The Smart Bird Feeder

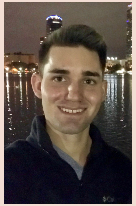
Senior Design Project - Group 7

The Smart Bird Feeder

Design Goal

To build a smart bird feeder that maximizes the potential of the hobby! By emphasizing automatic features and designing around common feeder problems, our team has created the perfect bird feeding device.

Our Team



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Project Features

Species Detection

Photo Storage

Pest Deterrent

Smart Application

Notifications

Project Motivation

- Bird feeding is time consuming
  - Too much time is spent waiting for the desired species
  - Too easy to miss the bird encounters
  - Keeping track of the bird feed levels
  - Cataloging which species have been seen

- Predators and backyard pest
  - Other animals will consume the bird feed
  - These pests scare away other creatures
  - Waste bird watcher's time and resources

- Space in the market
  - No product exists that incorporates smart features and deterring mechanisms
  - Our group recognized the potential in the market

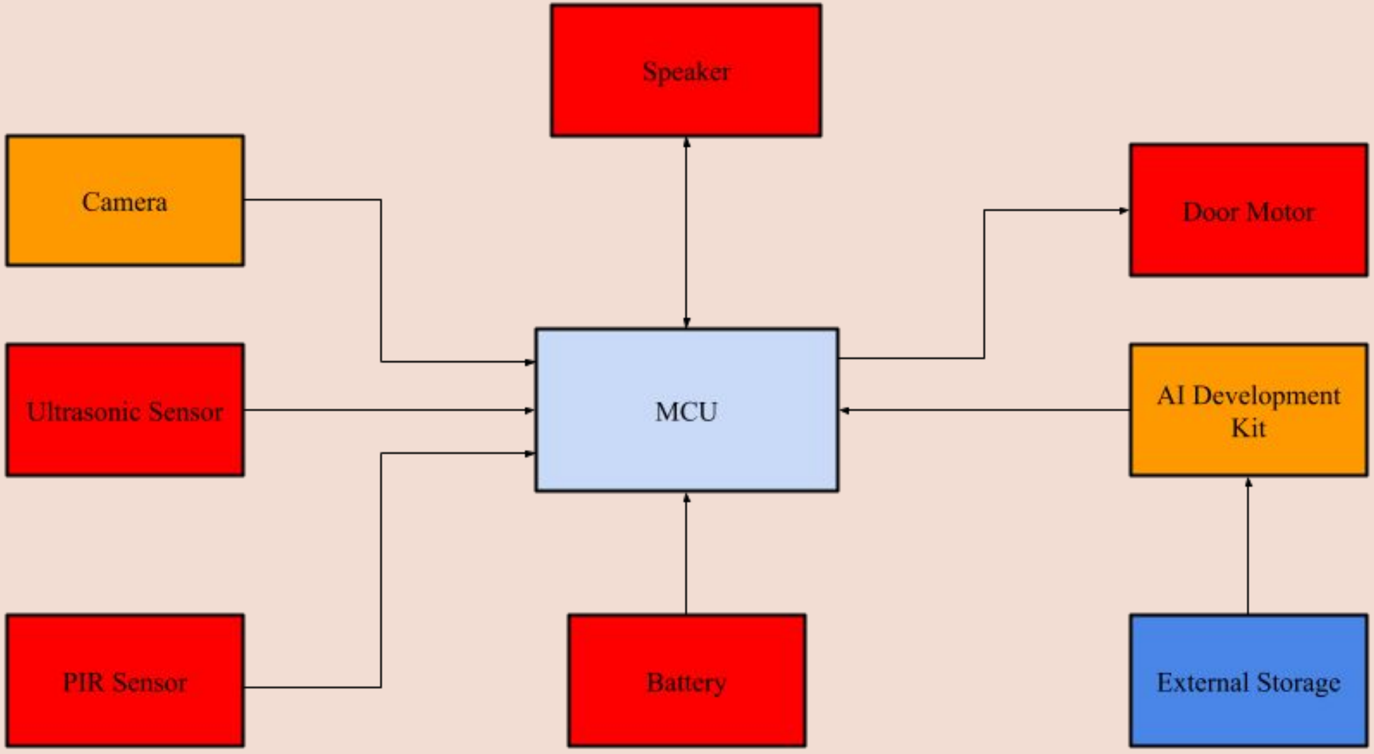
Project Goals and Objectives

- Maximize the users time by incorporating smart elements into the hobby
    - Incorporate species detection using machine learning
    - Auto-cataloging and saving memories
    - In-depth notification systems
    - Accompanying smart phone application
- Design deterrent mechanisms to combat backyard pest
    - Block access to feed with hatch mechanism
    - Scare away pest with alarm
- Fill the space in the empty market

Engineering Requirements

Engineering Requirement	Specification
Accuracy of bird species and squirrel detection must exceed a certain confidence level to capture images.	≥ 90%
The dimensions should not exceed the size of a common bird feeder.	≤ (8" x 8" x 14")
The system should have enough power to run for a certain amount of time.	≥ 2 hours
Duration of external battery recharge should not exceed a certain time.	≤ 7 hours
The alarm speaker should have a certain output range.	60-95 dB
Hatch door closing time should close within a certain amount of time.	≤ 3 seconds
Users will be notified of a new bird memory within a certain time period.	≤ 10 seconds

Hardware Block Diagram

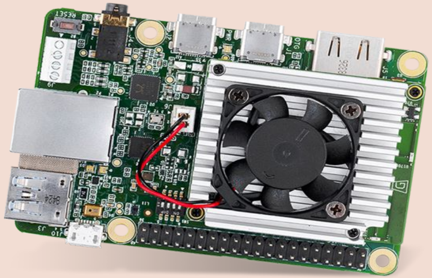


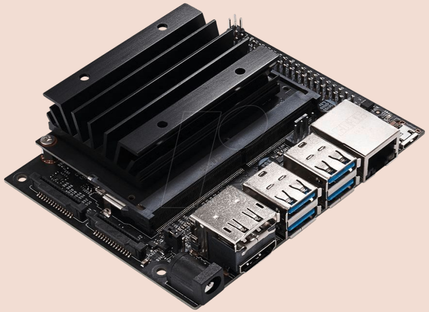
Machine Learning Technology Comparisons

What we need:

- Machine learning capable hardware for object detection of bird species & squirrels
- GPIO pins to communicate with our custom PCB

<u>Options Under Consideration</u>





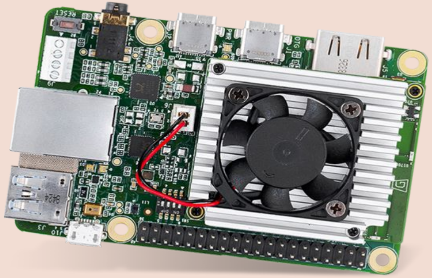
Coral Dev Board

- First device considered
- Edge TPU Python API
- Existing Edge TPU computing models that can be adapted
- Created to work well with TensorFlow Lite models
- 1, 2, or 4GB LPDDR4 SDRAM

Jetson Nano

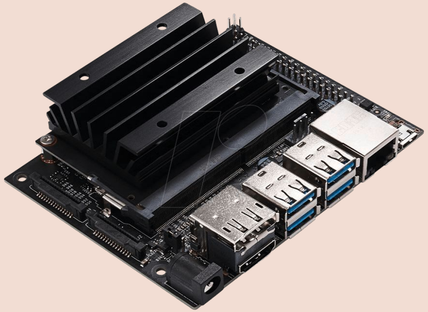
- Can run multiple ML models in parallel.
- 4GB LPDDR4 SDRAM
- No on-board Wifi included (but may be added)
- JetPack SDK with full Linux OS that contains libraries and APIs for deep learning

Machine Learning Technology Comparisons



Google Coral Dev Board

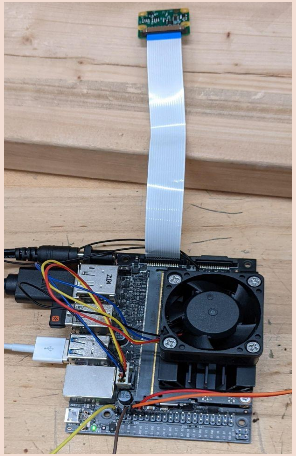
	Coral Dev Board	NVIDIA Jetson Nano Developer Kit
CPU	Quad-core Arm Cortex-A53, plus Cortex	Quad-core ARM Cortex-A57 MPCore processor
CPU Clock Frequency	1.5GHz	1.43GHz
GPU	Edge TPU coprocessor; Vivante GC70000Lite	128-core NVIDIA Maxwell @ 921 MHz
Cache	32 KB L1 Instruction Cache; 32 KB L1 Data Cache	48 KB L1 instruction cache per core; 32 KB L1 data cache per core | L2 United Cache: 2MB
Communication	On-board WiFi included	On-board wifi module not included (can be installed)
USB Ports	1 USB 3.0 Type-C port, 1 USB 3.0 Type-A port, and 1 USB 2.0 Micro-B serial port	4 USB 3.0 ports, 1 USB 2.0 Micro-B port
Price	Starting at $129.99	$99.99



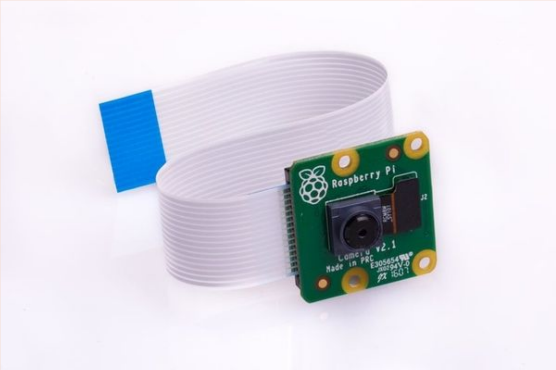
Jetson Nano Developer Kit

Machine Learning Technology Choice – Jetson Nano + Raspberry Pi Camera Module v2

- Our team decided to go with the NVIDIA Jetson Nano 4GB development kit due to a wide array of features, impressive processing power, integrated OS, prebuilt machine learning libraries and modules, cost, and great community support.
- Jetson Nano pairs with the Raspberry Pi V2 8MP camera module to capture bird images and live video
- Purchased cooling fan for $13.50 to keep the Jetson Nano module within a reasonable temperature range
- Purchased Intel Dual Band Wireless-AC 8265 Device + antennae for $25.99 for WIFI communication with user application

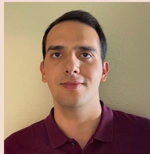


Jetson Nano Developer Kit w/ Raspberry Pi Camera installed



Raspberry Pi 8MP Camera Module V2

Intel Dual Band Wireless-AC 8265 Device



Microcontroller

- Specifications: Type of communication, number of pins, operating voltage, and size.
- The microcontroller must support 5 peripherals - 7 I/O pins are required
  - 2 for transmitting and receiving data from the Jetson Nano via UART
  - 1 for Motor and hatch control
  - 2 for the ECHO and TRIG pins on the ultrasonic sensor
  - 1 for the External speaker
  - 1 for the PIR sensor
- The CPU speed can be tempered, as most of the processing is being performed by the Jetson Nano. For our requirements, 16 MHz is an ideal speed.
- As the device is reliant on battery power, it's important to get a MCU with low power options available.
- Choice: MSP430G2553

	MSP430FR6989	MSP430G2553	ATmega328P
Cost	$9.43	$3.38	$2.63
GPIO pins	83	24	23
Speed	16 MHz	16 MHz	20 MHz
Architecture	16-bit	16-bit	8-bit
Memory	128 KB	16 KB	32 KB
Operating Voltage	1.8V ~ 3.6V	1.8V ~ 3.6V	1.8V ~ 5.5V
Program Memory Type	FRAM	FLASH	FLASH
RAM Size	2 KB RAM	0.5 KB	2 KB SRAM
SPI	4	2	Yes
UART	2	1	UART/USART
I2C	2	1	Yes
Package	80-LQFP	20-PDIP	28-DIP

Motor Control Requirements

The motor will be used in conjunction with the hatch door to complete our defense mechanism features. It will be powered by the MCU when the Jetson Nano monitors predator activity.

- Specifications: cost, torque, speed, size, acceleration, and power

	Brushed DC Motor	Brushless DC Motor	Stepper Motor	Servo Motor
Lifetime	1,000 to 3,000 hours	over 10,000 hours	over 10,000 hours	over 10,000 hours
Torque	0.49 mNm at 5VDC	0.021 Nm at 12VDC	490 mNm holding at 5VDC	0.148 Nm at 6VDC
Efficiency	75%-80%	70%-90%	~65%	over 85%
Cost	$3.22	$14.95	$26	$7.95
Voltage/Current (typical)	1.5 - 24V 4A at 3V	4 - 24V 5 - 15mA	1.68A at 2.8V	200mA - 10A
Control Complexity	No MCU needed	MCU needed for feedback	MCU needed to send pulses	MCU needed to send PWM

Motor Control Requirements

Listed are a few of the servo motor options the team considered.

- Specifications: weight, torque, power, cost, and speed.

	SG90	FS90-FB	FS0403
Weight	9g	13g	5g
Torque	1.8kg/cm	1.5kg/cm	0.7 kg/cm
Maximum rotational angle	180°	180°	120°
Cost	$2.75	$7.95	$5.50
Voltage/Current (typical)	4.8 (.2A)	6V (.2A)	5V (0.2A)
Speed	0.1 sec/60°	0.1 sec/60°	0.08 sec/60°
Size	32 x 32 mm	24 x 22 mm	20 x 20 mm

Motor Selection – Servo

- Solid torque, efficiency, cost, and power requirements
- Requires PWM signal from the microcontroller in order to specify the position

Micro servo motor + placement
on The Smart Bird Feeder

Distance Sensor Technology

The design calls for sensor technology to measure the remaining bird feed in order to alert the user of low-feed levels.

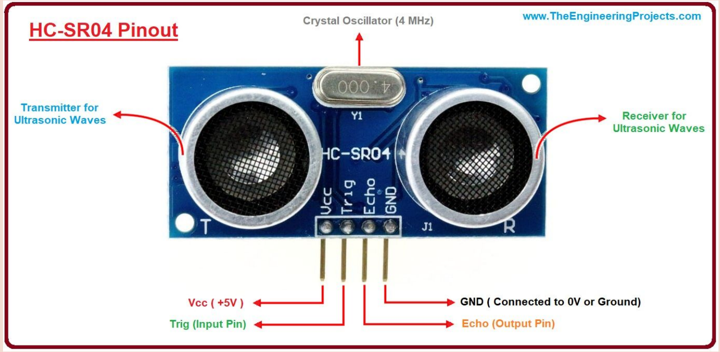
- Specifications: Distance (minimum range), power consumption, environment variables, cost

	Ultrasonic Sensor	Infrared Sensor	LIDAR
Strengths	• Distance measurement • Works well in dark environments • Low power consumption	• Small devices • Works well in dark environments • Can measure complex objects	• Extreme range and accuracy • Fast update rate • Good for small objects
Drawbacks	• Distance constraints • Unsuitable for fast moving objects	• Minimum detection range too large • Higher price than ultrasonic sensor	• Minimum detection range too large • Higher price than other two options

Ultrasonic Sensor Comparison

The sensor will be used to monitor bird feed levels
Key specifications:

- Range
- Uncertainty
- Cost
- Experience and ownership



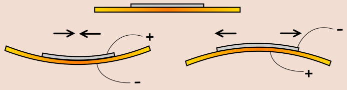
HC-SR04 Ultrasonic RangeFinder

	HC-SR04	Grove
Operating Voltage	5 V	5 V
Working Current	15 mA	8 mA
Working Frequency	40 kHz	40 kHz
Maximum Range	4 m	3.5 m
Minimum Range	2 cm	3 cm
Measuring Angle	15 degrees	15 degrees
Dimensions	45 x 20 x 15 mm	50 x 25 x 16 mm
Accuracy	3 mm	2 mm

Alarm Design

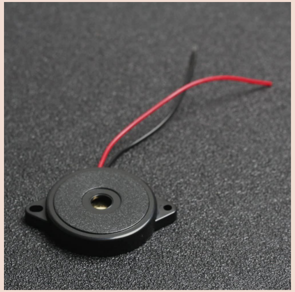
In order to maximize the time birds could spend feeding, the device is equipped with an alarm system to scare away pest.

- Alarm will sound in the range of 75-90 dB
- Piezoelectric speakers are cheap and small in size
- PWM signal strength can emit sounds of different loudness
- Activate when the machine learning processor detects a pest
- Anything past 90 dB might be dangerous to little ears, the goal is to provide an annoyance, not damage



The Piezoelectric Effect

	DUDUA Piezo Alarm	Fielect Piezo Alarm
Resonant Frequency	3.9 +/- 0.5KHz	4.0 +/- 0.5 KHz
Rated Voltage	12 V	5.0 V
Operating Voltage	3 ~ 24 V	1 ~ 30 V
Max Current Consumption	10 mA	5 mA
Min. Sound Output at Rated Voltage	95 dB	80 dB



Fielect Piezo Alarm

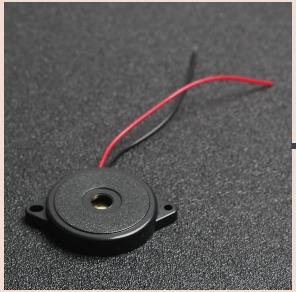
Design Challenge: Alarm Failure

Problem:

- Alarm was not functioning as advertised
    - Failed to emit at or above 80 dB; alarm was abnormally quiet
- The circuit proved to work properly, which ensured the team that the issue was solely due to manufacturing

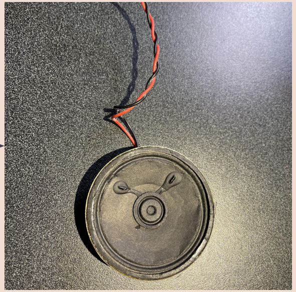
Solution:

- Utilized a pre-owned alarm available at the time to replace old alarm
- The new alarm met the sound requirement so the team decided to continue with this design



Original malfunctioning Fielect piezo alarm

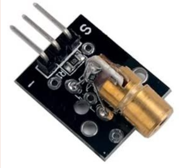
Swapped for functional pre-owned piezo alarm



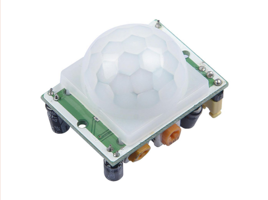
Motion Sensor Technology Comparison

The sensor will be used to detect movement at the feeder and trigger object detection to run:
Key specifications:

- Range
- Current Consumption
- Practicality
    - Possible beam misalignment
    - False positives



DIYmall Laser Transmitter Module



DIYmall HC-SR501 PIR Motion IR Sensor

	Laser Sensor (transmitter + photoresistor)	PIR Sensor
Operating Voltage	3.3-5V	4.5V - 20 V
Working Current	< 40 mA	65 mA
Maximum Range	~ 3 m	3 - 7 m
Measuring Angle	N/A	120 degrees
Dimensions	6.5 x 18mm	24mm*32mm*25mm

Design Challenges: Power Concerns

One of our teams biggest design challenges in SD2 was power consumption.

- Jetson Nano's machine learning software is power hungry (1.5 A)
- Original design considered three Lithium ION batteries in series 3.7 V (2.5 A)
- This would provide less than 2 hours of use

Jetson Nano Power Testing

Action	Average Current Consumption
Powering up	0.6 A
Powered up with no program running	0.4 A
Starting up program (no object detection)	0.6-0.7A
Program running without object detection	0.5A
Program running with object detection	1.1 A (max)

Possible solutions

TalentCell rechargeable
12 V 6000 mAh battery pack

Larger battery

- Increase the voltage and current of the battery to better match the requirements of the system
- New battery - 5 V (12 A)

Lower power consumption

- Ran various current test on the Nano
- Turning off the machine learning program - Cut consumption by ~50%

PIR Sensor

- By incorporating a passive infrared (PIR) sensor, we could shut off the machine learning code when not in use
- Saved power = Nano savings (~ 0.6 A)

PIR Sensor

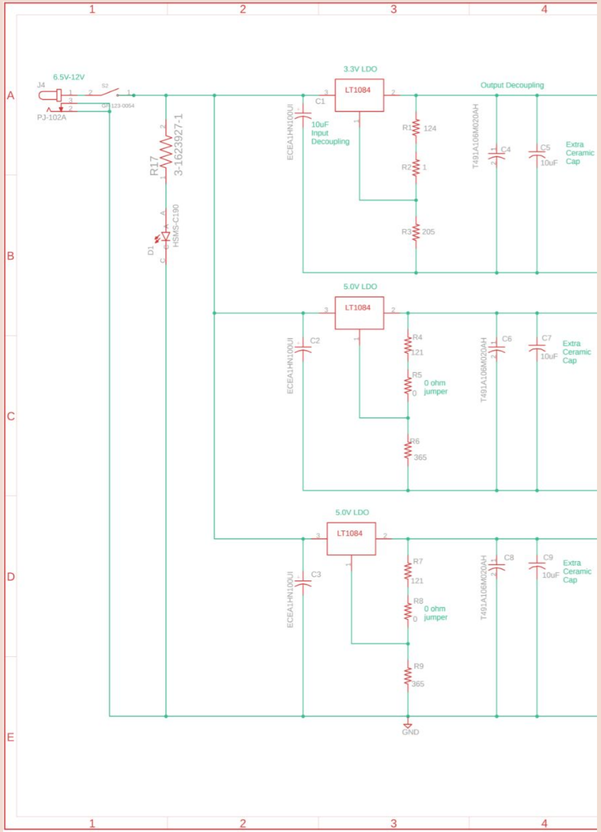
Power Distribution

Given our bird feeder relies on battery and solar power, power consumption was of prime importance in our design decisions. When possible we chose components with low consumption and always utilized power saving features.

- Current consumption average = 0.7 A

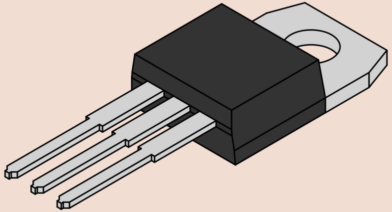
	Voltage Requirement	Current Requirement
Nano Developer Kit	~5 V	0.4 - 1.1 A
MCU	1.8 - 3.6 V	Operating: 230 uA Standby: 0.5 uA
Servo Motor	4.8 - 6 V	500 mA
Speaker	5 V	4 - 6 mA
Fan	12 V	0.137 A
Ultrasonic Sensor	5 V	15 mA
PIR Sensor	5 V	65 mA
Total	3.6 - 12 V	1.2 - 1.8 A

Voltage Regulators & Converters

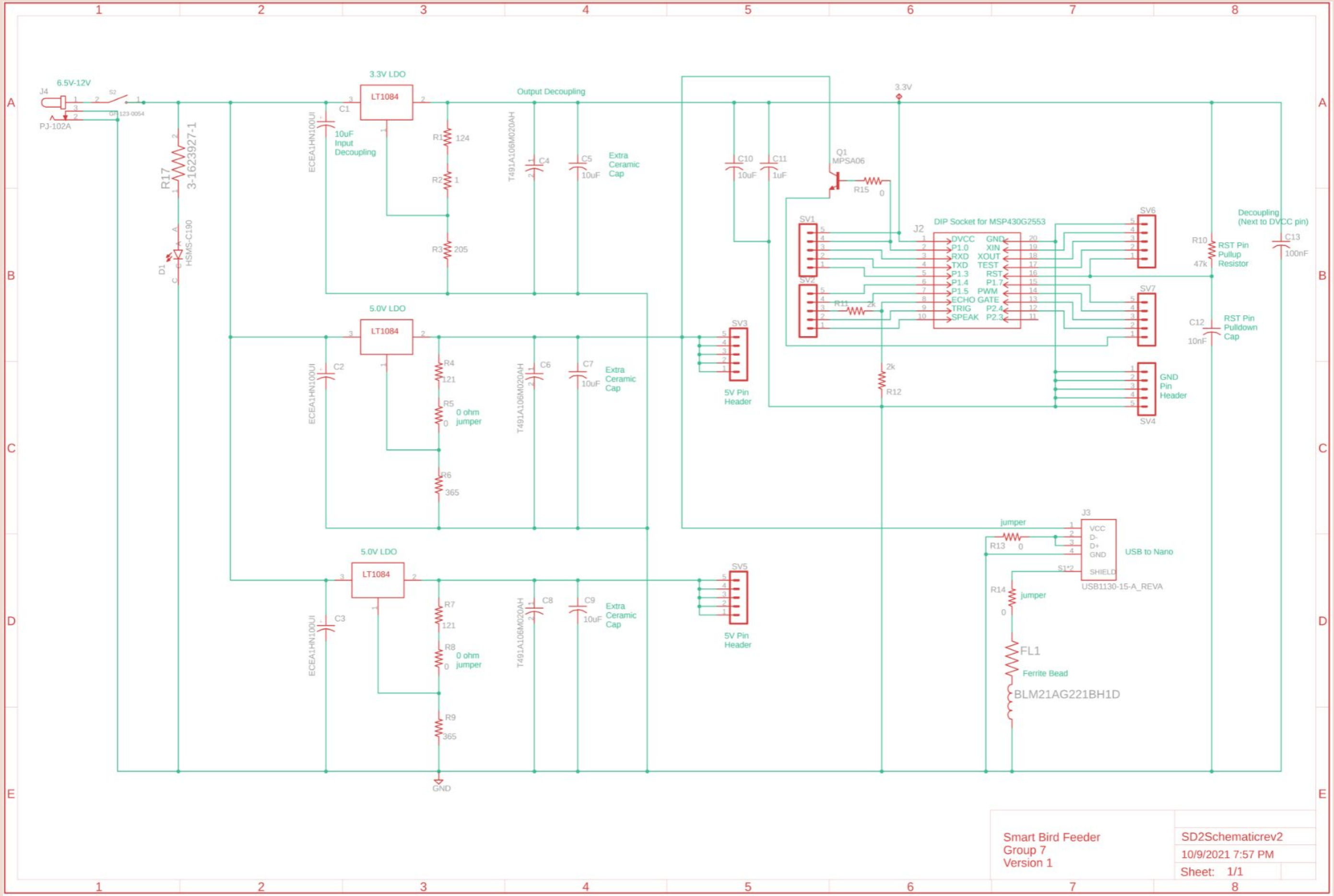


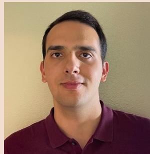
Referenced from datasheet

There are two voltages that is needed to supply in our system. We are supplying 3.3 volts for the MCU and supplying 5 volts for the remaining components, which includes the development kit for object detection. We also have a battery that stores a higher voltage than is required (12V), and with the utilization of voltage converters, we are converting this voltage down to those required in our system.

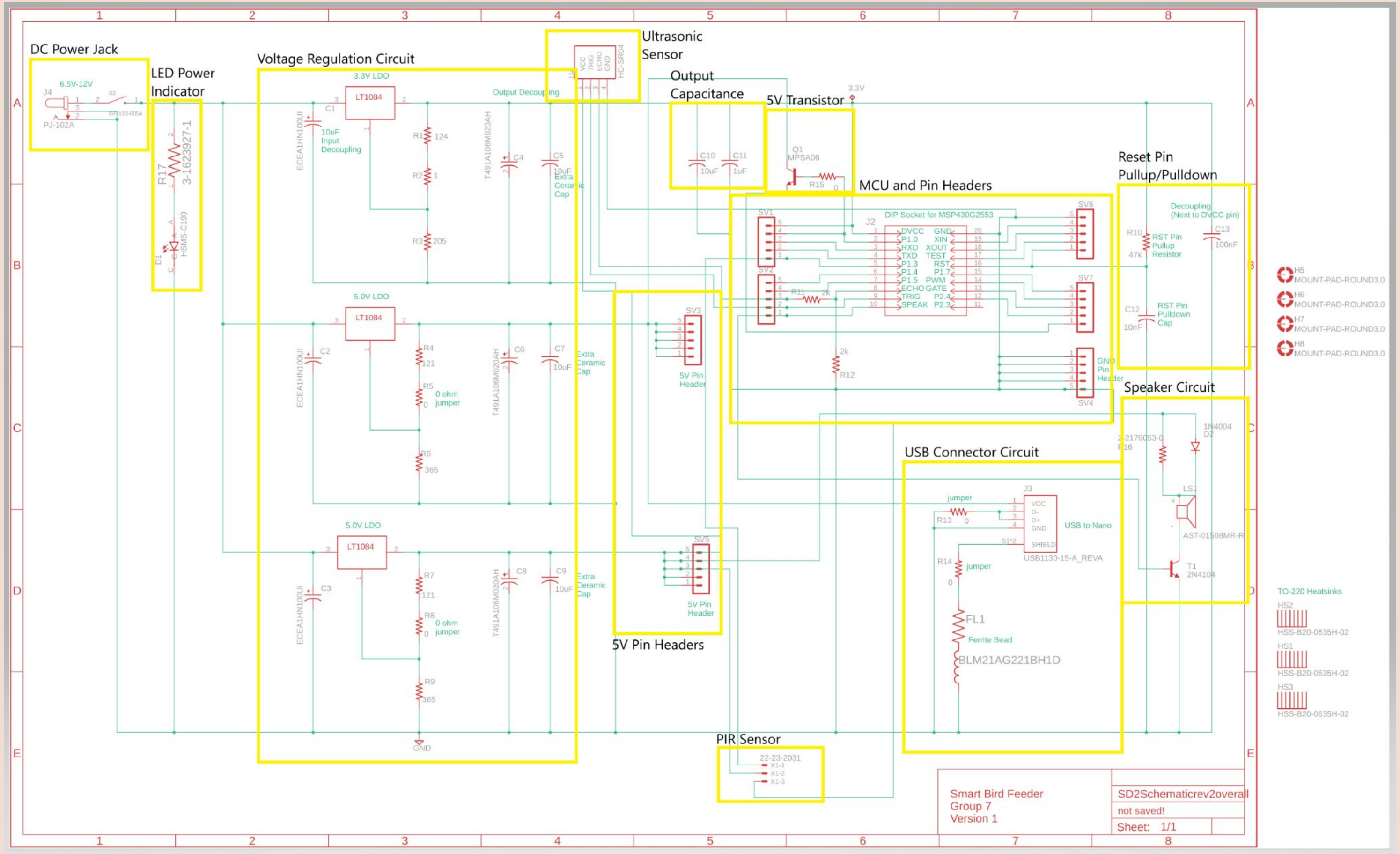


PCB Schematic

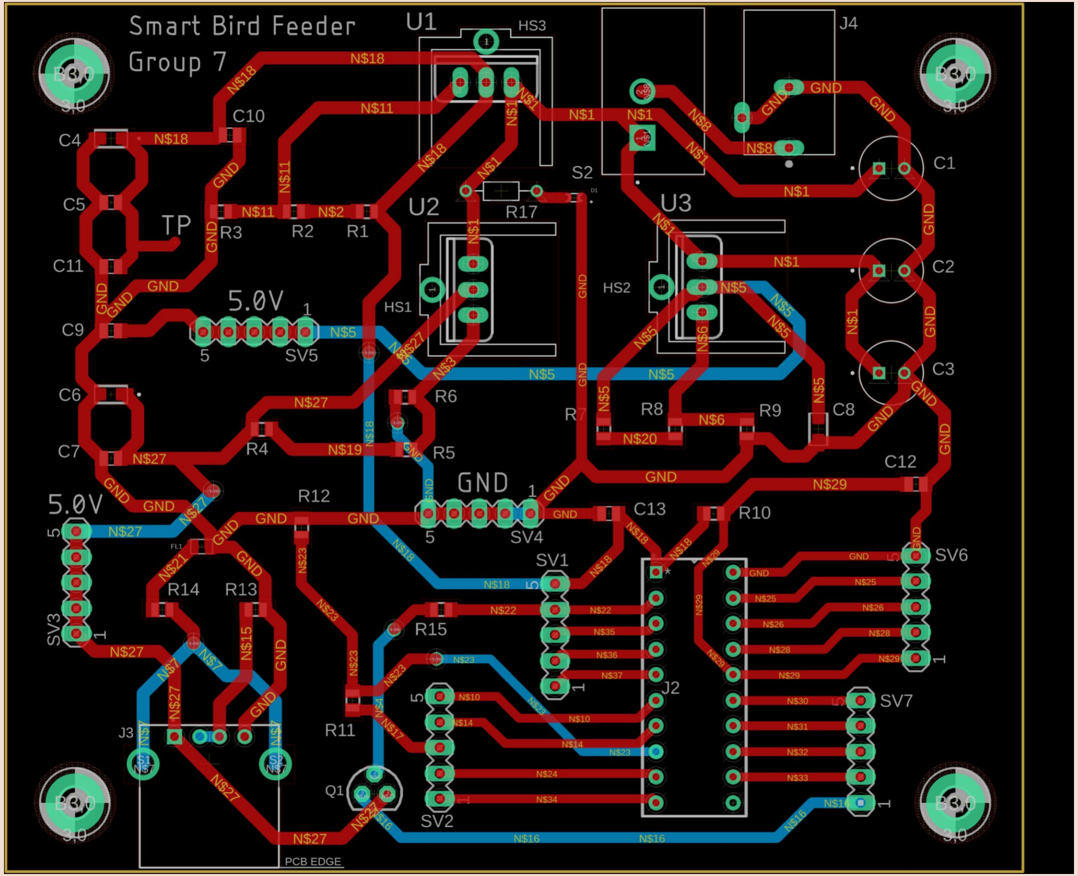


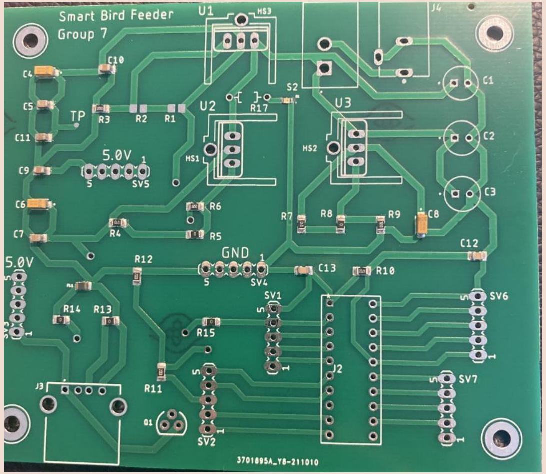


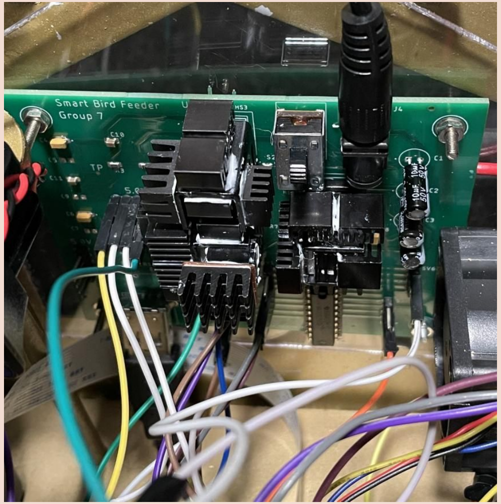
Overall Schematic



PCB Board Layout







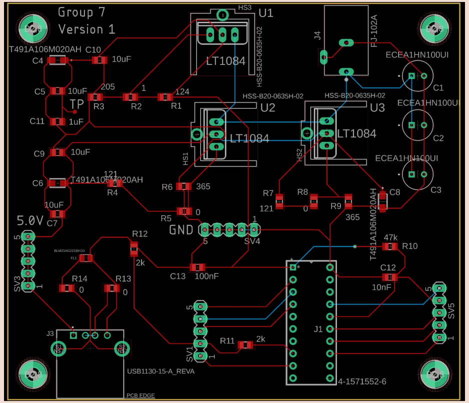
Design Challenge:
PCB Thermals & Trace Width

Problem:

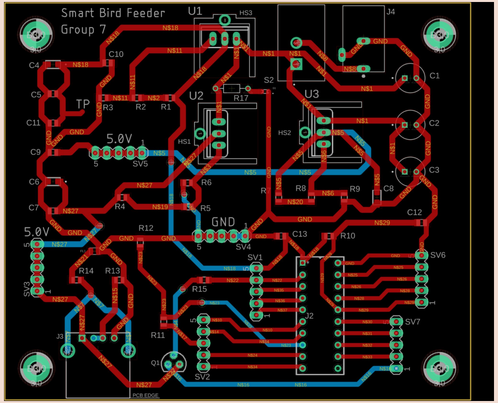
- The linear voltage regulator used to supply 5V to the Nano was producing a lot of heat
- Traces on original manufactured PCB were too thin; large resistance of the traces resulted in a drop in voltage
- The only way to turn the PCB on/off was to plug/unplug the DC power jack (time consuming and disruptive to the system)

Solution:

- Installed additional heat sinks on voltage regulators
  - Also installed cooling fan on the inside of the feeder to mitigate heat
- Widened the traces and reordered PCB
- Included a power LED indicator and surface-mounted switch to indicate when the PCB was being powered

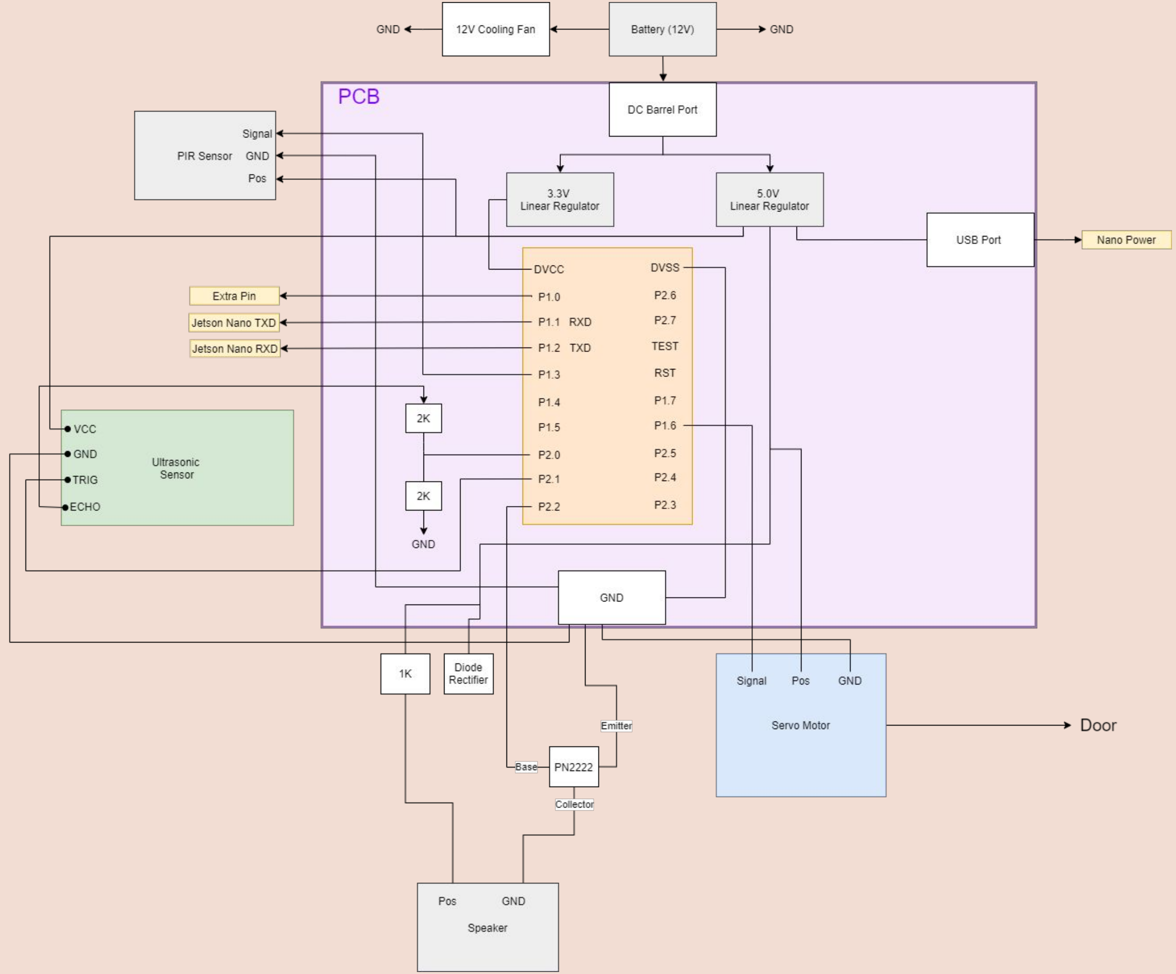


PCB schematic (before trace-width fix)



PCB schematic (after trace-width fix)

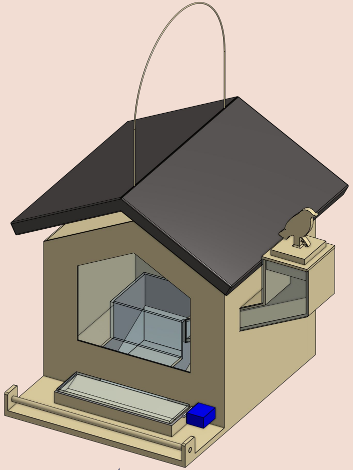
Hardware Schematic

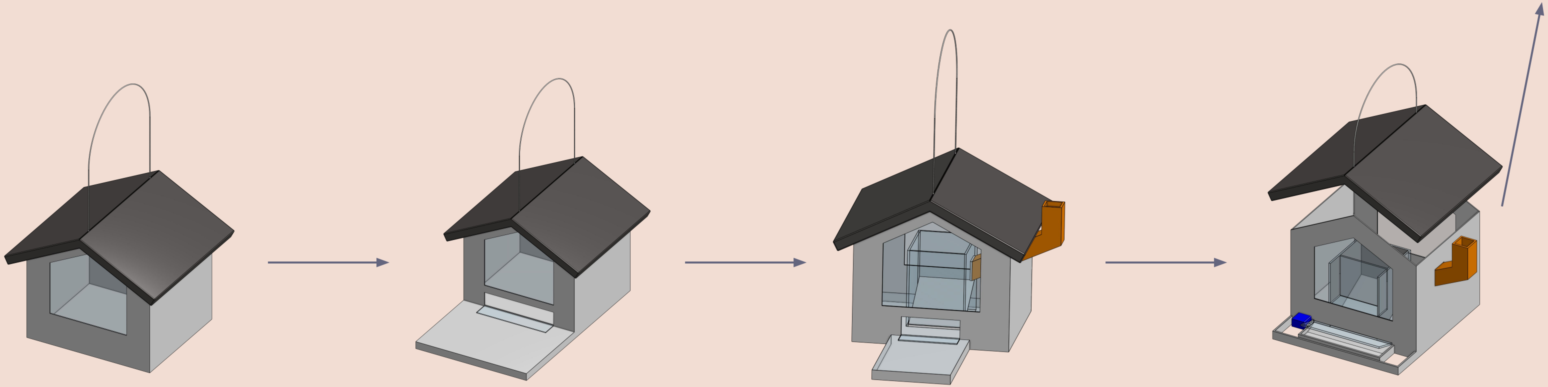


Bird Feeder Structural Design

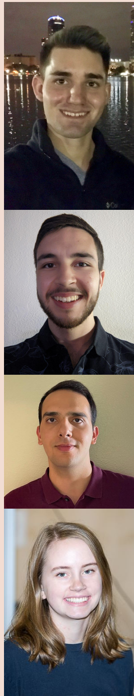
- Purchased assembled birdhouse retail
- Rendered a 3D model of the birdhouse in CAD
- Design choices:
    - Trough design
    - Servo placement
    - Feed container design
    - Chimney design (3D printed)
    - Bird perch
    - Electronics housing
    - Camera placement

Final Design Choice

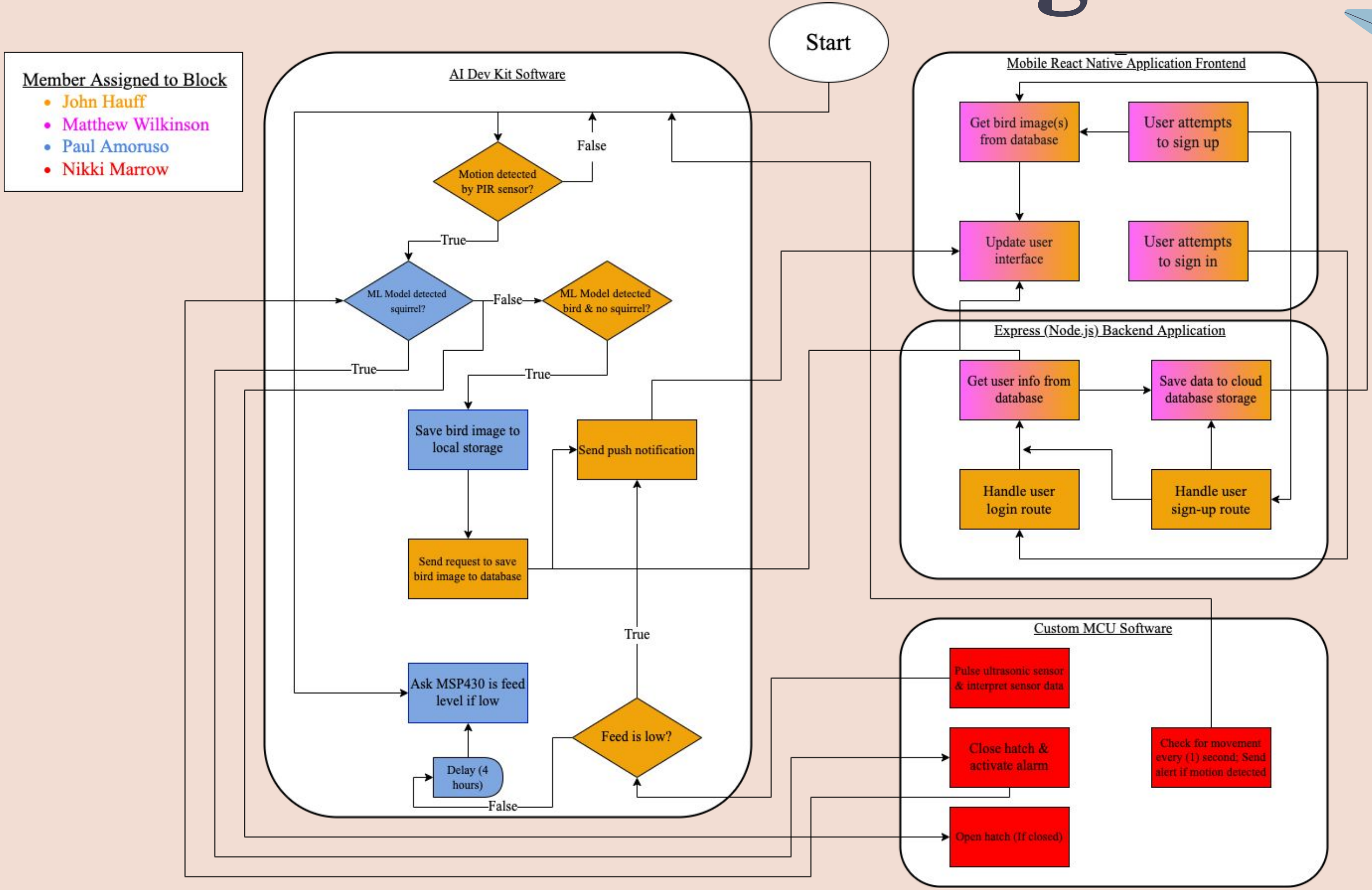




Start
(retail birdhouse)

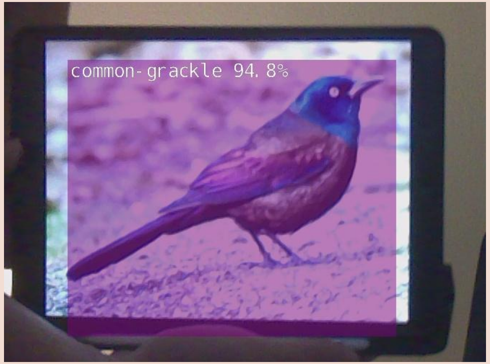


Software Block Diagram

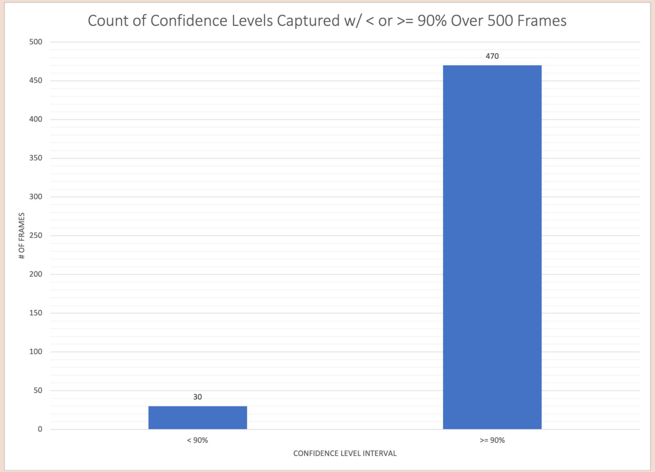


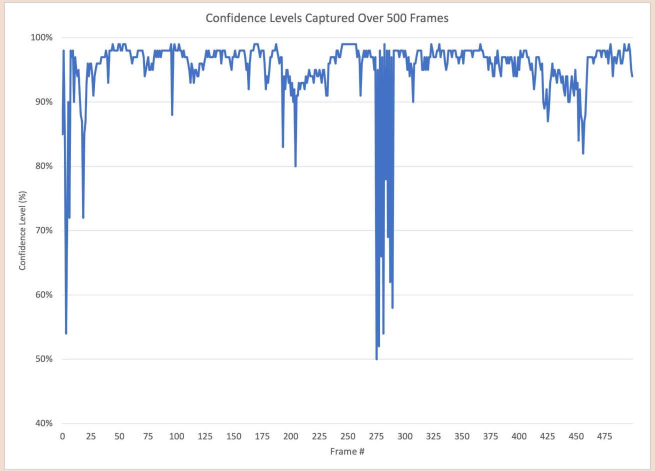
Jetson Nano & ML Model Software

- NVIDIA JetPack SDK provides detectNet for running object detection ML models
- A pre-trained SSD-MobileNet V2 ML model will be retrained for object detection of bird species and squirrels using PyTorch
    - Using a Pascal VOC dataset annotated with Computer Vision Annotation Tool (CVAT)
- All software designed & used for the ML model is written with Python
- Raspberry Pi camera sends video feed to ML model
- Once bird and bird species is detected, image is saved and sent to cloud database
- Otherwise, close hatch and sounds alarm
- UART serial communication between Jetson Nano and MSP430 MCU



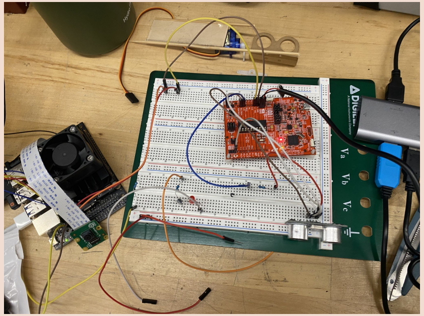
Common Grackle detection made by trained ML model



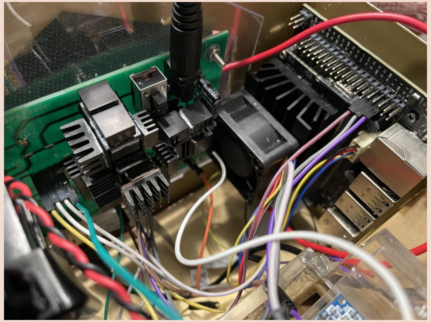


MSP430G2553 Software

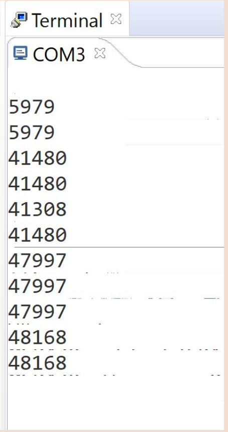
- Tasks:
  - Ultrasonic Sensor
    1. Send command from Jetson Nano to the MSP through UART
    2. MSP sends signal to ultrasonic rangefinder sensor and receives back the raw data
    3. MSP converts raw data into a distance in micrometers
    4. Read feed levels
    5. Send data to Nano via UART
  - Alarm
    1. Send command from Nano to MSP through UART
    2. MSP sounds the alarm
  - Hatch
    1. Send command from Nano to MSP through UART
    2. MSP closes or opens the hatch
    3. MSP sends a message to the Nano notifying it that it has completed the task
  - PIR Sensor
    1. Constantly monitors the signal output of the sensor using ADC on the microcontroller
    2. Sends a signal to the Jetson Nano when motion is detected
- How we did it:
  - UART serial communication between Jetson Nano and MSP430 MCU
  - Flashing C programs onto the MSP430 using Code Composer Studio
  - Messages transmit as a stream of characters



Prototyping UART communication (Nano <-> MSP430)



Final assembly for UART communication (Nano <-> MSP430)



Data received by the MSP from the Ultrasonic Sensor

Full Stack Development Technologies

A few other tools used to help create our application:

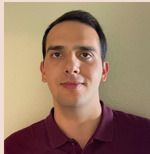
Expo is a framework that allows users to test React applications
- Applications can be modified and restested quickly
- Expo Go app allows the program to run the application directly on smartphones
- Essential for testing changes

MongoDB:
- noSQL database
- MongoDB Atlas offers a cloud database

Node.js + Express:
- Backend API uses Node.js runtime environment with the Express framework
- Routes all REST API requests

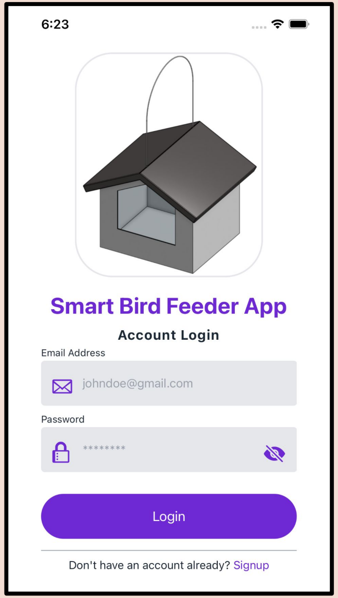
Application Development Framework

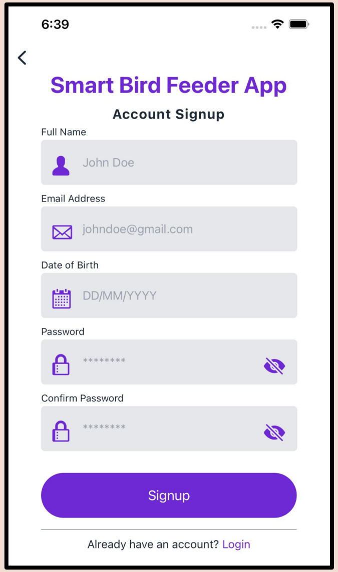
After comparing with Flutter, the React Native framework was used to build the mobile application
- Javascript based application
- Works well in MERN stack applications due to the synergy of coding in Javascript
- Varied documentation and support given it's popularity
- The group has familiarity in React Native, as we've worked with it in the past

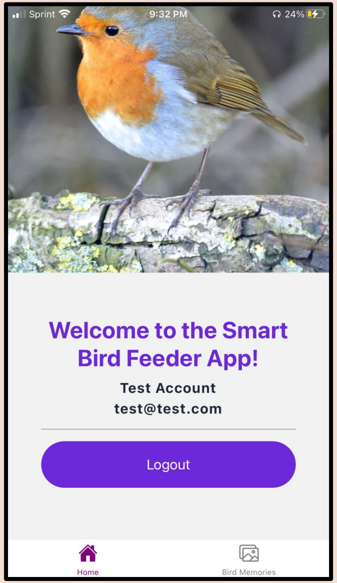


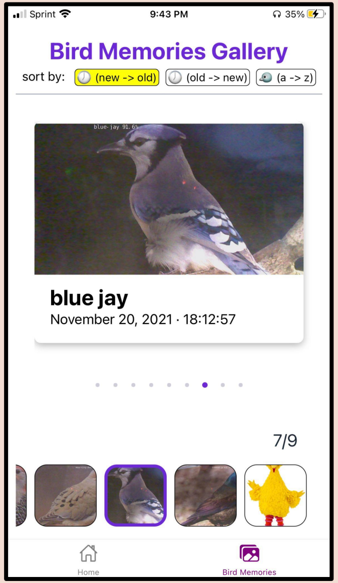
Mobile Application Design

- There will be three main pages
  - Login/Sign up
  - Home
  - Bird Memories

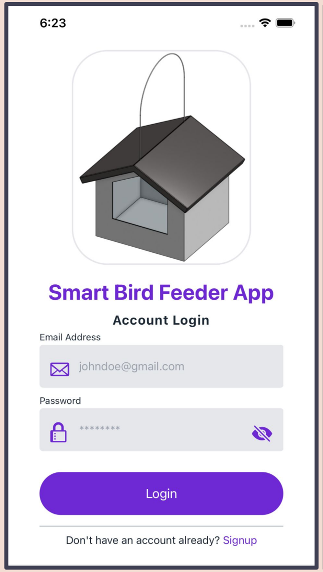


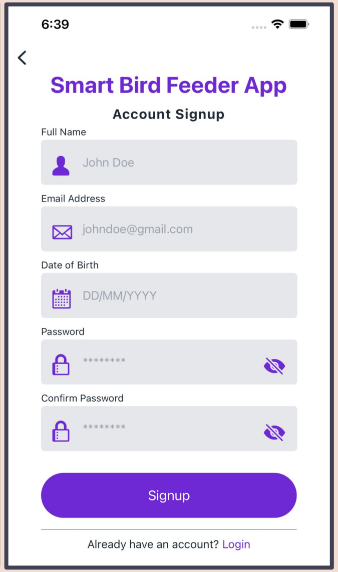






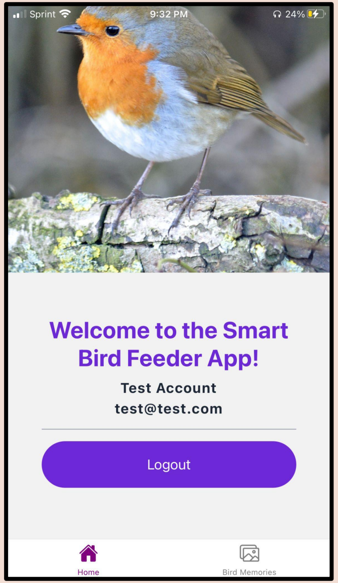
Application Design





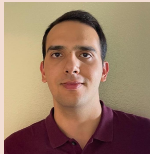
Login/Signup

- One time process
- User inputs name, email, DoB, and their password

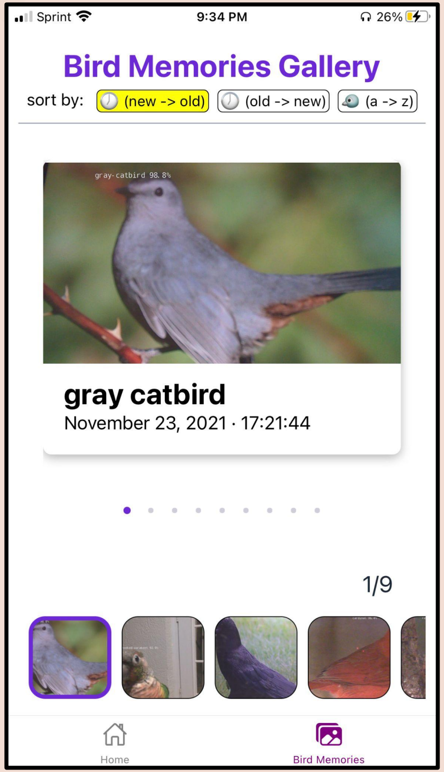


Landing page

- Navigation Options: Welcome page, memories page, and logout
- Notification bar will pop up during feeding events, with a species tag.



Application Design



Bird Memories page

- Access any of the previously saved bird memories
- Bird memories gallery, with picture and name of the species highlighted
- Sort by date/time acquired or species name
- Convenient scrollable thumbnail image list & pagination dots
- Pull-down refresh function

Notifications

- When a new bird appears to eat from the feeder
    - Species tag nested in the notification
- Notifications for low bird feed
- Notifications appear as a pop up, even when not on the application

Design Constraints

These constraints help highlight the various concerns and constraints that play a integral part of the schedule and the selections of parts that make up the system,

- Economic
  - Self-funded by the group
- Environmental
  - Renewable energy
  - Safe for the environment
- Social
  - Affordability
- Ethical
  - Does not infringe on any existing patents
- Health & Safety
  - Does not hurt birds or squirrels
- Manufacturability
  - Availability of parts
- Sustainability
  - Longevity of the product
- Time
  - Length of the semester
  - Testing parts
  - Wait time for delivery on parts

Standards

IEEE 802.11

Institute of Electrical and Electronics Engineers Standards Association, provides standards for wireless connections for fixed, portable, and moving stations within a local area. The standard describes such things as functions & services needed by devices to operate in networks as well as the mobility within networks.

Battery

IEEE Std 1013™-2019 standard is known as the IEEE Recommended Practice for sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems. Used to understand battery usage within a system where the load exceeds the output of the photovoltaic array.

C Language

ISO/IEC 9899 international standard which defines the programming language. The joint effort between ISO and IEC contains the preliminary elements, characteristics of environments to translate and execute C programs, language syntax, constraints, semantics, and library facilities.

UART

UART is a simple interface which allows transmission of bytes between two parties. It uses one wire and transmits data in the same direction over the wire, and can be implemented with one wire to transmit in one direction (half-duplex) or with two wires to allow bidirectional simultaneous transmission (full-duplex).

IPC PCB

Institute for Printed Circuits is known as the Association Connecting Electronics Industries, which aims to ensure a standardization of the assembly and production requirements of electronic equipment and assembly. (IPC-221)

Bill of Materials (Budgeting)

Financing to date

	Item	Quantity	Price/Unit ($)	Cost ($)
1	NVIDIA Jetson Nano 4GB Dev Kit	1	99.00	99.00
2	Raspberry Pi Camera V2-8 MP	1	28.99	28.99
3	Intel Dual Band Wireless-AC 8265 Device	1	25.99	25.99
4	DC Power Pigtails Cable	1	8.99	8.99
5	4Pcs SG90 9g Micro Servos	1	10.99	10.99
6	HiLetgo Cp2102 USB 2.0 to ttl module	1	5.39	5.39
7	E-outstanding 5PCS PCB Mount	1	5.99	5.99
8	TalentCell Rechargeable 12 V 6000 mAh DC Battery Pack	1	40.86	40.86
9	Bird feeder	2	22.00	44.00
10	PIR sensor	1	9.99	9.99
11	Nvidia fan	1	13.50	13.50
12	PVC flooring	1	20.19	20.19
13	Hatch	1	6.99	6.99
14	Plexiglass	1	30.06	30.06
15	DIP socket	1	3.99	3.99
16	TO-220 Heatsink	3	0.39	1.17
17	USB 1130-15	1	0.82	0.82
18	124 ohm SMD Res	5	0.26	1.3
19	1 ohm SMD Res	5	0.37	1.85
20	0 ohm SMD Res	15	0.41	6.21
21	365 ohm SMD Res	8	0.33	2.64
22	DC Port	1	0.64	0.64
23	PCB	5	6.40	31.98
24	USB to Barrel Jack cable	1	8.99	8.99
25	SWITCH SLIDE SPST 8.5A 125V	1	1.29	1.29
26	MSP430G2553 Microcontroller	1	3.45	3.45
27	PCB fan	1	~9.99	0.00 (recycled)
28	Ultrasonic Sensor	1	3.95	0.00 (recycled)
Grand Total				**$411.81**

Project Management Tools

ClickUp

Discord

Text Messaging

GitHub

Work Distribution

John Hauff

John is the project manager, oversees meetings, and plays a large role in software development

- Project manager
- ML model training (Primary)
- Application Development (Primary)

Paul Amoruso

Paul is focused on software development and the construction of the birdhouse

- ML model training (Secondary)
- UART communication (Primary)
- Mechanical birdhouse construction (Primary)

Nikki Marrow

Nikki manages electrical work for the project and peripheral functionality

- PCB design & Power (Primary)
- Peripheral (Servo, ultrasonic sensor, alarm) functionality (Primary)
- UART communication (Secondary)

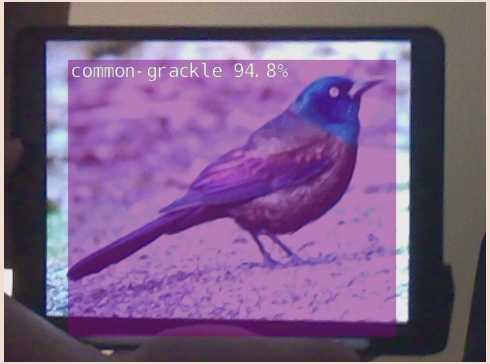
Matthew Wilkinson

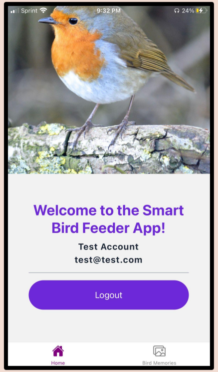
Matthew assists with software development, mechanical construction, and spearheads documentation/presentation work

- Application Development (Secondary)
- Peripheral (PIR sensor) functionality (Secondary)
- Documentation/Presentation creation and updates (Primary)

Future Milestones

- Train the machine learning model to incorporate more species
- Solar panels
- Mobile app extensions
  - Live streaming
  - Search functionality
  - Manual controls for hatch door





Thank you!

Are there any questions?