Smart Door Lock

Team 10

Client - Diane Rover

James Gossling - Hardware System Design

Hailey Lucas - Embedded System Design

Jackson Lopata - Mechanical Design

Eric Reusch - Software System Design

Isaac Stich - Embedded System Design

Christian Williams - Embedded System Design

Frankie Mago - Machine Learning Algorithm Design

Project Vision

Our goal is to use machine learning in an embedded system that has real world applications and solves physical problems that could be integrated into the ISU curriculum. We have chosen a Smart Door Lock that recognizes a user by their voice and a specified keyword to lock or unlock a door.

Project Vision

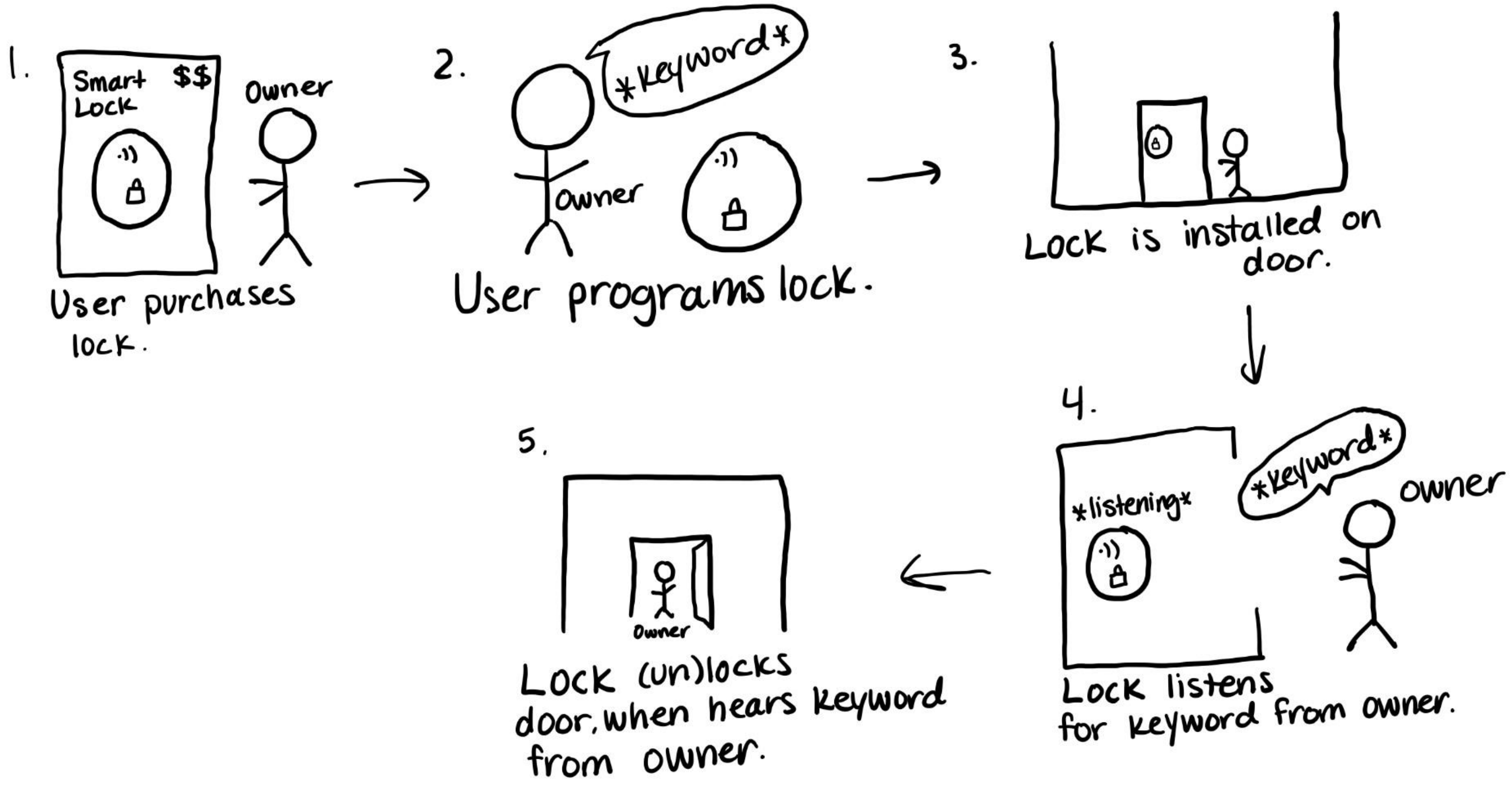
Goal: Embedded Machine Learning project for ISU class

Project: Smart Door Lock

Use Cases:

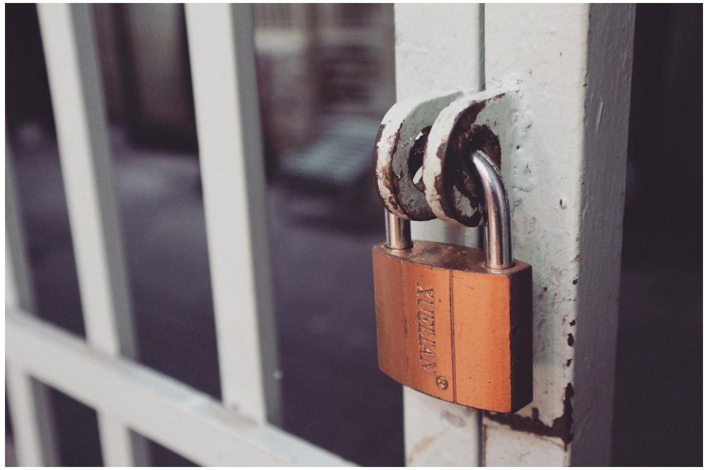
- **Class:** project from start to finish, experience with embedded machine learning, hardware and software components
- **Commercial:** convenience, additional security

Conceptual Sketch



- Designing physical mechanism to turn the lock
- Training a machine learning model for keyword and voice recognition
- Connection between hardware, embedded device, and ML model

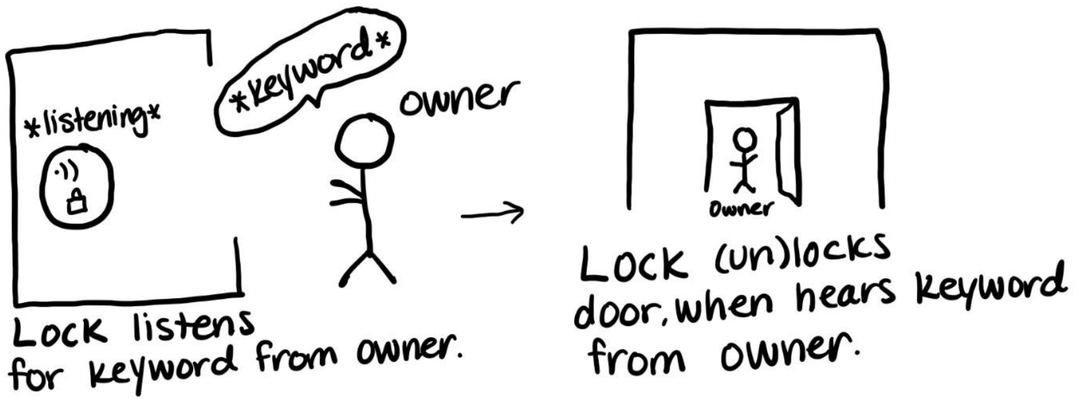
Users & Needs



- Property Owners
  - Convenient way to (un)lock doors
  - Secure internal and external doors
- Locksmiths/Safe Companies
  - New product to sell to customers
  - Integrate Smart Door Lock on safes
- Insurance Companies
  - Potential for less claims due to more secure buildings
- Security Companies
  - New product to sell to customers
  - Increase in security for properties & products

Requirements

- Incorporate machine learning to an embedded system
- When the programmed user says their keyword, the door (un)locks
- Only the programmed voice works
- Users must agree to having voice recorded with purchase of lock
- Appropriate technical complexity for an ISU course
- Easy for the user to program a keyword
- Easy to install

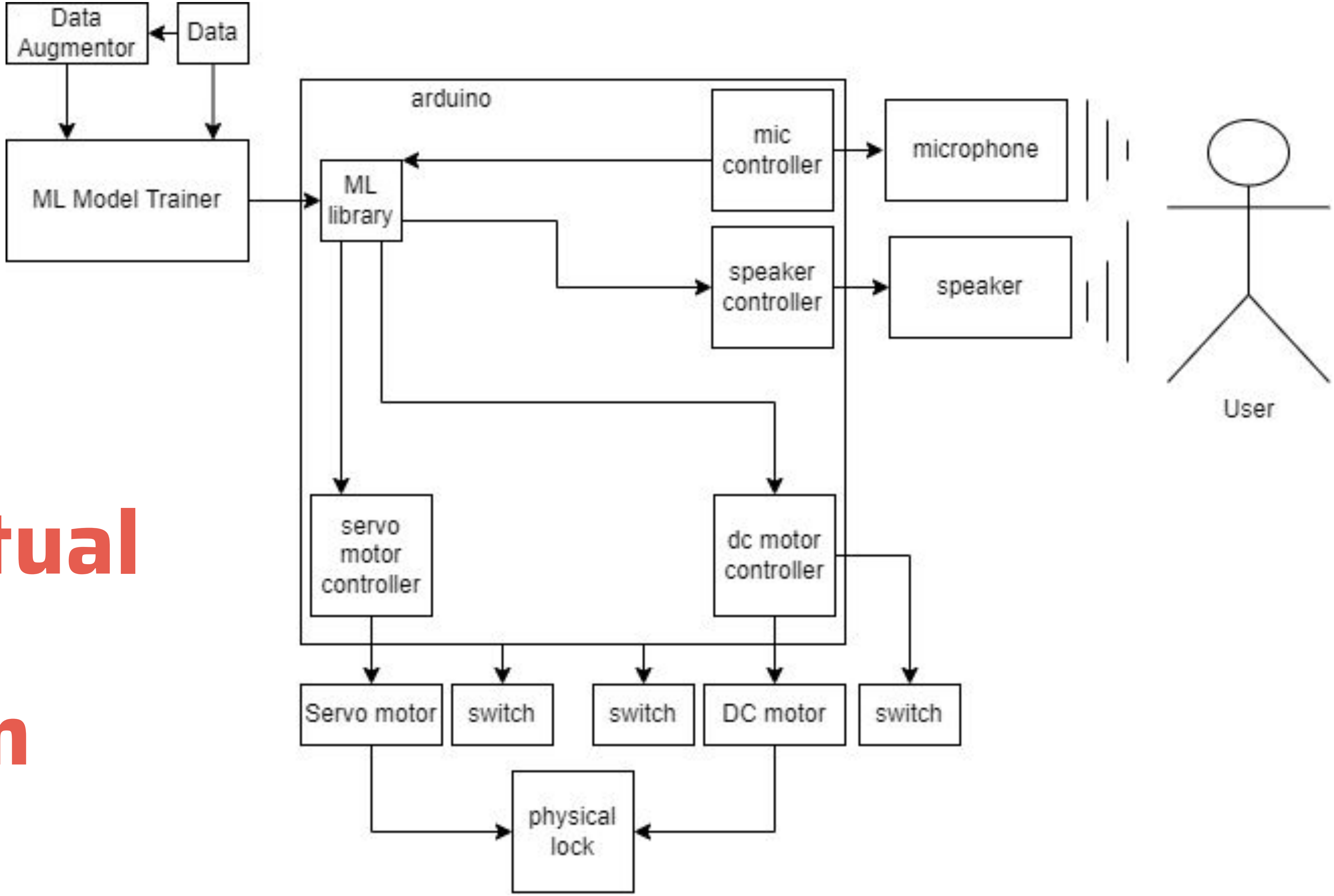


Constraints

- Machine Learning accuracy of 90% on voice and keyword recognition
- (Un)locks the door within 5 seconds
- Memory/computational power of our embedded device
- Mechanical design size: must be small enough to fit on door lock

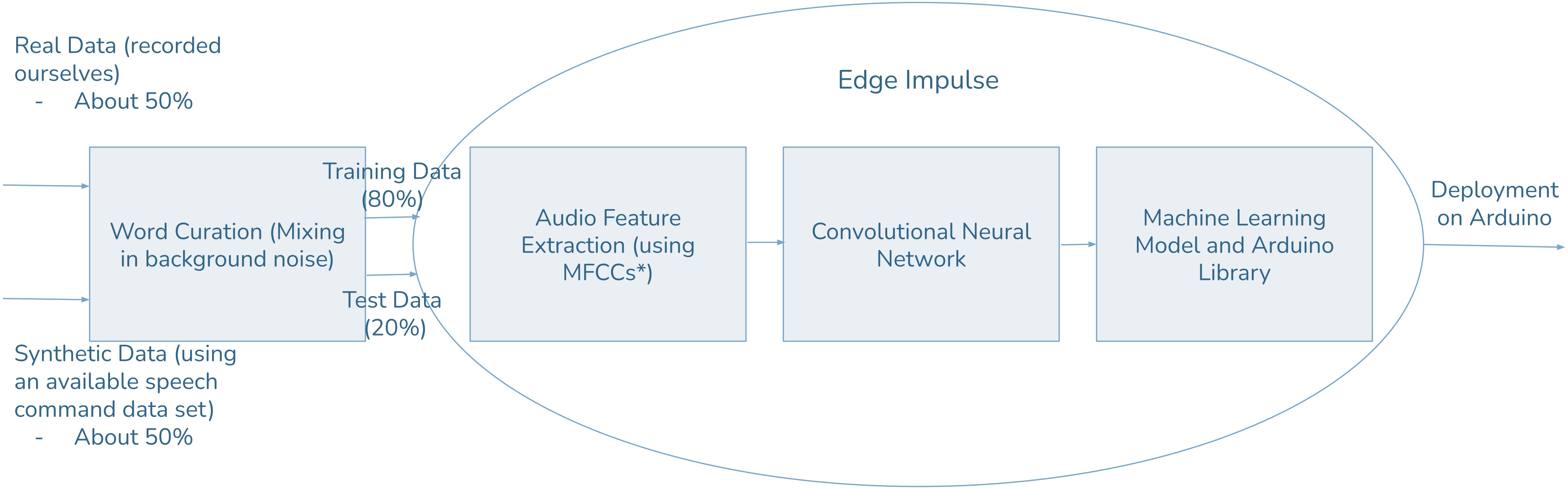
Standards

- Follow ANSI Grade 3 requirements for lock
  - Strength & Durability
- Follow BHMA Residential Security Grade C requirements for lock
  - Strength, Durability, and Finish
- IEEE Standards for AI & Autonomous Systems
  - IEEE P7001 (Transparency)
  - IEEE P7002 (Data Privacy)



Conceptual Design Diagram

System Design - Machine Learning

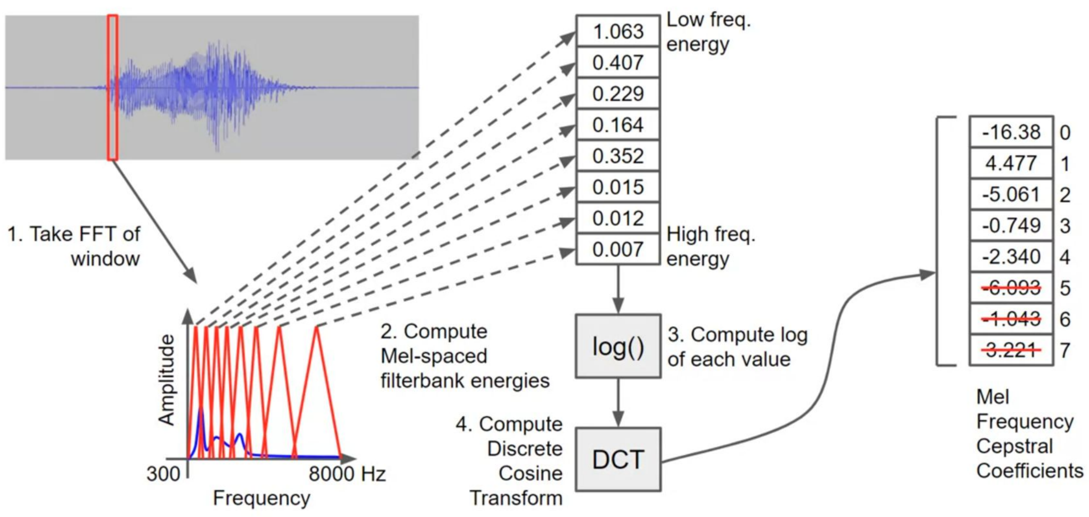


*MFCCs: Mel-Frequency Cepstral Coefficients

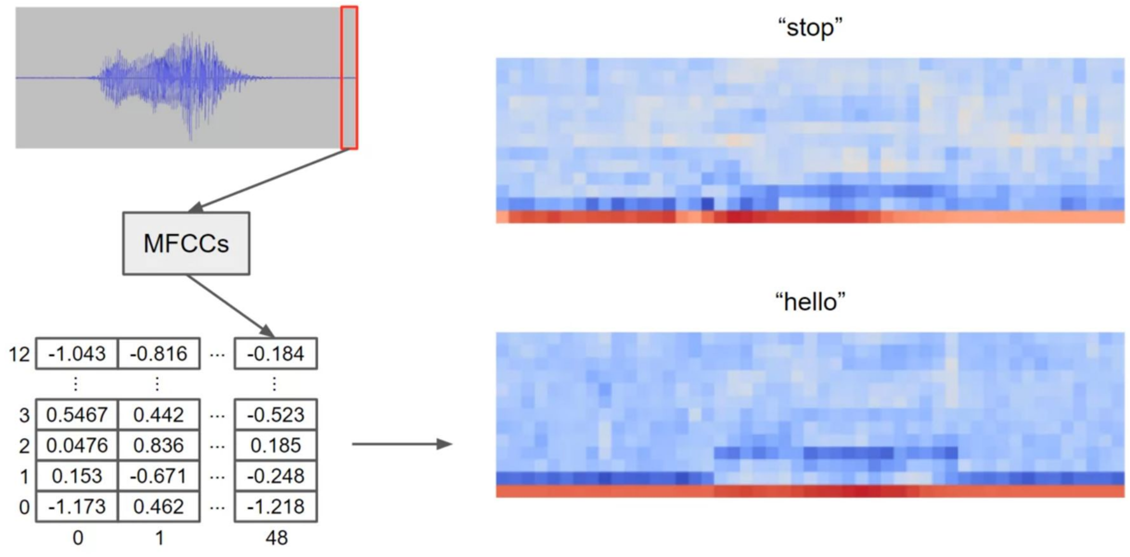
System Design - Machine Learning

MFCCs background:

Mel Frequency Cepstral Coefficients (MFCCs)



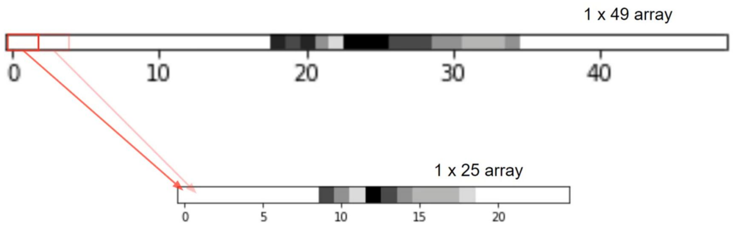
Mel Frequency Cepstral Coefficients (MFCCs)



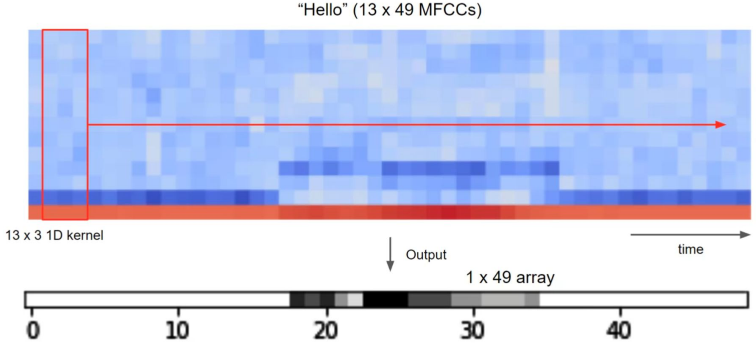
System Design - Machine Learning

Neural Network architecture/background:

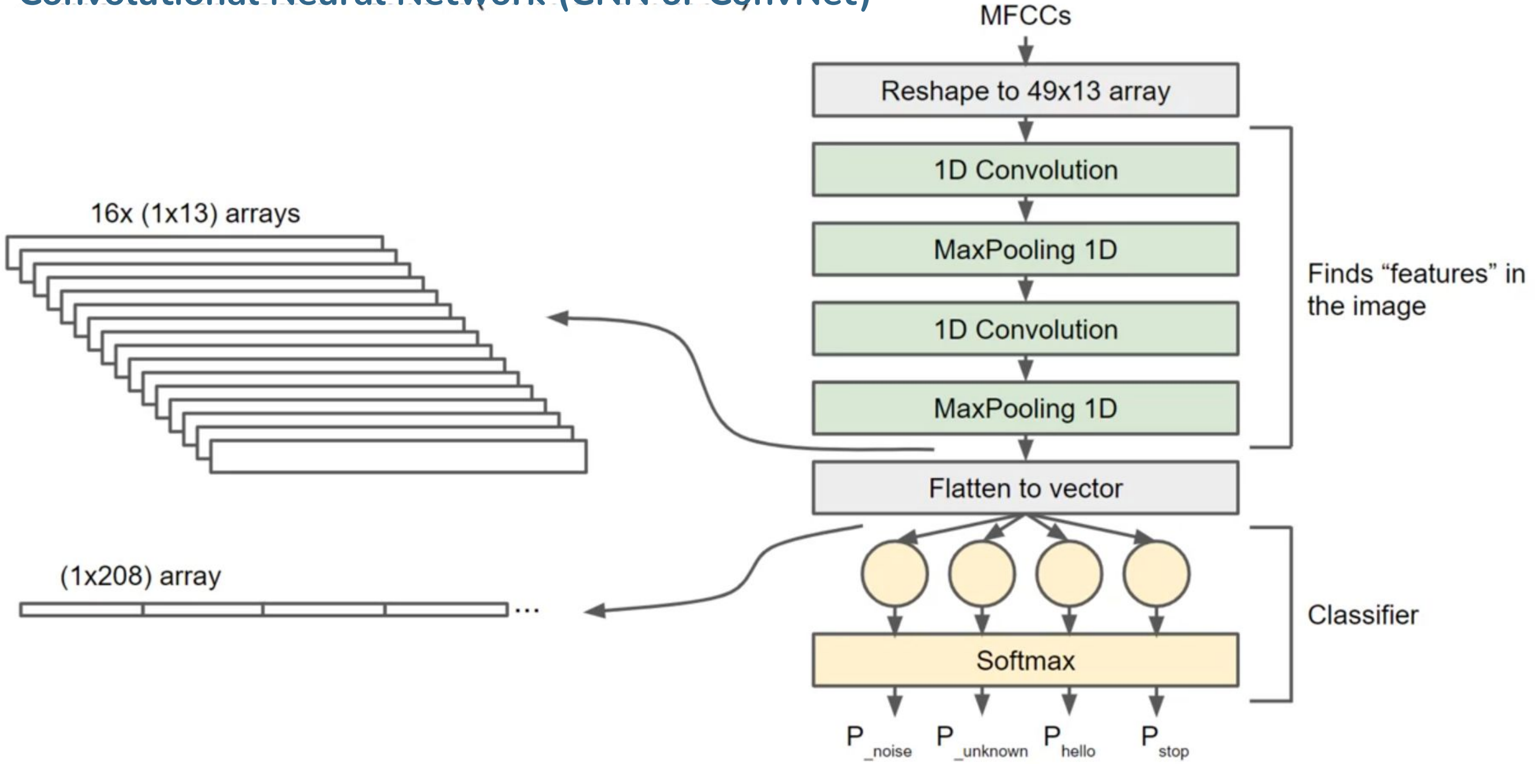
1D MaxPooling



1D Convolution



Convolutional Neural Network (CNN or ConvNet)



Prototype From Coursera/Edge Impulse

Keyword spotter Neural Network testing results (using 80% of the data for training):

Last training performance (validation set)

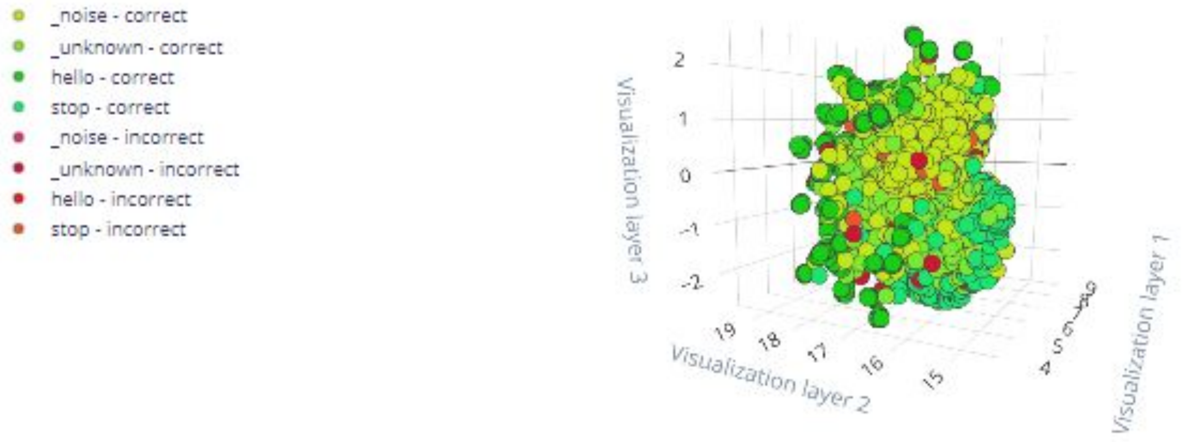
ACCURACY
93.3%

LOSS
0.24

Confusion matrix (validation set)

	NOISE	UNKNOWN	HELLO	STOP
_NOISE	98.7%	0.9%	0%	0.4%
_UNKNOWN	4.8%	87.7%	2.0%	5.6%
HELLO	0.4%	0.8%	98.8%	0%
STOP	3.1%	7.9%	0.9%	88.1%
F1 SCORE	0.95	0.89	0.98	0.90

Feature explorer (full training set) ?



F1 Score takes both false positive and false negatives into account. Therefore, it performs well on an imbalanced dataset.

Prototype From Coursera/Edge Impulse

Keyword spotter model testing results (using 20% of the data for testing):

Model testing results

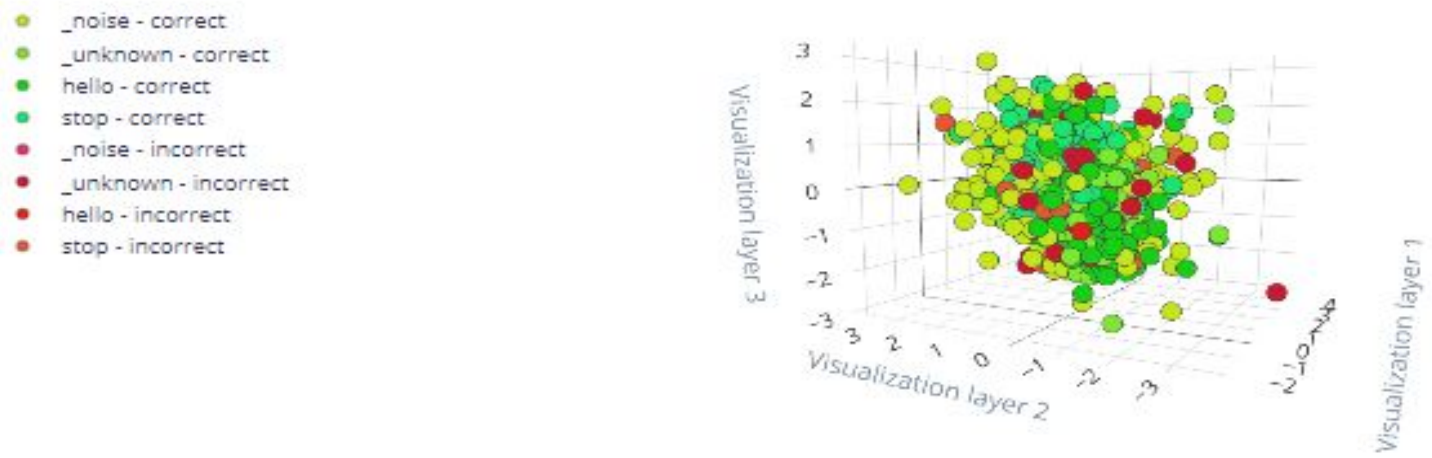
%

ACCURACY

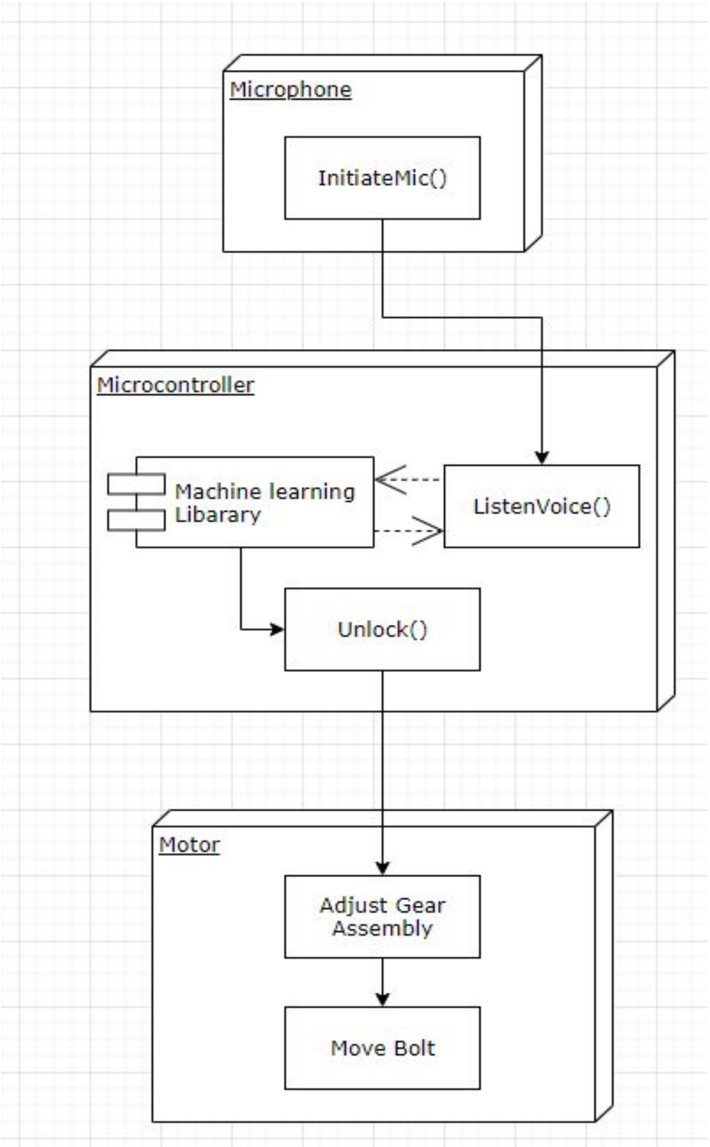
89.42%

	_NOISE	_UNKNOWN	HELLO	STOP	UNCERTAIN
_NOISE	98.3%	0%	0%	0%	1.7%
_UNKNOWN	3%	76.3%	4.3%	5%	11.3%
HELLO	0.3%	1.3%	96.3%	0.3%	1.7%
STOP	3%	4%	0.3%	86.7%	6%
F1 SCORE	0.96	0.84	0.96	0.90	

Feature explorer ?

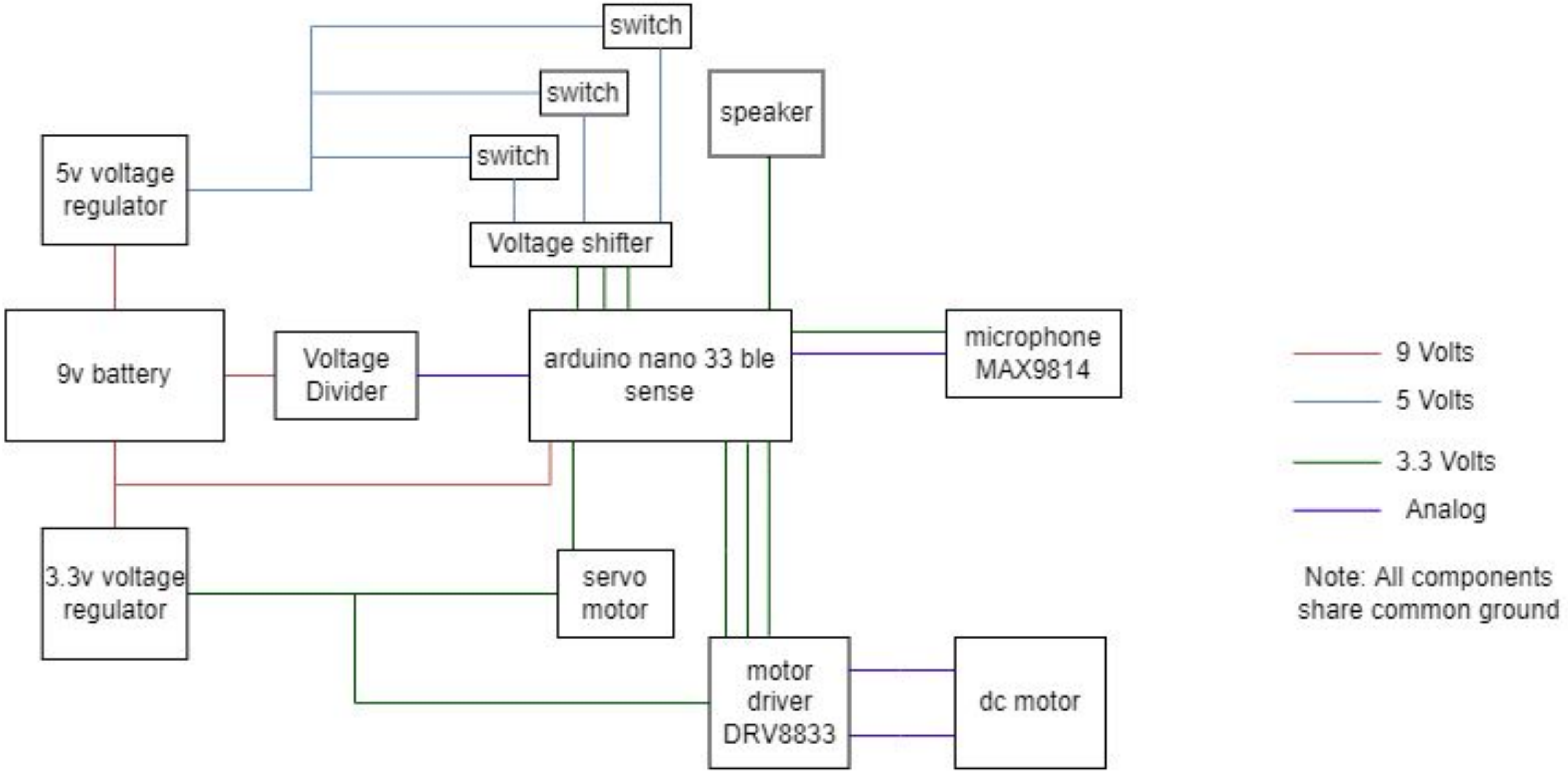


Software System Design



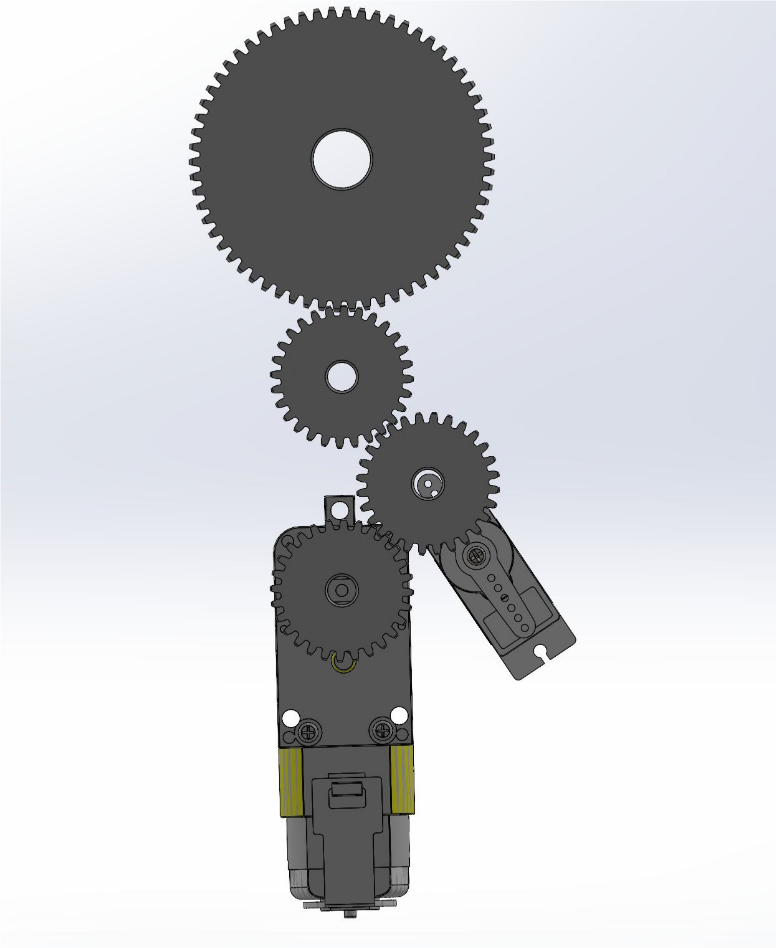
- Hardware controlled by Arduino
- References machine learning library supplied by edge impulse
- Arduino Programming language (very similar to C)
- Testing will be executed through hardware or serial monitor via Arduino IDE

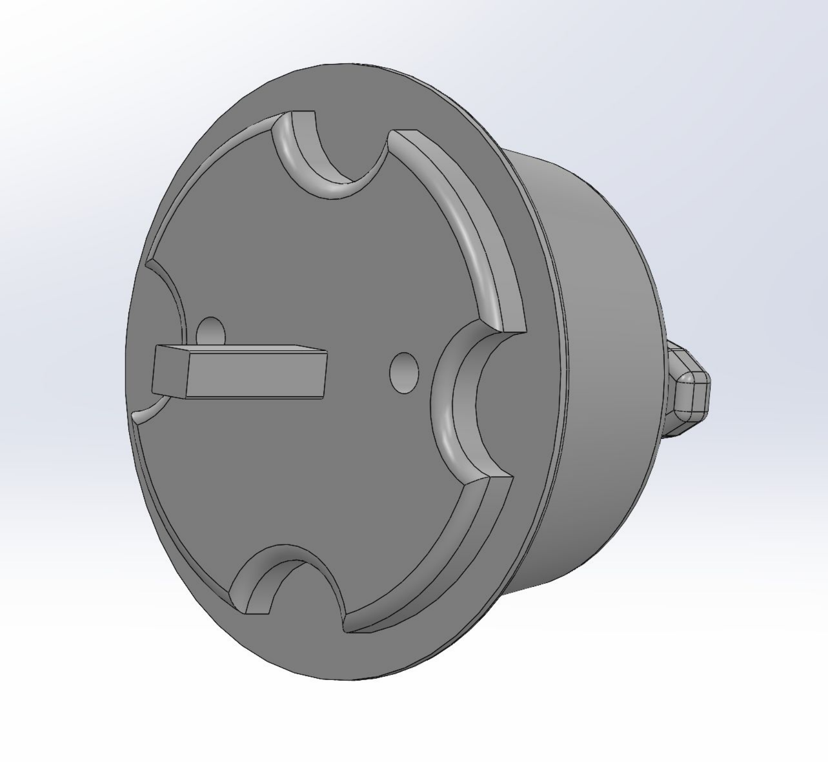
Hardware System Design & Complexity



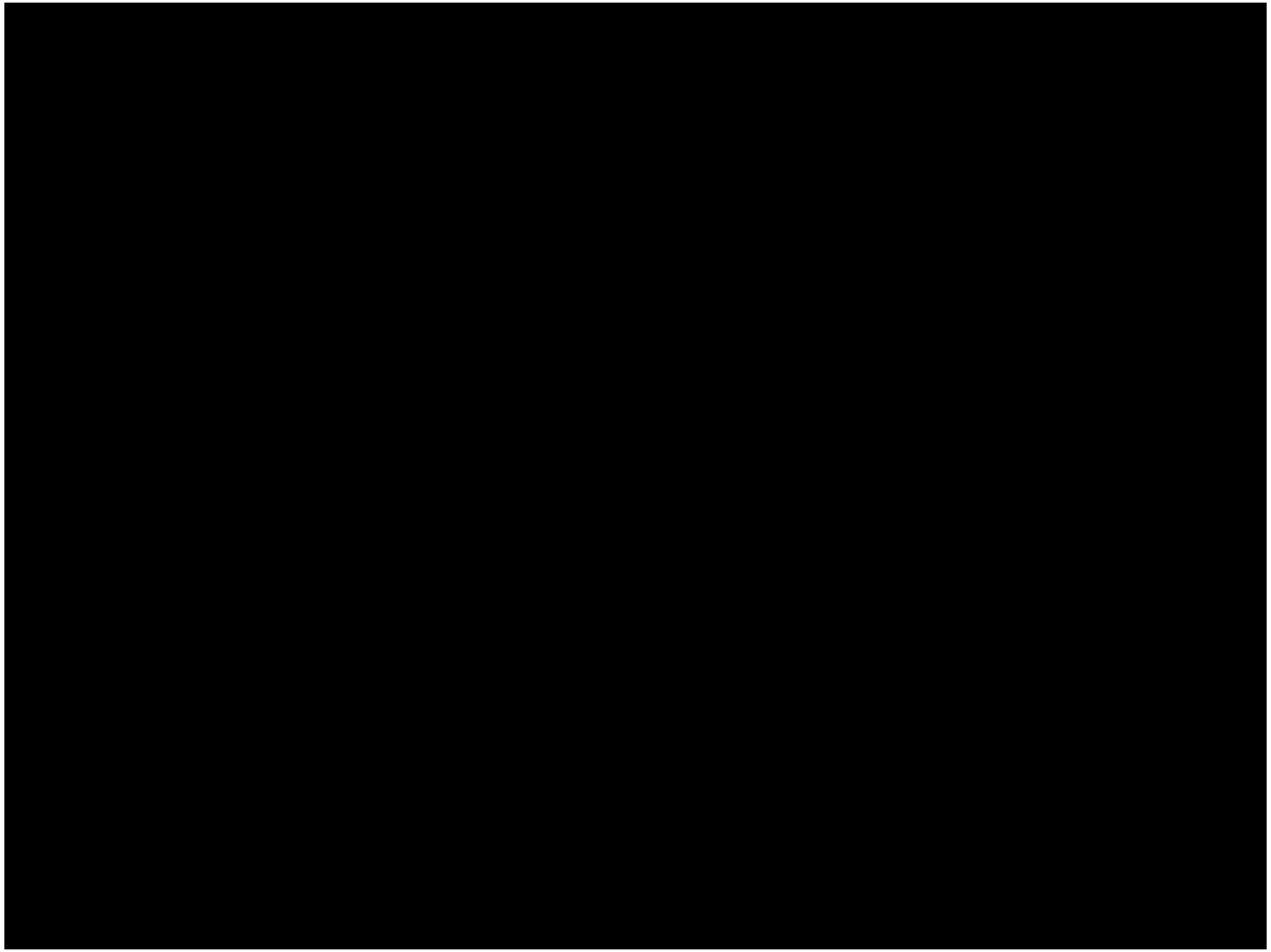
Mechanical System Overview

Mechanical System Design



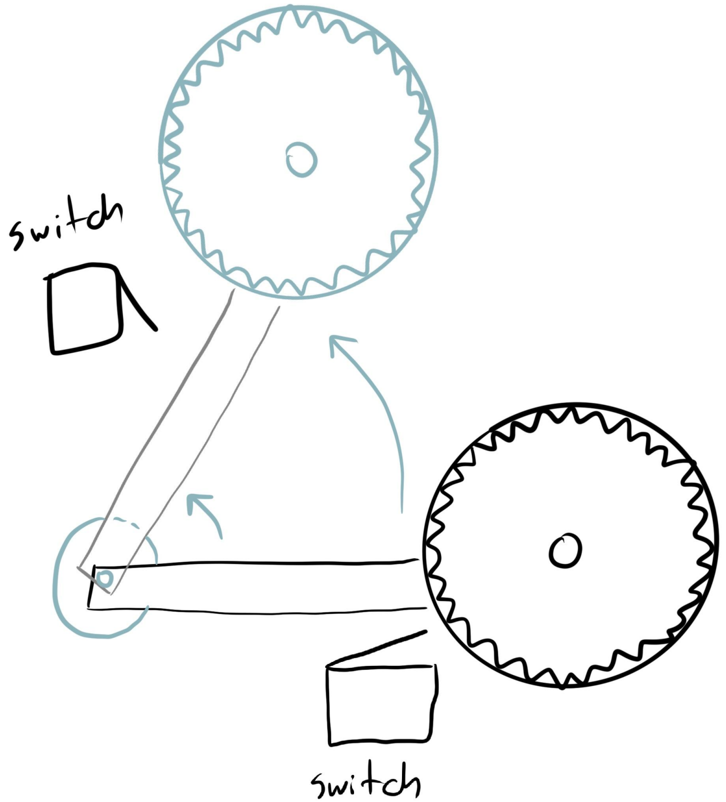


Mechanical Prototype



Design Complexity

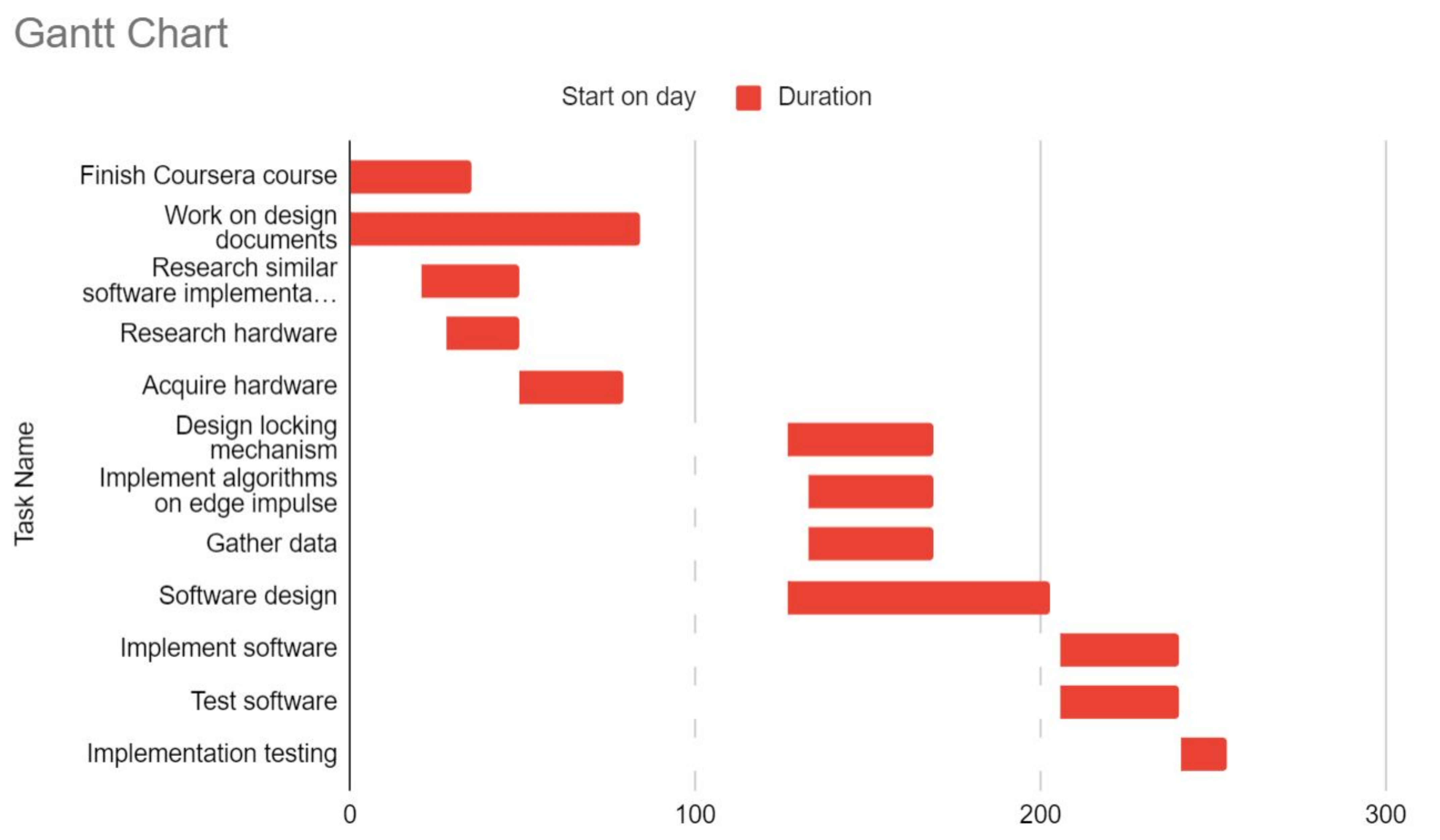
- Torque and RPM requirements
  - Different motors, different voltages
  - Different gear chains



- Positional requirements of motors
  - Switches will need to be placed precisely so the Arduino knows when the gear chain is engaged/disengaged, and when the lock is fully locked/unlocked.

Project Plan

Task	Risk Management/ Mitigation
Gather Data	Unable to gather enough data for training. Risk: 0.6 The data is biased. Risk: 0.7 Mitigation: 1. Gather more data. 2. Gather more data from more people with underrepresented characteristics. 3.Use more audio resource packages as more data.
Implement Algorithm On Edge Impulse	Accuracy is not as high as we want it to be. Risk 0.5 Mitigation: Redesign different aspects of the algorithm (nodes, layers), gather more data, gather more diverse data



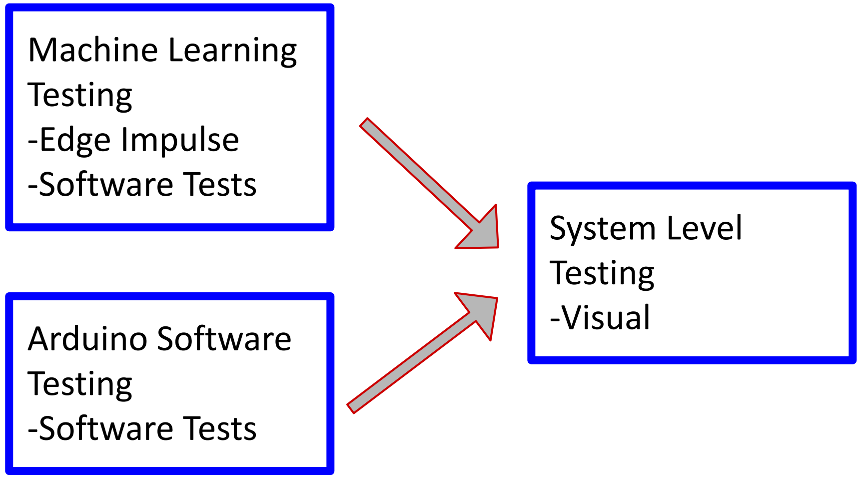
Gantt Chart
Start on day
Duration
Finish Coursera course
Work on design documents
Research similar software implementa…
Research hardware
Acquire hardware
Design locking mechanism
Implement algorithms on edge impulse
Gather data
Software design
Implement software
Test software
Implementation testing
Task Name
0
100
200
300

Project Plan – Schedule/Milestones

- Progress is determined by higher accuracy

Milestone	Metric
ML algorithm detects a specific person saying a keyword(ML version 0.1)	90% accuracy
ML algorithm differentiates between different people saying the keyword(ML version 0.2)	90% accuracy per person
ML algorithm can detect a given user's voice and their user-defined keyword(ML version 0.3)	90% accuracy
Microcontroller moves motor to unlock door on correct keyword recognition(ML version 1.0)	Motor switches consistently within 5 seconds of receiving keyword

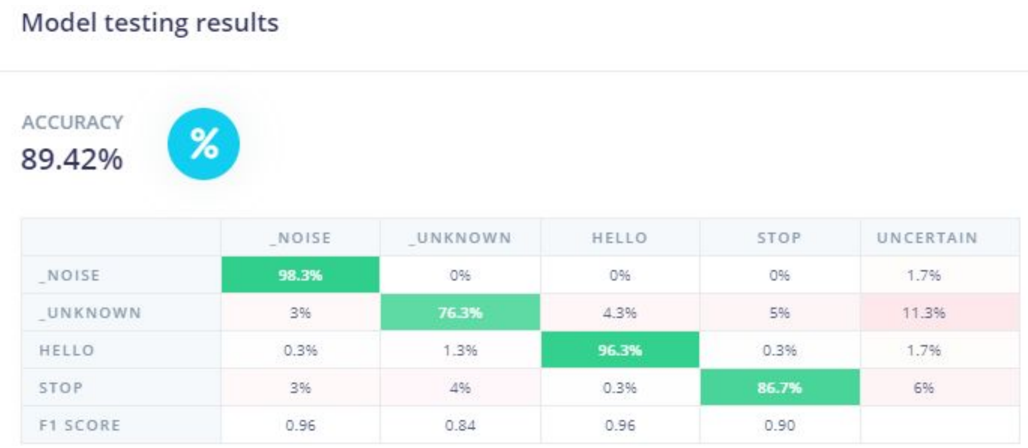
Test Plan



- Two units to be tested.
  - Machine Learning
    - Keyword Recognition - how accurate is the neural network in identifying keywords.
    - Use Edge Impulse to help with testing.
  - Arduino Software
    - Use the Arduino IDE and serial monitor to check that our sampled data from the microphone is correctly stored and sampled.
    - Visually check for working motors.
    - Ensure that the Machine Learning model is getting the correct data.

Test Plan

- We will do testing in a variety of ways
  - Visual
  - Edge Impulse
  - Software Tests



Model testing results

ACCURACY
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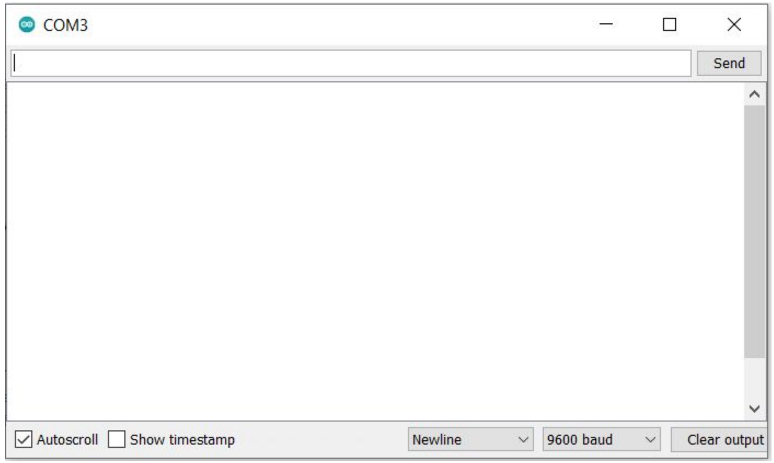

- System level testing
  - After individual component verification
  - Including The mechanical portion of the lock
  - Ensure that the system responds accordingly to a keyword or non-keyword.

Test Plan

- Acceptance Testing - requirements
    - Measure time taken to respond to an audio input
    - Accuracy of Keyword detection in the Machine Learning Model
        - Use Edge Impulse
    - Endurance
        - Can the physical device withstand frequent use?

Requirement	**Metric**
Time to Respond	< 5 second
Keyword Detection Accuracy	>= 90%
Endurance	> 10,000 uses

Individual Contributions

- **James Gossling** - designing system and sourcing hardware
- **Jackson Lopata** - Mechanical design, mechanical parts selection, and hardware part selection.
- **Hailey Lucas** - Research in embedded machine learning, motor libraries, Arduino language & IDE
- **Eric Reusch** - Arduino interfacing and general software design.
- **Francis Mago** - Research into training a keyword spotter (data acquisition, data curation, MLM architecture). Familiarization of processing data samples in the Edge Impulse to create Arduino libraries.
- **Isaac Stich** - Familiarization of Arduino Microcontroller and communication with motors.
- **Christian Williams** - Familiarization of Arduino hardware and libraries, hardware and similar devices research

Conclusions

- Completed Planning and are working to finish design before end of semester.
- Completed Coursera Course on Machine Learning
- Begun the process to acquire hardware for project
- Next semester
  - Purchase required materials and begin building
  - While waiting for hardware work on coding and creating the MLM.