Critical Design Review

Group 12

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Bird Initiated Rubbish Disposal System

Brought to you by Justin Phelps [Team Sponsor]

MEET THE TEAM

Aiden Nipper

Photonic Science and Engineering

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Photonic Science and Engineering

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Electrical Engineering

Donovan Reynolds

Computer Engineering

Problem & Motivation

- Littering is still a problem
  - Current solutions to clean up public spaces involve extensive energy costs
    - Volunteer Cleanup
    - Convict Labor
    - Salaried Street Cleaners
- The best solutions are just out of reach
  - Access to and education on proper waste disposal
  - Discouraging single use items

"While humanity struggles to learn basic cleanliness, it falls upon birds to tidy up the mess"
–ChatGPT 3.5

- Birds are:
  - Omnipresent
  - Intelligent enough to form correlations
  - Cheap to bribe

Goals & Objectives

- Promptly rewarding birds that bring trash
  - For the conditioning machine to have a chance at training birds, the most critical element is quick and decisive activation of the reinforcing stimuli
  - The BIRDS must be able to respond to a trash submission within a short period of time in order for the bird to associate the action of submitting trash with receiving food
- Consistent bird and trash detection verdicts
  - Other animals, such as squirrels, will not be able to interact with the BIRDS
  - Similarly, it would be disastrous for bird conditioning for a valid trash item to not be rewarded or the opposite of a non-valid object being rewarded. Such cases could threaten the conditioning or form unanticipated behaviors.
- The BIRDS should be robust
  - Should be able to survive outdoors for long periods of time
  - Most critical sections for weatherproofing are the food storage, so the food does not spoil and the internal circuitry of the processing boards

Engineering Specifications

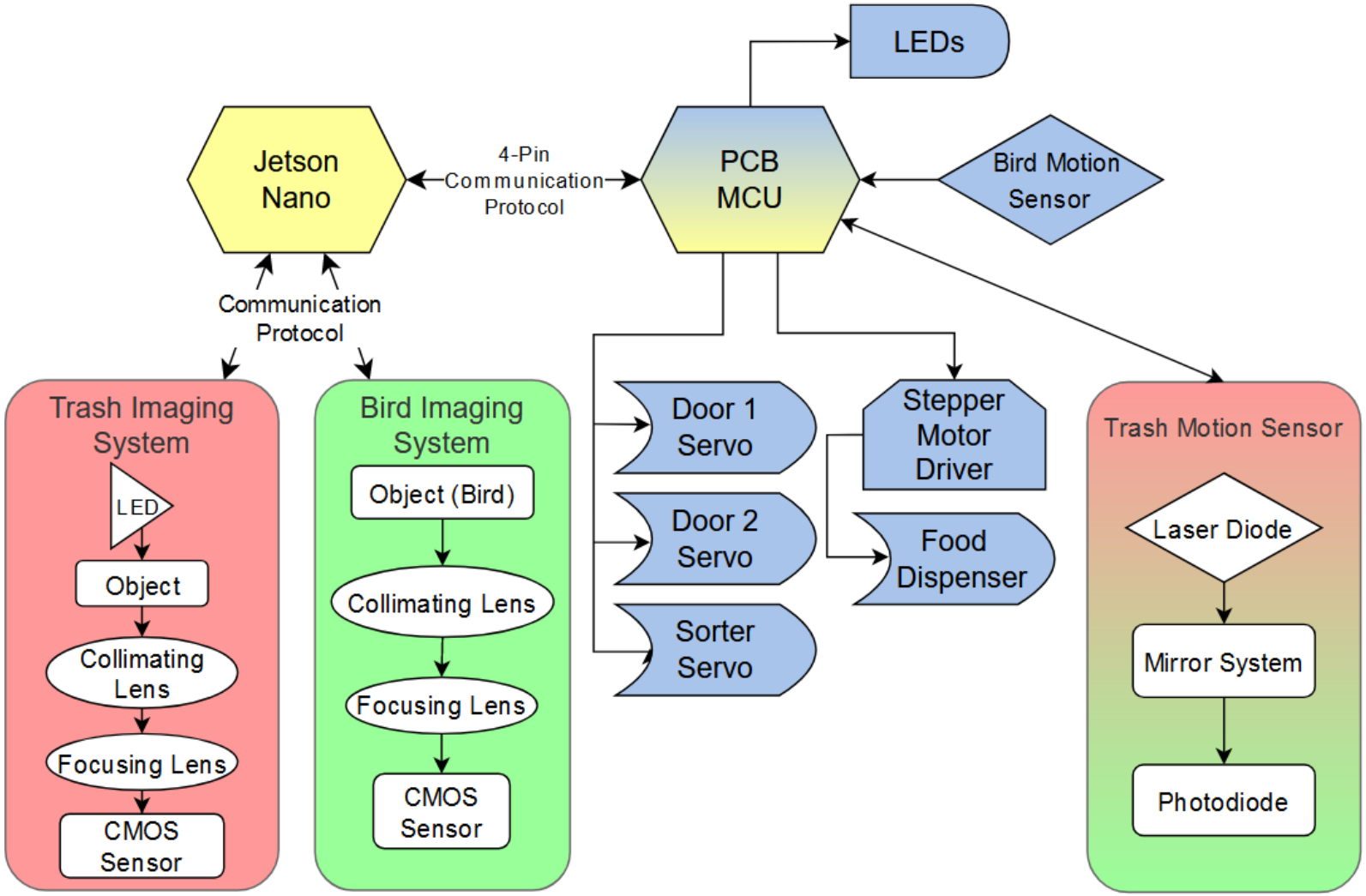
Electrical	Component	Parameter	Specification
	Power Supply	Charge Density	Power all functions for a week
	PCB	Central Control	Low power draw
	Motors	Reliability	Operate without fail 95% of the time
	Image Processor	Computational Power	Deliver a verdict within 2 seconds of taking the image.
	Status Displays	Human Interface	Simple, cheap, and weatherproof

Optical	Component	Parameter	Specification
	Collimating Lens (Trash)	FOV	25°
	Collimating Lens (Bird)	FOV	90°
	Focusing Lenses	Focal Length	10-20 cm
	CMOS Sensors	Resolution Size	640 x 480
	Red Laser Diode	Spot Size	6mm @ 5m distance
	Photodiode	Wavelength Range	400-1100nm
	Mirror	Wavelength Range	400-700nm

Engineering Requirements

System/Feature	Requirement
Accuracy of Bird Image Recognition	≥ 90%
Accuracy of Trash Image Recognition	≥ 85%
Accuracy of Bird Motion Sensor	≥ 50%
Accuracy of Trash Motion Sensor	≥ 90%
Time duration of Input Door from Bird Detection	≤ 3 sec
Time duration of Trash Sorter verdict	≤ 3 sec
Time duration of Food Dispenser from Trash approval	≤ 2 sec

Hardware Block Diagram



Work Distribution

Aiden	Will
Rodrigo	Donovan

Peripheral Devices

Motion Detectors

- Bird Detector
  - Uses a Capacitive Sensor to read changes in the dielectric properties surrounding a sensing conductor
  - We built our own by charging and reading the discharge time of a large conductor plate that will serve as the sensor
- Trash Detector
  - Uses a Laser and Photodiode to detect when an object breaks the laser path as it passes through

Actuators

- Food Dispenser
  - Uses a 5 Vdc Stepper Motor for its high torque and precise control
  - Will rotate a screw conveyer to dispense bird feed down to the food receptacle
- Door Actuators
  - Uses two 9-gram Servo Motor to operate two semicircle doors that grant access to the Analysis Chamber
- Trash Sorter
  - Uses one 9-gram Servo Motor to rotate the analysis plate towards Trash Storage or the Discard Chute

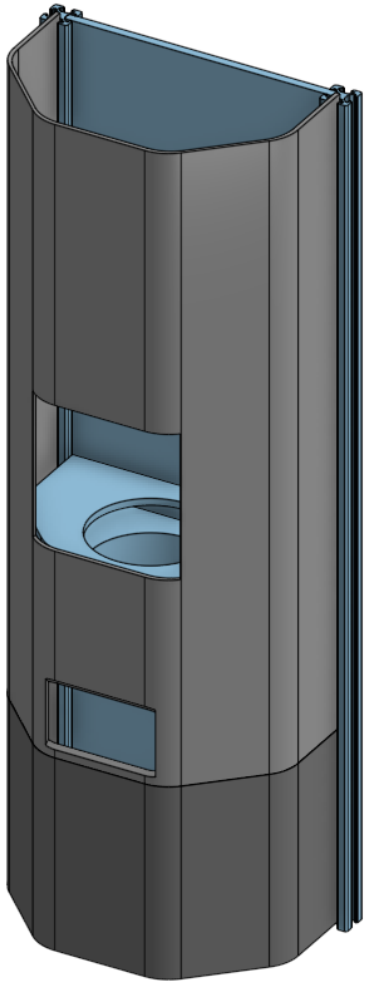
Jetson Communication

- Simple 4-pin connection to the Jetson Nano to activate and receive the verdict of the image processing cameras
  - 2-pins for “Activate Bird Camera” and “Is Bird?”
  - 2-pins for “Activate Trash Camera” and “Is valid item?”

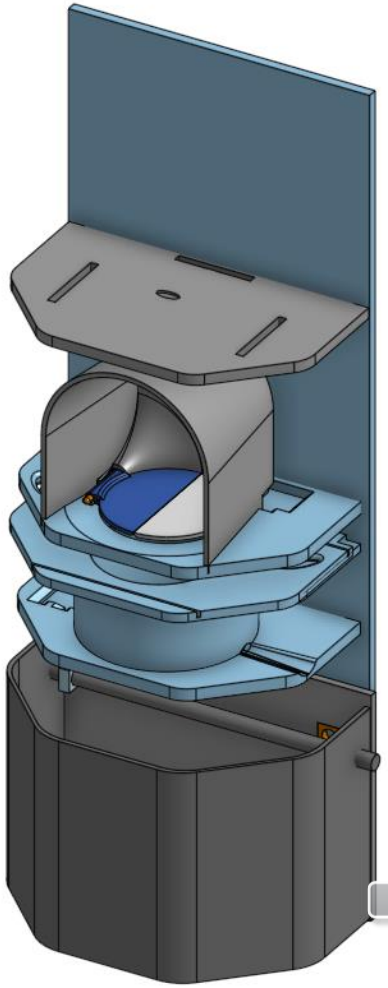
A B.I.R.D.S. House

The body in which to house the internal organs

- Four general sections (from top to bottom):
  - Food Storage and Food Dispenser
  - Trash Intake, Bird Platform, and Food Delivery
  - Laser Break Plane
  - Analysis Chamber
  - Discard Chute & Trash Storage
- Removable Trash Storage
- Unwanted Items will be discarded out the Housing
- Will (probably) have a transparent Outer Shell
- Removable Outer Shell for ease of maintenance
- System Plates will go through Backplate and be permanently secured



[With Outer Shell]



[Without Outer Shell]

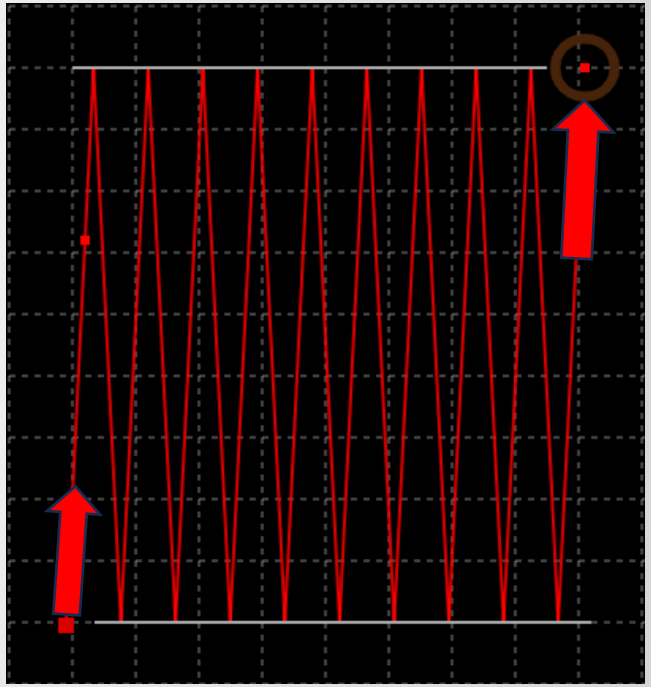
Laser Motion Sensor Selection

Photodetector Specifications

	Solar Cell	Photodiode	Photoresistor
Data Rate	34.2 Mbps	2 Gbps	N/A
Rise Time	N/A	1 µs	10 ms
Spectral Bandwidth	400nm - 700nm	500nm - 1000nm	400nm - 900nm
Cost	$15.50	$0.40	$0.20

- Photodiode has fastest rise time and a low cost

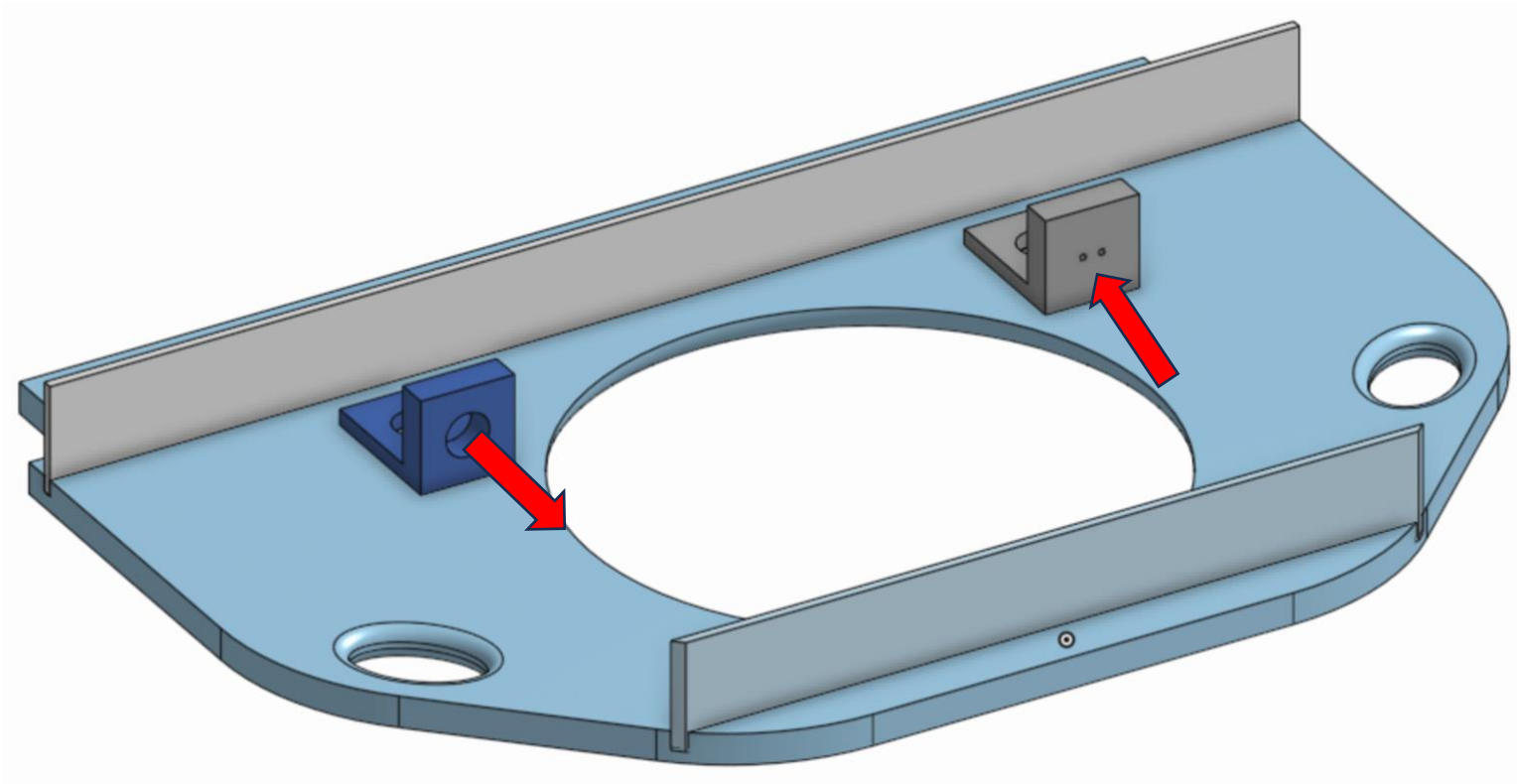
Laser Grid



- Single laser diode will send laser through mirror system into photodiode

Laser Motion Sensor Design

Integration



Lens System Hardware Selection

Sensor Specification

	CMOS	CCD
Readout Noise	5 e^-	3 e^-
Power Consumption	2.5V	12V
Readout Time	10ms	500ms
Price	$50	$200

- There is more noise created by the CMOS sensor
- Readout time and power consumption are very low

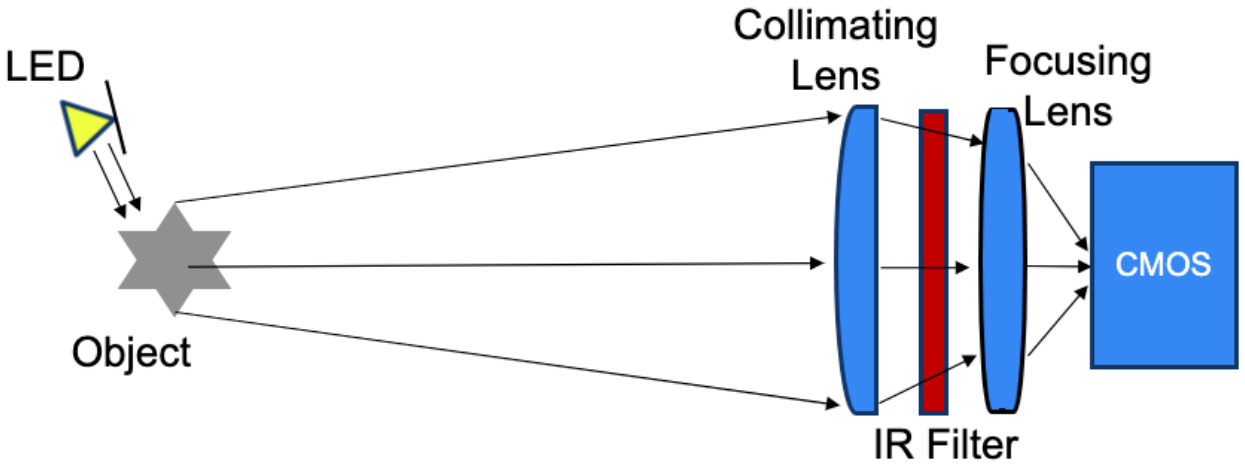
Lens Selection

Lens shape	**Ideal conjugate ratio**
Biconvex	< 5:1
Plano-convex	All
Plano-concave	Infinite, larger finite (> 5:1)
Biconcave	< 5:1
Meniscus	Varies; dependent upon curvature and polarity

- The objects to be imaged will be far away from the front of the lens
- The image formed by the lens will be close to the back of the lens
- Leads to a large or infinite ideal conjugate ratio
- If a second lens is used, it would have a much smaller ideal conjugate ratio

Lens System Hardware Design

General 2-Lens System



- An infrared (IR) filter is needed to block out all IR wavelengths that could interfere with the desired image
- 2-Lens system was designed to acquire greater minification of image onto CMOS sensor

Bird vs. Trash

- FOV
  - Bird – 90 deg
  - Trash – 25 deg
- Focal Length
  - Bird – 10-20cm
  - Trash – 15cm

Microcontroller

What we need:

- Low power mode to draw less power when reading sensors
- Enough GPIO pins to support our peripherals
- Interrupt capabilities
- Cheap
- Development board for easy testing and debugging

[ATmega328PB]

[MSP430]

[ESP32]

Development Board Selection

- Because almost every microcontroller has the features that we are looking for, we decided to try to minimize cost.
- Another goal was to use Arduino IDE to make writing the embedded software very simple giving much more time and focus to the machine learning section.
- To minimize cost we wanted to pick a development board that someone in the group already owns
- Our final choice of development board was the Arduino Uno

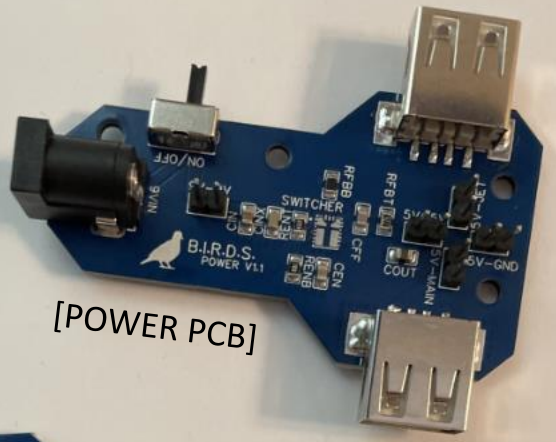
Device	Flash	RAM	GPIO Pins	Programming Language	Price
Arduino Mega 2560	256 KB	8 KB	54	Arduino IDE	Already Own
Arduino Uno	32 KB	2 KB	14	Arduino IDE	Already Own
MSP430FR6989	128 KB	2 KB	83	C	$26.59
MSP430G2553	16 KB	.5 KB	24	C	Already Own

Microcontroller Selection

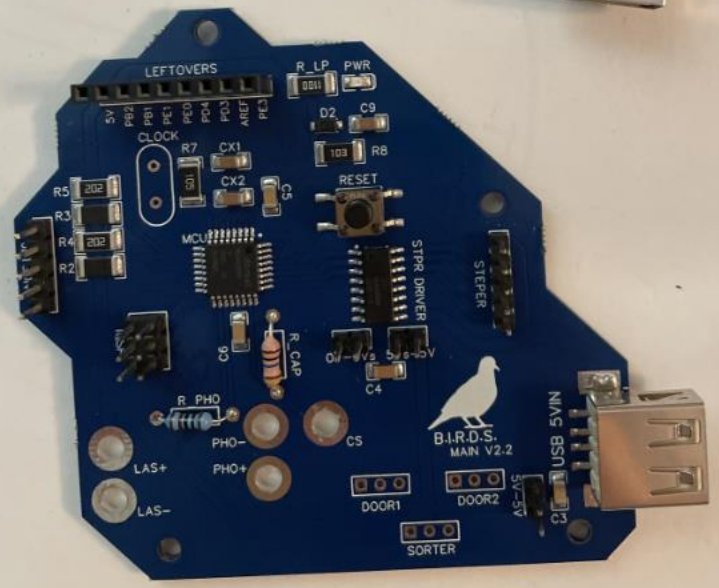
- Since we are using Arduino, we are sticking with the ATmega series of MCU
- Flash memory is more than what we need
- EEPROM is only for storing specific data when powered off
- The I/O pins are important we have more than we need
- PWM channel the size doesn't matter as long as we have 3
- We may need a couple ADC channels but all of these have way more than necessary
- Price was the biggest selling point for the ATmega328PB

Device	Flash KB	EEPROM KB	RAM KB	I/O Pins	16-bit resolution PWM channels	Serial UARTs	ADC Channels	Price
ATmega328PB	64	2	4	27	11 (10 bit resolution)	1	11	$1.63
ATmega640	64	4	8	86	12	4	16	$5.7
ATmega1280	128	4	8	86	12	4	16	$16.2
ATmega1281	128	4	8	54	6	2	8	$13.6
ATmega2560	256	4	8	86	12	4	16	N/A
ATmega2561	256	4	8	54	6	2	8	$25.4

PCB Design



[POWER PCB]



[MAIN PCB]

Power Board

- Since we are powering two computing boards (Jetson Nano & Main), one board powers both
- Easier to debug and repair if something goes wrong
- Has multiple Jumper-Pin breakers for testing and control
- Takes in 9 Vdc from a 120 Vac to 9 Vdc wall adapter Outputs 5 Vdc to two USB-A female ports
- 96.608 % Efficient Buck Converter circuit from TI's WEBENCH application

Main Board

- Controls and coordinates all peripheral devices
- Programed through ICSP
- Has an isolatable stepper driver circuit that can be independently powered or powered by the Main
- Powered by 5 Vdc USB-A cable or ICSP pins
- Power LED (of course)

Machine Learning Technology Comparison

What we need:

- Hardware capable of performing an object detection of a bird within our allotted time of 1 second
- GPIO pins to communicate with our processor on our custom PCB.
- Needs to be able to run 2 different machine learning models either in parallel or quickly swap.

Final Consideration Options:

Nvidia Jetson Nano

- Can run multiple machine learning models in parallel
- The most expensive option with original price
- The most versatile because of its gpu
- 4 USB ports for easy access of peripherals
- Has a prebuilt library for machine learning called jetpack

Coral Dev Board

- Works very well with TensorFlow architectures
- Has easy access to Wi-Fi and Bluetooth
- Has prebuilt machine learning models on TensorFlow hub that can be easily integrated

Raspberry Pi 4 + Coral Accelerator

- This was the first idea for machine learning
- Coral Accelerator helped match this to contenders
- Is a very popular choice for projects
- Is very commonly sold out, or being resold for much more than its value
- Might run into issues with multiple pieces of hardware working together

Machine Learning Technology Comparison

- We need a device that can work well on a number of architectures
- We need a device that can respond quick enough to meet our 1 second image processing goal
- We need a device that we can receive quickly to start testing
- We need a device that can handle 2 different models for a bird and for detecting a cigarette

Neural Net Framework Benchmark

Model	Framework	NVIDIA Jetson Nano	Raspberry Pi 4 B + Coral Accelerator	Coral Dev Board
MobileNet V1	TensorFlow	61.6	14.9	15.7
MobileNet V2	TensorFlow	72.3	18.2	20.9
ResNet-50 V2	PyTorch	27.7	52	56
ResNet-18	PyTorch	200	DNR	DNR
YOLOv3-320	Darknet	40	DNR	DNR
VGG – 19	MXNet	100	200	DNR
Unet	Caffe	55.5	200	DNR

Hardware Specifications Machine Learning

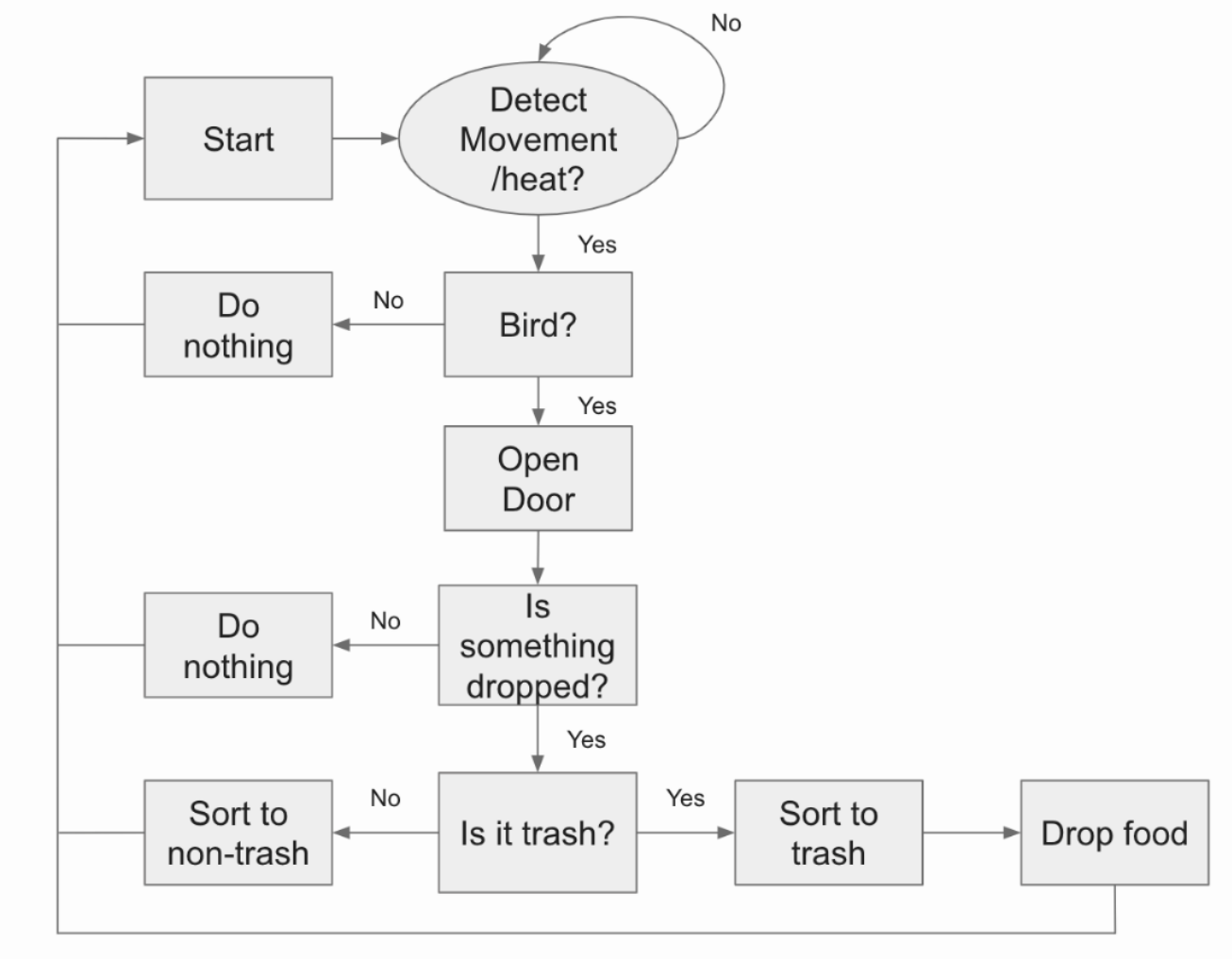
	Coral Dev Board	NVIDIA Jetson Nano Developer Kit	Raspberry Pi 4 Model B + Coral USB Accelerator
CPU	Quad Cortex-A53, Cortex-M4F	Quad-core ARM A57	Quad core Cortex-A72
Clock Rate	1.5 GHz	1.43 GHz	1.8 GHz
GPU	Integrated GC7000 Lite Graphics + Google Edge TPU coprocessor	128-core Maxwell @ 921 MHz	Google Edge TPU coprocessor
Cache	32KB L1 instruction and data cache, 1MB unified L2	48 KB L1 instruction cache and 32 KB L1 data cache, 2 MB of L2 Unified Cache	48 KB L1 instruction cache and 32KB of L1 data cache, 1MB of L2 Shared Cache
RAM	1 or 4 GB LPDDR4 Memory	2 or 4 LPDDR4 Memory	1, 2, 4, or 8 GB LPDDR4 Memory
Flash	8 GB eMMC, with a MicroSD slot for expandable storage	16 GB eMMC, with a MicroSD slot for expandable storage	Expandable MicroSD slot for program and Operating system

Machine Learning Technology Choice

For our choice of machine learning technologies, we chose to go with the NVIDIA Jetson Nano 4GB.

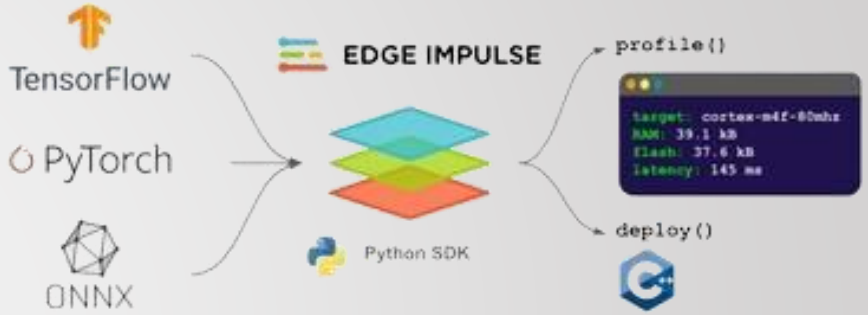
- This board comes with an easy way of installing a wide array of libraries called Jetpack SDK
- This was the most versatile option guaranteeing performance
- Had a very easy setup with a microSD card using a tutorial from NVIDIA.
- A wide array of tutorials from NVIDIA on how to import prebuilt models and create your own object detection models.
- This was in stock and came within a few days of purchase.
- Very easy to add Wi-Fi and Bluetooth capabilities should we need them in the future

Software Block Diagram



Training Machine Learning Platform

- To be able to do object detection we need a place to train our custom model since the Jetson isn't powerful enough for training.
- We decided to pick a cloud-based platform that could train object detection models from prebuilt weights on a neural network framework.
- This pick was Edge Impulse and one of the biggest selling points was the ability to export the model to the specific jetson library



[Example shot of our Object Detection for cigarettes]

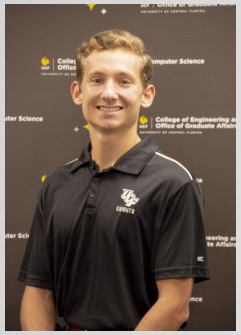
Budget

Item	Price	Quantity
Microcontroller	$13	1
Nvidia Jetson Nano	$150	1
Servo Motor	$10	3
Stepper Motor	$13	1
Custom PCB	$20-$30	2
Housing Material	$200	1
LED Light Source	$15	10

Item	Price	Quantity
Collimating Lens	$23.50	2
Focusing Lens	$20	2
IR Filter	$5	2
CMOS Sensor	$25	2
Laser Diode	$13.18	1
Photodiode	$0.32	20
Mirror	$0.28	50
TOTAL	$796.58	

Work Distribution

Aiden Nipper



- Lens System Design (Trash Camera)
- Laser Motion Sensor Design
- Housing & Structural Design

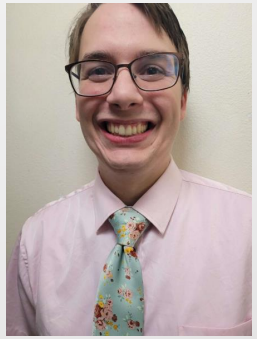
Will DiSalvo

- Lens System Design (Bird Camera)
- Laser Motion Sensor Design
- Structural Design

Rodrigo Guerra

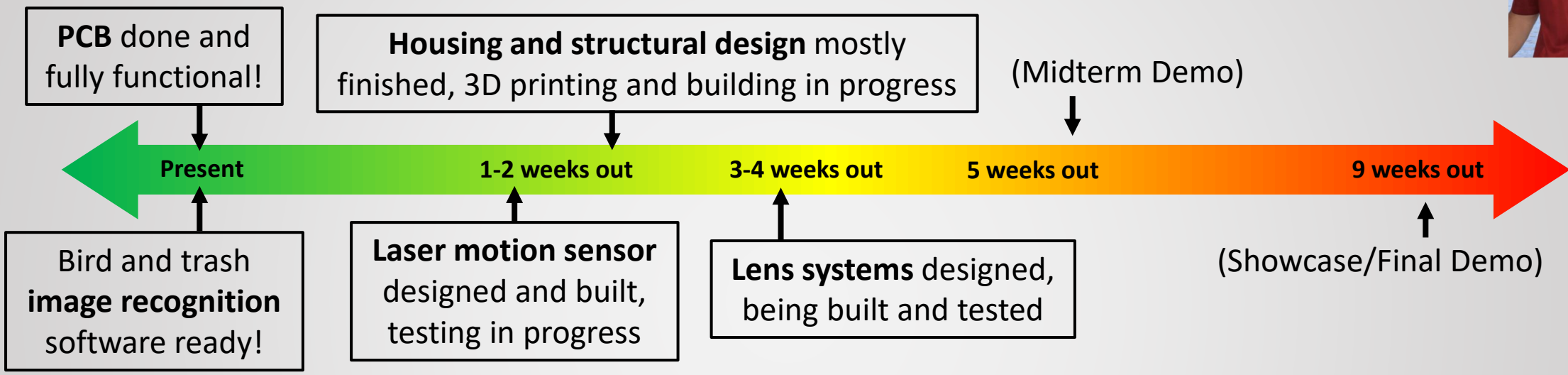
- PCB Design
- Wiring and Soldering
- Housing & Mechanical Design

Donovan Reynolds



- Machine Learning (Jetson)
- Embedded Software
- Website

Progress and Future Milestones



- Anticipating system to be built at least one month before showcase, with hope of obtaining data through field-testing
- Hope for the project is that others improve design and use it to train birds in a specific area
- Having the BIRDS in major cities and/or universities could slowly begin to change the way our streets look

THANK YOU!