Smart Laser Toy for Cats

Senior Design II Final Presentation
Group 3

Our Team

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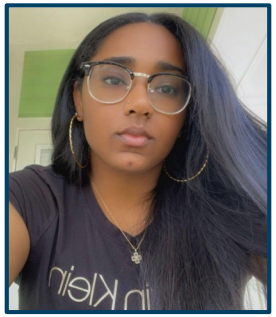

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Project Features

The Smart Laser Toy for Cats will have a ***motion sensor*** that once enabled, will turn on a ***colored collar detection system*** to ensure the correct pet is present. Once detected, the ***laser system*** will activate for a preset time.

Main Features:

- Passive Infrared Motion Sensor
- Color Detection System
- Multi-Lens Laser System
- Mobile Application

Project Motivation

- Create a cost-effective toy that adds more flexibility and user control to a traditional laser cat toy
- Allow those who are very busy to stimulate their cat without needing to be present
- Help those with hand mobility problems interact with their cat while playing with them

Current Market Comparisons

	PetSafe Bolt	Saolife Automatic Toy	Friends Forever Laser	Smart Laser Toy for Cats
Motion Activated	No	No	No	***Yes***
Laser Scanning Pattern	Randomized	Randomized	Circular	***Randomized or Chosen***
Placement	Ground	Higher ground	Ground	Higher ground
Rechargeable Battery	No	Yes	No	No
Manual Play Mode	Yes	No	No	Yes, from app
Shut-off Time	15 minutes	10 minutes	15 minutes	10 minutes
Mobile App	No	No	No	***Yes***

Compared to other market products, the Smart Laser Toy for Cats appeals to more audiences because it can be **motion activated**, has a **randomized or selected laser scanning pattern,** and has a **mobile application** for users.

Project Goals

Basic

1. The toy shall be portable and lightweight.
2. A mobile application shall be created to allow the owner to communicate with the toy.
3. Wirelessly communicate between a mobile application and the device.
4. The use of optics and photonics shall be utilized to differentiate between multiple pets.
5. The toy shall automatically turn on when motion is detected.
6. A color detection system shall enable the laser system when it detects a cat.
7. **The laser system shall generate different scanning patterns.**

Advanced

1. **The device shall be enabled when a cat approaches from the front or sides of the device.**
2. Implement optical beam shaping elements to optimize the shape of the laser.
3. The system shall provide owner analytics and insights into the owner's cat playtime behavior.
4. The collar tag shall be water resistant.

Stretch

1. **Allow the owner to create custom pattern sequences.**
2. Make the mobile application cross-platform.
3. The toy shall automatically shut down when the cat reaches a "too-close" distance.
4. The device shall be waterproof.

Project Objectives

Core

1. Design an enclosure that is less than 15 pounds and holds PCB, motion detection, and laser system.
2. The mobile application and device will communicate via bluetooth signal.
3. The device will only operate for a cat using a color detection system that recognizes red, green, and blue colors from an LED collar tag, brightened and focused by the design of a Fresnel lens.
4. A passive infrared motion sensor will be designed to automatically turn on the color detection system.
5. Two wedge prisms will steer the laser diode into different scanning patterns.

Advanced

1. The mobile application has the following features: play time and number of times pattern changes.
2. One laser diode will be used to show scanning patterns on the floor through the design of a lens system.
3. Use four passive infrared sensors around the rectangular-shaped device to ensure maximum field of view for pet detection.
4. Use silicone adhesive to make the collar water-resistant.

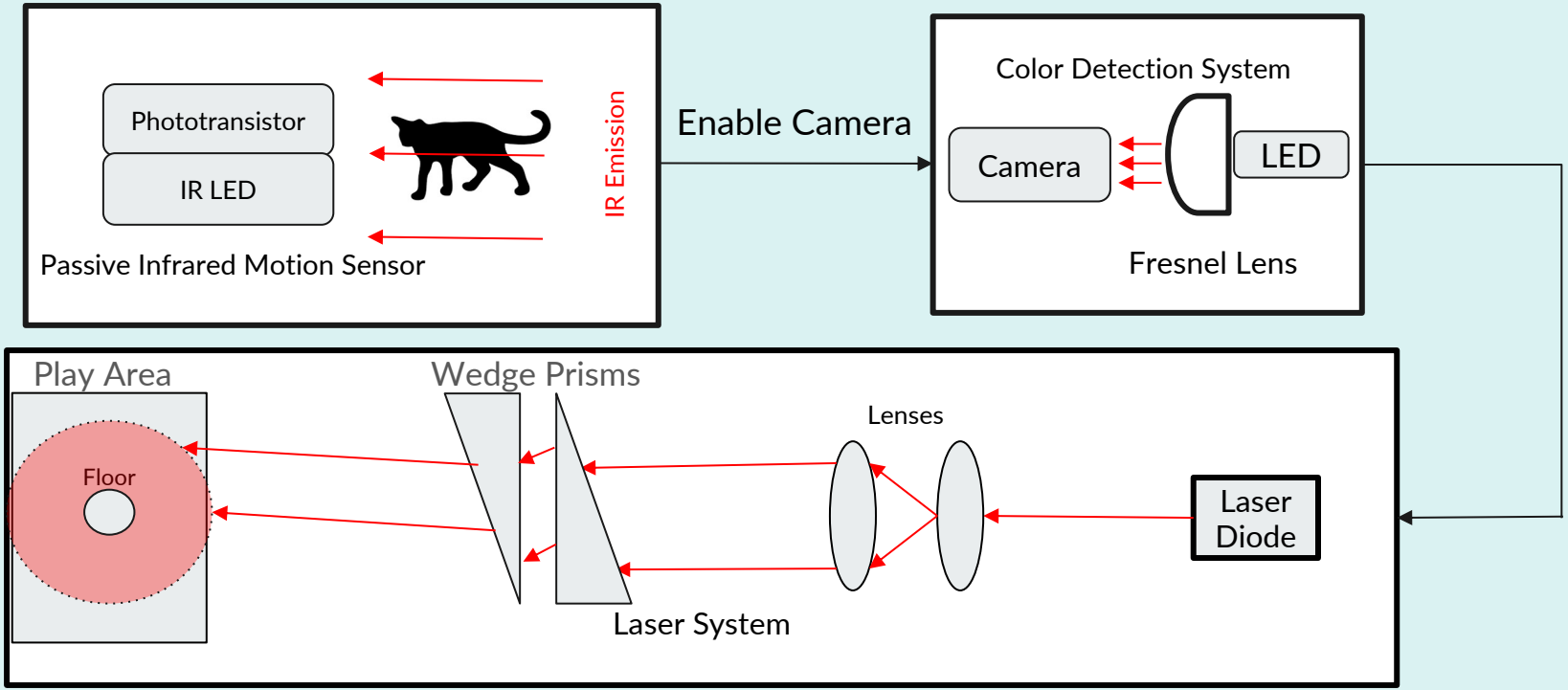
Stretch

1. Passive infrared sensors will have a “too close” range setting that enables an automatic shut-down process when the cat is 5 centimeters away from the laser.
2. The mobile application will include custom sequences that the user can create, and cat profiles.
3. Use IPX-7 LEDs to make the collar waterproof.

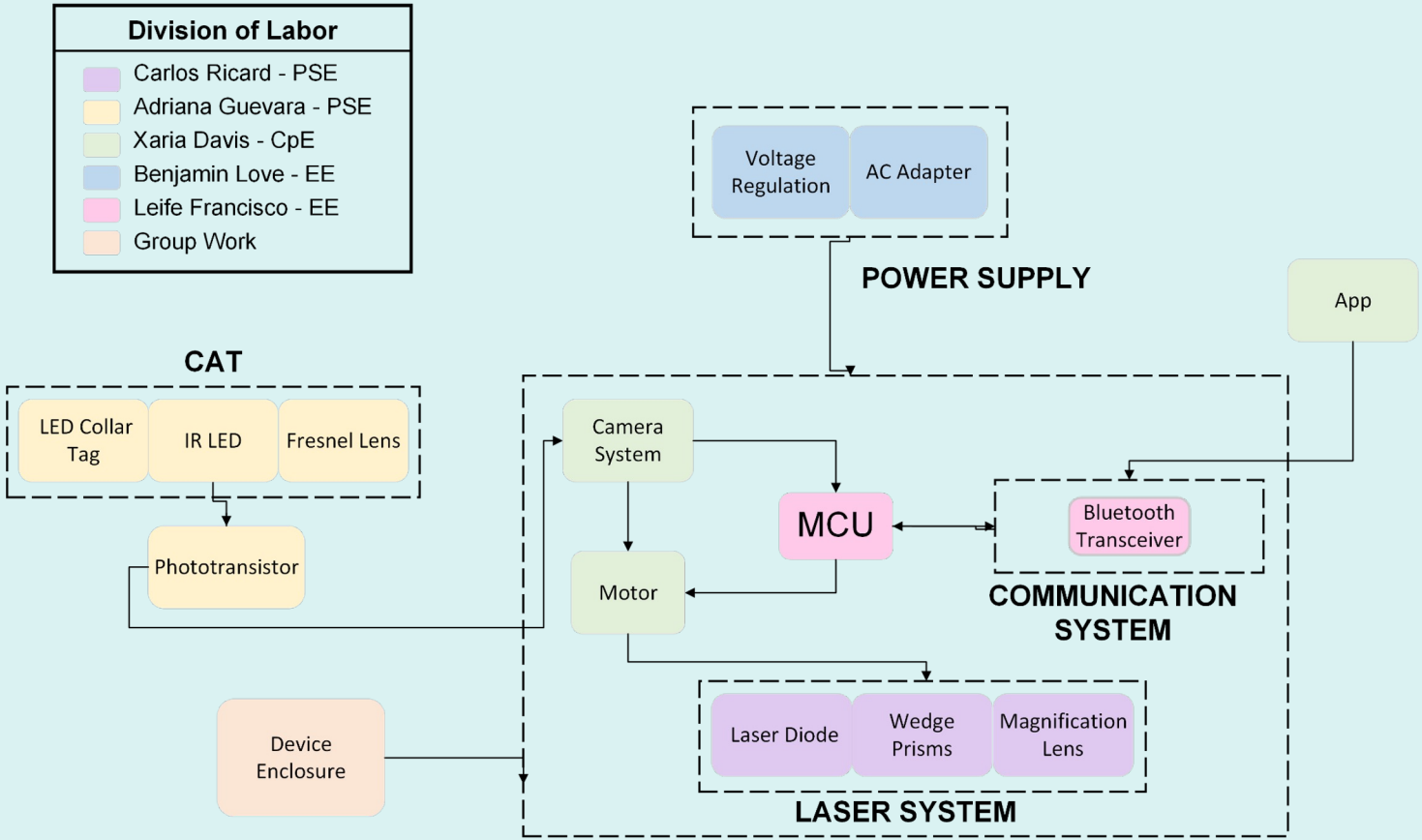
Engineering Specifications

Component	Parameter	Specification
Laser System Power	Laser Power	1 mW
Laser System Wavelength	Laser Wavelength	630 - 690 nm
Passive Infrared System	Detection Range	0.5 to 1.5 ft
Passive Infrared System	Detection Wavelength	940 nm
Passive Infrared System	Response time	t < 15 seconds
Printed Circuit Board	Size	Size < 900 cm^2 (30 cm * 30 cm)
Printed Circuit Board	Purpose	House all non-optic systems
Bluetooth Based Communication System	Range	10 ft
Bluetooth Based Communication System	**Response time**	**t < 30 seconds**
Power System	Power Consumption	< 15 W
Power System	Runtime	10-15 minutes
Collar Activation System	Focal Length	20 mm
Collar Activation System	**Range**	**0.5 to 3 ft**
Mobile Application	Latency	t ≤ 200ms
Laser Movement System	**Play Area**	**645.2 in^2 (at 1 m distance)**

Optical Schematic Overview

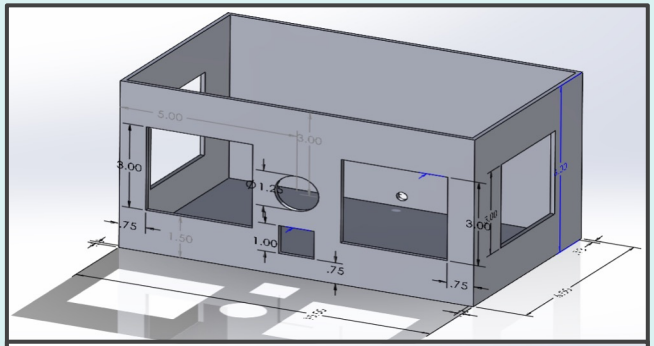


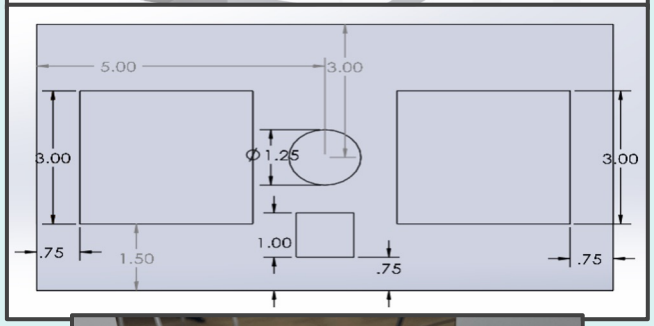
Hardware Block Diagram

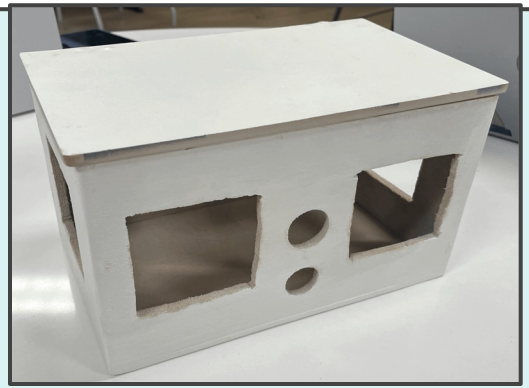


Enclosure Design

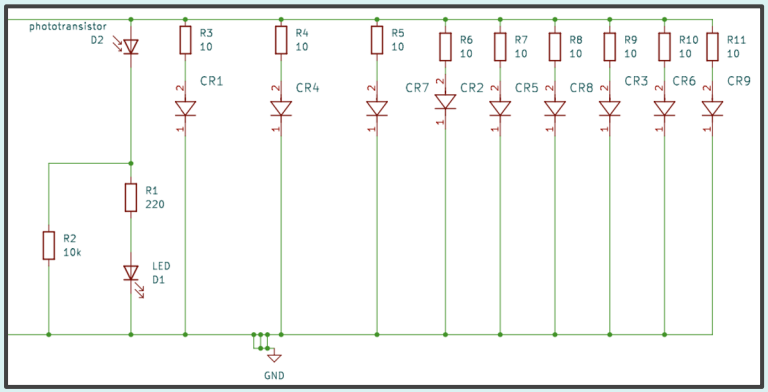
- The enclosure is 10 inches x 6 inches x 6 inches
- The laser will be output from the center circle
- The motion sensor PCBs are 3 inch squares, 4 are placed on the box.
    - One on each side and two on either side of the laser output
- The camera for the color detection system will be placed under the laser output area
- All electrical and optical components will be placed inside the box
- Brackets were designed to hold each component in place

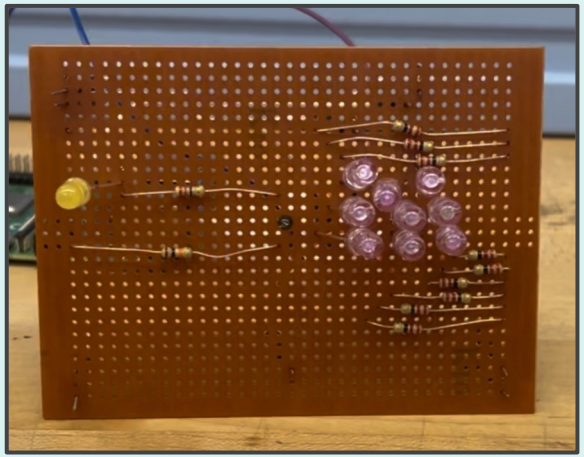






Motion Sensor Design





- Passive infrared (PIR) motion sensor is used to determine if a pet is present or not
- Created with a phototransistor and IR LEDs
- LEDs are arranged in a 3x3 grid formation to transmit as much light possible
- The IR light will “bounce” off moving object to be received by the phototransistor
- Use of visible light LED to indicate whether motion was sensed or not

Phototransistor and IR LED Selection

Phototransistor

Model	MTD8000M3B-T	TEST2600
Voltage (Collector Emitter Breakdown)	20 V	70 V
Collector Current	1 mA	50 mA
Wavelength	880 nm	950 nm
Viewing Angle	160°	60°
Orientation	Top View	Universal

IR LED

Model	QED223A4R0	WP710A10SF4C
Forward Voltage	1.7 V	1.3 V
Current	100 mA	50 mA
Wavelength	880 nm	881 nm
Viewing Angle	40°	34°
Radiant Intensity	25 mW/sr	7 mW/sr

Through demoing the PIR sensor, we determined key factors that help achieve our goals:

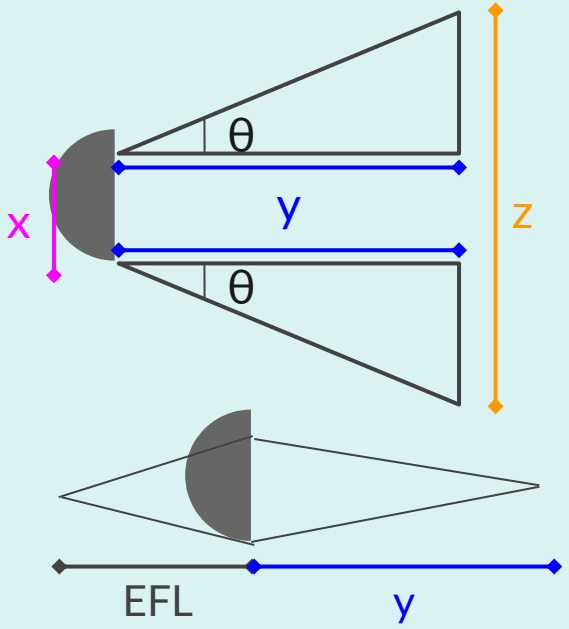
- Viewing angle of phototransistor and IR LED
- Mount type for phototransistor and IR LED
- Radiant Intensity of LED
- Matching wavelengths

Increased Motion Sensor Distance

Unable to implement due to cost constraints, but recommended for future models.

Paraxial Ray Height Equation

$$tan(\theta) = \frac{h/2}{EFL}$$



Variables:

x = diameter of lens = 50 mm

y = detection distance = 18 in

z = average length of a cat = 18 in

h = height of light source = 50 mm

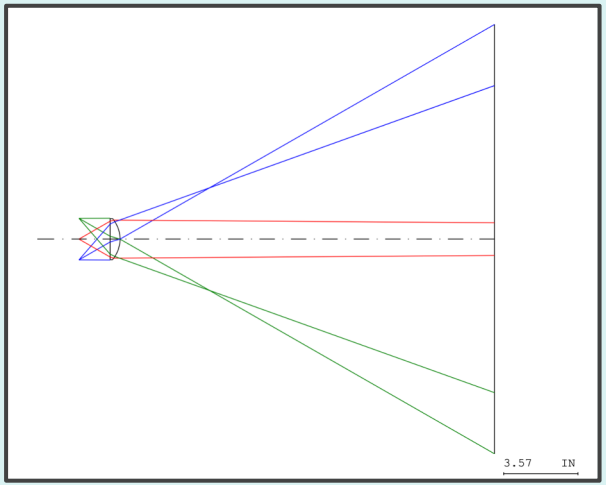
Solve:

θ = angle of detection

EFL = focal length

Increased Motion Sensor Distance Cont.

Diameter of 50 mm lens equates to 52.5 mm focal length, catalog lenses have 50 mm EFL



Plano-Convex Lens	#32-970	#48-795
Material	N-SF11	N-SF11
Coating	Uncoated	NIR I
Refractive Index (n)	1.76182	1.76182
Reflectance	7.60%	1%
Transmission	92.40%	99%
EFL	50 mm	50 mm
Diameter	50 mm	50 mm
Cost	$47.50	$65.00

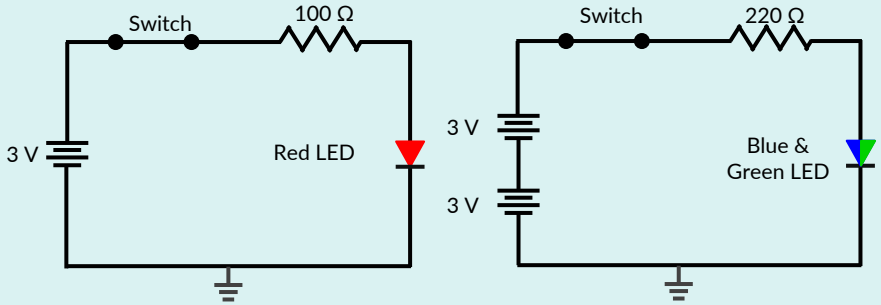
```
rsi 0 0 1 1
     New lens from CVMACRO:cvnewlens.seq
     Position  1, Wavelength =     880.0 NM
              X             Y             Z          TANX          TANY        LENGTH
 OBJ      0.00000       1.00000       0.00000       0.00000      -0.57384
   1      0.00000       0.13924       0.00000       0.00000      -0.29473       0.00000
 STO      0.00000       0.00000       0.00000       0.00000      -0.57384       0.49253
   3      0.00000     -10.32907       0.00000       0.00000      -0.57384      20.75306
 IMG      0.00000     -10.32907       0.00000       0.00000      -0.57384       0.00000
                              OPD =     0.000 Waves
```

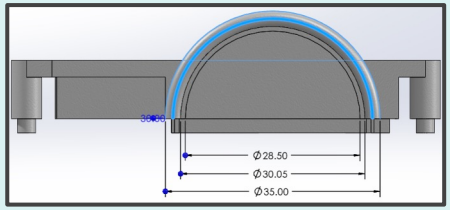
Transmission Equation

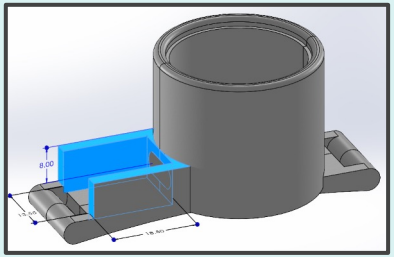
$$T = 1 - \frac{(n-1)^2}{(n+1)^2}$$

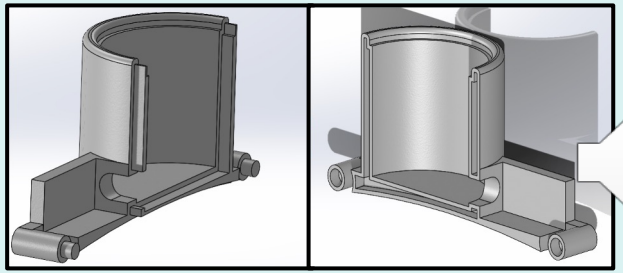
Cat Collar Tag Design

- The LEDs are powered by a 3 V button cell battery
  - The forward voltages of the blue and green LEDs are higher than 3 V and therefore require two batteries in series
- Operating current in below 20 mA
- High luminosity chosen for the LEDs for optimal viewing
- Custom designed holders for the LED, lens, resistor, battery, and switch
- Divet in the design to hold Fresnel lens
- Sealed with silicone glue to make the holder water resistant
  - Waterproof switch is used



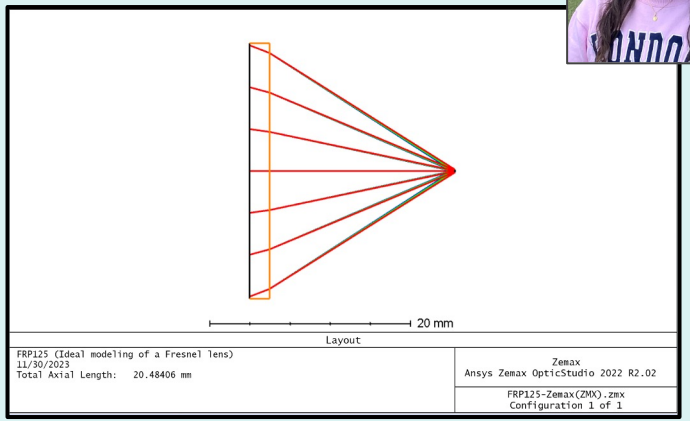


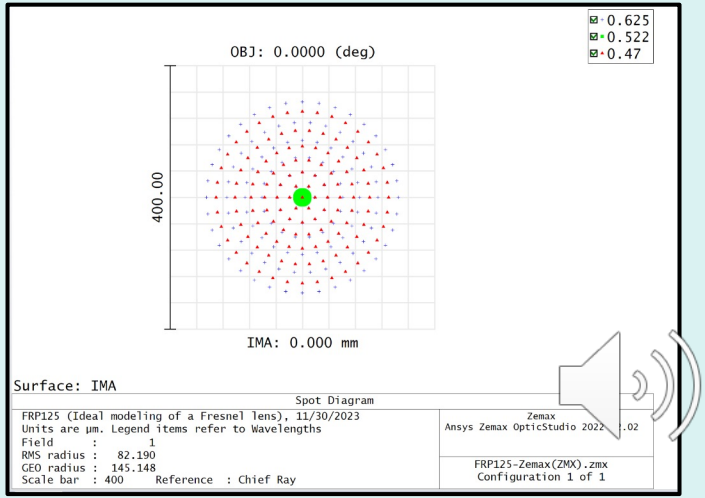




Fresnel Lens Design

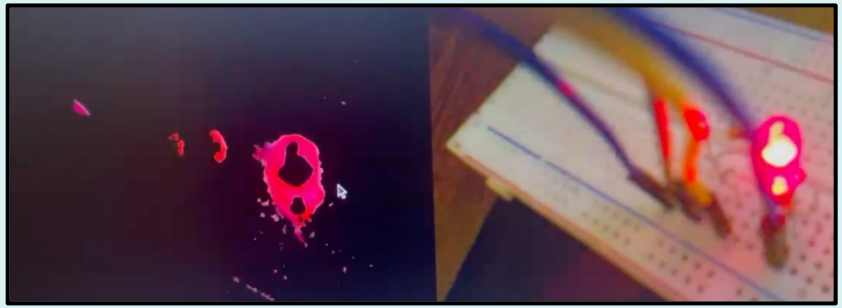
- Thinner lens with short focal length is ideal for the collar design
- To reduce costs of the Fresnel lens, an acrylic (PMMA) lens was acquired from a project kit to reduce costs
- To ensure the lens met our design needs, the lens was simulated in Zemax to analyze spot size
- A precise spot size is not needed since the lens is designed to carry the light further to the camera
    - 20 mm focal length has a small spot size for the green LED but disperses the red and blue light more
- Rings are 0.2 mm apart





Color Detection

- Color detection system uses a Raspberry Pi 4 and Pi Camera 2 to implement a color detection system using a mask in OpenCV
- Masking is designed to enable the laser once a certain threshold has been reached to not confuse colors in the room as the pet

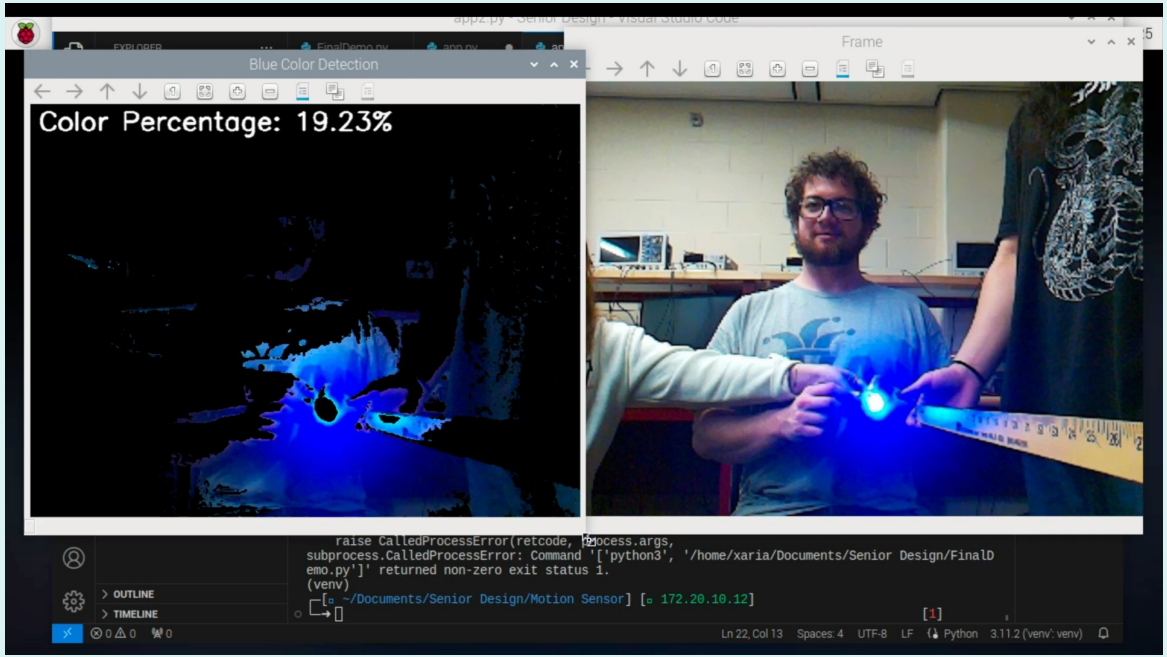


	Arducam IMX291	Camera Module v2
Module Compatibility	Windows, Linux, Mac OS, Raspberry Pi	Raspberry Pi
Camera Size	3.4 cm x 3.8 cm	2.5 cm x 2.4 cm
FOV	160°	62.2°
Price	$49.99	Already Owned

*The Camera Module v2 was chosen to reduce budget costs

Color Detection Program

- Process:
  - Captured image is converted to HSV (Hue, Saturation, Value) color space for better color discrimination
  - Color specific threshold is applied to isolate the LED's color



Hardware Part Selection Process: MCU

Chip Name	MSP430FR6989 1IPZ	ATMEGA2560-16AUR	ESP32-WROVER-E-N8R8
I/O pin number	83	53	38
Cost/1 Unit	$3.79	$14.46	$3.00
Reference Design	MSP-EXP430G2ET	Arduino Mega	ESP32-DEVKITC
Size (mm)	14x14x2	16x16x1.20	18x31.40x3.30
ADC	12 Bit	10 bit	12 Bit
Clock	16 MHz	16 MHz	40 MHZ
PWM Outputs	12	10	16

Hardware Part Selection Process:

Bluetooth Module

Name	QN9080-001-M17	CC2564	NINA-W102-00B	ESP32 WROVER E
Bluetooth Mode	BLE, V5.0	EDR, BLE	BLE, EDR, V4.0	BLE,EDR,V5.0
Peak Current	4.3 mA	8 mA	130 mA	80 mA
Flash Memory	256 Kb	NA	16 Mb	NA
Integrated Antenna	Yes	No	Yes	Yes
Cost/1 Unit	$20.14	$6.84	$7.55	$3.00
Manufacturer	NXP USA	TI	U-blox	ExpressIF

Why the ESP32:

- Widely Used
- Integrated Antenna
- Wifi & Bluetooth Options

Technology Choice: Power Supply

	Integrated Battery	Alkaline Battery	External AC Adapter	Integrated AC Adapter
Runtime	Limited	Limited	Infinite	Infinite
Internal Dimensions (approximate)	88 * 46 * 22mm	62 * 56 * 18mm	N/A	76 * 53 * 32mm
Waste Cells?	No	Yes	No	No
Supply voltage	3.7v/cell	1.5v/cell	5v DC	120v AC

Tech Choice/Hardware Selection: Voltage Regulator

What is needed:

- 5v to 3.3v voltage regulator with low noise and stability at 5v for ESP32 module.

Name	Switching	Low Dropout	Linear (others)
Output Noise/Ripple	>10mV	<40µV	<40µV
Efficiency	>95%	60%	60%
Input/Output ΔV	>>2v	<2v	>2v
# of Components	5 or more	3	3

Name	AP2114HA-3.3TRG1	LM1117LD-3.3	TCR2EF33LM	TLV70033DDCR
Output Current	1A	800mA	200mA	200mA
Supply Voltage	2.5v-6v	<15v	1.5v-5.5v	2v-5.5v
Dropout Voltage	450mV-750mV	1.2V	150mV-200mV	175mV-250mV
Manufacturer	Diodes Incorporated	Texas Instruments	Toshiba	Texas Instruments

Hardware Part Selection Process: AC Adapter

- Adapter provides 15w continuous at 5v DC
- Switching topology is upwards of 95% efficient
- Selected sideways form factor can fit in US market power strips

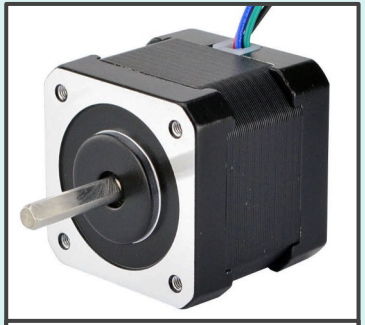
Name	PSC15R-050	SWI18-5-N-P6	GST18A05-P1J
Form	Wall, vertical	Wall, horizontal	Desktop
Input Connector	Multi-blade	NEMA 1-15P	IEC 320-C14
Output Connector (Dimensions)	2.1mm ID * 5.5mm OD * 10.0mm L	2.5mm ID * 5.5mm OD * 9.5mm L	2.1mm ID * 5.5mm OD * 11.0mm L
Cost/1 Unit	$12.99	$16.87	$17.18
Manufacturer	Phihong USA	CUI Inc.	Mean Well USA Inc.

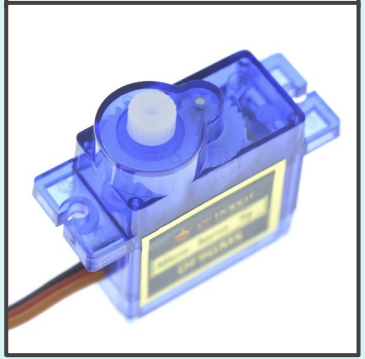
Technology Choice: Motors

What is needed:

- Small, low-power motors
- Shouldn't compromise on precise control of laser movement.

	Steppers	"Hobby" Servos
Method of Control	External IC, multiple PWM signals	Single PWM signal
Current Draw	>1.5A/phase	<500mA
Size	42.3 x 42.3 x 48mm	22.6 x 12.2 x 30mm
Mass	350g	9g
Step Precision	<<1 degree	1 degree



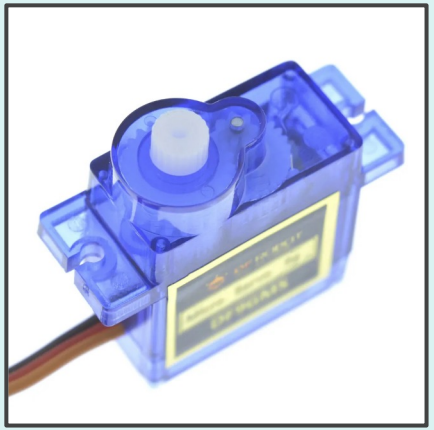


Hardware Part Selection Process: Servo Motors

What is needed:

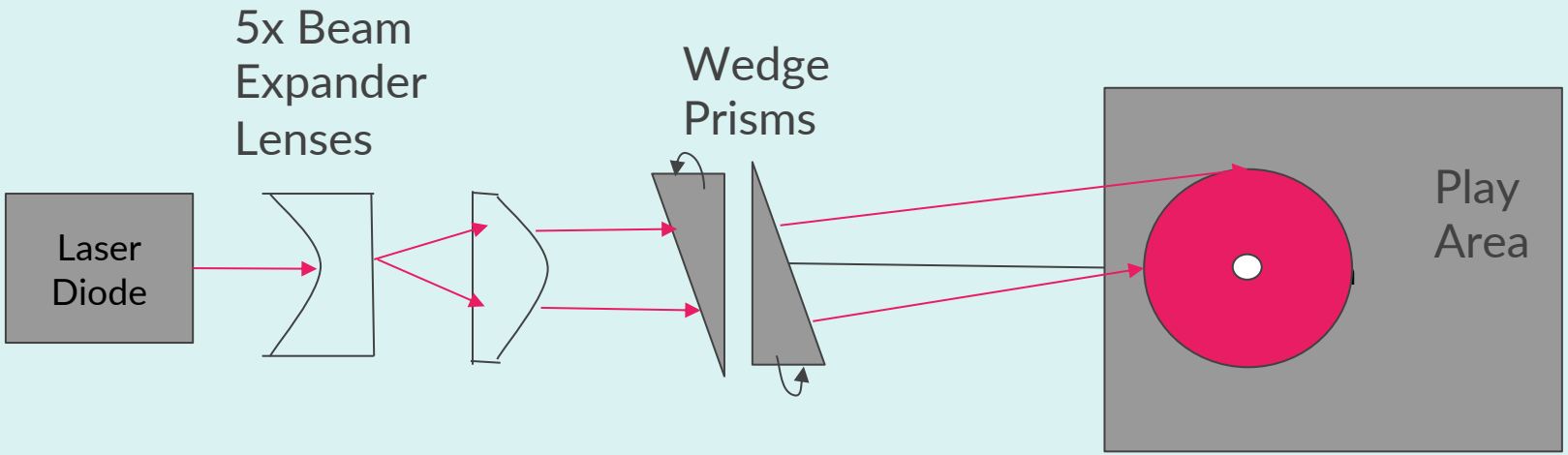
- Small
- Fast
- Low-power
- Continuous rotation

Name	SER0043	FXX-3037-TOP-ND	ROB-09065
Degrees of Freedom	Continuous	120 degrees	160 degrees
No-load Speed	0.12s/60 degrees	0.17s/60 degrees	0.15s/60 degrees
Working Current	<500mA	500mA-900mA	Unknown
Size	22.0mm * 12.5mm * 29.5mm	40.7mm * 19.7mm * 42.9mm	23.1mm * 11.7mm * 29.0mm
Cost/1 Unit	$3.62	$12.00	$9.95
Manufacturer	DFRobot	Terasic Inc.	SparkFun



Laser System

- The Laser system utilizes a low power red laser diode to emit a coherent beam of light.
- The Light is then expanded by 5 times its original spot size as it passes through the two lenses.
- The beam of light is then steered within the play area by rotating the wedge prisms at varying directions and speed.



Laser Diode

- Exposure can damage the eye
- Red Laser diode (650 nm) (safest wavelength for cat)
- FDA Classification: IIIa (<1 mw)
- Operating current (<35 mA)
- Operating voltage (2.6-5 VDC)

Laser diode comparison			
Laser	**VLM-650-03 LPT**	**VLM-520-04 LPT**	**1054**
Output Power	< 1 mW	< 1 mW	< 5 mW
Wavelength	650 nm	520 nm	650 nm
Classification	IIIa	IIa	IIIa
Price	$13.97	$19.95	$5.95

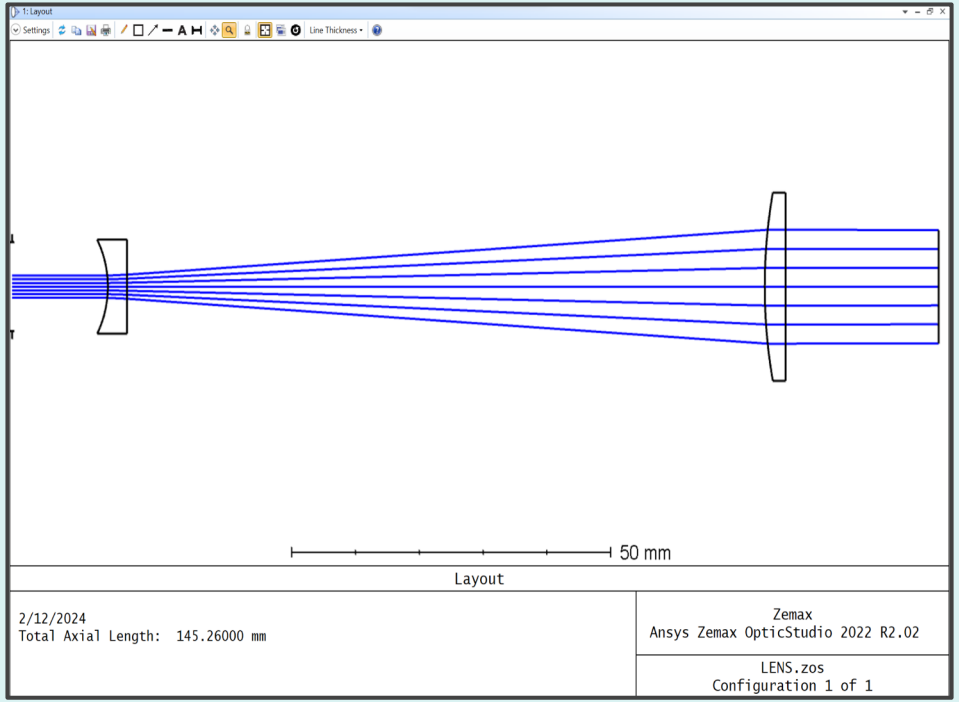
Laser Module VLM-650-03 LPT- Amazon

Beam Expander

Lenses:

- Plano concave lens f_1=-25 mm
- Plano convex lens f_2=125 mm
- M=f_2/f_1= 125 mm/25 mm = 5 x magnification
- Spacing= 125 mm - 25 mm= 100 mm
- 5x expansion to potentially create an image using a stencil

Lens	Focal Length	Spacing	Price
LC1054	-25 mm	100 mm	$43.43
LA1986	125 mm		
48-678	-15 mm	60 mm	$55.25
32-479	75 mm		



Wedge Prism

- When two wedge prisms with the same orientation and both are spun in the same direction and speed, the angle of deviation is doubled
- 1 in. diameter
- The 10° wedge prisms would deviate the laser beam by 20°
- The play area for an operating distance of 1 meter is 36.4 cm or 14.3 in. radius circle

PS814 - Ø1" Round Wedge Prism, 10° Beam Deviation - Thorlabs

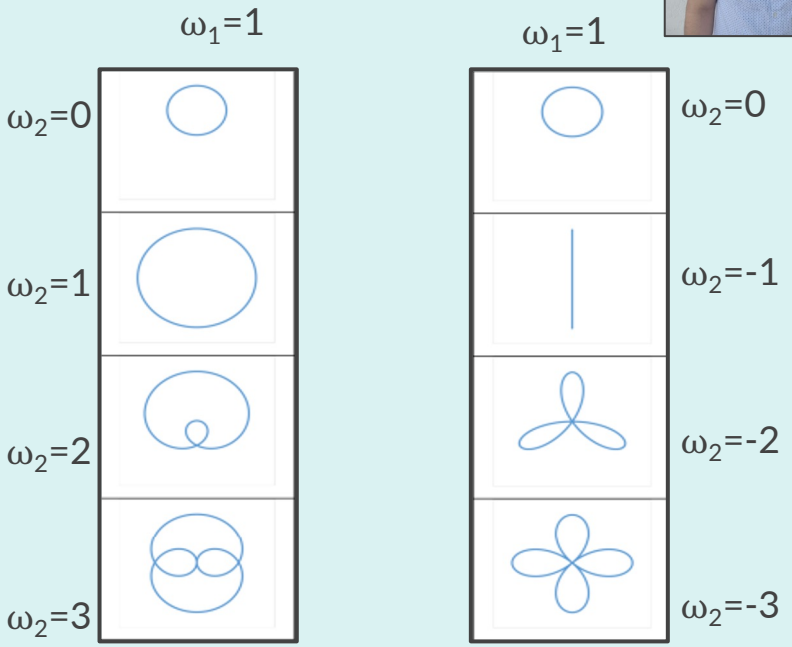
$$r = 1\,m * tan(20°) = 36.4\,cm = 14.3\,in$$

Rose Curve Generation

- When the two wedge prisms are rotated at different speeds and different directions, various patterns of laser steering can be generated
- Shapes are described by the equations

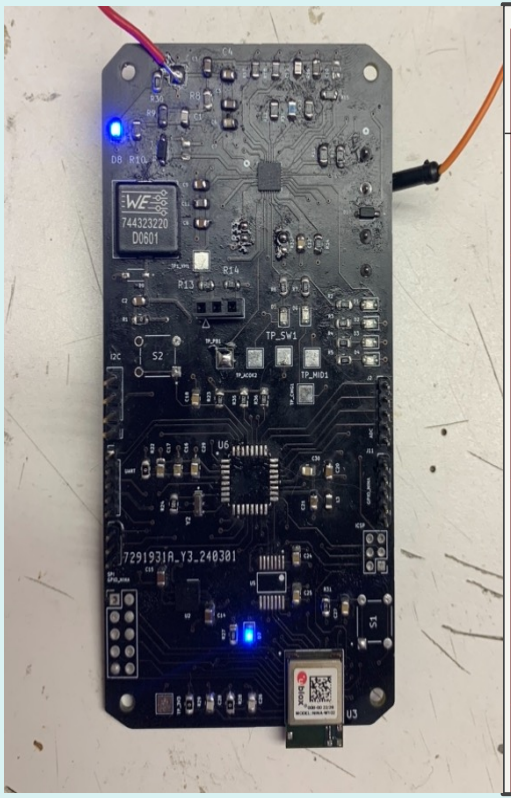
$$y(\omega_1,\omega_2)=(r_1+r_d)*\sin(\omega_1 t)+r_2*\sin(\omega_2 t)$$

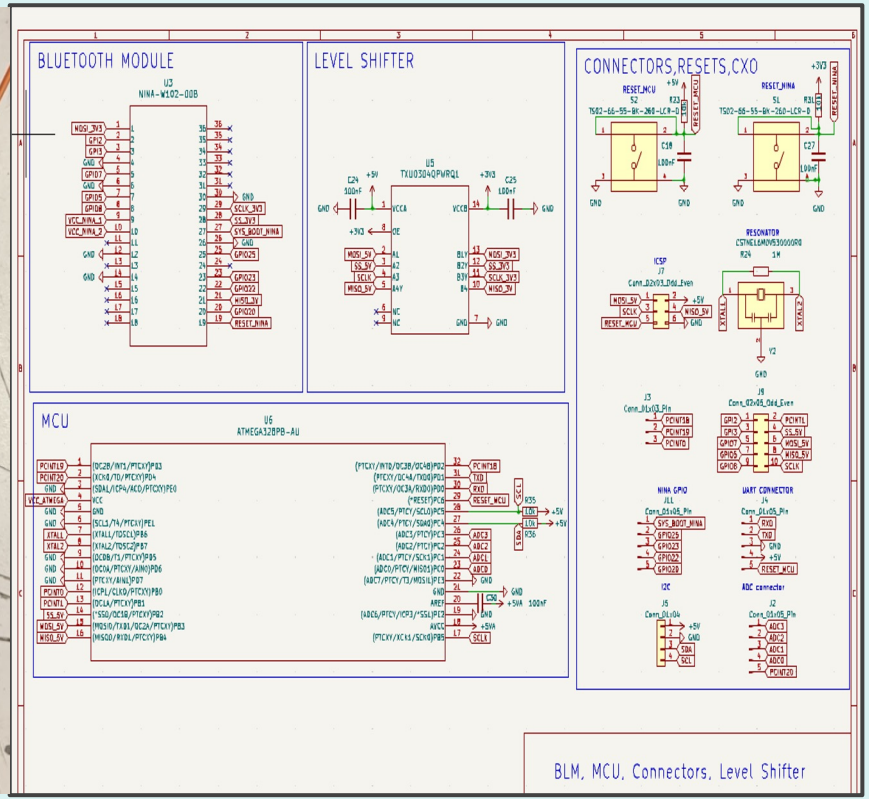
$$x(\omega_1,\omega_2)=(r_1+r_d)*\cos(\omega_1 t)+r_2*\cos(\omega_2 t)$$



From Thorlabs

Schematic (V2): Microcontroller and Supporting Components





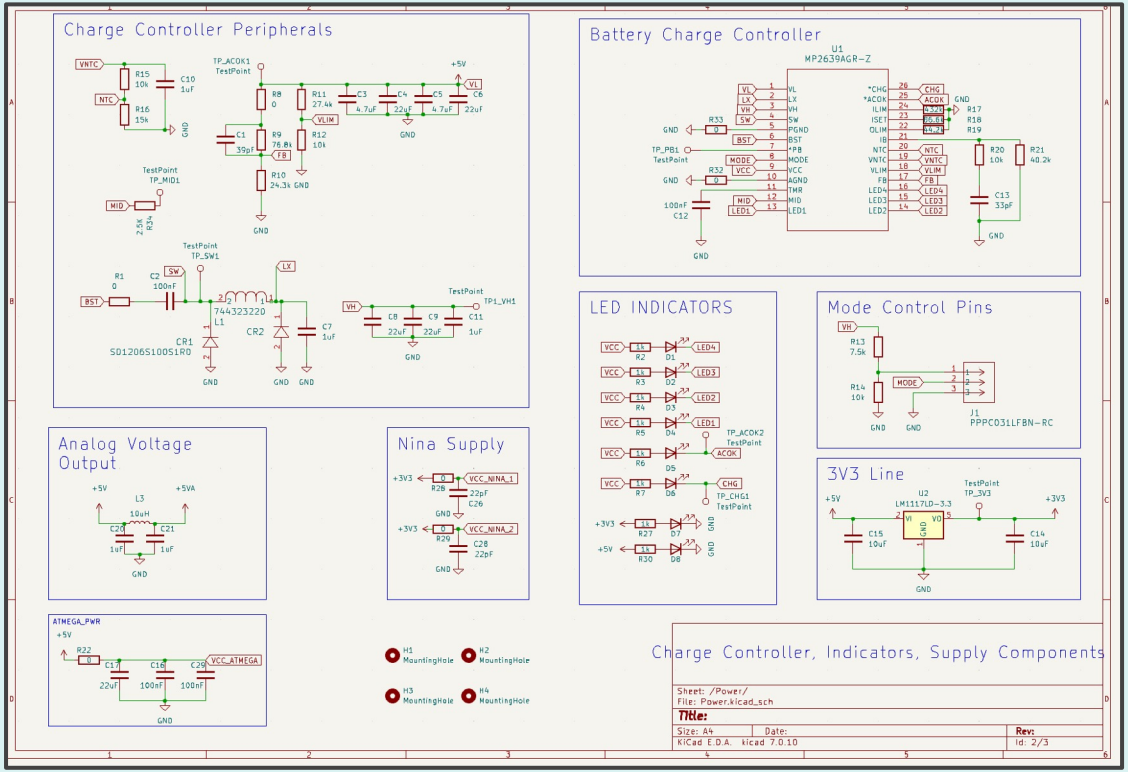
Features:

- Microcontroller
- Charge Controller

Purpose of second version:

- Cost
- Size
- Charging

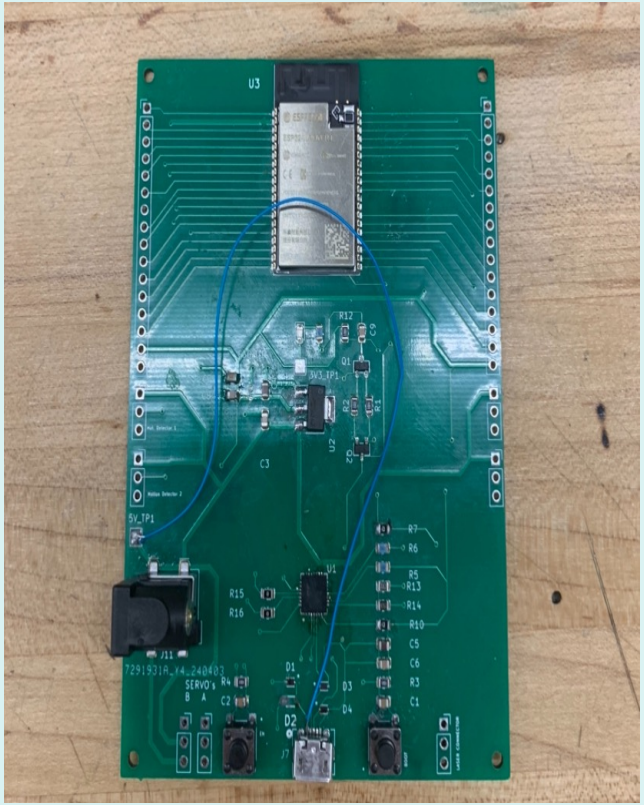
Schematic (V2): Charge Controller

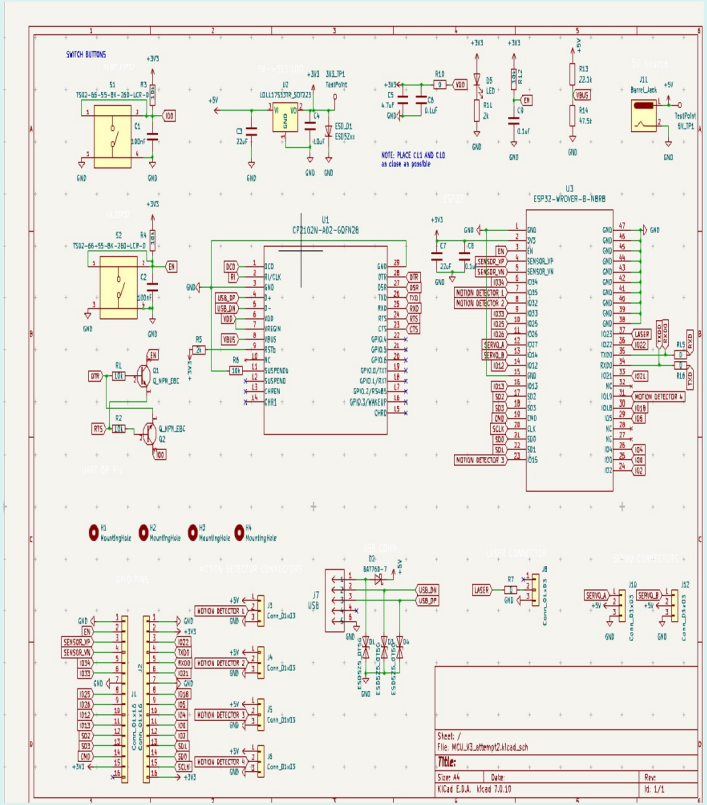


MPS Controller :

- Two cells in series (2s)
- Two 5v switching converters
- Highly sensitive to board layout
- Development board performed well, but V2 did not meet same standard, deemed unreliable for final

Schematic (V3): Microcontroller and Supporting Components





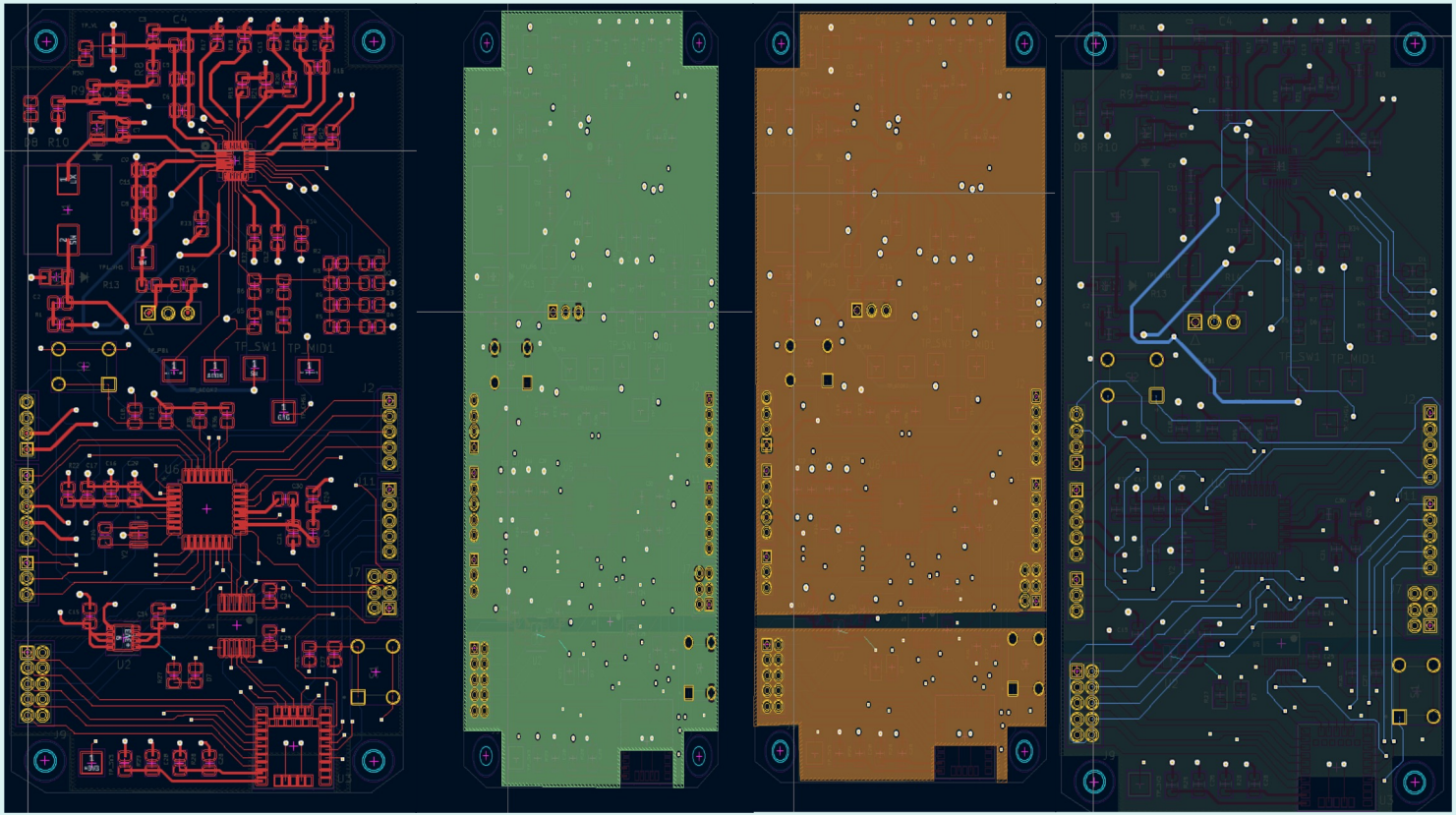
Purpose of third version:

- Cost
- Ease of Use

Main Differences:

- Combined MCU and BLM
- USB to UART converter

PCB V2



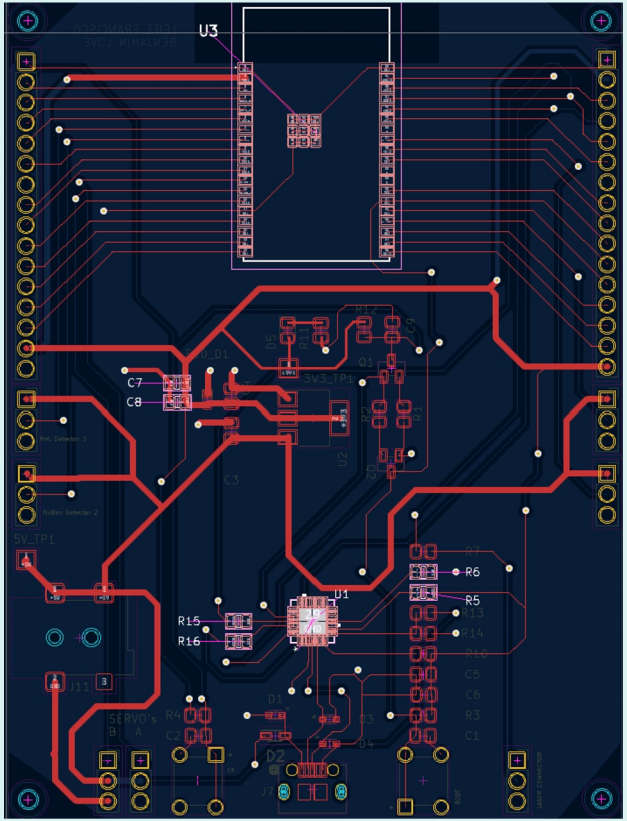
Reason for the Layout:

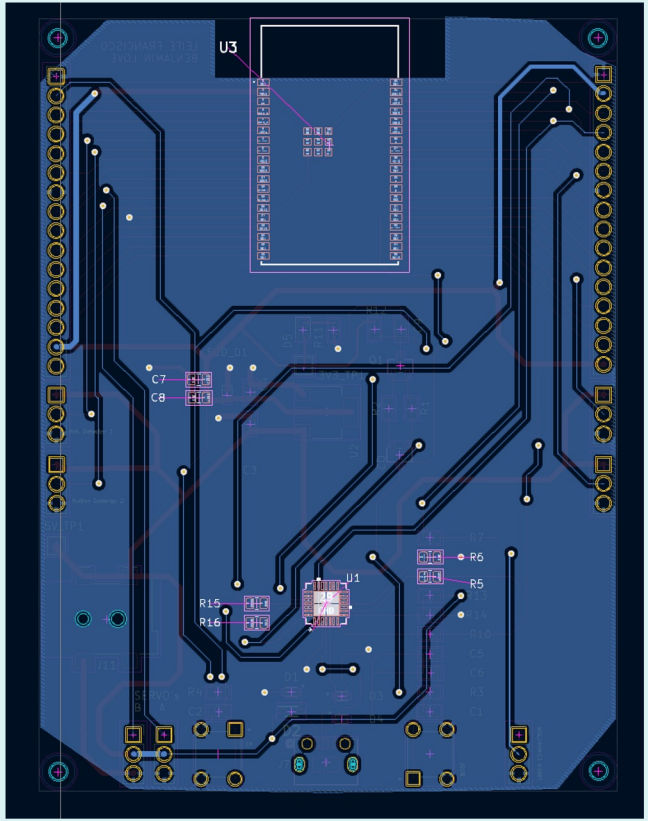
- Layers
- Size (1.9 in*3.9in)

Trace Widths:

- Signal, Power, and High current traces.

PCB V3





Reason for the Layout:

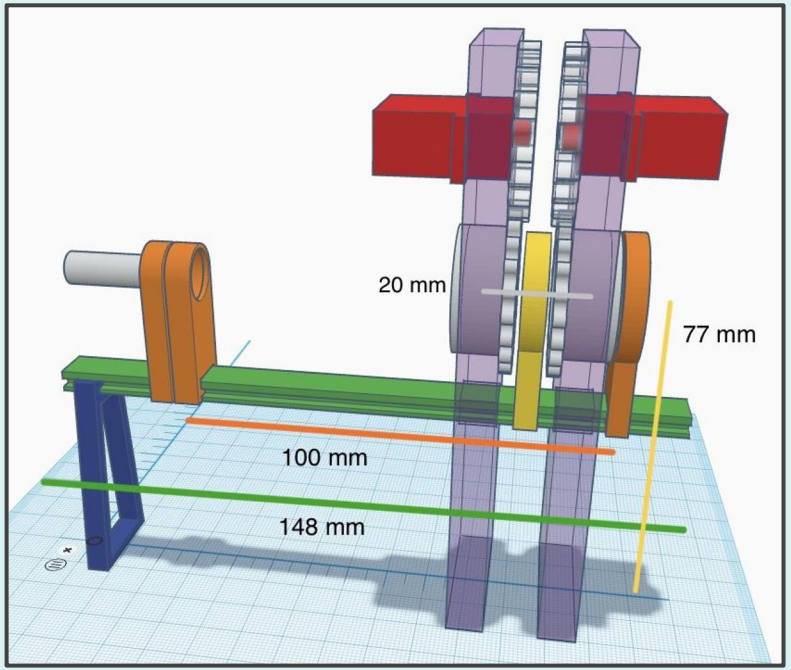
- 2 Layer
- Size (3.9 in * 3.9 in)
- Reduced Cost
- Ease of Troubleshooting

Trace Widths:

- Signal Trace width 0.15 mm.
- Power Trace width 0.75 mm.

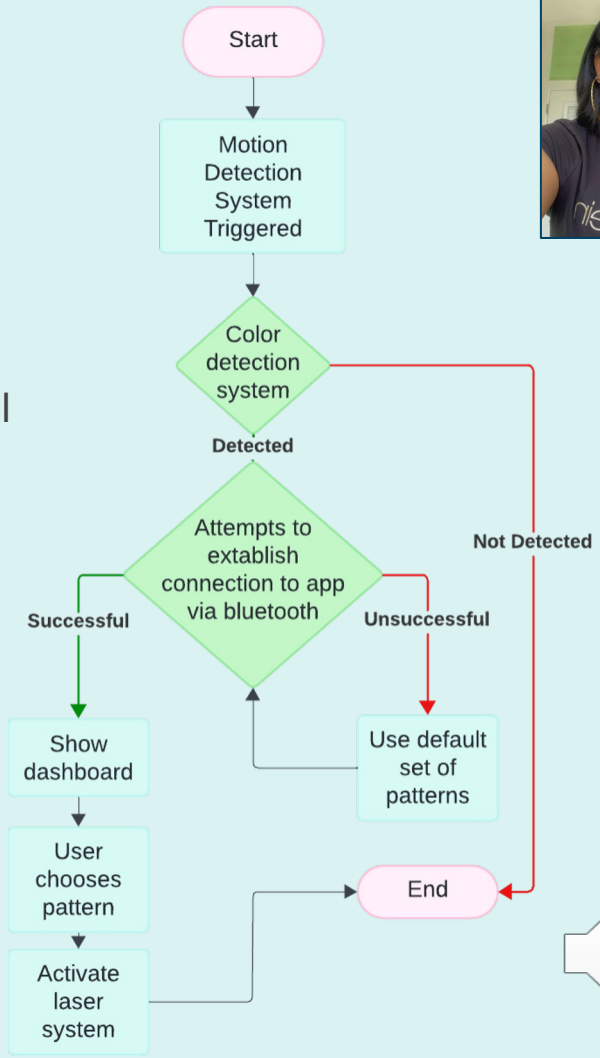
Structural Design: Laser Movement System

- Designed in TinkerCAD and 3D printed
- Main rail is 148 mm long to fit in enclosure
- Optical center is at a 77 mm height to accommodate other systems
- Planar lenses spaced 100 mm apart, wedge prisms 20 mm apart
- 1:1 motor/wedge prism gear ratio
- From left to right:
  - Laser diode → plano-concave lens → wedge prisms → plano convex lens
  - Wedge prisms placed between plano lenses to allow clearance for motors



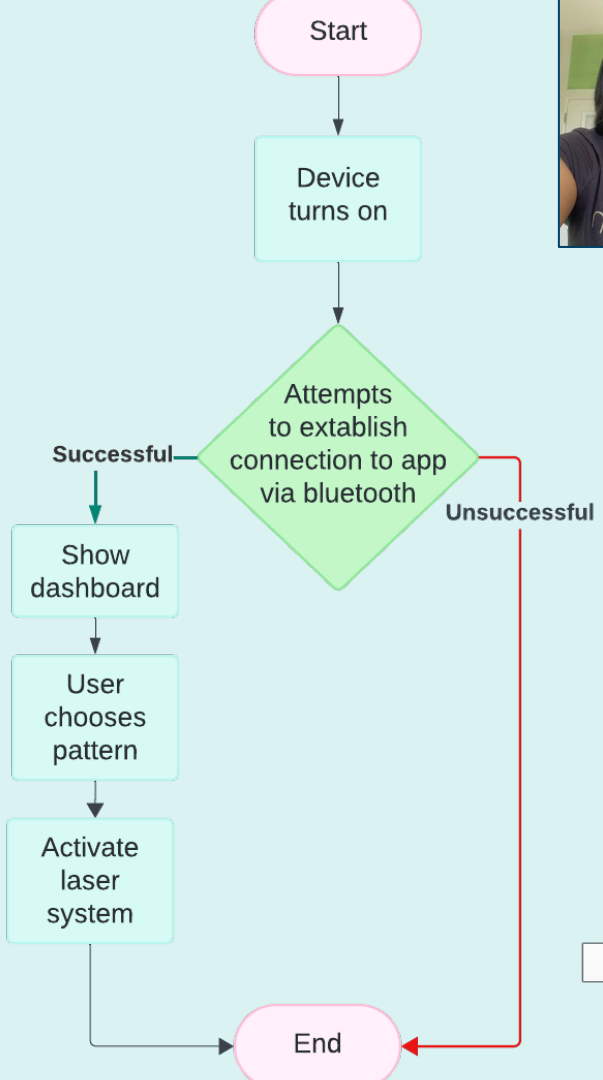
Software Block Diagram

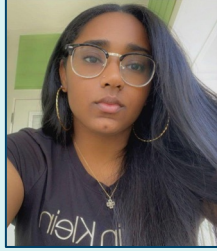
- Outlines the flow of software if the motion detection system is triggered
- If connection to the app is unsuccessful, laser system will play a default set of patterns

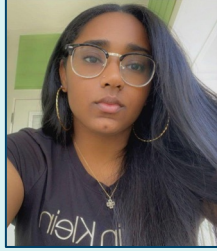


Software Block Diagram

- Outlines the flow of software if the device is manually powered on by the user
- Beneficial for instances when the user wants to be involved in their cats playtime







Full Stack Development Technologies

Operating System: Apple iOS

- As of February 2024, Apple holds majority of the smartphone market share in the United States at 61.26%
- Gen Z and millennials (our target audience) are more likely to be iPhone users

Front-End

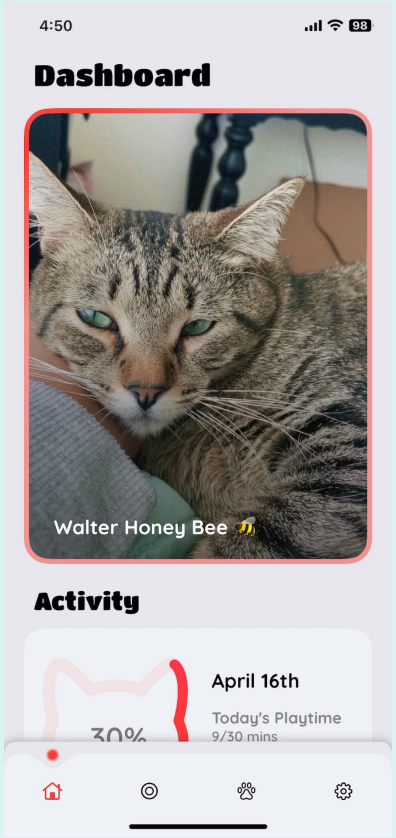
- UI Framework: SwiftUI
  - Declarative syntax
  - Adaptive design
- User Experience: User-friendly and intuitive but also playful and fun
- Design: Custom UI components, animations, transitions
- Tools: Dribbble, Mobbin, Figma, Xcode, Git/Github

Back-End

- Language: Swift
- Firebase, application development platform provided by Google
  - Database: Cloud Firestore
  - Authentication: Firebase Auth
  - Storage: Firebase Storage
- Using Google's Firebase over Apple's CloudKit allows use of the same backend services with other operating systems (e.g. Android)

Mobile Application Design

Mobile Application Design



Standards

LED Safety Standards (IEC/EN 62471 Eye Safety)

- Permissible exposure time for an exempt group (posing no photobiological hazard) is approximately 10,000 seconds, which is equivalent to 2.8 hours, which we will not surpass.

Laser Safety Standards (FDA CFR 1040.10 Laser Products)

- Class IIIa range from 1 to 5 mW of power and levels of laser radiation are considered to be either an acute intrabeam viewing hazard or chronic viewing hazard.

Bluetooth Safety Standards/Standards (Bluetooth Core Standard V4.0)

- Overview of bluetooth modulation, the RF signal chain requirements, and general guidelines for purchasing bluetooth integrated circuits; gives a guideline for EMI/EMC testing.

Standards for Pet Products

- Shall meet safety standards for children toys, no harmful chemicals, durability, no sharp or protruding parts that can harm the pet, no choking hazards

Budget

Item Purchased	Unit Cost	Quantity	Total
Fresnel Lens	$7.00	3	$21.00
Microcontroller/Bluetooth	$2.00	1	$2.00
3 V Battery Cells	$0.50	3	$1.50
Laser Diode	$15.00	1	$15.00
Switches	$2.00	3	$6.00
Electrical Tape	$1.50	1	$1.50
Printed Circuit Board	$10.00	1	$10.00
Phototransistors	$2.70	4	$10.80
Plano Concave Lens	$36.00	1	$36.00
Plano Convex Lens	$38.00	1	$38.00
10° Wedge Prisms	$50.00	2	$100.00
IR LED	$0.50	36	$18.00
Red LED	$0.70	1	$0.70
Blue LED	$0.25	1	$0.25
Green LED	$0.50	1	$0.50
PCB Components	$28.00	1	$28.00
Raspberry Pi 4	$60.00	1	$60.00
Pi Camera 2	$20.00	1	$20.00
			$369.25

Work Distribution

Task	Primary Person	Secondary Person
Motion Detector	Adriana	Leife
Color Detection Tags	Adriana	Xaria
Color Detection Code	Xaria	Adriana
Laser Movement System	Carlos	Benjamin
Laser Movement Structure	Benjamin	N/A
Printed Circuit Board	Leife	Benjamin
Battery System	Benjamin	Leife
Enclosure	Adriana	Leife
Integration Code	Xaria	Benjamin
Mobile Application	Xaria	N/A
Bluetooth System	Leife	Benjamin

Thank You!