Process: Exposure with mask → Bake → Flood Exposure without mask → Develop (AZ300MIF developer solution)



Clean & Litho #1:
- Clean using sample and remove oxides. Apply photoresist (PR)
- Follow Litho process with S/D mask

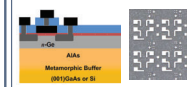


Ni S/D Deposition & Liftoff:
- Apply Ni everywhere using Physical Vapor Deposition-250 (PVD-250)
- Remove PR using acetone (liftoff)
- Anneal to form Nickel Germanide (NiGe)

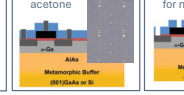


PEALD of GeO_x and Al_2O_3:
- Plasma-Enhanced Atomic Layer Deposition (PEALD)
- Thin atomic layer of GeO_x and Al_2O_3 to form oxide layer.

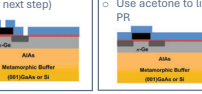
Litho #4 & PVD #5 Contacts:
- Use Litho process for G/S/D contact pads
- PVD to lay contact metal
- Liftoff to remove final PR



PVD #4 Via metal deposit:
- Use PVD to deposit metal stacks (TiN/Pt/Au)
- Liftoff PR using acetone

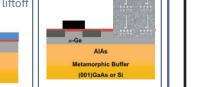


Litho #3 for G/S/D:
- Use Litho process to etch via for source/drain/gate terminals
- Leave PR (needed for next step)



Litho #2 & PVD #2 (Gate Metal):
- Follow Litho process with gate mask
- Use PVD to lay gate metal
- Use acetone to liftoff PR

PVD #3 for FOX:
- Field Oxide (SiO_2) to isolate devices from each other
- Use PVD to lay SiO_2



Measurement

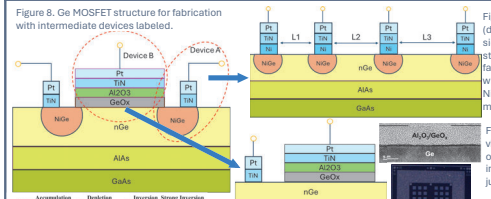


Figure 8. Ge MOSFET structure for fabrication with intermediate devices labeled.

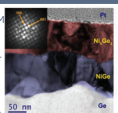


Figure 9. TLM (device A) side profile structure for fabrication with Ni/TiN/Pt metal stack.

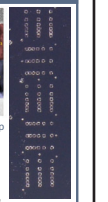


Figure 10. a) Top view of MOSCAP on wafer, b) TEM image of MOSCAP junction.

Figure 11. a) Top view of TLM structure on wafer, b) TEM image of TLM growth stack.

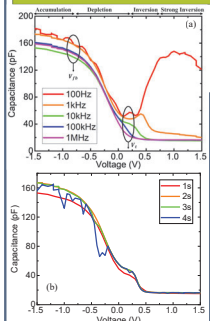


Figure 14. a) Capacitance-voltage with varied frequency with 1s delay, b) Capacitance-voltage with 10kHz and varied delay times.

Figure 12. MOSCAP (device B) side profile structure for fabrication with GeO_x / Al_2O_3 oxide layer and TiN/Pt gate stack.

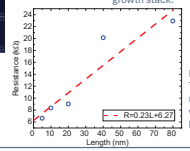


Figure 13. Total TLM resistances with linear best fit.

- MOSCAP (device B) characterizes the gate-body capacitance needed to determine C_{ox} (influences I_{on}), V_{fb} (influences V_t), and **minority carrier impacts**. CV measurements take an AC signal with fixed amplitude superimposed on a changing DC bias.
- Low frequency input, 100Hz, allows capacitance to move through depletion region into inversion.
- $C_{max} = 170\ pF, A = 120\mu m^2$
- $C_{ox} = 11.8\ fF/\mu m^2$
- Simulated NSFET has $A = 288nm^2$, using $C_{ox} = 11.8\ fF/\mu m^2$, $C_t = 3.4\ aF$
- Simulated C_t and C_t calculated using measured C_{ox} are in the same range. This provides validity to the gate structure proposed in this project.

- TLM (transmission line model) allows for characterization of the **source/drain contact resistance** using I-V measurements.
- IV measurements are taken between pairs of contacts (shown in Fig. 9). The slope in the linear regions of the IV curves is the total resistance between the contacts.
- $R_T = \frac{R_S}{W}L + 2R_c$
- $2R_c$ is the y-intercept (Fig. 13). $R_c = 3.13k\Omega$
- using $C_{ox} = 11.8\ fF/\mu m^2$, $C_t = 3.4\ aF$
- $\rho_c = R_c A_c = 3.13k\Omega \cdot 2500\mu m^2 = 0.78\Omega cm^2$
- Resistivity, ρ_c, is a material property indicating opposition to current flow. This is additional resistance that the device has support in addition to the desired operation.

Conclusion

- Successfully designed devices that outperform Si counterparts.
  - **~17x** better **ON current** than similar spec silicon device [3].
  - **~15%** improvement in **subthreshold swing** compared to silicon.
  - Performed at **~23% lower supply voltage** (0.65V to 0.5V) → lower power consumption at similar performance levels.
- Implications for better battery life and increased performance for devices utilizing Ge NSFET technology over silicon nanosheet.

References

[1] R. Joshi, S. Karthikeyan and M. K. Hudait, "Germanium Nanosheet-FETs Scaled to Subnanometer Node Utilizing Monolithically Integrated Lattice Matched Ge/AlAs and Strained Ge/InGaAs," in IEEE Transactions on Electron Devices, vol. 70, no. 3, pp. 899-907, March 2023, doi: 10.1109/TED.2023.3238376.
[2] "Photoresists," Photoresists AZ and MicroChemicals TI resists, https://www.microchemicals.com/products/photoresists.html.
[3] D. Jang et al., "Device Exploration of NanoSheet Transistors for Sub-7-nm Technology Node," in IEEE Transactions on Electron Devices, vol. 64, no. 6, pp. 2707-2713, June 2017, doi: 10.1109/TED.2017.2695455.

Simulation of Thermal Transport in Resistive Memory Arrays

LEFT TO RIGHT: Logan Johnson, Aaryan Dhawan, Evelyn Chua, Hao Xiang Liew, Yuanzhi Zhang, Sakib Shadab

CHALLENGE

To accurately model, simulate, and calculate the thermal characteristics of an experimental form of random-access memory based on memresistors, called Resistive Random-Access Memory Arrays, or ReRAM.

SME: Amrita Chakraborty and Aaron DeFilippo

Customers: Marius Orlowski and Mariusz Orlowski

Evelyn Chua Penang, Malaysia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I wish to become a digital design or VLSI engineer working in top world tech companies and probably teach ballet during my free time.

Course Comment: It was fun working with people from different majors and learning something totally new for our project. Great experience!

Aaryan Dhawan Fairfax, Virginia

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I wish to work on future computer processing technologies at companies like AMD, Nvidia, and Apple.

Course Comment: It was really fun being able to work on a large scale project with a big team.

Logan Johnson Tomball, Texas

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Aspirations: I want to propel innovations within the semiconductor industry, contributing to the development of cutting-edge technologies.

Course Comment: I enjoyed the rigor of this year-long project and I'm happy with all the progress that our team has made.

Hao Xiang Liew Penang, Malaysia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: To develop, research, and contribute to the cutting-edge of computing technologies.

Course Comment: This course has effectively facilitated an environment where theoretical knowledge is applied to real-world engineering challenges, encouraging me to engage in problem-solving, critical thinking, and collaborative teamwork.

Sakib Shadab Dhaka, Bangladesh

Bachelor of Science in Computer Engineering
Computer Engineering

Aspirations: I am eager to hone my skills in coding and learn more about software engineering throughout my career, with a high interest in AI and ML.

Course Comment: This course gives an experience of teamwork similar to industry for an interesting foray into a topic outside of my study.

Yuanzhi Zhang Guangzhou, China

Bachelor of Science in Computer Engineering
Chip-Scale Integration

Bachelor of Science in Electrical Engineering
Electrical Engineering

Aspirations: I am eager to push the boundaries of technological advancement in the semiconductor industry beyond the limitations of Moore's Law.

Course Comment: This course offers a comprehensive exploration of subject matter through hands-on projects and collaboration.

Simulation of Thermal Transport in Resistive Memory Arrays

Customer: Dr. Mariusz Orlowski **Subject Matter Experts:** Dr. Amrita Chakraborty, Aaron DiFilippo **Mentor:** Kenneth Schulz
Team Members: Hao Xiang Liew, Aaryan Dhawan, Evelyn Chua, Yuanzhi Zhang, Sakib Shadab, Logan Johnson

Motivation

Pros: ReRAM has higher density, faster switching speeds, and lower power consumption than conventional memory technologies.
Cons: Thermal buildup can cause data loss and permanent damage in ReRAM.

Resistive RAM (ReRAM) is a non-volatile memory technology that works by changing the electrical resistance over a solid-state material – referred to as a "memristor". ReRAM has many benefits over conventional RAM but comes with a major operational drawback with heat buildup within the device, causing potential data loss and permanent damage.

Objectives

Measuring temperature at the cells is impossible physically due to its size. Simulation is the only way to research the thermal behavior of ReRAM. Our project developed the model and simulations for ReRAM.

As the physical ReRAM device is too small to accurately measure temperature at a cell, simulation tools and theoretical computation is the only way to understand the thermal characteristics of the device. The simulation model must:

- Exhibit the same heating and cooling behavior seen by our customer.
- Detailed enough to locate local temperatures at memory cell locations.

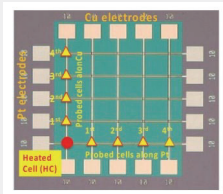


Image Credit: M. Al-Mamun and M. Orlowski, "Electron tunneling between vibrating atoms in a copper nano-filament," Nature News

Device Characteristics

During a Set, the nanofilament is built. A Reset ruptures the filament.

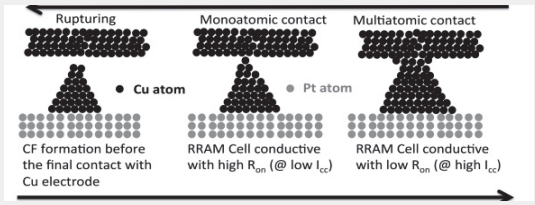


Image provided: M. Al-Mamun and M. Orlowski, "Electron tunneling between vibrating atoms in a copper nano-filament," *Sci. Rep.*, vol. 11, no. 1, pp. 1–13, 2021.

A Set is the equivalent to Logic 1; A Reset is equivalent to Logic 0.

- The experimental device uses a 5x5 electrode array, with **Copper** electrodes on the top and **Platinum** electrodes on the bottom, separated by a dielectric material – **Tantalum Oxide** (TaOx).
- The electrodes create a cross-hatch design, where each intersection is a memory cell.
- The copper electrodes experience a Redox reaction with a positive bias voltage, causing copper ions to fall and build up on the platinum electrode, creating a nanofilament: **This is a Set Operation.**
- A negative voltage at a large compliance current (mA range) is applied to the copper electrode which causes joule heating and the filament ruptures. **This is the Reset Operation.**

Predecessor Work

We must expand to a 5x5 array in a realistic environment.

Our predecessor team was able to determine that **ANSYS**, a modeling and simulation software, would be the best tool to understand the thermal characteristics of the device. They were able to model and simulate a **2 Copper, 1 Platinum electrode array** (2x1 array).
However:

- They used a **low resolution model.**
- Certain **material properties were using incorrect units**, thus the simulation data was inaccurate
- Environmental factors like **convection and radiation** were not taken into account.

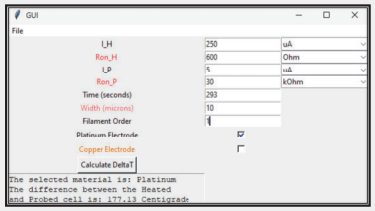
Calculations and GUI

More specifically, our customer would like to know the **difference in temperature between two memory cells/filaments that share an electrode.**

Using

$$\Delta T = \frac{Qd}{KA_{cross}t}, Q = I^2Rt$$

Where T = Temperature , Q = Heat Energy

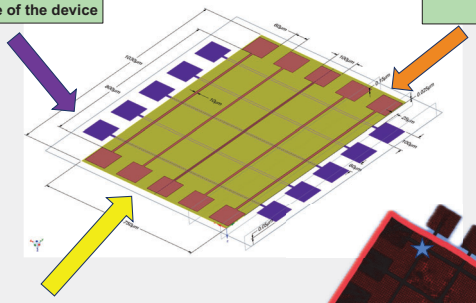


By using electrical characteristics of the two filaments, we can find the overall temperature change in the electrode.

Computer Model

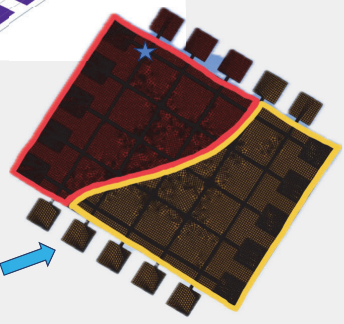
Platinum electrodes can be found on the underside of the device

Copper electrodes can be found on the top of the device



The Tantalum Oxide dielectric sheet sits between the electrode layers

The heat spreads across the entire device during a simulated critical switching cycle – the heated cell is denoted by the blue star



Calculations vs Simulation

Using Flux Rate EQ, we can find the heat energy generated during a heating cycle.
We can take the temperature values at different cells in our simulation to validate the model and behavior.

Our Customer has a range of acceptable heat energy based on the strength of the filament. Being within this range means the simulation is correct.

Time (s)	Heated Cell Temp (C)	Probed Cell Temp (C)
0	900	22
1	900	819

Midpoint of Heating, We heat the filament for 2s.

$$\Delta T = 819°C - 22°C = 797°C$$

$$K = Thermal\ Conductivity\ of\ Filament = 300$$

$$A_{cross} = Cross\ Section\ Area\ of\ Filament = \pi * (10 * 10^{-9})^2$$

$$t = Time\ of\ Heating = 1\ s$$

$$d = Height\ of\ Filament = 25 * 10^{-9}$$

$$Q = \frac{\Delta T K A_{cross} t}{d} = \frac{(807°C)(300)(\pi * (10 * 10^{-9}\ m)^2)(1\ s)}{25 * 10^{-9}\ m} = 3\ mJ$$

For cycles that take seconds, we expect heat to be in millijoules.

Using the temperature data from our simulation, we can calculate the heat energy a probed filament experiences and verify the computer model.

Conclusion

- Our model uses a coarse meshing with a fine mesh around the filament, which allows for much finer and accurate temperature readings around the filament, which is orders of magnitude smaller than everything else in the model.
- Our model's mesh takes less time with more accurate results than our predecessor.
- Meshing has good tradeoff between simulation time and accuracy.
- GUI now matches ANSYS simulations results, which concludes that our simulation parameters and results are correct.
- Average temperature increases with a wider electrode.
- Unit Changes which leads to better comparison in GUI.
- Fixed the convection parameter to simulate cooling.
- Filament geometry now conical instead of cylindrical, which is more accurate.

Best result: Simulated 5x5 array with correct parameters and meshing and found a reasonable cooling time.

Future Work

- Further enhancements using:
  - Radiation
  - Simulations that represent consecutive full switching cycles
  - Analyzing the effects of multiple active filaments in operation
- Polish off existing work.
- Work on manuscript to publish current findings in a peer-reviewed journal.

Acknowledgements

Thank You to the Following for Their Contributions:

- Dr. Marius Orlowski
- Dr. Amrita Chakraborty
- Aaron DiFilippo
- Kenneth Schulz

Guest Speakers in order of appearance:

In addition to our project sponsors and subject matter experts, there were many others that significantly contributed to the success of this class. We want to take this opportunity to express our deep-felt appreciation and thanks for their contributions.

- **Alana LaFerriere**
  Key Tech, Inc.
  Ethics and making intentional career choices

- **Ethan Brooks**
  General Dynamics-Mission Systems
  Detailed Design & other info I wish I **k**new when I was in MDE

- **Dr. Creed Jones & Dr. Tim Talty**
  Virginia Tech ECE
  Graduate school opportunities and considerations

Best in Course Recognition for Base Course Performance

Fall 2023

ECE 1004–Introduction to ECE Concepts
- JJ Feeney
- Chelsea Spivey

ECE 2024–Circuits and Devices
- Connor Balint
- Won Jae Chung

ECE 2214–Physical Electronics
- Sean Sechtman
- Jabari Simpson

ECE 2514–Computational Engineering
- Jason Albanus
- Mason Digiorgio
- Eric Yung

ECE 2544–Fundamentals of Digital Systems
- Aaron Kanefsky
- Stephanie Rodas Arias
- Ian Sizemore

ECE 2714–Signals and Systems
- Rahul Muthuraman
- Jacob Ramirez

ECE 2804–Integrated Design Project
- Alex Betz
- Nate Guevara
- Isham Harris
- Nick Meier
- Rahul Muthuraman
- Lucas Polanco

ECE 2804 Integrated Design Project: Home Audio System Design

LEFT TO RIGHT: Nate Guevara, Alex Betz

CHALLENGE

The project tackles the issue of accommodating the different speakers in a home audio system, as not all can be sufficiently powered through a standard audio jack. To resolve this, the home audio system employs a class-D amplifier to enhance the audio output, enabling diverse speakers to be effectively driven. In support of the amplification, the system incorporates a 3-band equalizer, granting users the ability to fine-tune bass, midrange, and treble frequencies, customizing the audio experience to their preferences. Moreover, a spectrogram feature is integrated to provide a visual representation of the audio.

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Alex Betz Lynchburg, Virginia

Bachelor of Science in Electrical Engineering
Electrical Controls, Robotics, & Autonomy

Aspirations: After getting my bachelors, I hope to goto graduate school here at Tech and get my masters in Power Systems Engineering

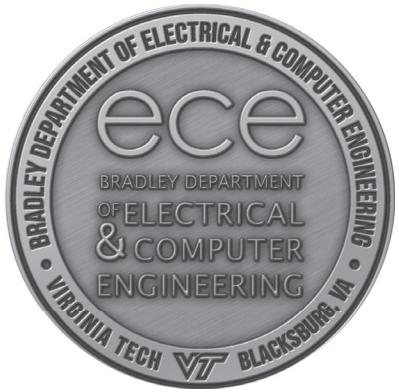
Course Comment: Taking Integrated Design Project gives students a hands-on opportunity to design an entire project from the ground up. This comes with the support a typical classroom setting gives you. This class properly prepares you for not only the major design experience but also for your future career.

Nate Guevara Fairfax, Virginia

Bachelor of Science in Electrical Engineering
Space Systems

Aspirations: I aspire to be commissioned into the Space Force as a Developmental Engineer, closely working with DoD partners and engineers alike

Course Comment: The Integrated Design Project challenged me to think outside the box. We were given a set of constraints and freedom in how we chose to achieve milestones. This allowed us to try new things and make mistakes without consequence.



Home Audio Design Project

Team: Alex Betz & Nate Guevara
Instructor: William Yu

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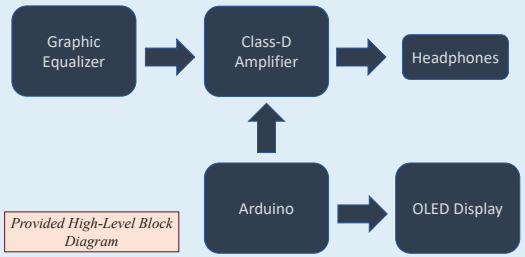
Background

In this project, we built a full home audio system, consisting of a class-D amplifier, a three-band graphic equalizer, and a spectrogram using an OLED display.

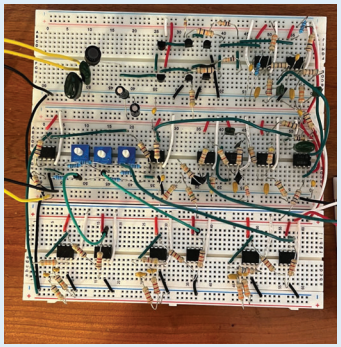
Class-D amplifiers are a type of switching amplifier that gained popularity due to their high efficiency. Designing this system involved signal processing, electronic circuit design, and microcontroller interfacing and coding. Using components limited to those found in first-year ECE take-home kits, this challenge proved to be difficult.



Provided High-Level Block Diagram

Constraints

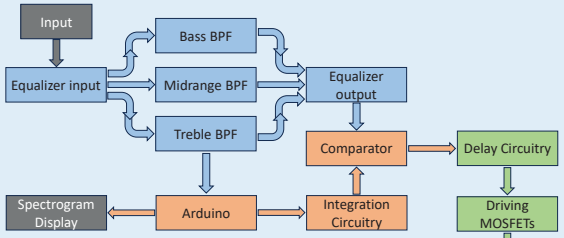
- All bandpass filters used must have a Q-factor of 1
- The equalizer must produce gain and attenuation
- The modulator must have a carrier frequency at or larger than 30kHz
- Shoot through current of the driving transistors must be less than 100mA
- The output of the low-pass filter under a 390Ω load must produce positive gain



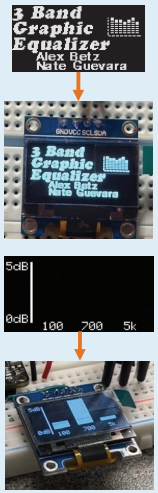
Equalizer and Amplifier Stages

System Design

Filter Design
The system begins with our implemented equalizer design, consisting of three bandpass filters represented by the blue blocks.
- Each filter has a potentiometer connected to its output.
- The output of each filter and potentiometer combo is mixed using a signal combiner with the input audio wave to create balance.



Modulation
Orange blocks represent the modulator, which transforms the audio signal into a Pulse Width Modulation (PWM) signal.
- The Arduino provides a square wave as the carrier
- The circuitry shifts the PWM down, integrates it, and amplifies it to cover any audio signal properly.



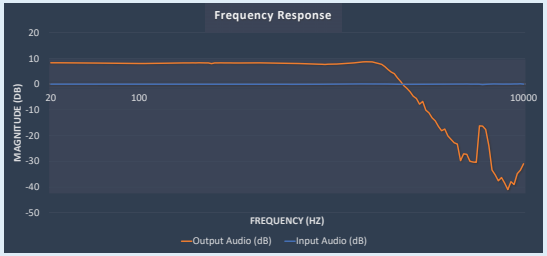
Creating a PWM signal with an Arduino
- Takes advantage of built-in timers on ATMega328
- PWM techniques: Direct register manipulation
- Count-up with toggle mode to generate ~50kHz square wave

OLED Display
2 Screens:
- Welcome Screen: Static
- Spectrogram Screen: Dynamic

Amplification
The amplifier stage, depicted in green, amplifies the signal using a MOSFET driver.
- Delay is implemented by filtering the modulator output and comparing it against a reference voltage.
- A logic gate separates the high and low sides of the MOSFET driver.
- This generates an amplified PWM signal, which is then converted back into an audio signal with a low-pass filter.

Audio Output
Finally, the filtered audio signal is sent to the load resistance (headphones).

Testing Results



Frequency Response
- The gain of the amplifier is 9dB in the audio range.
- The carrier frequency is attenuated 15dB at 50kHz
- The shoot through current is limited to just 64mA.
- The output is low noise with little to no audio quality loss.
- There is some parasitic impedance still leaking from the power rails to the output. While this has been greatly reduced, when no audio is playing the noise can be heard.

Sound Quality & Noise
- Equalizer had a noticeable impact on tone and color of the sound when using headphones
- Arduino usage for both PWM and display caused unwanted noise.
- EMI that originated from modulator stage was reduced with a 1nF capacitor
- Remaining noise likely due to parasitic impedance.
  - Full removal of noise requires transfer to protoboard or PCB.

Future Steps

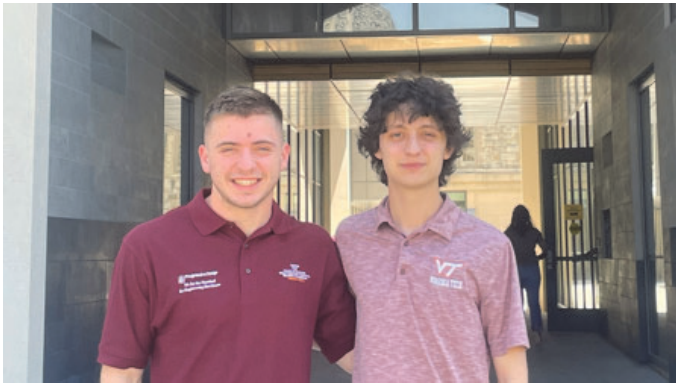
Enhancing Modulator Efficiency and Compactness
- The modulator currently undergoes a 3-step process involving a magic op-amp for voltage shifting, an integrator, and finally an amplifier.
- Consideration has been given to streamlining this process into two steps by integrating first. This would allow the second step to involve only shifting and amplification, achievable with a magic op-amp.

Achieving Modulator Equilibrium at 0V
- A crucial aspect of the amplifier is ensuring the modulator's equilibrium is precisely at 0V.
- The main concern is the conversion of the square wave into a triangle wave.
- An offset triangle wave can distort the audio wave, causing undesired amplification and attenuation where it should remain unchanged.

Adjusting Power Source to USB Availability
- Instead of relying on an oscilloscope as the power source, consideration is given to obtaining power from a USB source.
- Implementation of a buck inverter would enable obtaining negative voltage, enhancing versatility by eliminating the need for a dedicated 5V and -5V pin.

Replacing Output Low-Pass Filter with Butterworth Filter
- Current observations reveal a minor peak at the cutoff frequency, likely due to the quality factor exceeding 1.
- Switching to a Butterworth low-pass filter would maintain the same slope while keeping the quality factor at 1, particularly advantageous as the peak occurs in the treble range.

ECE 2804 Integrated Design Project: Infra-Red Radioteletype



LEFT TO RIGHT: Isham Harris, Nick Meier

CHALLENGE

This project involves designing a communication system that extends the transmission distance of an IR LED and photodiode, using specified frequencies and data rates, within strict component and power constraints.

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Isham Harris Highland, New York

Bachelor of Science in Electrical Engineering
Photonics

Aspirations: Once graduated, I hope to use my degree in the workforce, obtain my FE and PE, and become an engineer who upholds the standards of Virginia Tech.

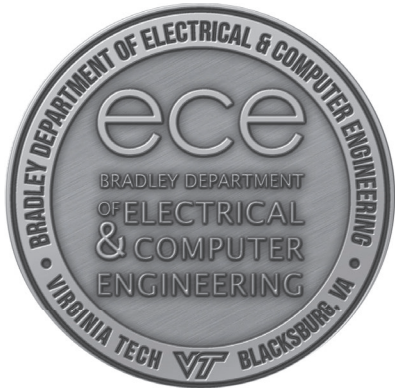
Course Comment: Nick and I found our greatest success in preplanning and asking lots of questions. Dedication to the project on selected days, regardless of its phase, let us accomplish our goals quickly. This structure also allowed us to ask Dr. Milburn the correct questions during class time.

Nicholas Meier Millstone, New Jersey

Bachelor of Science in Computer Engineering
Cybersecurity and Networking

Aspirations: I apsire to pay the price of success with hard work, authenticity, and patience.

Course Comment: This course has allowed me to digest material from both inside and outside my classes. Collaborating closely with a teammate and regularly providing milestone updates enabled me to engage deeply with a project and its stakeholders, giving me practical, hands-on experience.



Infrared Radioteletype Project

Team: Isham Harris and Nick Meier
Instructor: Dr. Tyler Milburn

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Objective

Overview

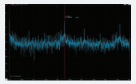
The project aims to create a modern Radio Teletype (RTTY) system that communicates over an infrared (IR) photodiode, focusing on maximizing communication distance within a power constraint for the transmitter. The system leverages an Arduino Uno for handling the TTY and modem functionalities, while transmission and reception are achieved through an IR LED and photodiode, respectively, accompanied by analog electronics for signal amplification and filtering. Achieving short-distance communication is straightforward, but extending this reliably to greater distances poses a significant challenge, especially under the limitation of 1mA current through the IR LED.

Requirements

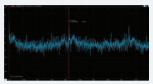
- Use an IR LED and photodiode; limit IR LED current to 1mA.
- Implement 2295Hz and 2125Hz for mark and space signals, with 45.45 baud rate and 8-bit ASCII in a UART frame.
- Apply signal amplification and noise reduction for long-distance communication.

Testing and Validation

2295 Hz



2125 Hz



These figures illustrate two distinct peaks, affirming that the system's parallel filters are finely tuned to clearly isolate the target frequencies of 2295 Hz and 2125 Hz

Lessons Learned

Iterative Design

We learned to research, test, and verify a component's functionalities. This minimizes the need to retrace steps by ensuring errors within a system are not from previous components.

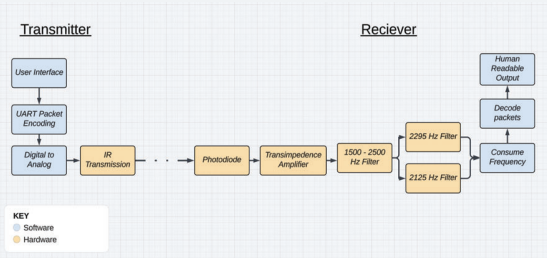
Documentation

Thorough documentation allowed us to easily communicate our progress with our SME. By clearly recording the rationale, tests, and outcomes, it enabled efficient troubleshooting and informed adjustments, accelerating the project's development and success.

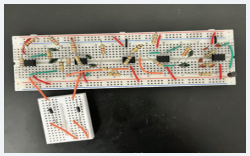
System Design

High Level Approach

- The transmission side begins with a simple series circuit to send out signals through the IR LED.
- The photodiode and transimpedance amplifier intercept that signal and convert it to a usable voltage.
- An initial filtration system is then used to gain the device as well as filter out outlying frequencies we will not need.
- The signal is then heavily amplified in order to achieve long distance transmission.
- The parallel filters take the amplified signal and attenuate all frequencies not at 2125 or 2295 Hz. The now filtered signal is then fed into an Arduino input.



Final Design

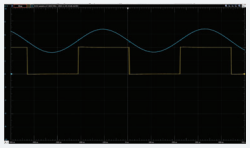


Condensed Circuit

The final circuit design is neatly assembled on one breadboard, with orange wires for connections between different stages and green wires for connections within a stage, ensuring a clean and organized setup.

Signal Processing

The signal processing begins with measuring the period between detected rising edges to determine the frequency, and subsequently maps this frequency to a binary value using predefined thresholds for '1's and '0's. Once a start bit is detected, the system collects the subsequent bits to form a packet and decodes the packet into characters using ASCII mapping, then outputs the decoded message for validation.

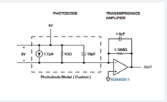


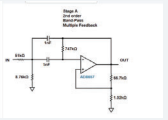
Receiver

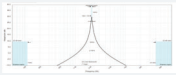
The initial inverted square wave from channel 2 is refined by filtering out unwanted frequencies, resulting in a smooth signal. At 15 feet, the final interpretable signal maintained a 3V peak-to-peak voltage.

We extend our deepest gratitude to Professor Tyler Milburn for his invaluable guidance and mentorship throughout the Integrated Design Project. His extensive expertise in Electrical and Computer Engineering (ECE) has not only enlightened us but also inspired a deeper understanding and passion for the field.

Hardware







Filter Specs

- Intrinsic filter gain along with our amplifier gain totals to a gain of 101.
- Passband of both high Q filters set to 50 Hz.
- Initial, noise reducing, filter set to attenuate frequencies outside of the 1.5k-3k Hz range.

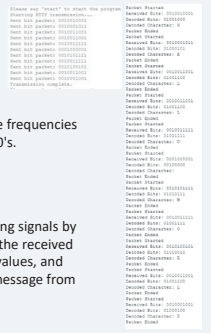
Transmission

- 1 mA limitation on IR LED transmitter.
- Transimpedance amplifier used to convert LED current into output voltage.

Software

Encoding Data

The transmitter encodes data by converting characters into 10-bit packets using mark and space frequencies to represent binary '1's and '0's.



Decoding Data

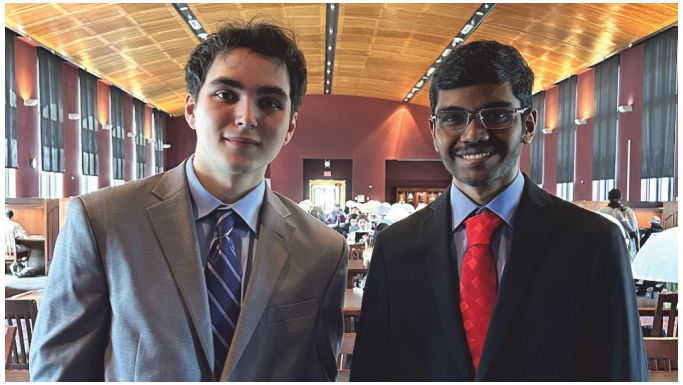
The receiver decodes incoming signals by measuring the frequency of the received signal, mapping it to binary values, and reconstructing the original message from the encoded packets.

Further Improvements

Encryption

Incorporating encryption into the system would significantly enhance its security and privacy. By implementing algorithms such as AES (Advanced Encryption Standard), messages could be encrypted before transmission, safeguarding sensitive information transmitted over the airwaves.

ECE 2804 Integrated Design Project: SpO2 Pulse Oximeter



LEFT TO RIGHT: Lucas Polanco, Rahul Muthuraman

CHALLENGE

The goal of this project is to create an accurate SpO2 pulse oximeter, which measures heart rate and oxygen saturation. The circuit for this project uses only simple components found in a lab kit such as resistors, capacitors, and op-amps. Using these components, filters and amplifiers are created to make the signal output from the sensor usable. The output signal is then sent to an Arduino which handles all the signal processing and calculations. The Arduino uses algorithms to exclude any outliers and calculates the heart rate by measuring the time between the peaks of the signal and calculates the oxygen saturation with a formula that is directly proportional to the ratio of red and infrared light absorbed by the finger.

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Lucas Polanco Chantilly, Virginia

Bachelor of Science in Computer Engineering
Software Systems

Aspirations: I aspire to enter industry as well as further my education through self-study.

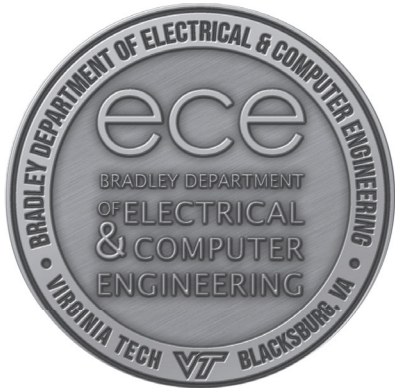
Course Comment: During my time at Virginia Tech, IDP is by far the most enjoyable course that I have had the pleasure to take. We used all the concepts we had previously learned in a practical application. This course gave me confidence in the skills and knowledge I have acquired and I feel prepared to start more challenging projects.

Rahul Muthuraman Virginia Beach, Virginia

Bachelor of Science in Computer Engineering
Machine Learning

Aspirations: After completing my Bachelor's degree, I aspire to further my knowledge by pursuing a Master's degree in Computer Engineering here at Virginia Tech.

Course Comment: Integrated Design Project was one of the more exciting classes I took last semester. It lets students apply all the theoretical information they have learned up until sophomore year on a practical and hands-on project. After completing this course, I feel better prepared to work on projects that require innovation and collaboration to overcome design challenges and constraints.



SpO_2 Monitoring System

Team: Rahul Muthuraman, Lucas Polanco
Instructor: Md Adnan Sarker

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VIRGINIA TECH

Background

The SpO_2 pulse oximeter is an important tool used in healthcare and fitness. You have most likely seen or used one before. Whether it was at a hospital or you may be wearing one now in the form of a smartwatch. These monitors provide vital information about respiratory and cardiovascular function in a convenient and small form factor.

Blood contains two types of hemoglobin, oxygenated and deoxygenated. Both types have different absorption coefficients as shown in Figure 1. Which means that Oxygenated hemoglobin absorbs more infrared light compared to deoxygenated hemoglobin. While deoxygenated hemoglobin absorbs more red light compared to oxygenated hemoglobin. Using the ratio of red and infrared light absorbed by hemoglobin, the sensors accurately show the amount of oxygen saturation.

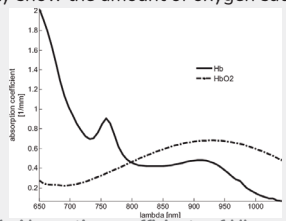

Figure 1: Absorption coefficients of Hb vs. HbO_2 [1]

Objective

- Design a SpO_2 pulse oximeter that accurates displays the heartbeat and oxygen saturation on an OLED display using the sensor given as shown in Figure 2.
- Complete this design only using parts found in a lab kit such as resistors, capacitors, op-amps, and an arduino

Figure 2: SpO_2 Sensor

Circuit Design

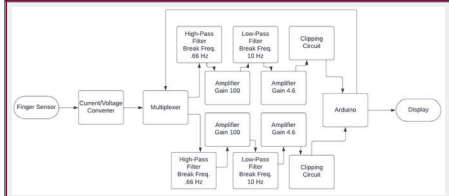

Figure 3: Block Diagram of SpO_2 Pulse Oximeter System

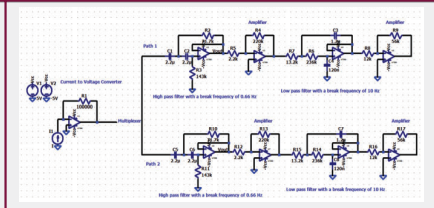

Figure 4: Circuit Diagram of SpO_2 Pulse Oximeter System

As shown in Figure 3, two paths were designed for the two LEDs in the SpO_2 sensor. Each path contains the following:

- High Pass Filter: To remove the DC offset since DC has a frequency of 0 Hz.
- Low Pass Filter: To remove any high frequency noise from surroundings.
- Amplifiers: To make the signal usable for the Arduino since the voltage after the amplifiers is low.

A current to voltage to converter was used to convert the current produced by the photodiode into voltage. All filters used were second-order butterworth filters. The signal was amplified to be within a readable range of the arduino. A multiplexer was used to power both LEDs at the same time since they are in anti-parallel configuration in the SpO_2 sensor.

Software Design

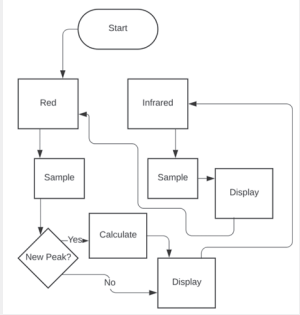

Figure 5: Finite State Machine of Arduino Code of SpO_2 Pulse Oximeter System

The software calculates heart rate by identifying peaks in the waveform. Since the system can be volatile due to any movement of the sensor and changes in lighting, the software uses statistical analysis to only allow gradual changes in heart rate by ignoring possible outliers. Blood oxygen is calculated by finding an R-value, which is the ratio between the magnitude of the red LED signal and infrared LED signal and deriving a linear equation that relates R-value to blood saturation.

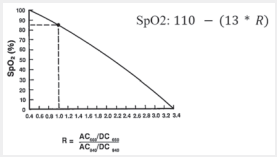

Figure 6: Equation to calculate oxygen saturation

Validation

To validate our design, the final output of the system was compared to a commercially available SpO_2 sensor. The variance between the commercially available sensor and our circuit was ±1% for the heart rate, and ±2% for the oxygen saturation. The display of the working SpO_2 pulse oximeter system is shown in Figure 7.

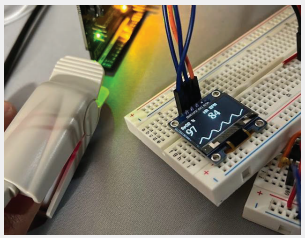

Figure 7: Output of SpO_2 Pulse Oximeter System

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References

[1] Principal component model of multispectral data for near real-time skin chromophore mapping - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Absorption-spectra-of-deoxygenated-Hb-and-oxygenated-HbO-2-blood-with-the-isosbestic_fig4_46034130 [accessed 5 Sep, 2023]

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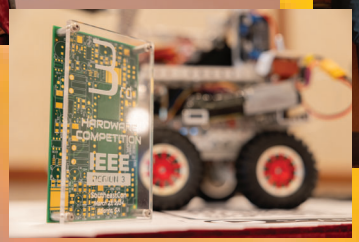
Proposed Lux Map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