Detecting Explosive Material via Optical Systems Observing the Behavior of Bees

Group 2

Introductions

We'll be right here!

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Photonic Science & Engineering

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Computer Engineering

Overview and Motivation

Detection Technology is critical for security. However, it tends to be expensive or limited in some way:

- Dogs and Mice require months of effort, trainers to bond with, and thousands of dollars, plus upkeep with specialized diets.
- PIDs only ever detect a handful of compounds, and it must both be attuned and a filter paid for.
- GC-MS machines and ETDs are exceedingly expensive.

Bees mostly **circumvent** these issues:

- They take hours to train, which lasts for four to five days.
- They cannot be trained for multiple compounds at once, but multiple groups of bees can be trained simultaneously instead.
- The training requires a lab setting, but no bonding or attunement is needed beyond that.
- The cost of using the bees is only raised by the technology used to house, transport, and observe them.

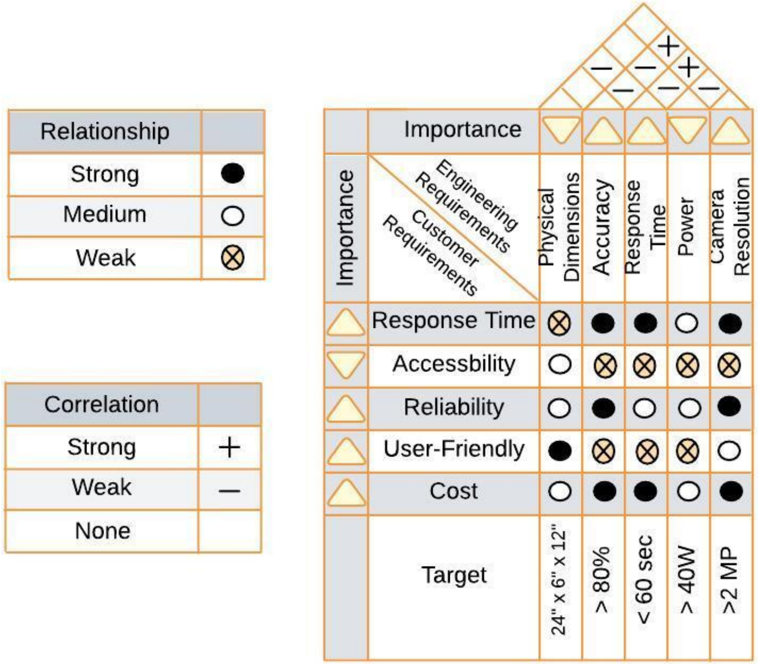
Goals and Objectives

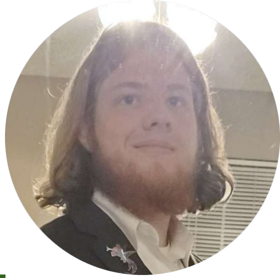
The overall goal of this project is to create a handheld portable device used to monitor trained bees for bomb detection. The device will be user-friendly and easily accessible given the user has access to trained bees. The prototype device should help decrease overall cost and time in bomb detection.

Basic Goals	Advanced Goals	Stretch Goals
Detect substances with greater than eighty percent accuracy	Detect substances with greater than eighty five percent accuracy	Detect substances with greater than ninety percent accuracy
	Response given within a minute.	Add more advanced statistics to the LCD display

Engineering Requirements

Overall Device Requirements	
Response Time	< 1 Minute [Visual Spectrum] <5 Seconds [Infrared Spectrum]
Battery Life	>30 Minutes
Weight	< 15lb
Accuracy	≥ 80% [Visual Spectrum] ≥ 60% [Infrared Spectrum]
Device Communication	LCD Screen, LEDs, USB
Device Dimensions	30” x 6” x 12”
Power	≤ 40W
Bee Chambers	2



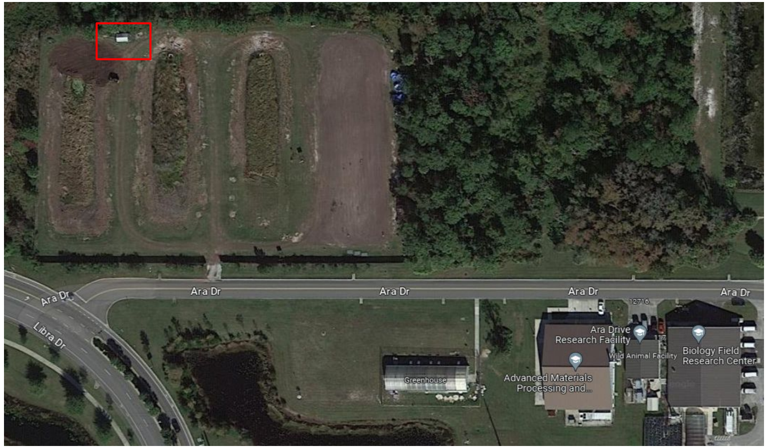


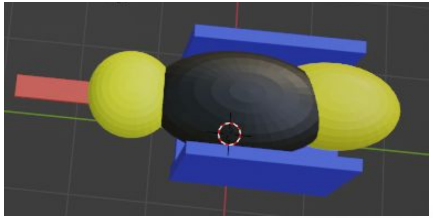
The Bees

- Superior Trainability.
- Small form factor vs Dogs.
- Equal vapor sensing threshold at 40 parts per billion.

The Training the Bees

- To train the bees, we have partnered with Patrick Bohlen, the head of the bee research division at UCF.
- The bees will be harvested from hive #2 at Biological Observation Field Three.
- Train will be done by Nicholas Johnson (speaking).
- Previously was to be done with one of Dr Bohlen's grad students, but they became unavailable due to family emergency.





The Training the Bees

- The train will be done by Nicholas Johnson (speaking).

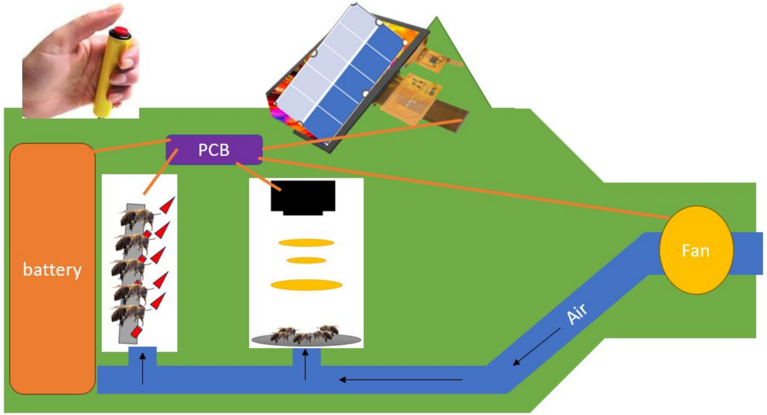
- After collection the bees will be refridgerated to slow their metabolism and make them easier to manipulate in to harnesses.

- To pavlov the bees the will be exposed to liquid TNT for 6 seconds at a time with the last 3 seconds of it being offered sugar water as a reward.

- Process takes about 4 hours for each bee.

Physical Design of the Device

- Hand-held.
- Compact.
- Light.
- Efficient airflow.
- Two bee chambers.
- Visual Result Output located at the top.

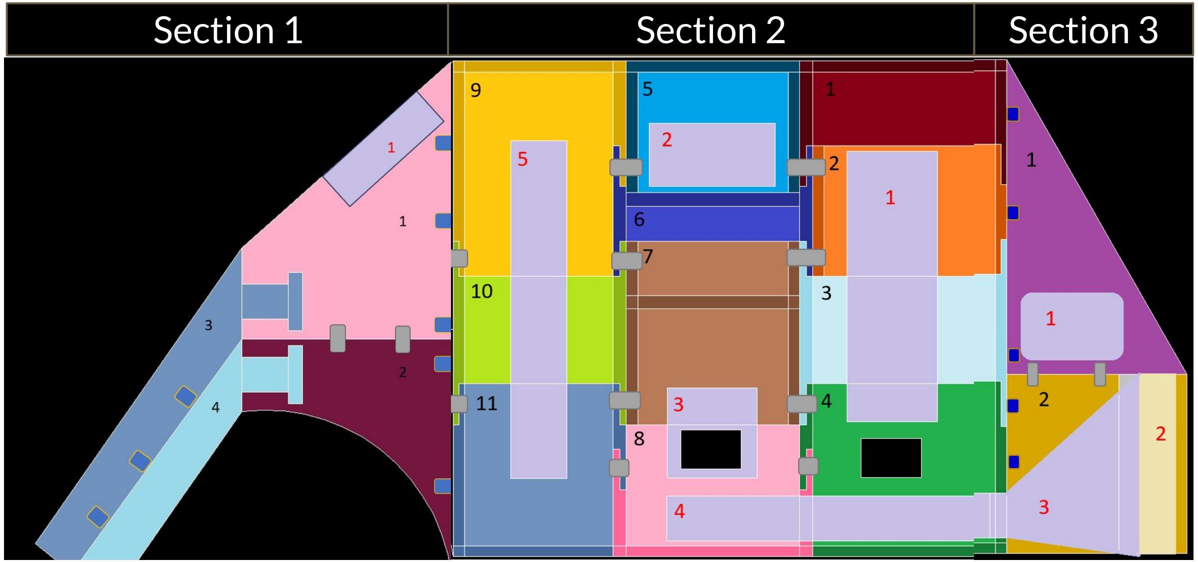


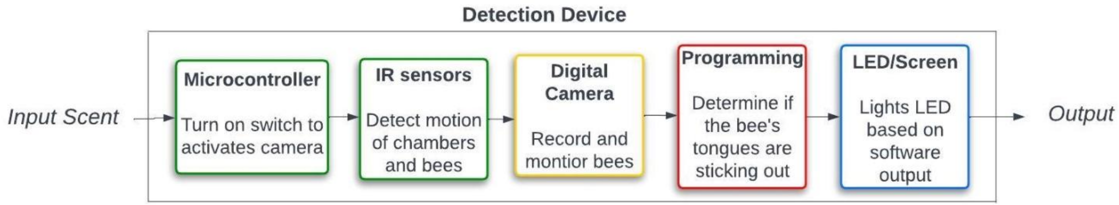
Fabrication of Device Structure

The device is made to be extremely modular in design.

This will allow onsite maintenance on the device to be as efficient and streamlined as possible and eliminate the risk of workers opening the bee sensing areas and unalignment of the optical components.

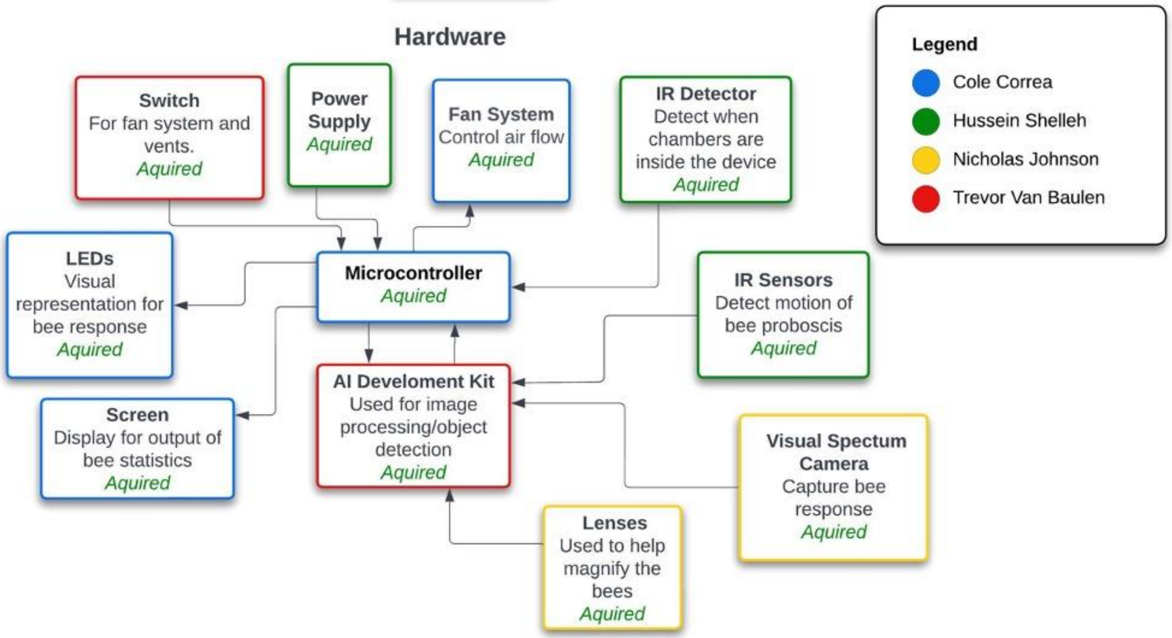
Also offers an easy slide and lock mechanism for loading the bees in.





Hardware Lineup

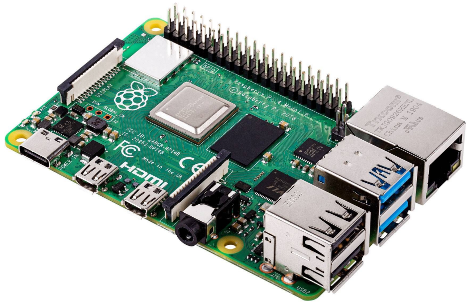
- Cole Correa developed the initial breadboard, code for the Microcontroller, Fans, LEDs, LCD, and IR Sensors.
- Hussein Shelleh primarily handled PCB modification, part solder and installation, and IR tuning.
- Nicholas Johnson focused on the 3D Printing, and the Camera and Lens apparatus.
- Trevor Van Baulen primarily focused on development of the Object Detection software on the AI Development Kit.



Microcontroller (MCU)

- Controls fan, IR sensor, LCD, and LED sub-systems.

- Chose ESP32.
- Initial Choice was to use the chip on Raspberry Pi 4 due to the RAM and GPIO pin count that the dev kit provides.
- Had to be changed for hardware and size complications - Uno is our third option.



Name	RAM	Voltage (V)	GPIO Pins	Clock Frequency	Price
MSP430	512 B	1.8-3.6	8	32 kHz	$13.29
Arduino Uno	512 B	2.7-5.5	14	16 MHz	$27.60
Raspberry Pi 4	2-8 GB	3-5	40	1.5 GHz	$35
ESP32-S3-WROOM-1	16 MB	3-3.6	36	80 MHz	$3.62

Fans

- Airflow control for sampling air around target.
- Must be relatively small, but also have good airflow and remain quiet - loud fans can disturb the bees.
- All options are small, so airflow and noise level are the focus.
- NoiseBlocker XS2 best fits our needs.

Name	Size (mm)	Noise Level (dB)	RPM	Airflow (CFM)	Voltage (V)	Cost
Anvision YDM4010B12	40 x 40 x 10	27.5	6200	7.56	12	$13.98 (for two)
NoiseBlocker XS2	50 x 50 x 10	16	4000	6.8	12	$12.95
Coolerguys CG2510H12-IP67	25 x 25 x 10	20	9000	2.1	12	$9.95
MakerFocus 3D Printing Cooler Fan	40 x 40 x 10	18	5000	5.75	12	$5.99

LEDs

- The LEDs are intended for lighting and output visualization.
- Must be small and bright, while also having low power requirements - good lighting is needed for the camera system without using too much electricity.
- Bojack Selected.

Name	Size (mm)	Voltage (V)	Wavelength (nm)	Current (mA)	Millicandela Rating (mcd)	Cost
XLUR12D	5	1.9	617	10	10	$0.29
WP154A4SUREQBFZGC	5	1.9-3.2	465-630	20	20	$1.92
5218559F	5	2.2-3.3	470-625	20	20	$0.88
Bojack 5mm LEDs	5	2.0 - 3.2		20	10	$12.99

LCD

- The LCD is for a more visually detailed output visualization.
- Must have sufficient resolution, while also remaining small and having low power requirements.
- ST7920 controller for SPI communication.
- Canaduino Selected.

Name	Size (mm)	Resolution	Voltage (V)	Cost
NHD-C12832A1Z-NSW-BBW-3V3	36 x 12	128 x 32	3	$12.80
MIKROE-4	62 x 44	128 x 64	17	$29.00
Canaduino LCD	93 x 70	128 x 64	5	$11.99

Battery Pack selection

- Wanted to ensure battery provided enough power while remaining slim.
- Initially selected Philips Respironics Battery due to the team already owning one.
- Battery stopped functioning, so TalentCell is our alternative.

Battery Pack	Philips Respironics Battery	AT:Tenergy Li-ion	TalentCell YB1208300-USB
Watt-Hour (Wh)	~98	~100	~100
Voltage (V)	14.4	14.4	12.6
Milliampere Hour (mAh)	6300	7000	8300
Dimensions (mm)	107.95 x 190.5 x 31.75	147 x 73 x 20	39 x 80 x 138

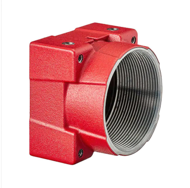
Infrared Sensors

- Looking for consistent functionality in both low-light and white-light environments.
- Absorption Sensors struggle to detect Bees; Motion sensor is less accurate but works.
- HC-SR501 Selected.

Part	Input Voltage (V)	Current (mA)	Wavelength (nm)	Sensor Type	Detection Cone	Price
HC-SR501	5-20	65	N/A	Motion	110°	$0.85
LL-503PDD2E	0.5-1.3	1	700-1200	Absorption	120°	$0.74
3DU5C	N/A-10	30	400-1100	Absorption	120°	$0.72

Camera Selection

- MD310C-BS was the first choice, ran into issues with the camera.
- Second choice was the Alvium 1500 C-120C.



Camera	MD310C-BS AmScope	Alvium 1500 C-120C	BoliOptics 5MP CMOS
Megapixels (MP)	3.1 MP	1.2 MP	5 MP
Frames Per Second (FPS)	83 FPS	52 FPS	60 FPS
Resolution	680 x 510	1280 x 960	640 x 480
Connection	USB 2.0	MIPI CSI-2, up to 4 lanes	USB 2.0

AI Development Board Comparison

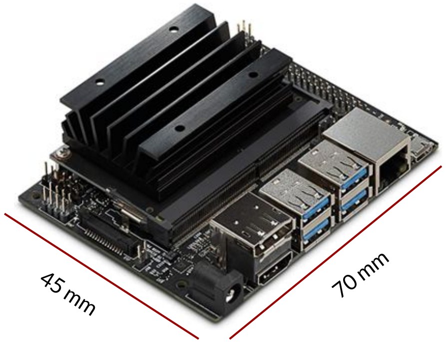
- The design of the system uses two subsystems.
- One of the subsystems utilizes Object detection software for the bee proboscis.
- Since this requires decent computing power, an AI development board is being used.

Technology		Jetson Nano		Google Coral		Raspberry 4 Pi	
Factors	**Weight**	Raw	Weight	Raw	Weight	Raw	Weight
Cost	35%	7	2.9	5	1.75	10	3.5
Performance	30%	9	2.7	7	2.1	4	1.2
Size	20%	5	1	8	1.6	6	1.2
Camera Port	15%	10	1.5	2	0.3	5	0.75
Total:		**8.1**		**5.75**		**6.65**	

NVIDIA Jetson Nano Development Board

Purpose:

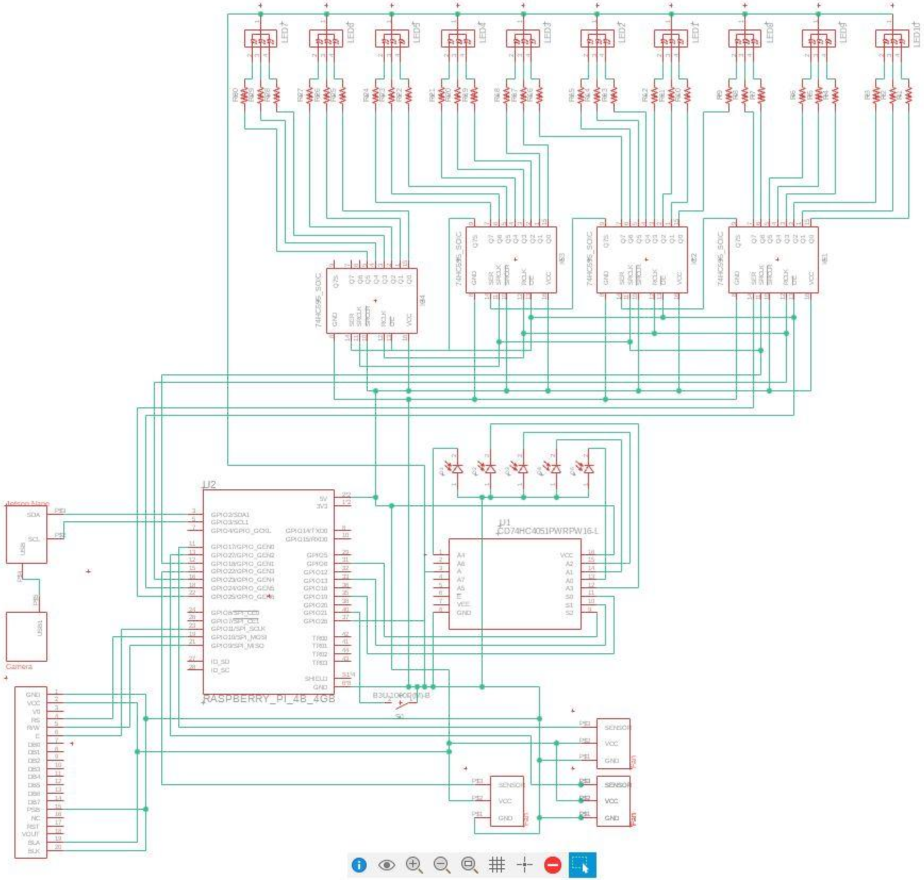
- Will execute object detection model on camera input and return the results.
- Utilizes GPU.
- Designed specifically for AI development.



Specifications	Values
GPU/AI Accelerator	128-core Maxwell @921 MHz/472 GFLOPS
CPU	Quad-core ARM A57 @1.43 GHz
Memory	4 GB 64-bit LPDDR4 25.6 GB/s 1600 MHz
Camera Ports	MIPI CSI-2 camera connection

Hardware Design Schematic

- ESP32
- LEDs
- IR Sensors
- Fans
- Jeston Nano
- LCD
- Switch/Button



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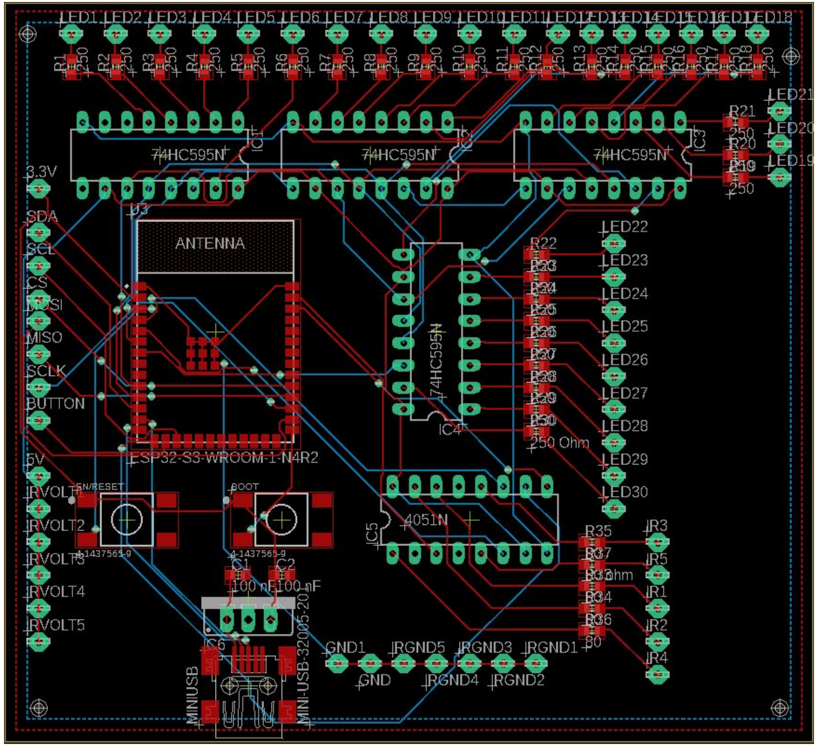
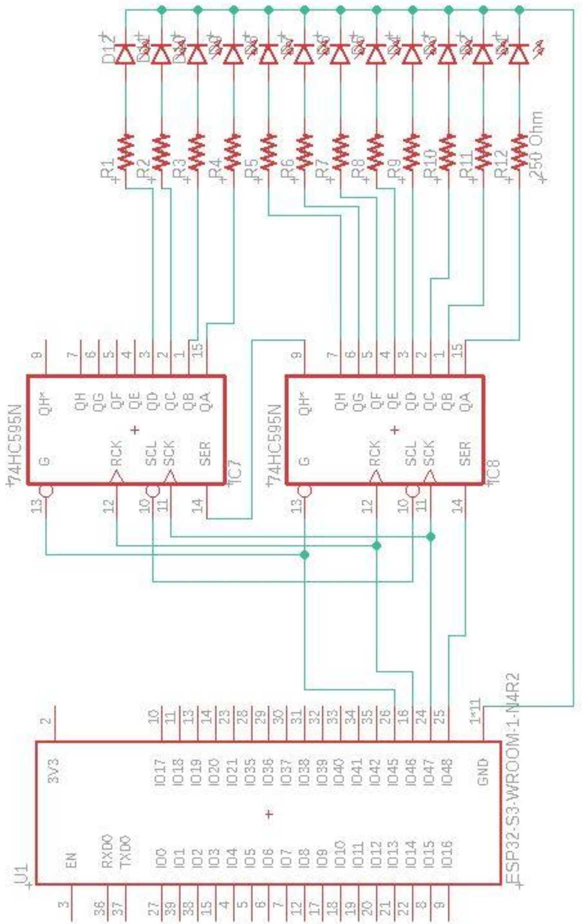


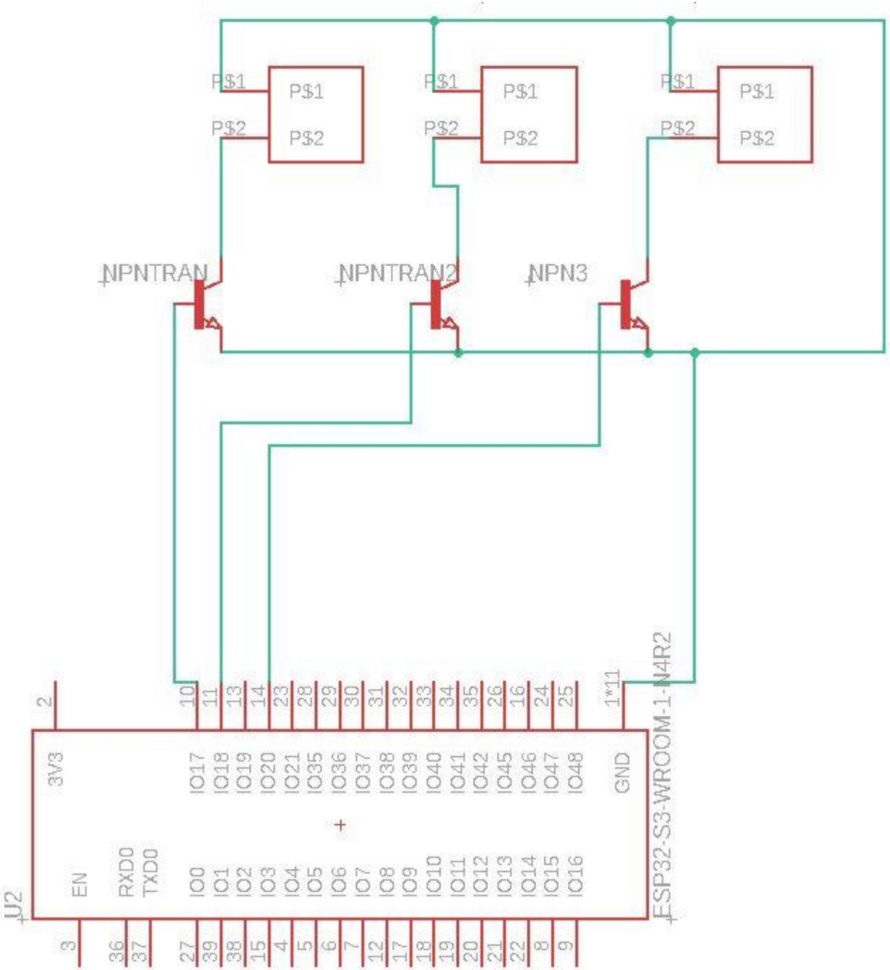
LED Schematic

- twelve LEDs.
- Two 74HC595 shift registers.



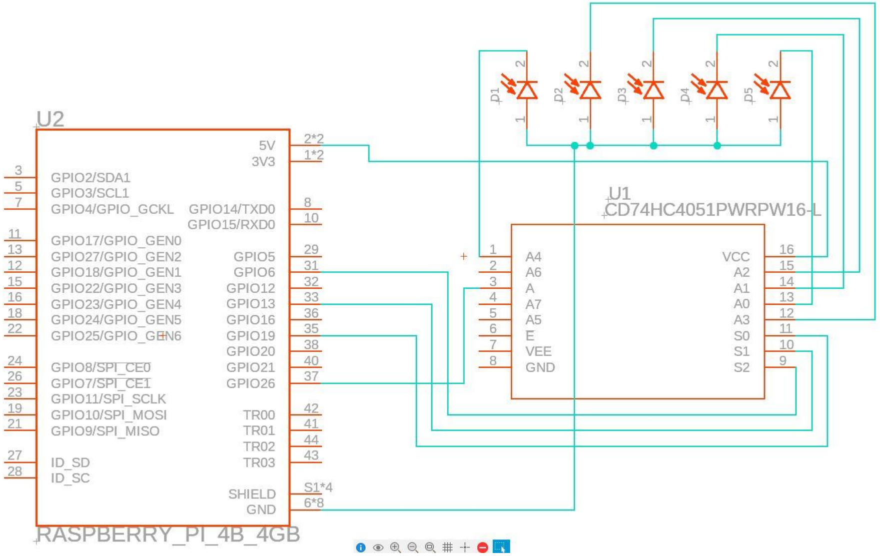
Fan Schematic

- 3 Micro Fans
- 3 NPN Transistors



IR Sensor Schematic

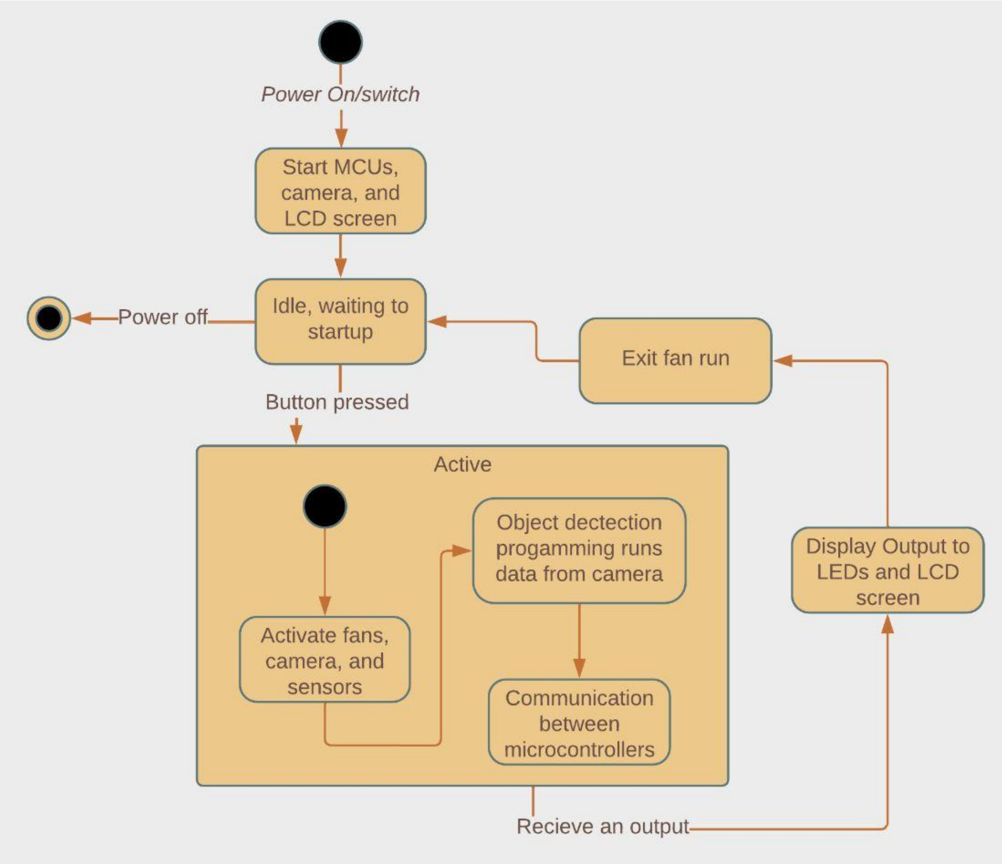
- Signals will be fed into Multiplexor due to analog pin limitations.
- Microcontroller can ‘read’ the outflow of electricity, which marks the bee as a ‘detect’.



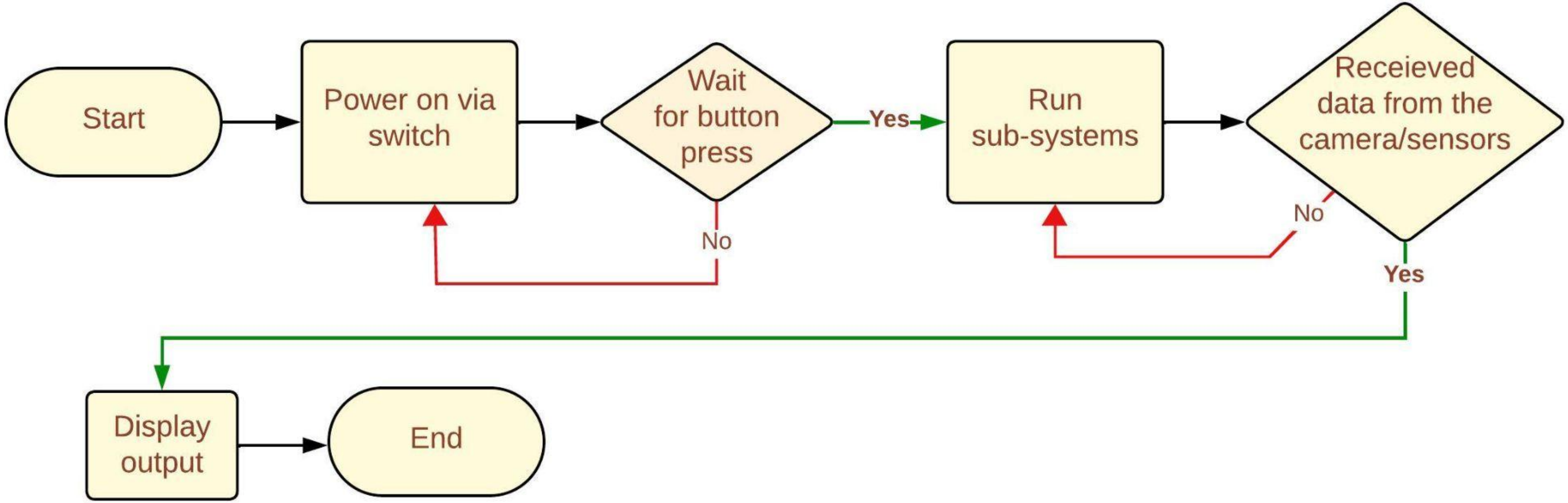
Software Design

- Our software design is split into two main parts: the embedded programming, and artificial intelligence (AI).
- The embedded programming will control many of the functions throughout our device and peripherals.
- Our AI software will deal with machine learning algorithms and object detection found within our camera system.

Software Design State Diagram



Software Design Input Flowchart



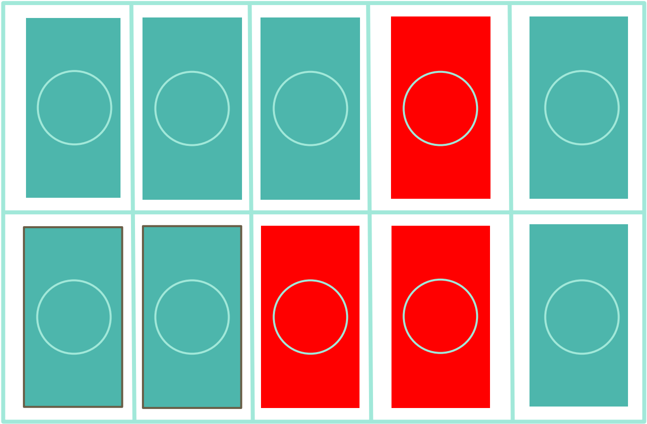
User Interface

- We decided to use two visual aid representations for our device.
- The LCD screen will show the results found from the IR sensor and camera systems. It will also display statistics relating to accuracy and response time.
- The LED interface will be made up of ten LEDs that will light up based on the results of each system.

LCD Screen

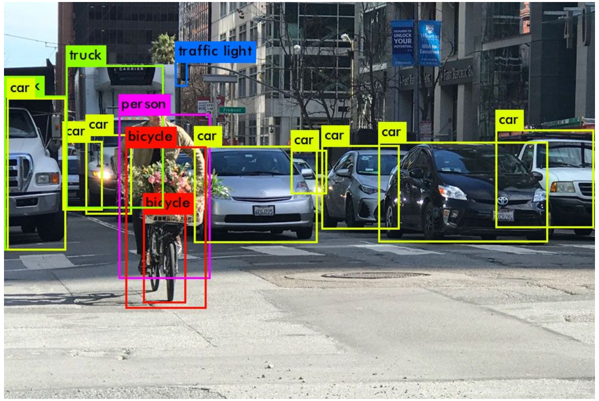
System	1	2	3	4	5
Camera					
IR Sensor					

Accuracy Percentage: xx%



Object Detection Model

- The secondary sub-system is utilizing an object detection model.
- Many models of object detection exist allowing for choice.
- The two main factors were FPS and accuracy.



Choosing Our Model

- Considered three separate models based off FPS and accuracy.
- FPS and accuracy can vary depending on the dataset used to train.
- For fair comparison, the MS COCO dataset was used.

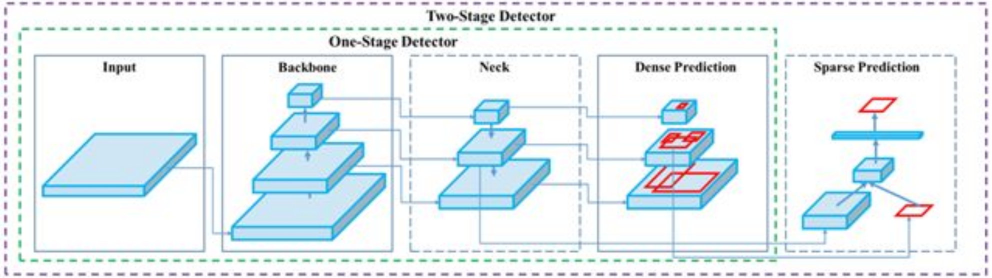
Model	YOLOv4	Faster R-CNN	SSD300
MAP (Mean Average Precision)	43.5%	43.9%	34.9%
FPS	~40	~5	~22

YOLOv4

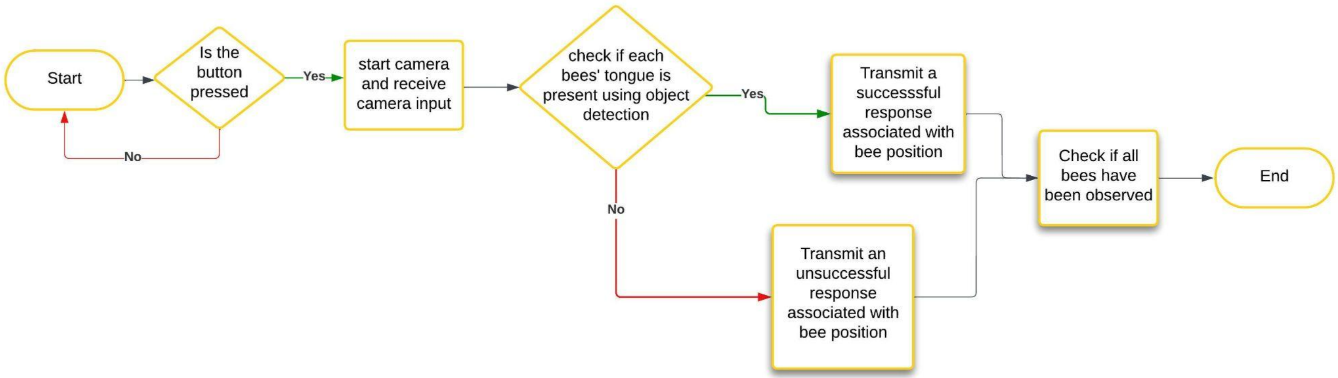
- YOLO (You only look once) is the object detection model that is being implemented.

- Using both bag of freebies and a bag of specials for dataset.

- A dataset is being created to train the model for our purposes.



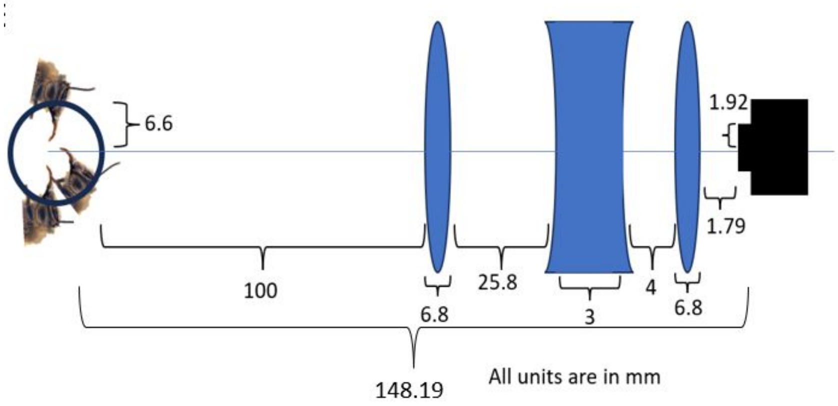
Camera Input for ML



Visual Spectrum Optical Design

- The optical lens and camera system has been perfectly optimized so that the camera can see the tongue of the bee that ranges from 0.7 - 1 mm in thickness.

- The lenses are also optimized the accommodate the range of heights of the bees, from 3 - 5 mm.



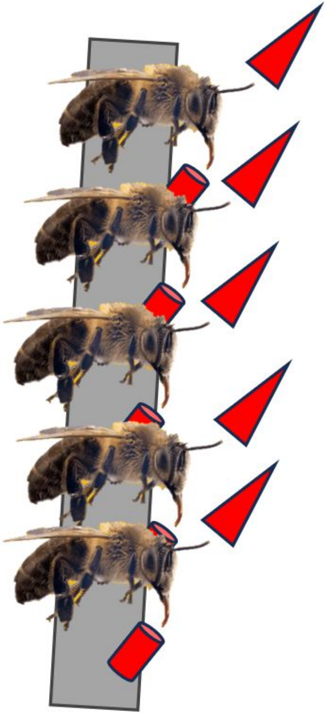
Infrared Spectrum Optoelectronic Design

- Objects that radiate heat still have an optical effect - just not (usually) on the visible spectrum.

- Bee proboscises emit a relatively small amount of heat - but enough to be detected through photodiodes. This isn't feasible for Low-IR sensors, however, so for financial reasons an alternative is used.

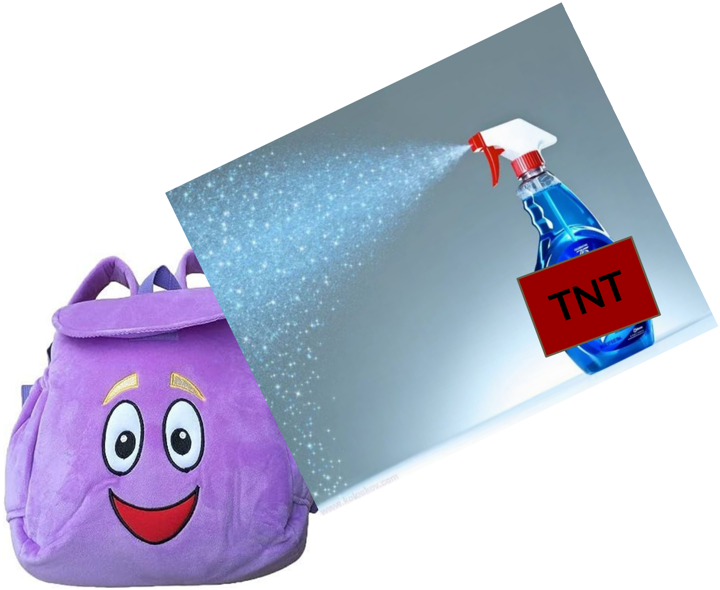
- IR can be used for motion detection - like for doors and paper towel dispensers.

- The motion from the proboscises will cause the sensors to send an electrical signal, which feeds back into the microcontroller.



Testing

- For testing our explosive detection device, we'll have several bags.
- Half will be sprayed with liquid TNT to mimic explosives found in more dangerous circumstances.



Challenges and Triumphs

Challenges:

- Initial uncertainty with project design.
- Growing budget, lacking sponsor.
- Infrared System complications.
- CMOS Camera difficulties.
- Training Object Detection without easy proboscis access.
- Microcontroller refusing to cooperate.
- Battery failing on us.

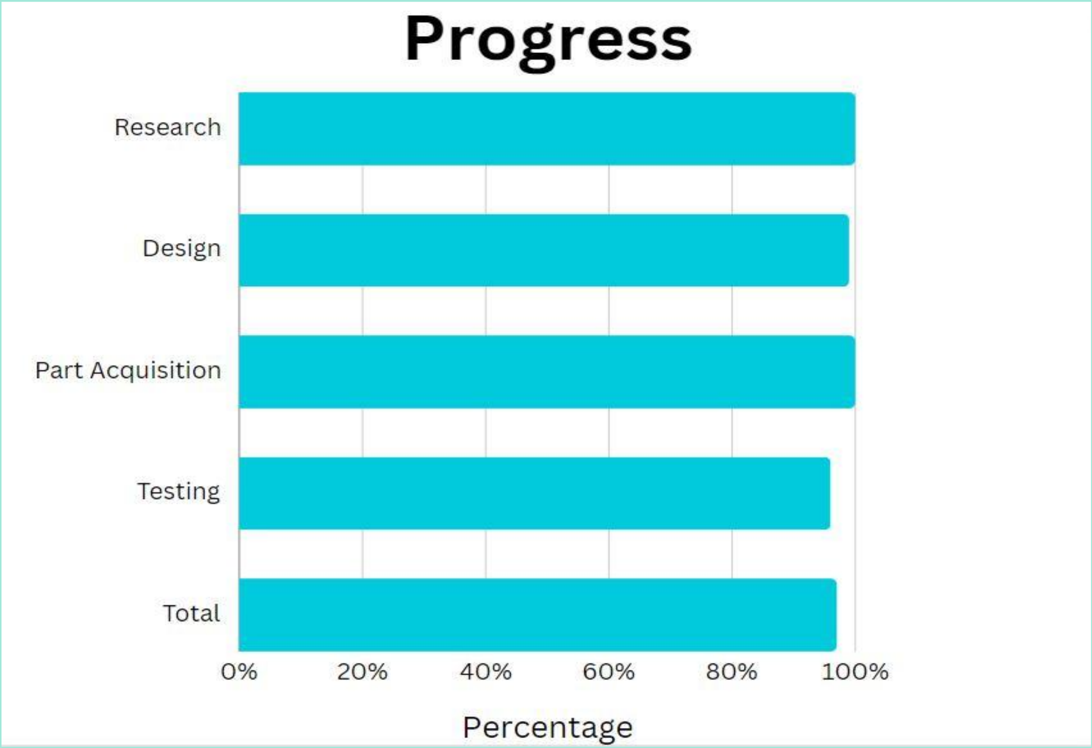
Triumphs:

- Visual Spectrum Lens System already completed and ready.
- Alternatives to live bees available for detection training.
- Existing backup options easing hurdles.
- CNC Mill and 3D Printing Models completed.

Budget (By 11/28/2023)

Item	Quantity	Price	Item	Quantity	Price
RGB LED	15	$16.19	Battery Pack	1	$56.28
LCD	2	$40.88	Fans	3	$43.72
Photodiode	10	$20.64	PCB Board (1st)	5	$119.41
MCU	1	$45.28	PCB Board (2nd)	5	$35.83
AI Dev Kit	1	$166.79	PCB Board (3rd)	5	$135.43
CMOS Camera (1st)	1	$181.04	PCB Components	N/A	$153.90
ALLIED Vis. Camera	1	$405.48	Bees	45	$35.00
Camera Adapter Set	1	$84.44	Ammonium Nitrate	1	$60.00
Lens	3	$169.98	Total		$2,145.17
3D Printer Filament Reel	1	$21.00			

Progress


Progress
Research
Design
Part Acquisition
Testing
Total
0%
20%
40%
60%
80%
100%
Percentage

To Do?

Task	Means of Accomplishing It
Finalize Object Detection Training	Final Runthrough in Progress
Finish 3D Printing	Nearly complete
Camera and Sensor Tweaking	Requires printed shell
Full-System Runthrough	Awaiting Prior Tasks




Thank you!

We appreciate your time and attention, and we hope to hear back from you all.