SYSTEM OF NETWORKED SENSORS FOR DETECTION AND CHARACTERIZATION OF UNDERGROUND ACTIVITY
FINAL PRODUCT PRESENTATION

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Technical Manager : Dr. Tomas Materdey
Customer Mentor: Cpt. William Shepherd

Team Members

Tyler McKean

Senior EE student

Augustus Standeven

Senior EE student

Vulindsky Fanfan

Senior EE student

Yohannes Kidane

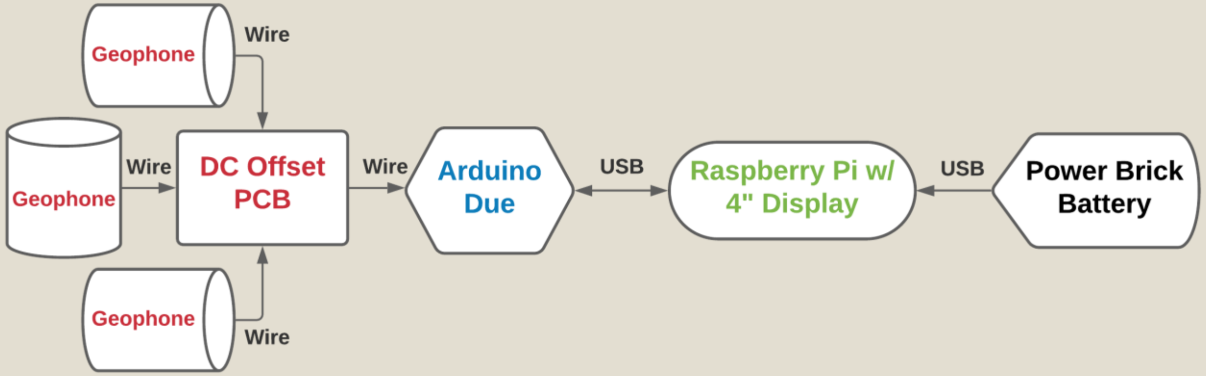
Junior EE Student

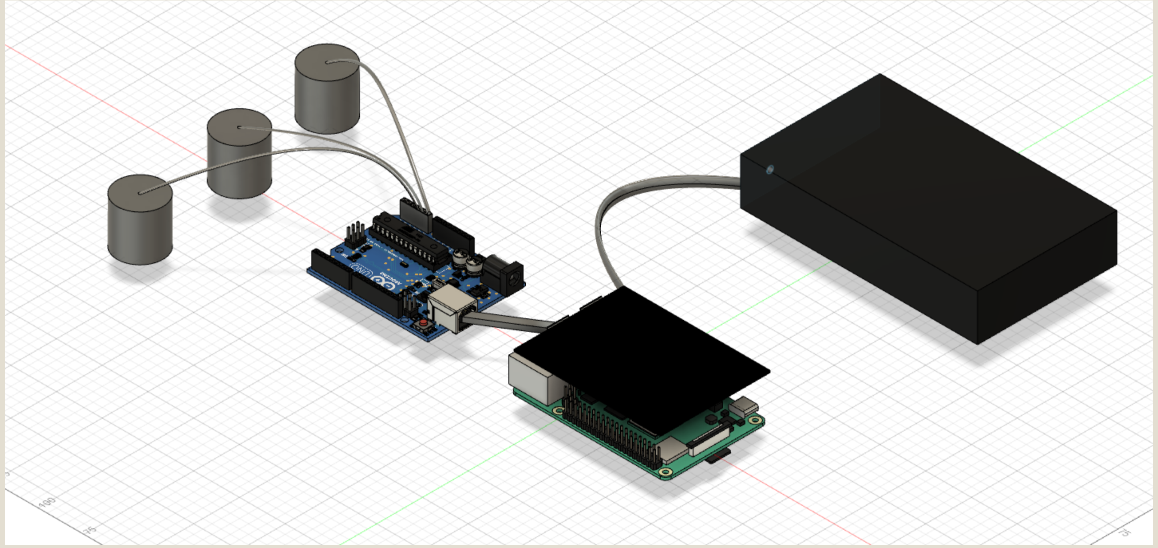
Problem Definition

- Designing a system of networked sensors for detection and characterization of unauthorized underground activity.
- Capstone Project Requirements:
  - Provide security for government property
    - Military bases at home/abroad
    - Government facilities
    - National Border Security
- Portable, durable, and unobtrusive
- Able to cover a 100-meter radius
- Cheap, Inexpensive Components
- Wireless Network of sensors
- Self-contained power source
- Able to process data and categorize types of signals
  - i.e., determine the likelihood of whether a signal received was from a passing truck or from a tunnel being dug.
- Able to send processed signal data to a smartphone/laptop for user to interpret data

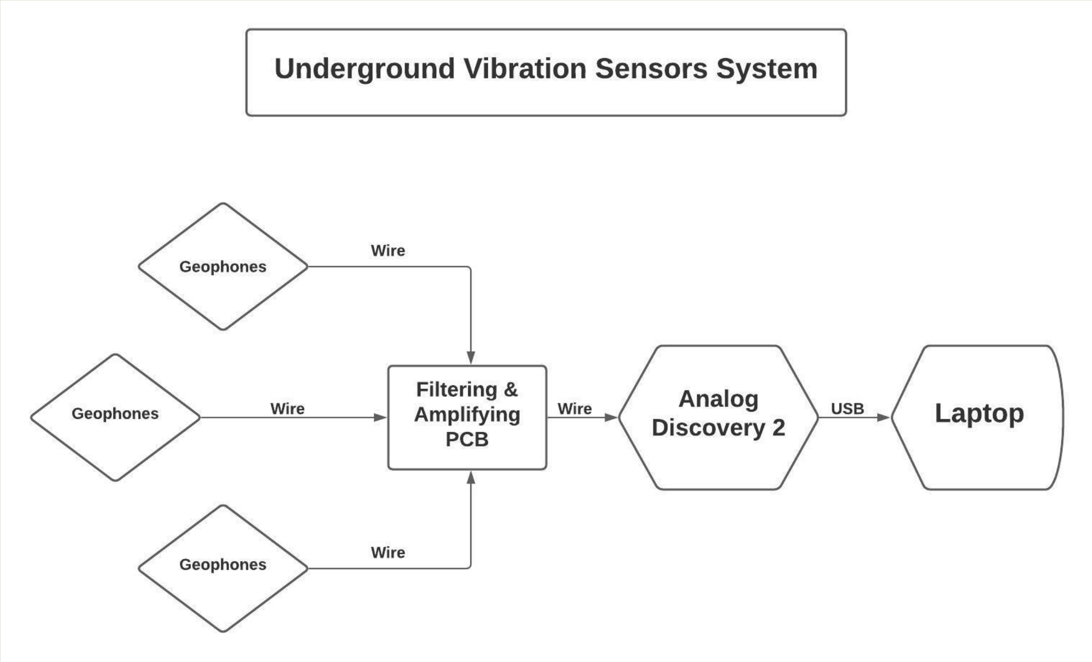
System Diagram

- **Geophone Sensors with DC Offset PCB**
  - Passive Vibration sensors will be offset by 1.65V to capture peaks and troughs of oscillations.
- **Arduino Due**
  - 12-bit Resolution for A/D Conversion
  - Sample Rate at 500Hz
  - Serial communication via USB port to Raspberry Pi for data logging.
- **Raspberry Pi w/ LED screen**
  - Data logging of Serial data from Arduino.
  - Python scripts that Preprocess logged data and Extracts Statistical and Analytical Features that are imported into a KNN Machine Learning Model.
  - Displays predictions of Vibrations to GUI, which includes History tab for previously occurred events.
- **Power Brick Battery**
  - Provides 12V 6000mAh/5V USB DC voltage

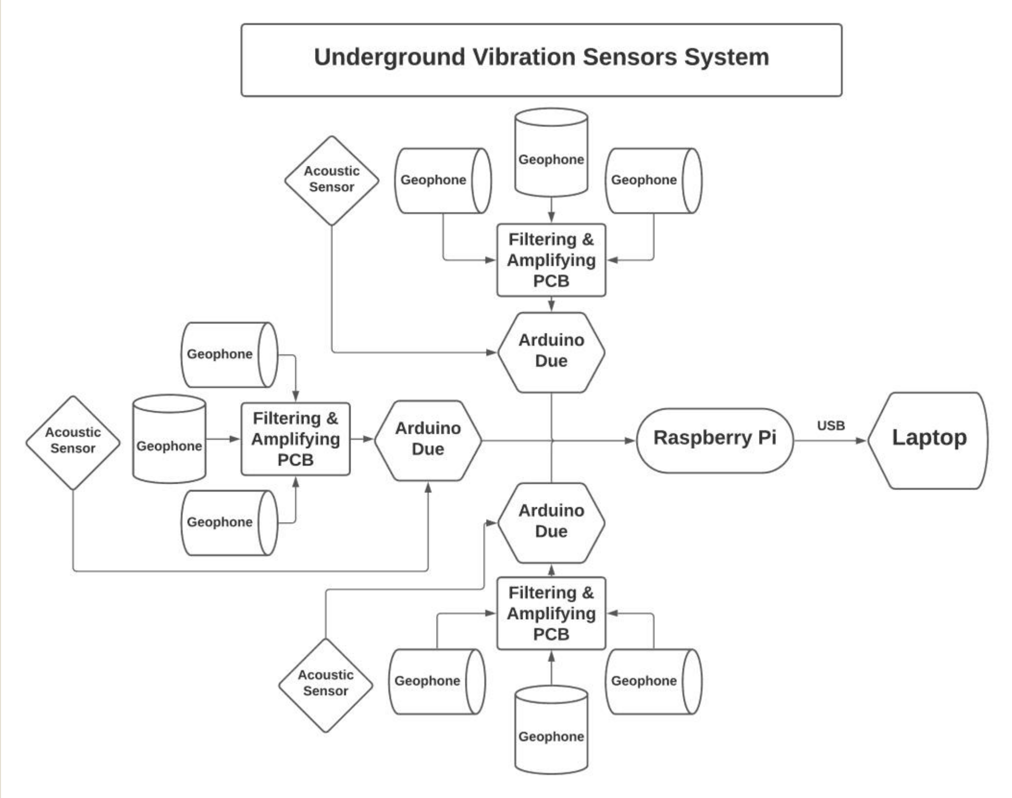




Design Improvements



First Prototype Design

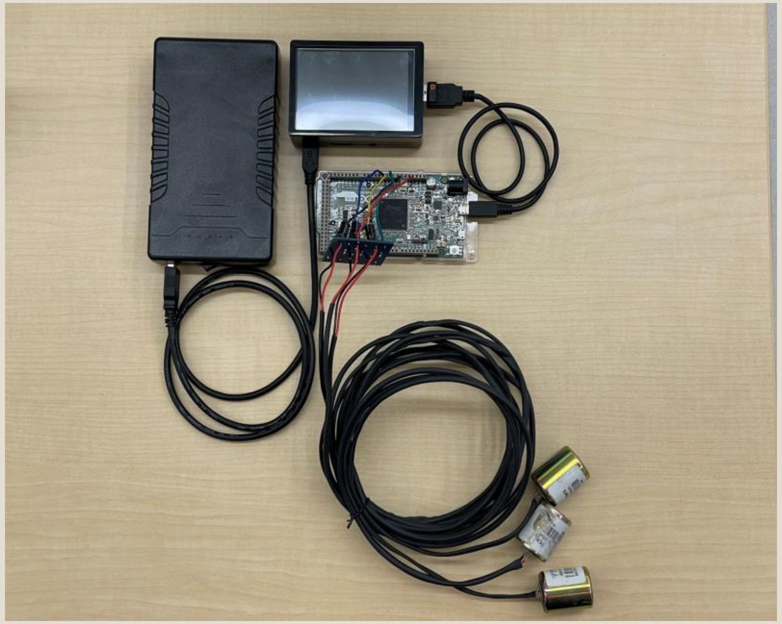


Second Prototype Design

Design Improvements

- All Components tied together, hardware has changed
- Replaced AD2 with Arduino for ADC of vibrations data
- PCB connected to Geophones
- 2-meter length insulated wires for Geophones
- Raspberry Pi gathers the vibration data and displays it to GUI
- Introduced Power Brick battery to make system portable

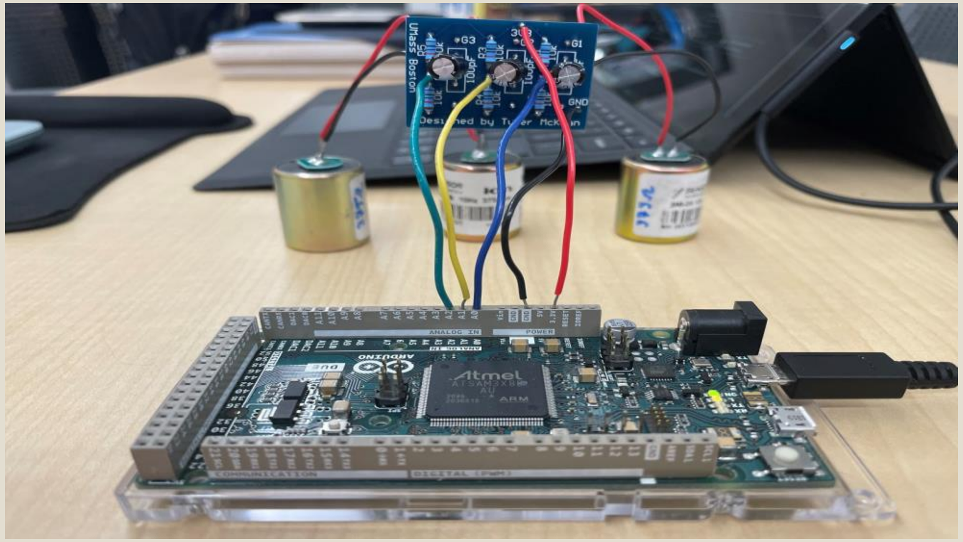
Initial Prototype

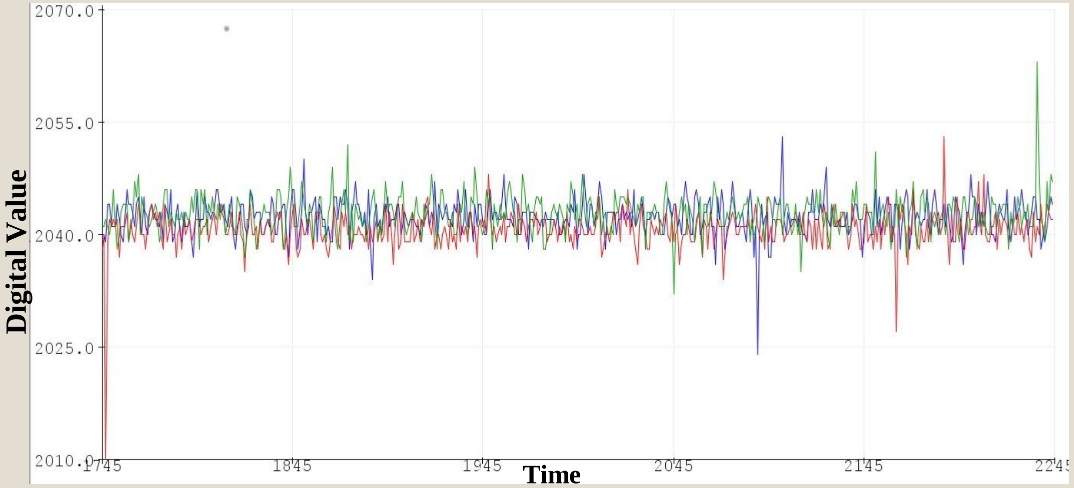


Final System Design

DC Offset PCB

- <u>Functionality</u>:
  - Reasoning:
    - Provide DC Offset to Geophone vibrations
    - Without DC Offset, Arduino would only capture the peaks and not the troughs of the oscillations
    - Allow Arduino to capture full oscillation information
  - Equal resistor values will lead to voltage divider of Vref/2
  - Digital values range from 0-4095 and will be centered around (2^12)/2 => 4096/2 = 2048
- <u>Results:</u>
  - PCB measurements vs expected values have low tolerance
  - Observed values from Arduino show 3 geophones (red, blue, green) centered just above 2040
  - PCB functioning as intended





PCB Input	Measurement (V)	Expected Value (V)	Tolerance (%)
A0	1.64962	1.65	0.02
A1	1.64984	1.65	0.01
A2	1.65023	1.65	0.01

Collecting Samples

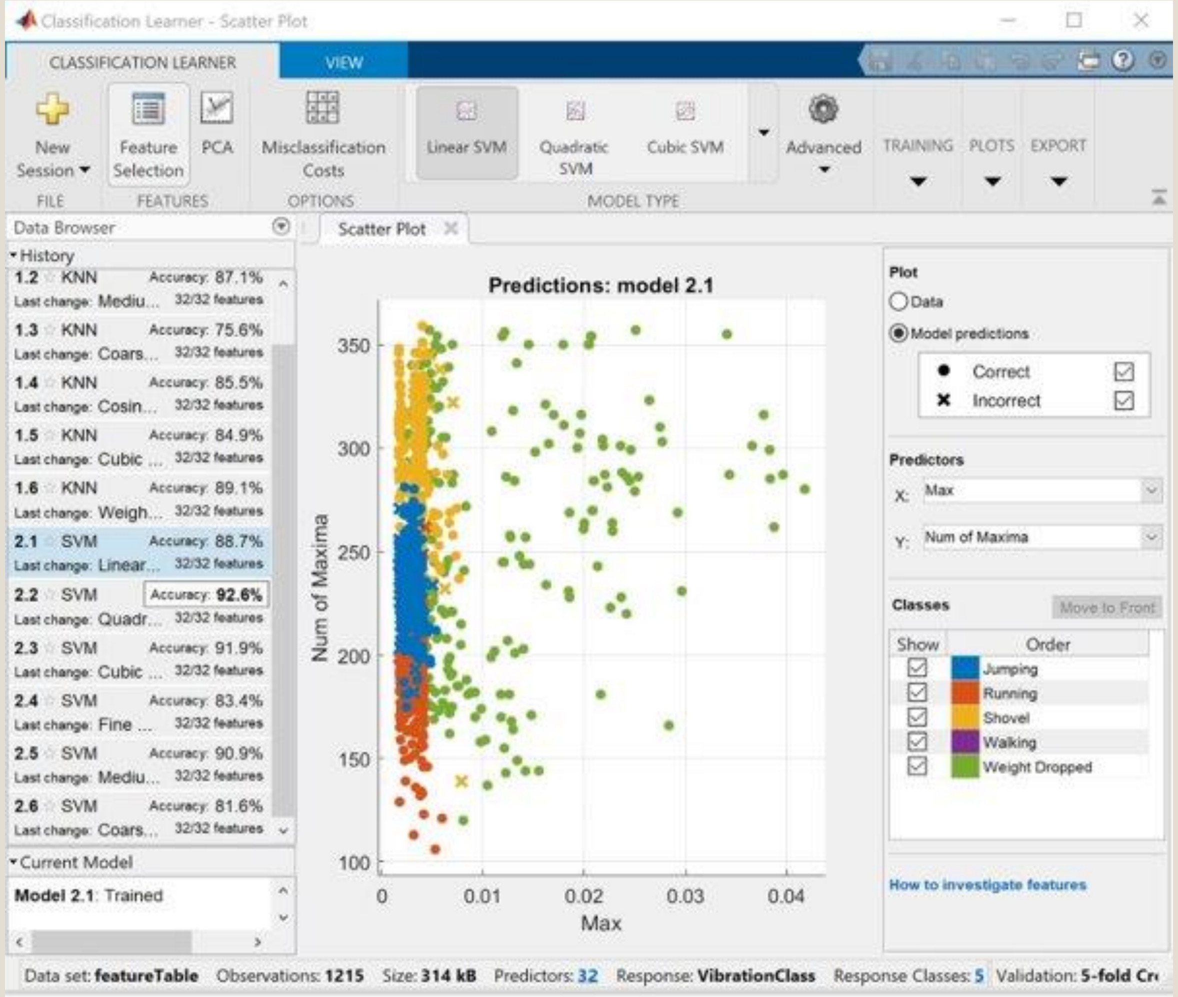
- Performed Signal Capture to obtain 1215 samples across 5 different Vibration Classes
  - 243 samples/each
- Recorded three 81 sec long observations
- Preprocessed in MATLAB to sparse data into 27 - 3 sec observations
- 27 x 3 Geophones = 81 observations
- 3 runs x 81 = 243 samples

- Time performing Test:
- 3 mins per run
- 15 runs total
- ~ 45 mins - 1hr total test length

Design Validation Tests

Test #1: Machine Learning Model

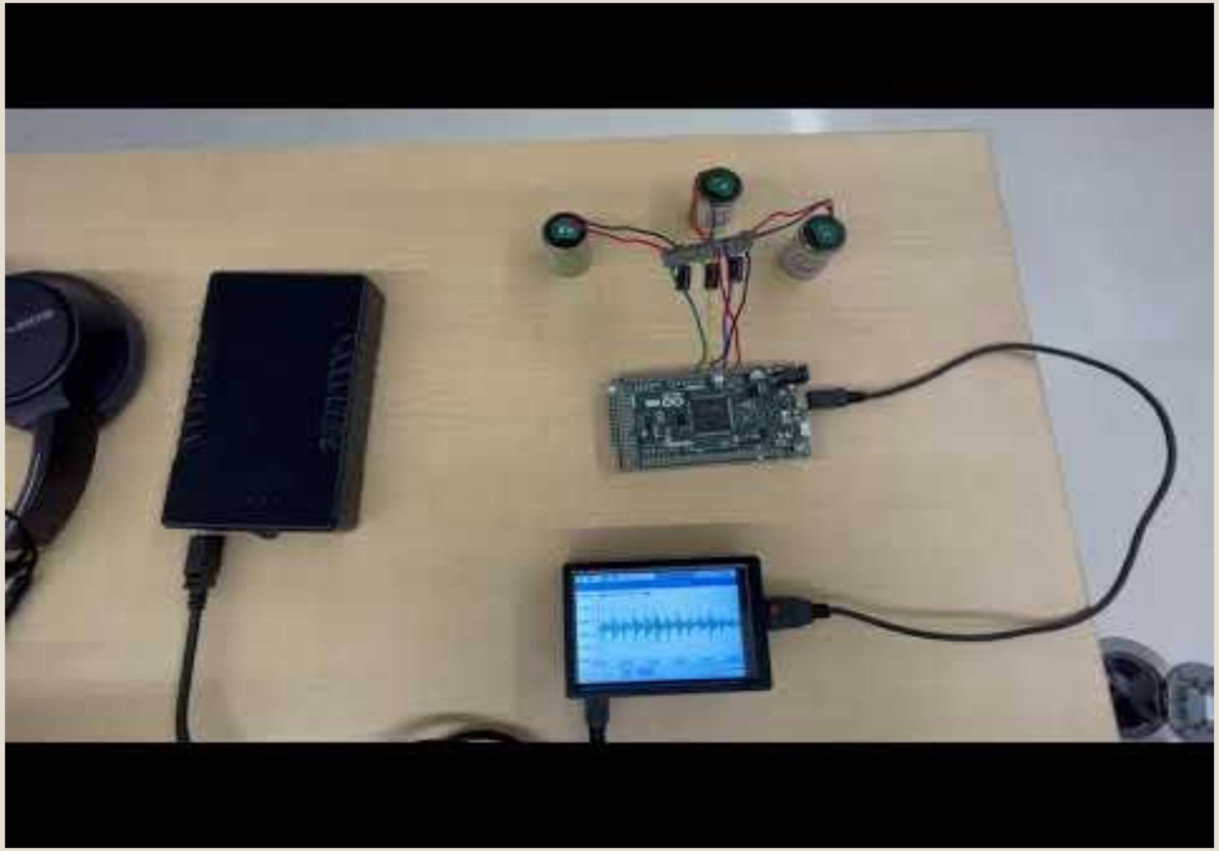
- Performed by: Tyler/Vulindsky/Augustus
  - Extract 32 Features from large set of signals
    - Mean, Max, RMS, etc...
  - Use data to train ML model in MATLAB
  - Validate same model/data in Python
  - Compare results from MATLAB/Python
- Problem Statement :
  - Classify vibrations to 70-80% accuracy
  - Build a Signal Library to classify



Design Validation Tests

Test #2: Data Acquisition & Logging

- Performed by Augustus/Tyler
  - Interconnections between Arduino and Raspberry Pi subsystems
  - Display vibration data to the LCD Display of Raspberry Pi
  - Additionally, saving the data to a .csv file that will be accessed by Python



Design Validation Tests

Test #3: Battery Life of Power Supply

- Performed by Tyler/Yohannes
  - Verify the Power Brick total battery life
  - Power Ratings: 12V 6000mAh/5V USB
  - Raspberry Pi: 5V/2.5A
  - Arduino Due: 3.3V
  - Power Daisy Chained from Battery-> Raspberry Pi -> Arduino Due
  - Calculated length: 15 hours

TalentCell Rechargeable 12V 6000mAh/5V 12000mAh DC Output Lithium-Ion Battery Pack

Validation Results

Test #1 Results

- Performed by: Tyler/Vulindsky/Augustus
  - Extract 32 Features from large set of signals
    - Mean, Max, RMS, etc...
  - Use data to train ML model in MATLAB
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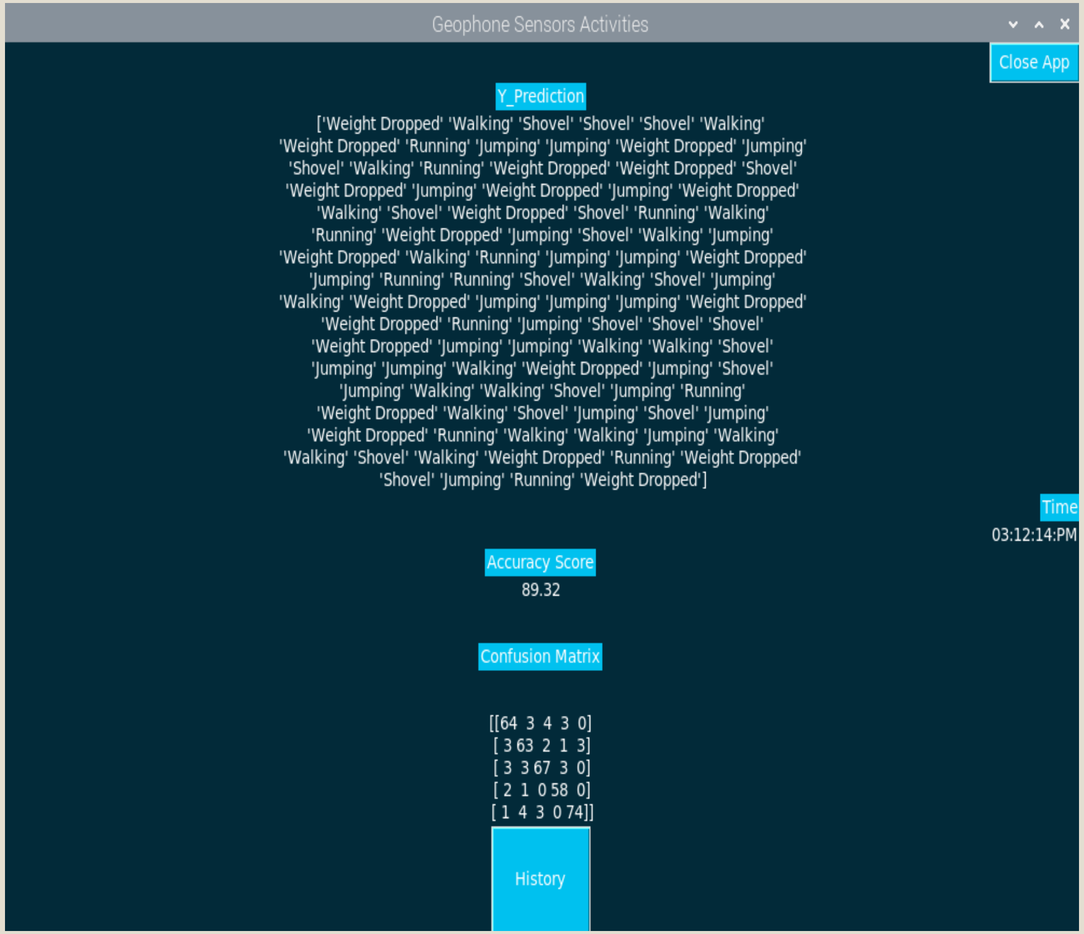
- Part of Machine Learning Toolbox

- Uses Supervised Learning to train different models of data - provided known inputs with known classes
  - UI allows us to train multiple models for reference to which model fits our expected vibration signals



Validation Results

Test#2 & 3: Data Logging and Battery

- Video shows data values captured and converted Arduino and serially sent and saved by Raspberry Pi
- Battery at Full Charge
  - Data acquisition started at 6:15pm and saved to .csv file on Raspberry Pi
  - Last recorded timestamp around 4:50am next morning
  - About 10 hrs 35 mins of Battery life
- Total test time ~ 11 hours

2	[18:15:00.251122 0.003687] 2042	2045	2044
3	[18:15:00.256513 0.005392] 2042	2044	2043
4	[18:15:00.261645 0.005133] 2043	2044	2042

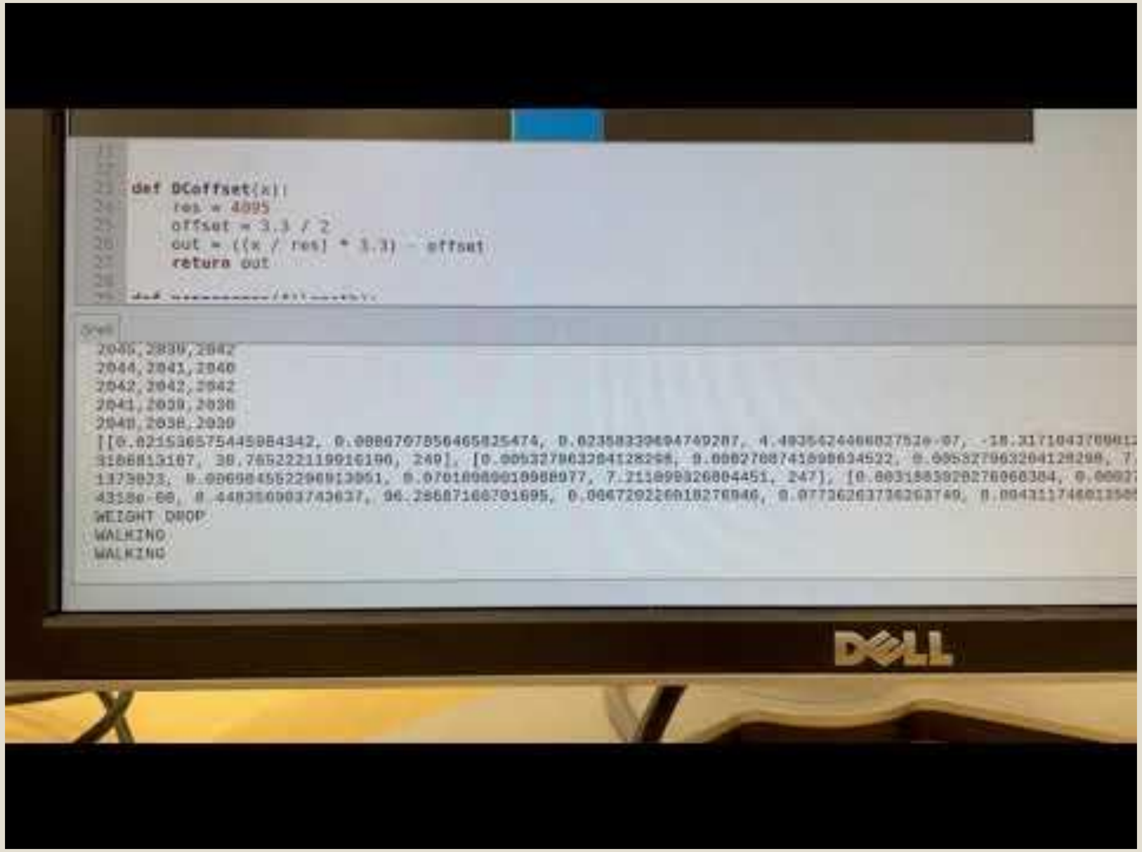
Initial recording time: 6:15pm

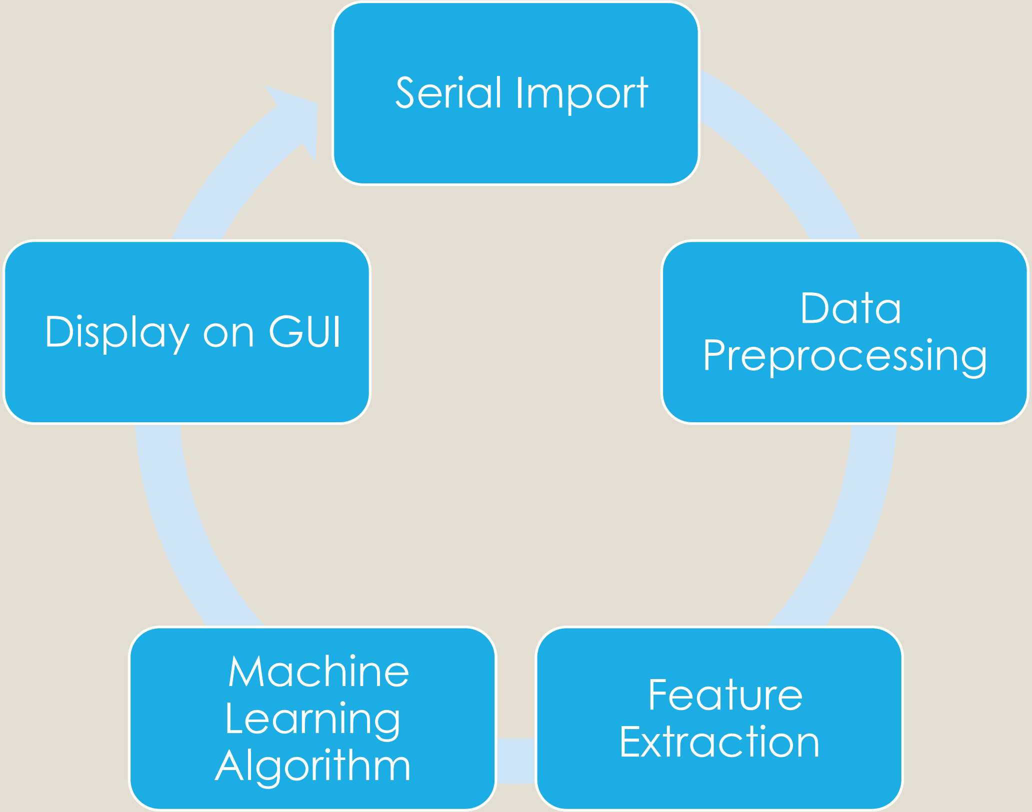
1048574	[04:50:48.883449 0.015818] 2043	2041	2042
1048575	[04:50:48.899638 0.016189] 2041	2040	2043
1048576	[04:50:48.916668 0.017031] 2043	2041	2042

data-03-28T-2021-00_00_00

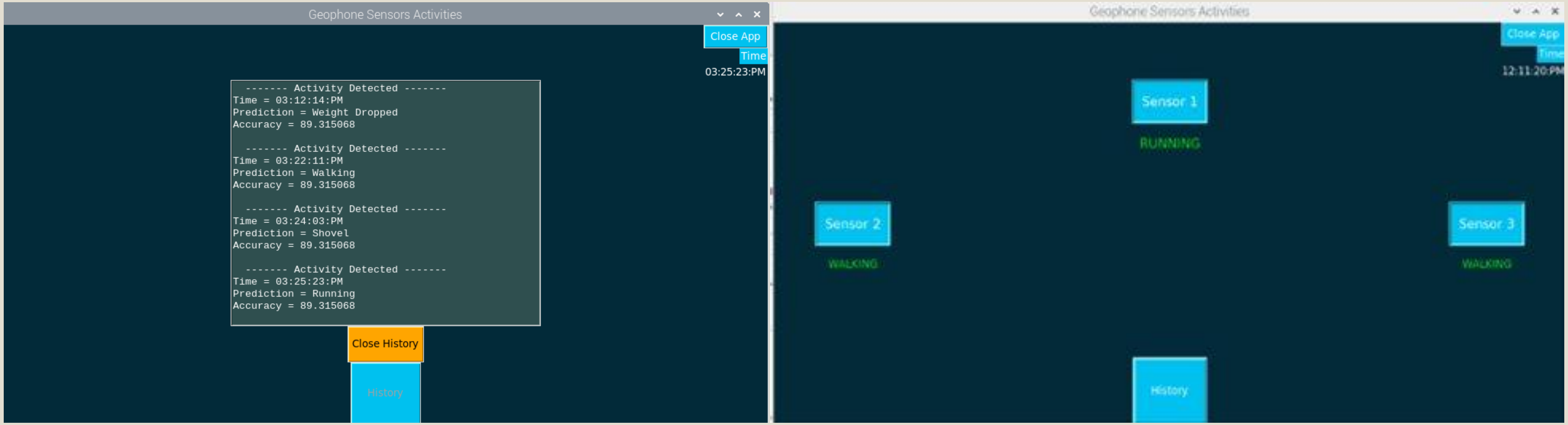
Final recording time: 4:50am

Real-Time Vibration Detection





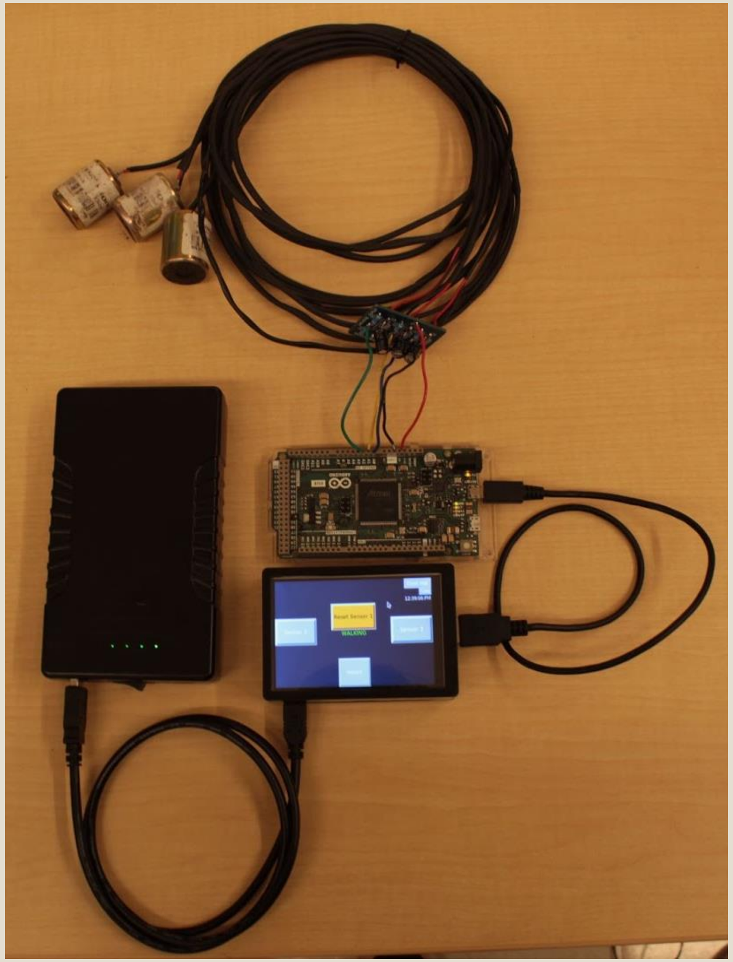
GUI



- GUI made in Python
  - Sensor tabs to display what each sensor predicts
  - History tab to look through previously classified signals and what time they occurred

Final Deliverables

- 9 Geophone Sensors
- DC Offset PCB
- Trained KNN Model that characterizes known vibrations to an 89% accuracy
- Arduino Due & Raspberry Pi 3 B+
- 6000mAh Lithium-Ion Power Brick Battery
- GUI that displays real-time data analysis to User via touch screen
- OneDrive folder with all software so that next team could continue and impove project next year



Final Budget & Components

- Vibration Data Acquisition
  - Geophones
  - Arduino Due
  - Raspberry Pi 3 B+ with LCD Display
- Data Analysis
  - Altium Designer
    - PCB Design and Simulation
  - LTSpice/PSPICE
    - Filter/Amp Circuit Analysis
  - Matlab Toolboxes
    - Signal Processing Toolbox
    - DSP Toolbox
    - Machine Learning Toolbox
- MATLAB
  - Classification Learner for ML model validation
  - Preprocessing/Feature Extraction
- Python
  - GUI Development / Data Logging
- Arduino IDE
  - ADC of Arduino Due


SM-24 Geophone

DC Offset PCB


Arduino Due

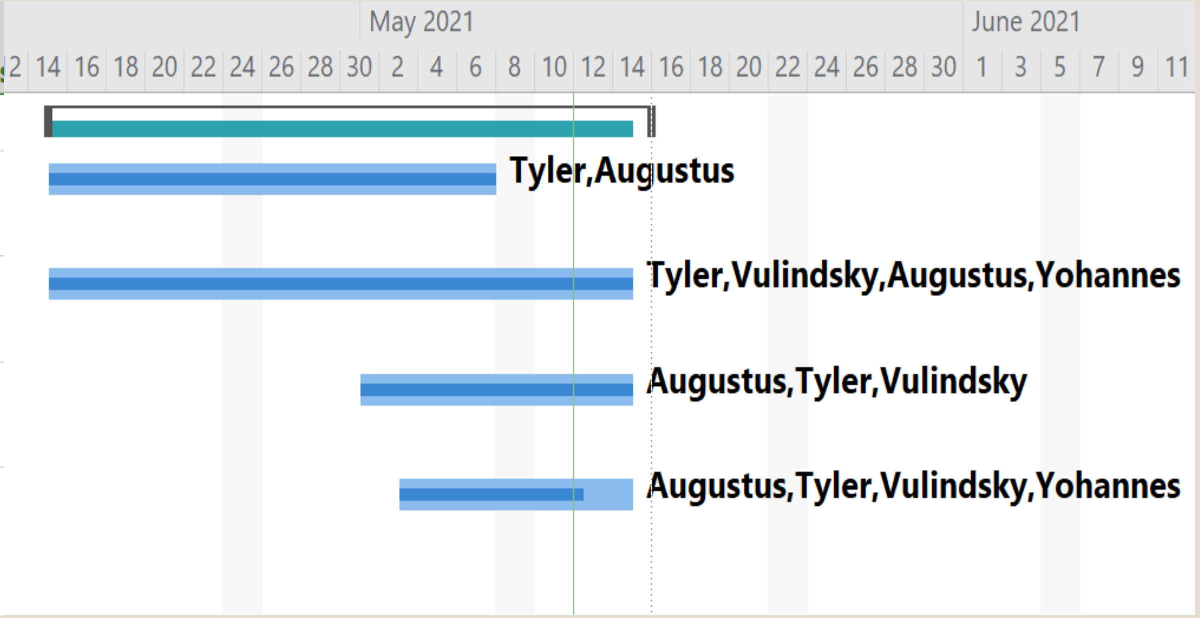

Raspberry Pi 3 B+ w/ LCD


Power Brick Battery

9 SM-24 Geophones	$540
BNC Adapter and Alligator Clips for AD2	$29
Arduino Due	$42
Raspberry Pi 3 B+	$35
Lithium Ion Battery	$38
Raspberry Pi 3 B+ Case and LED screen	$28
PCB Order	$20
Micro HDMI to HDMI Adapter	$11
Raspberry Pi 4 Touchscreen with Case & Fan	$37
SanDisk 256GB Ultra microSDXC	$35
	Total: $815

Project Management

Task Name	Duration	Start	Finish	Predece
Finishing Stage	**23 days**	**Thu 4/15/21**	**Sat 5/15/21**	
Prepare Final Poster & Video	17 days	Thu 4/15/21	Fri 5/7/21	
Prepare Final Product Presentation	22 days	Thu 4/15/21	Fri 5/14/21	
Prepare Final Deliverables	10 days	Sat 5/1/21	Fri 5/14/21	
Prepare Final Product Report & Individual Reports	10 days	Mon 5/3/21	Fri 5/14/21	



Team Roles & Communication

Team Members

- Cpt. William Shepherd (Stevens Institute of Technology
    - Customer Mentor
- Dr. Tomas Materdey (UMass Boston)
    - Technical Manager
- Tyler McKean (Senior EE Student)
    - Time Management, MATLAB/Python Feature Extraction, Classification Learner, Arduino Due, PCB
- Augustus Standeven (Senior EE Student)
    - Communications, MATLAB/Python Scripting, Signal Library, Raspberry Pi, Data Logging
- Vulindsky R. Fanfan (Senior EE Student)
    - Machine Learning, Python Implementation, GUI development and integration, Real time functionality of the system, Data Capture
- Yohannes Kidane (Junior EE Student)
    - Filter/Amp Design, Power Supply Management

Methods of Communication

zoom

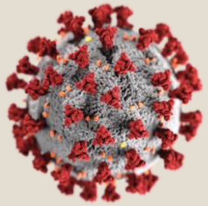
UMASS BOSTON

Weekly Meetings

Team Meetings : Mon/Wed/Fri 10:00-4:00 PM

CM/TM Meetings: Mon/Fri 3:00-4:00 PM

Ethical Considerations



Engineering Design Ethics

- Safety

IEC 60478 - Stabilized Power Supplies, DC Output

  - Right supply voltage to each component,

  Reassuring electrical safety as to not injure user or damage hardware.

  - Use insulated wires
  - Assure safe connections to onboard pins

- Design Requirements
  - Signals Classification
  - Self -sustained
- Economic Requirement
  - Stayed within budget
- ISO/IEC 25012 - Quality of Data
  - Accuracy, Consistency, Credibility
- ISO/IEC 25064 - User Needs Report
  - Accommodating User’s needs by reporting necessary data that is useful

COVID-19

- Precautions and Prevention
  - Masks and Weekly Tests
  - Transferring of equipment
  - Stayed at least 6 feet apart
  - Avoid crowds and poorly ventilated space

Future Work

Immediate Work

- Dataset Library
  - Improve library by collecting new dataset in different environments
- Battery
  - New battery to improve system sustainability
- Filter/Amplifier PCB
  - Amplifier for weaker/low vibration signals
  - Increase range of sensors
- Data Processing
  - Increase the number of features

Potential Improvements

- Wireless Geophones
  - Greatly improve range and flexibility of the system
- Cameras
  - Adding more functionality to the system such as image classification and/or facial recognition
- Accoutic Sensors
  - Detect and classify sound

Acknowledgements

- Our group would like to acknowledge the input and support of our Customer Mentor: William Shepherd and Technical Manager: Dr. Tomas Materdey
- Andrew Davis for ordering parts and lab access
- UMass Boston Engineering Department & Steven Institute of Technology

Questions

References

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