Remotely Controlled Diffused Surface Laser Beam Imaging System

Group 3

Madelaine Smith
Devin Benjamin
Daniel Oquendo
Miguel Ortiz

Motivation & Background

- Aid in outdoor high energy laser propagation experiments run by the Laser Plasma Laboratory @ CREOL UCF
- Current tests impacted by inefficient preparation process
  - Tests require high number of personnel
  - Equipment used is not intended for outdoor use and requires manual adjustment
  - Current solutions are few and costly

Objectives

- Design and build a remotely controlled system that can image and track a laser beam from collected light off a diffused surface
    - Build a remotely controlled zoom system
    - Design filter to control amount of ambient light introduced to the device
    - Use a camera system to detect, track, and collect vital information about tested beam profile

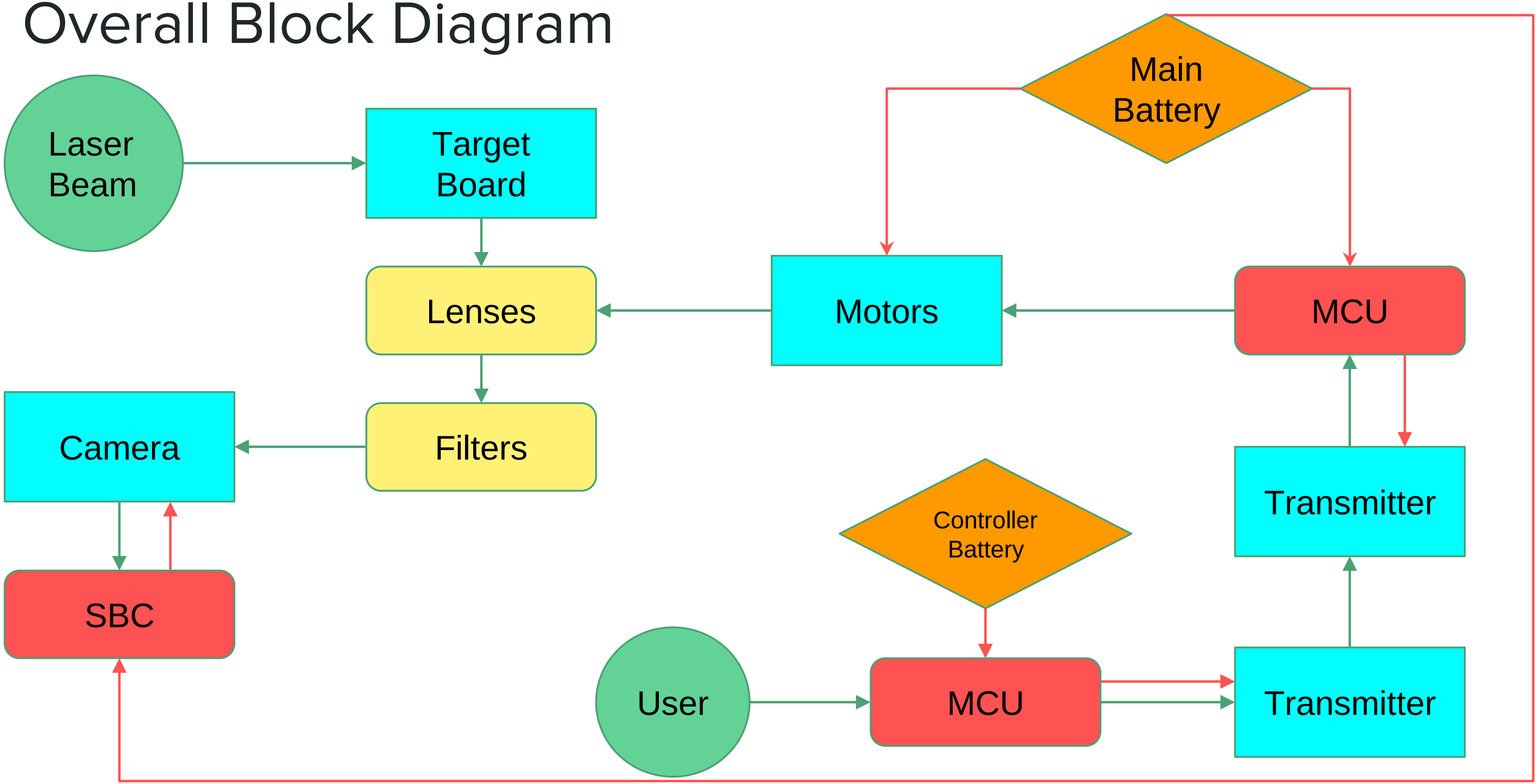
Goals

- Core
  - Battery-operated device
  - Transmit imaging data ≥ 3 meters of a given wavelength
  - Detect and track the beam and its characteristics on a diffused target board
  - Remote controlled adjustment
- Advanced
  - Solar-charged battery-operated device
  - Transmit imaging data > 3 meters of multiple wavelengths
- Stretch
  - Automated adjustment

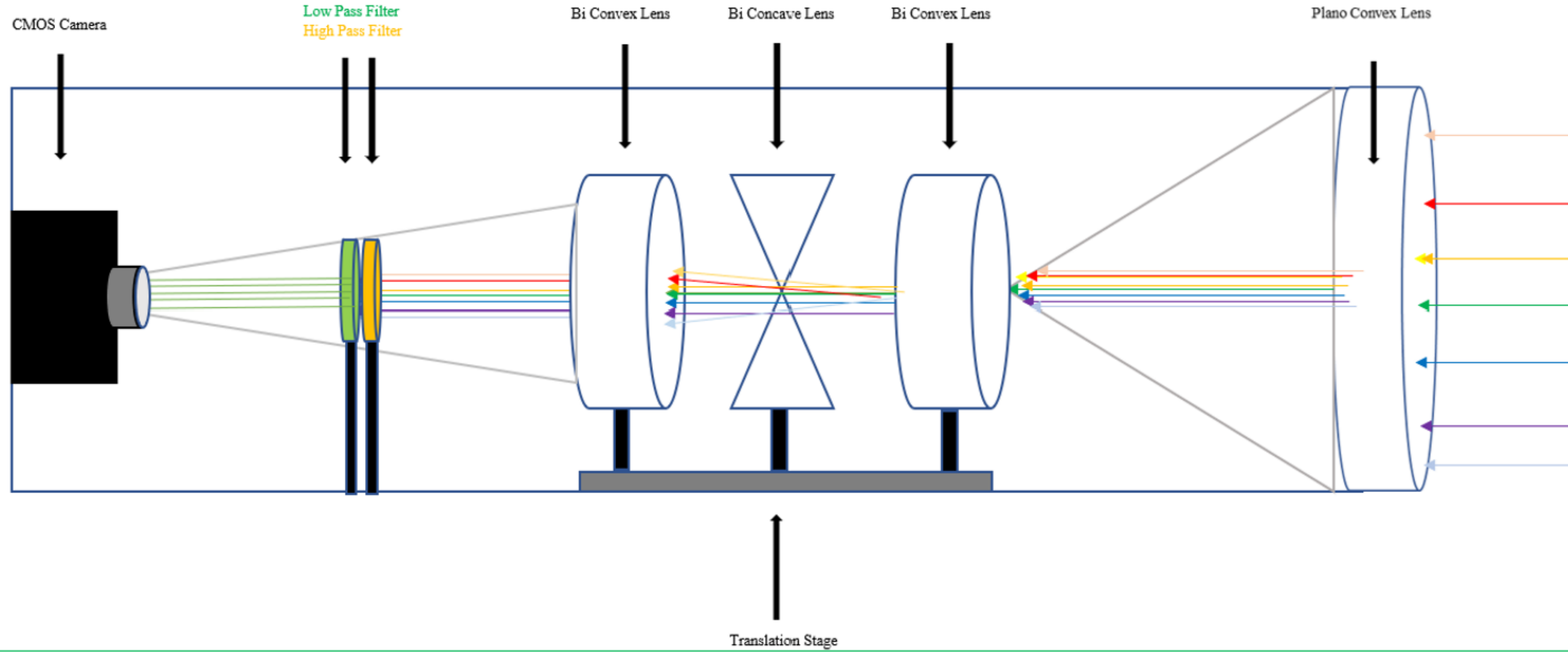
Requirement Specifications

Lens Zoom System	
Magnification	At least 3x
Length	Less than 12”
Camera Adjustment System	
Horizontal Tilt	90 degrees
Vertical Tilt	90 degrees
Remote Control System	
Wireless Connection	At least 3 m
System Delay	< 100 ms
Combined Filter/Lens/Camera System	
Weight	< 25 lbs
Size	< 4 ft^3
Power Discharge Time	At least 30 minutes between charges
Housing	Water/Weatherproof

Overall Block Diagram



Optical Design
(Original Design)



Band Pass Filter

532 nm Central Wavelength Band Pass Filter

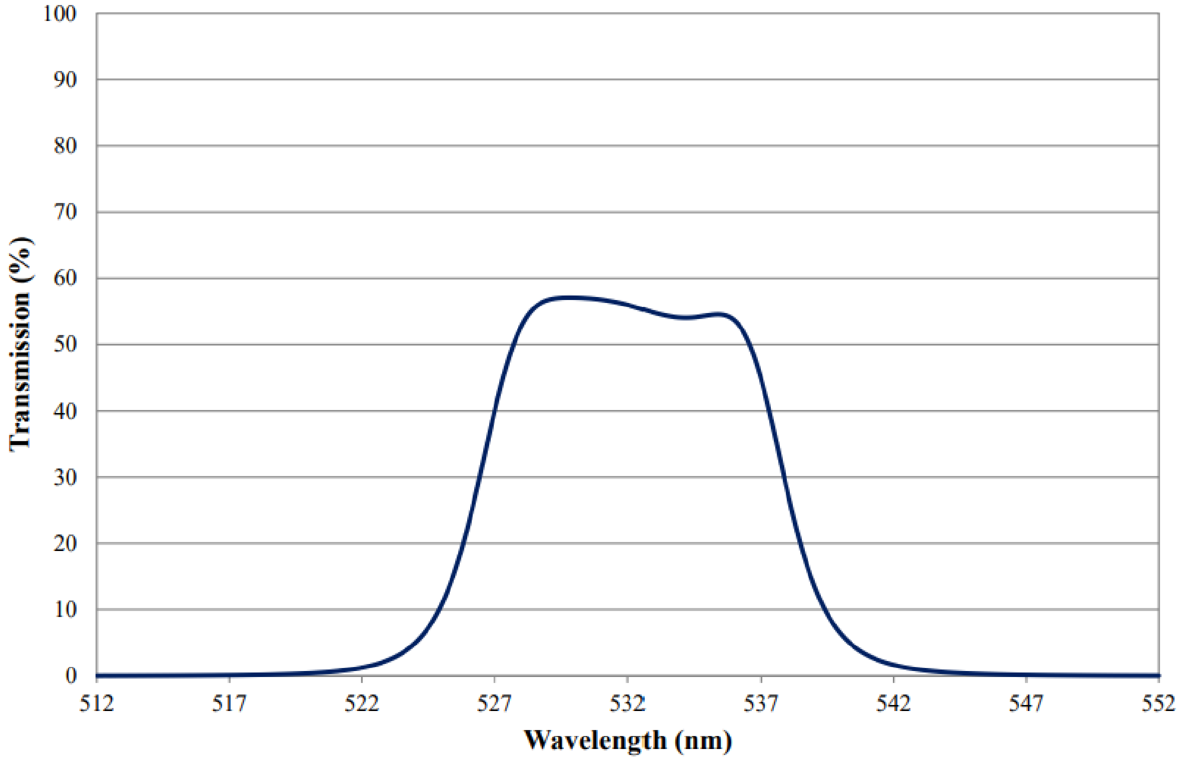
- This filter is used to block out the ambient light which will be introduced into the system.
- FWHM 10 nm
- Filters out 400 nm - 527 nm, 538 nm - 1200 nm
- Optical Density = 3
- Minimum Transmission roughly 45% @ 532 nm

The purpose of the filter is to absorb ambient light outside of the range of wavelength desired to be viewed for tracking by the system.

The diffused light beam being tracked is 532 nm and the passband filter has a high optical density to thoroughly block out the undesired noise.

Edmund Optics

532nm Bandpass Interference Filter: 10nm FWHM, OD≥3.0 Coating Performance
FOR REFERENCE ONLY



Provided by Edmund Optics Website:
https://www.edmundoptics.com/p/532nm-cwl-10nm-fwhm-25mm-mounted-diameter/20218/

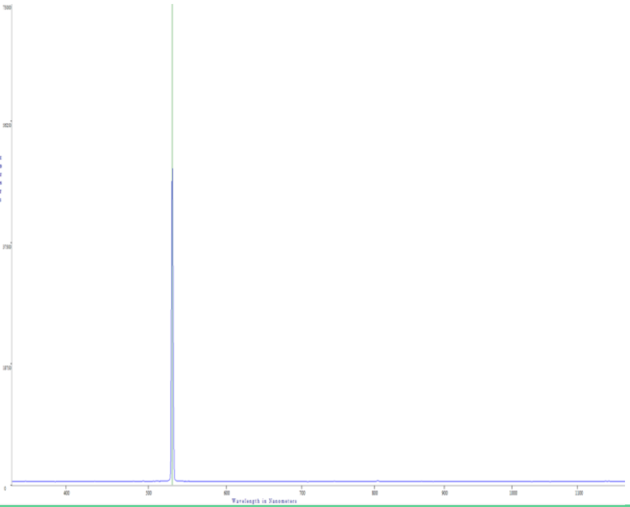
Edmund optics | worldwide
www.edmundoptics.com

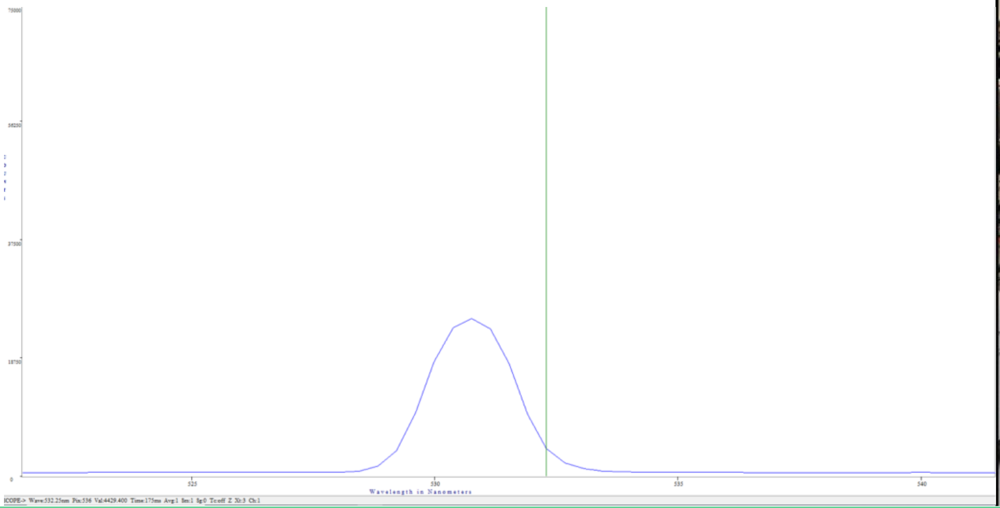
Laser Source

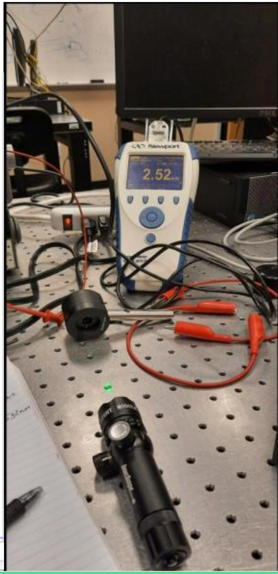
For this design two laser sources advertised with a central wavelength of 532 nm were tested in the laboratory to find the ideal laser source for the design.

Tests were run on both lasers in the laboratory.

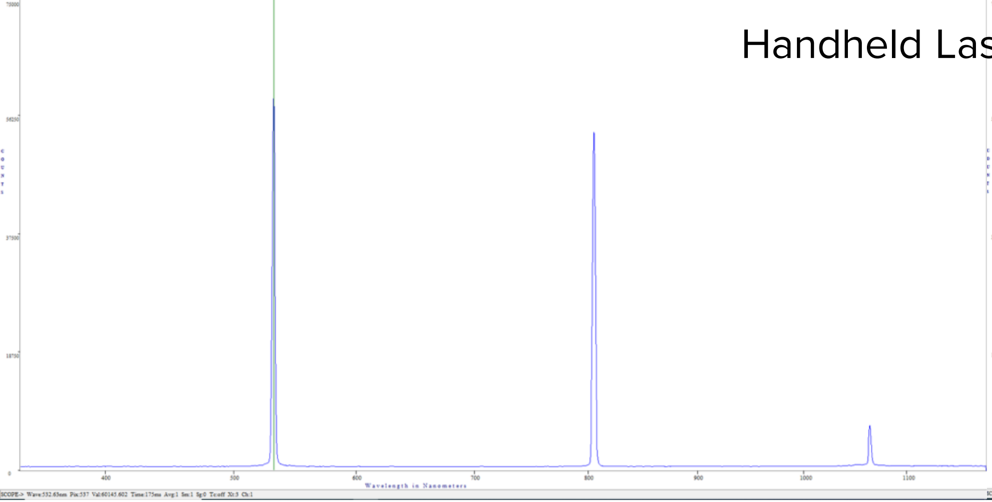
The scope laser (shown in the figure below) was advertised as a 5mW scope laser with a central bandwidth of 532 nm.
The scope laser was measured at 2.5 mW on the power meter. **(Bottom Right)**
When measured without the bandpass filter the central peak was not at 532 nm. **(Bottom Left)**
When tested with the spectrometer passing through the bandpass filter, the spectrum is not central at 532 nm. **(Bottom Middle)**
The scope laser is not ideal for this application.

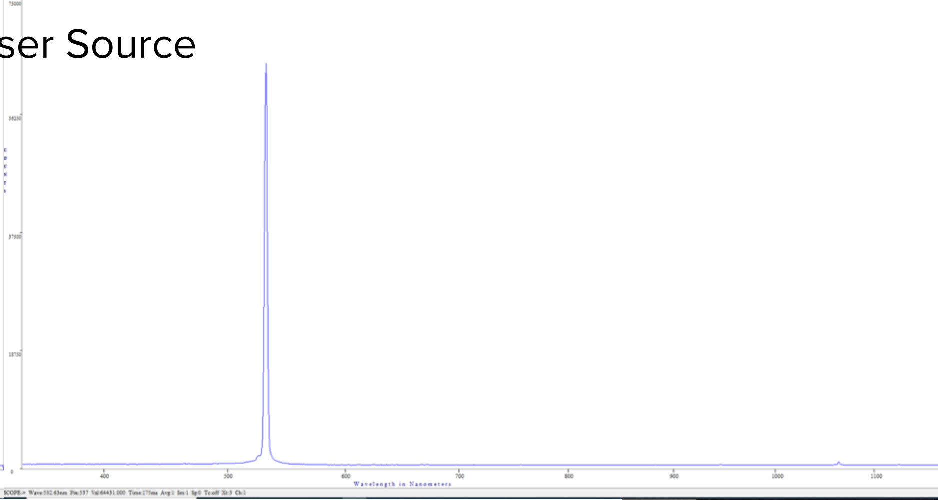


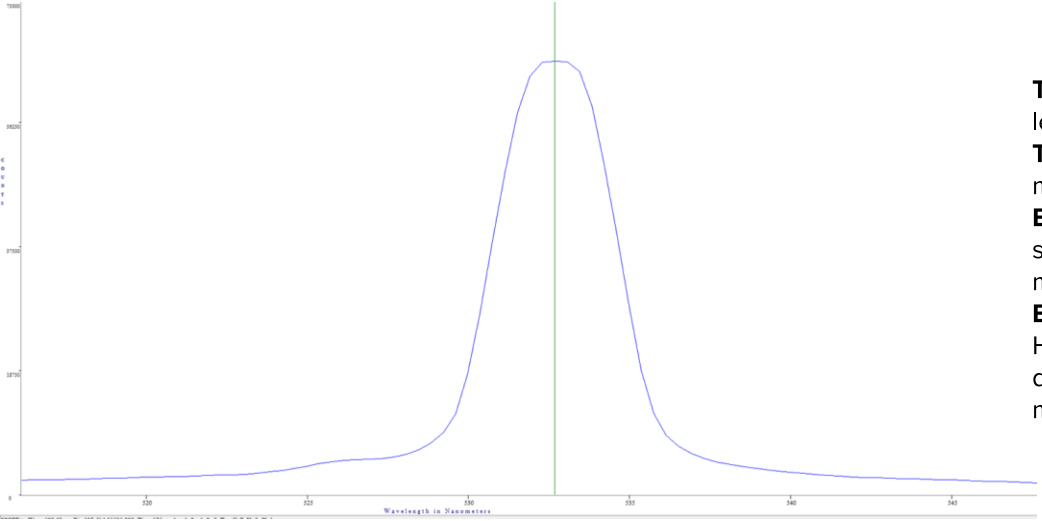




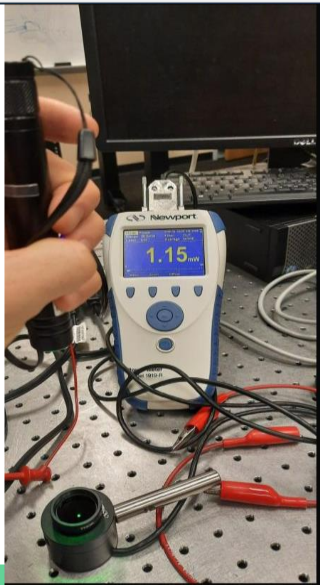
Handheld Laser Source







Top Left: Handheld Laser Full Spectrum (IF leakage)
Top Right: Handheld laser spectrum measured through bandpass filter.
Bottom Left: Zoom in on handheld laser spectrum measured through filter with the marker at central wavelength 532 nm
Bottom Right: Power Meter Reading of Handheld laser shone through a neutral density filter of OD2 measuring to roughly 100 mW as advertised.



PIN Photodiode
(Original Design)

300 nm - 1200 nm Si PIN Photodiode

- High responsivity (0.35 Spectral Sensitivity @ 532 nm)
- Low dark current (5 nA @ RV = 10V)
- High speed
- Small size
- Low cost
- Operating Voltage (0-10 V)

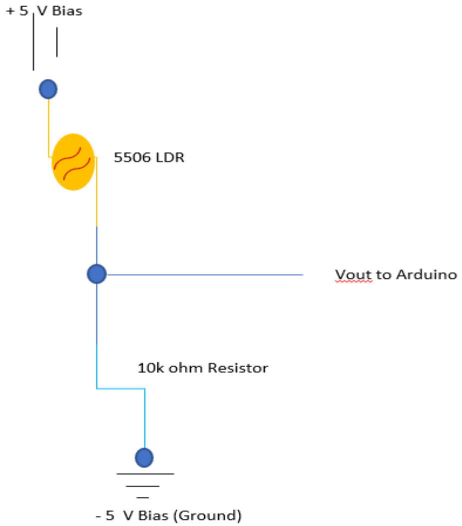
The Photodiode is going to be used to measure the ambient light of the systems environment. By creating a Transimpedance Op Amplifier circuit.

The PIN photodiode in reverse bias will current will be amplified and read as a voltage on the output which will have a linear Response proportional to the intensity of the incident light being shone upon the photodiode surface.

Part constraints, design difficulties, and more efficient approach were the reasoning behind changing the design to a different type of light detector.

Light Dependent Resistor

(Final Design)



Two LDR's were tested for this application. The 5506 CdS and 5549 CdS light dependent resistors. After extensive testing in the lab both LDR's were able to satisfactorily measure the lux of the desired freq was chosen for its lower voltage output readings when biased.

5506 Cadmium Sulphide (CdS) LDR

- High responsivity (0.95 Spectral Sensitivity @ 532 nm)
- Acceptable Response Time
- Small size
- Low cost
- Operating Voltage (0-10

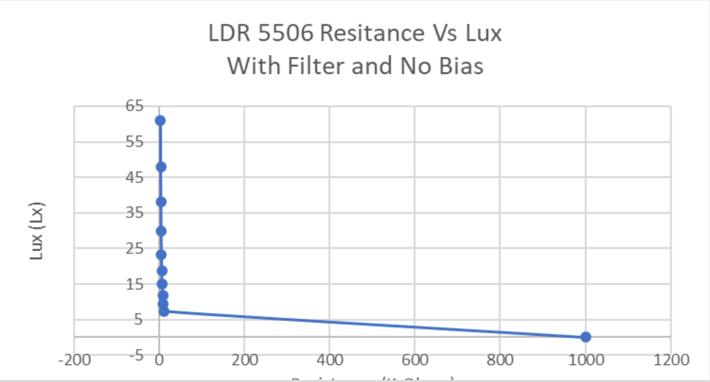
The 5506 LDR is a cheap and easy solution to the light detector design. This has a much higher sensitivity to the 532 nm light than that of the PIN Photodiode (almost 3x higher). The PIN Photodiode has a much faster response time to the light shone upon the surface, but for this application speed can be forfeited for sensitivity.

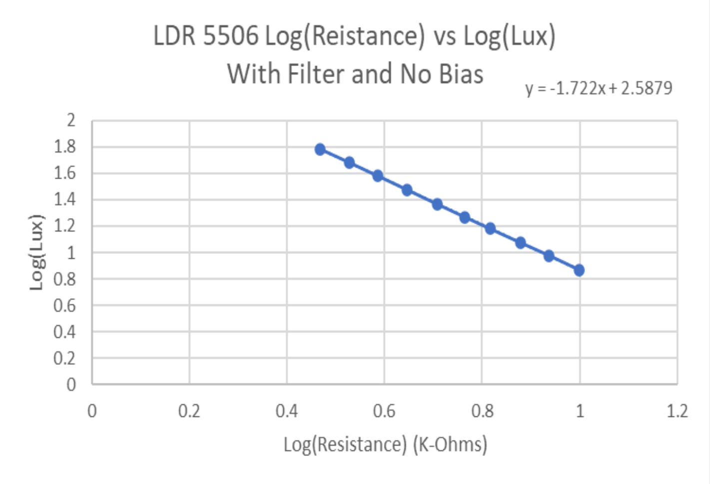
The 5506 LDR circuit is set up as a voltage divider circuit with a 10k resistor and a 5V bias to the LDR node. The output voltage is collected by the arduino and the signal is displayed on the LCD screen as a measured lux reading.

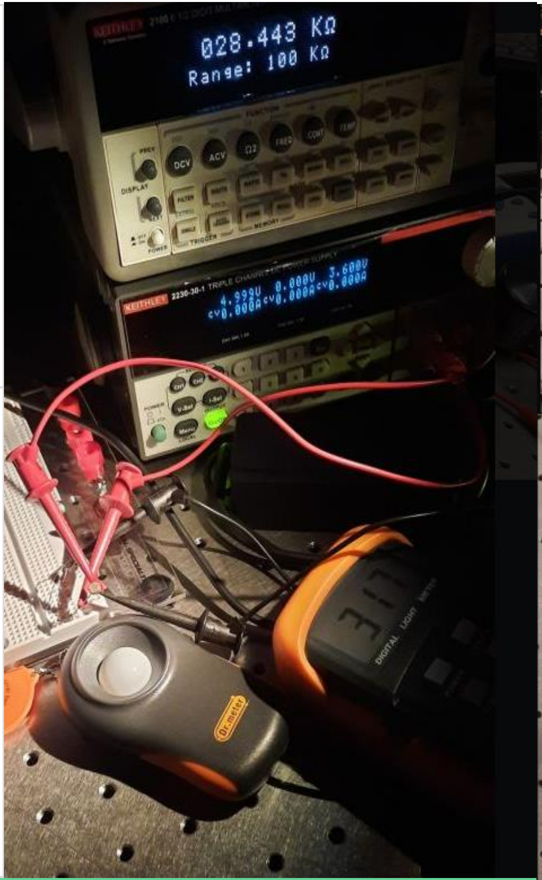
Lab Testing of 5506 LDR

LDR 5506 response to Fiber Light of varying intensities with no bias and corresponding response characteristics.

Resistance (K-Ohms)	Lux (lx)
1000	0
9.97	7.4
8.65	9.5
7.55	11.9
6.56	15.1
5.81	18.6
5.11	23.2
4.43	29.8
3.85	38.1
3.37	48
2.93	60.9

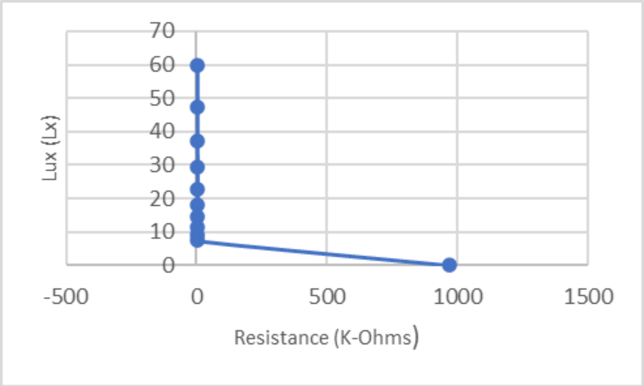


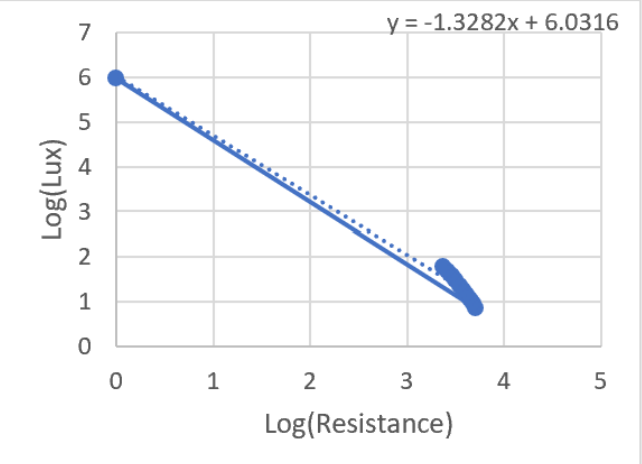


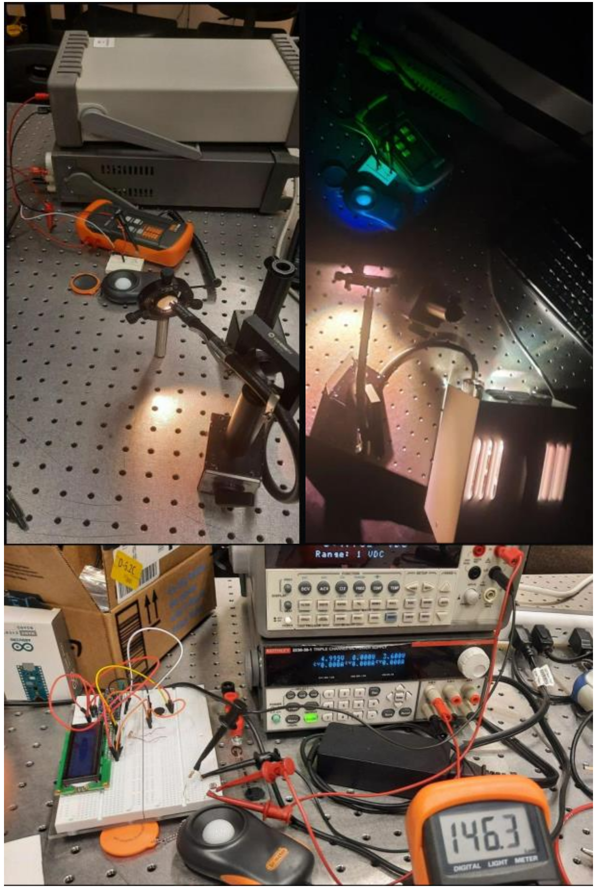


Lab Testing of 5506 LDR with 5V bias, Fiber light of varying intensities shone through Bandpass filter, and in voltage divider circuit.

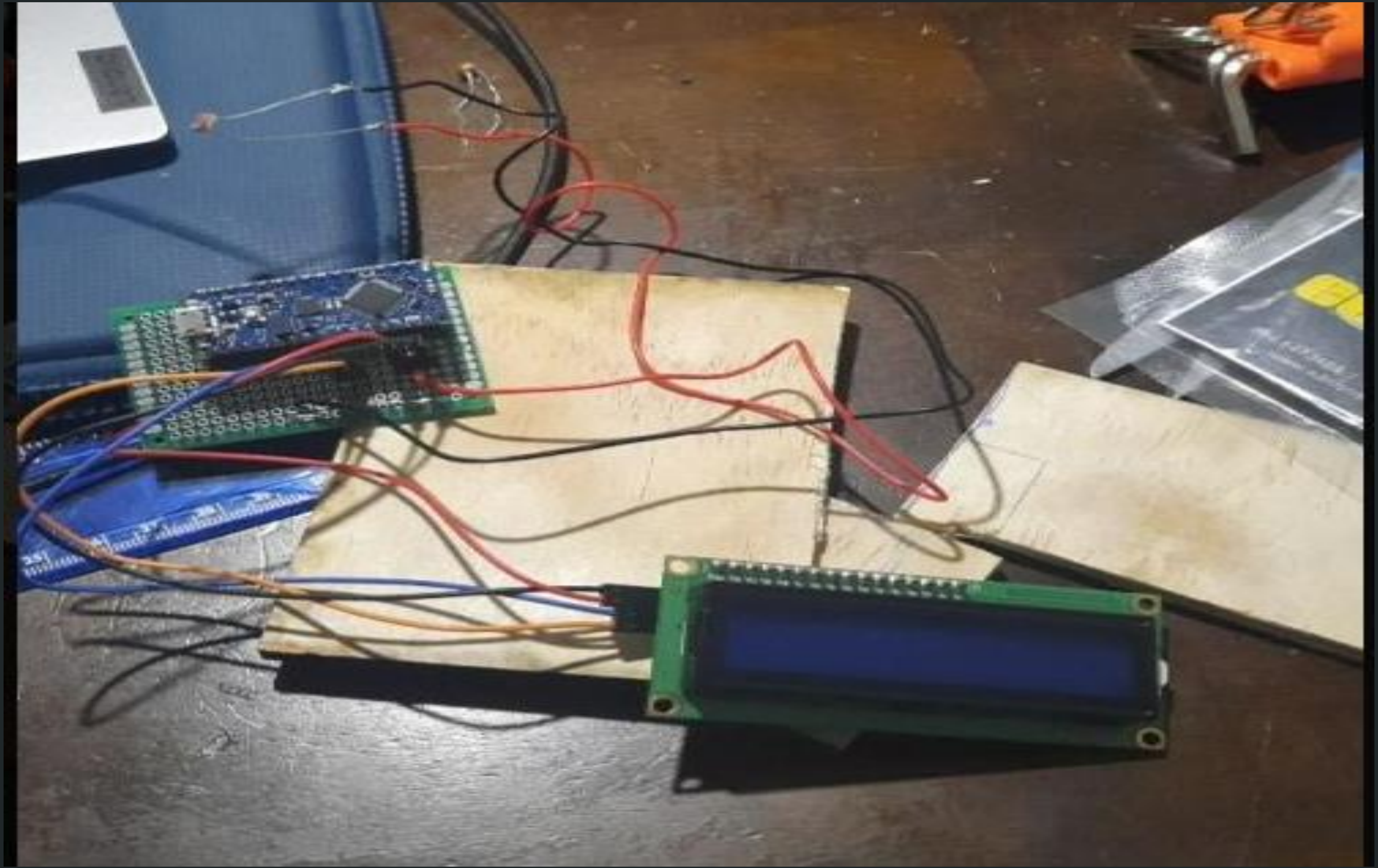
Resistance (K-Ohms)	Voltage (V) (Divider node)	Lux (lx)
0.968	0.18	0
5.16	2.50	7.3
4.83	2.66	9.0
4.50	2.83	11.3
4.15	3.01	14.4
3.83	3.12	18.1
3.53	3.29	22.6
3.19	3.46	29.3
2.90	3.61	37.3
2.62	3.75	47.5
2.37	3.85	60.0







Lux Meter



Camera

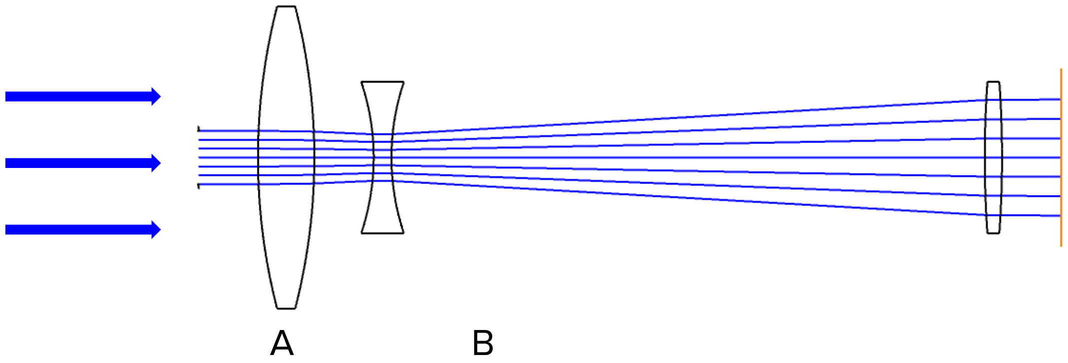
Logitech C615

● Frame rate	high	Bea
● Live stream		Bea
● Weight	low	Port
● Expense	low	Bud

The camera will capture the footage and images for the system

Accurate and efficient data collection

Lens system

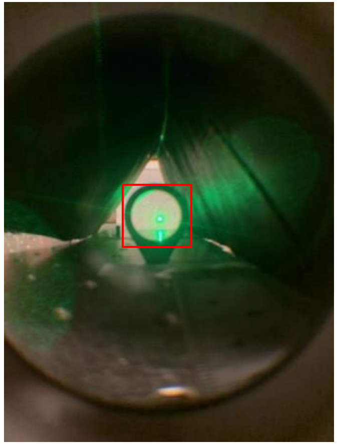


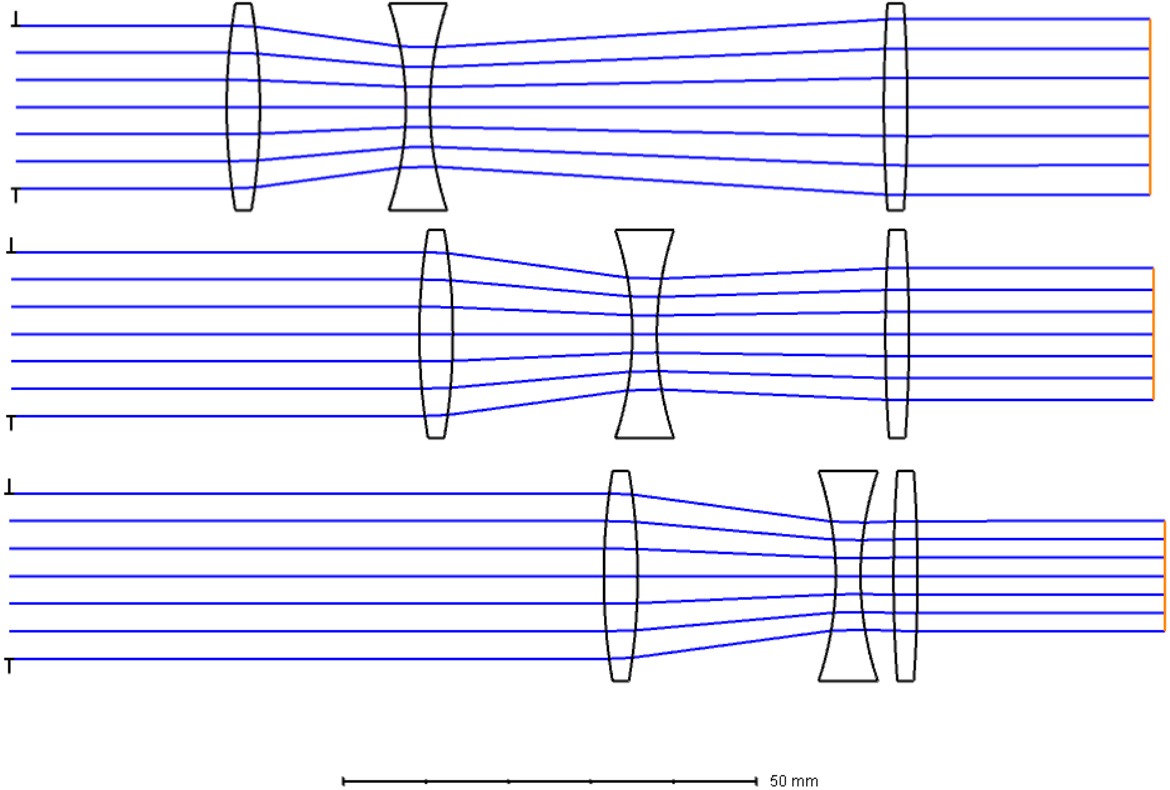
Lens	Radius of Curvature	Thickness	Diameter	Focal length	Back focal length
A	101.4 mm	9.5 mm	25.4 mm	100.0 mm	96.8 mm
B	-39.6 mm	3.0 mm	12.7 mm	-25.0 mm	-25.6 mm
C	179.8 mm	2.9 mm	12.7 mm	175.0 mm	174.0 mm

Zemax Simulations

Initial Simulation

Issues:
FOV: 12% of vertical image
Max Magnification: 1.8x

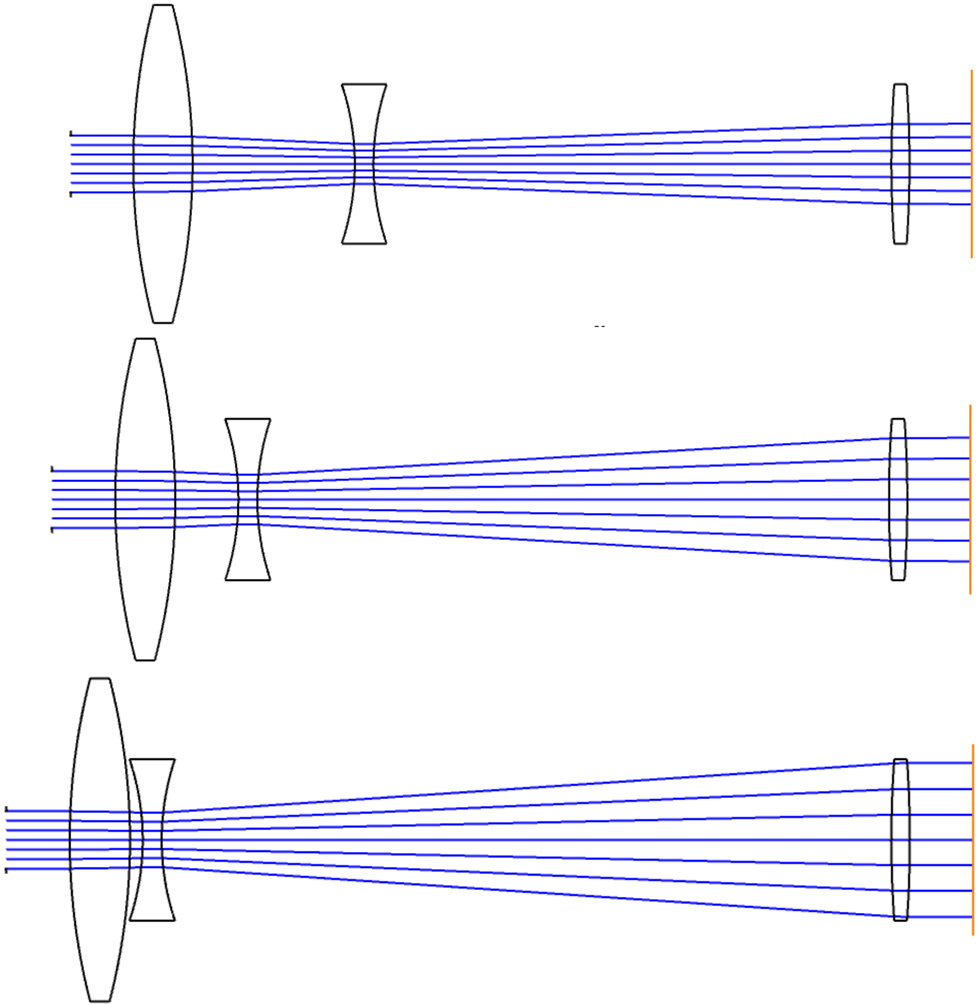




Zemax Simulations

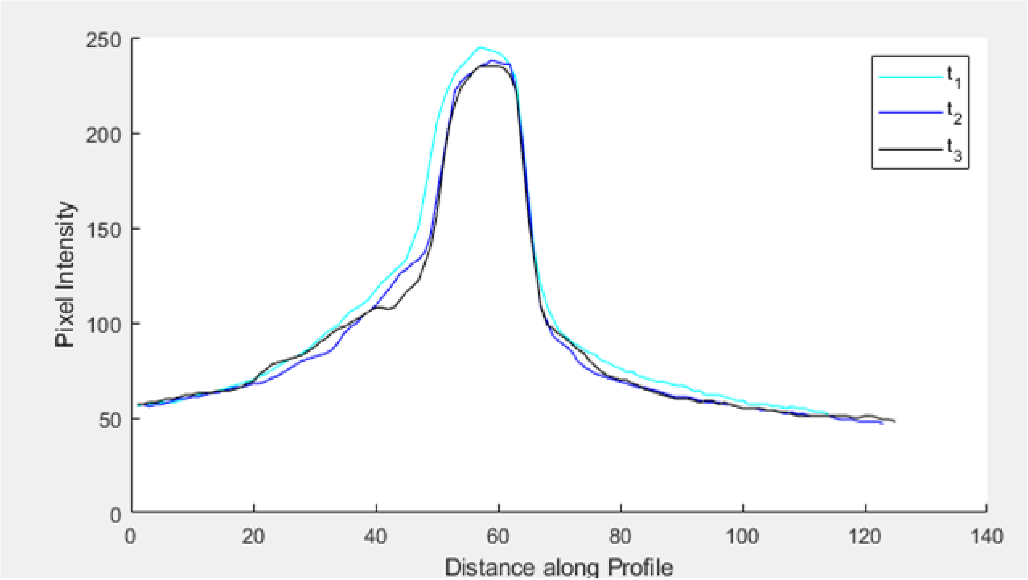
Final simulation

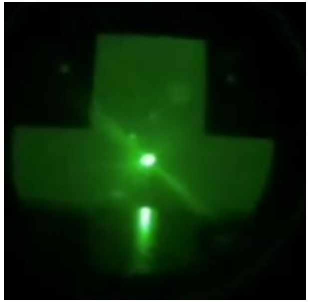
Rectification
FOV: 24% of vertical image
Max Magnification: 3x



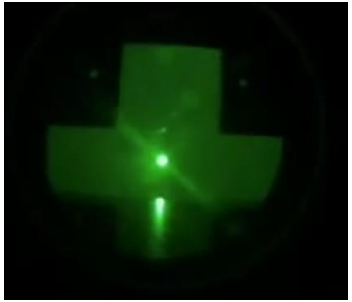
Intensity profile

Image processing of several frames can give an intensity profile and how it changes over time





t_1

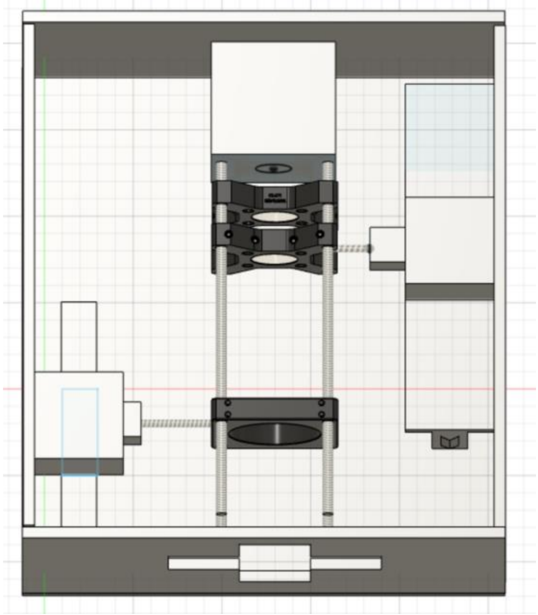


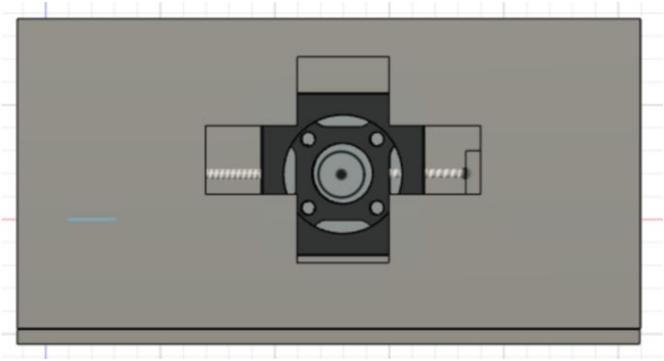
t_2

t_3

Mechanics: Filtering system

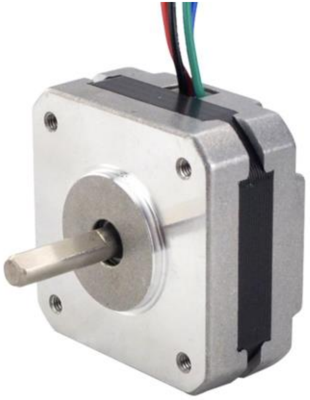
- Precise location
  - Four 8’’ rods
  - CAD designed components for precision
- Precise motion
  - Time pulley
  - V-slot rail
  - Motor
- Lightweight
  - 6 lbs
  - Minimum space

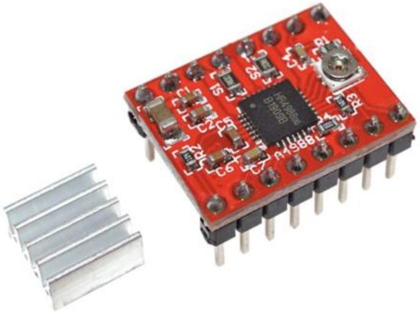




Mechanics: Nema 17 Motor & Driver A4988

- Rated voltage:
  - Motor - 3.7 volts
  - Driver - 8 volts
- Rated current:
  - Motor - 1 A
  - Driver - 2A
- Lightweight
- Accurate (bipolar)



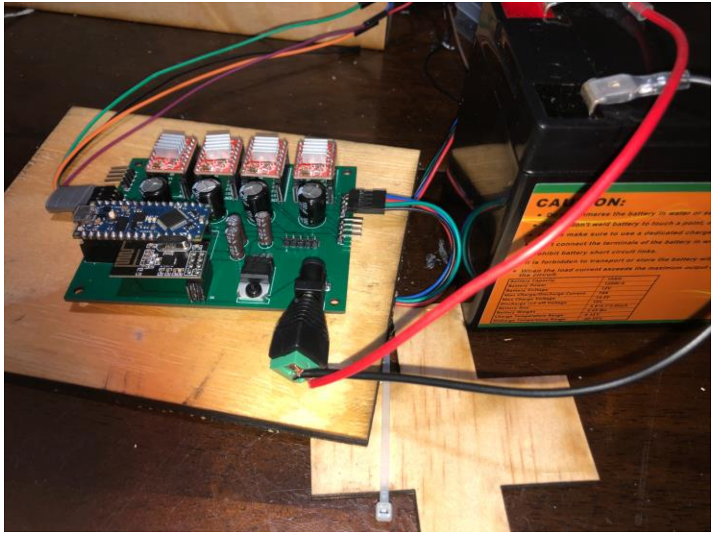


Power Source: Battery & Power regulator

- Lithium Iron Phosphate
  - 12 volts 10Ah
  - 120 watt hours
  - Light weight (2.43lbs)
- Power regulation
  - LD1085
  - Step down power

Power Distribution

- nRF24L01+
- Arduino Nano Every (ATMega 4809)
- Motor
- Motor Driver

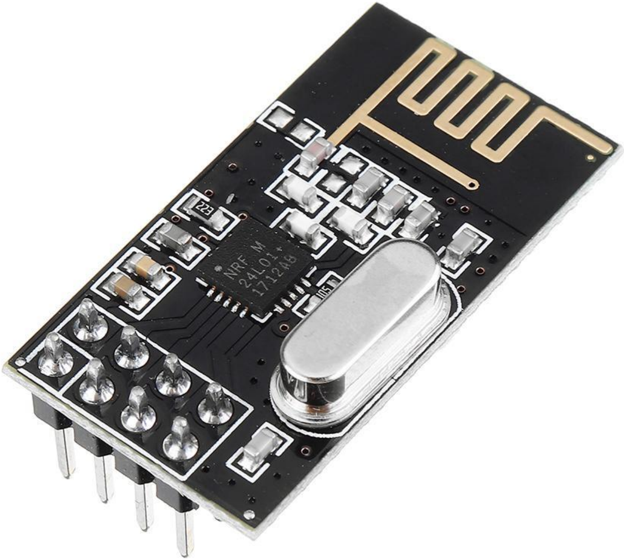


Wireless Communication Selection

Technology	WiFi	Bluetooth	RF
Implementation	Difficult	Easy	Easy
Cost	High	Low	Low
Effective Range	~100 m	~10 m	at least 800 m
Selection	X	X	✓

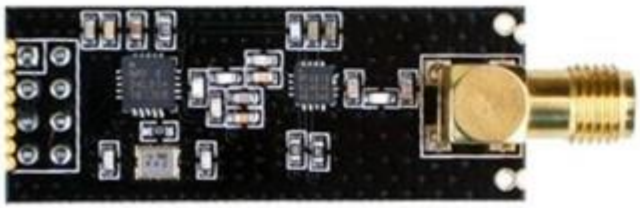
RF Communication: nRF24L01+

- 2.4 GHz ISM band
- Communication Range: 100m
    - Cannot change antenna
- Compatible with MCU and SBC used
- Receiver and transceiver interchangeable
- Operating Voltage: 3.3V



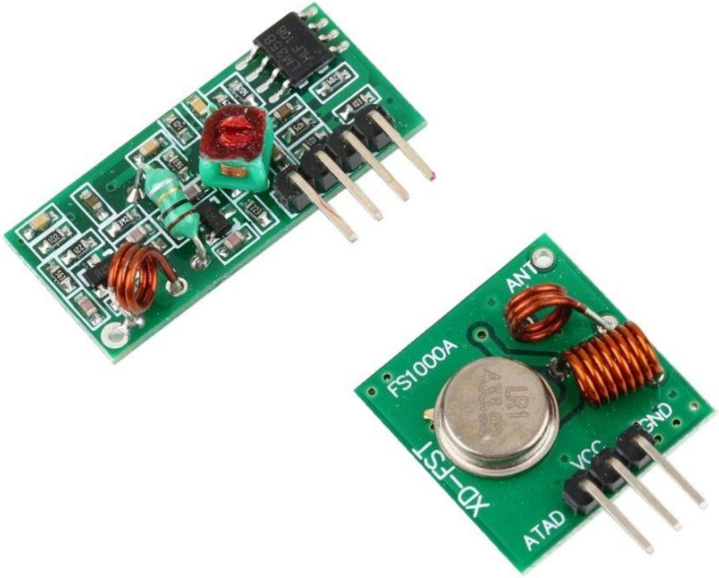
RF Communication: nRF24L01+PA/LNA

- 2.4 GHz ISM band
- Communication Range: 800m
    - Can extend if using different/altered antenna
- Compatible with MCU and SBC used
- Receiver and transceiver interchangeable
- Operating Voltage: 3.3V



RF Communication: FS1000A & XY-MK-5V

- 433MHz band
- Communication Range: ~ 50m
  - Dependent on antenna design
- Compatible with used components
- Receiver and transceiver not interchangeable
- Operating Voltage:
  - Transmitter: 3 - 12V
  - Receiver: 5V



RF Communication: Selection

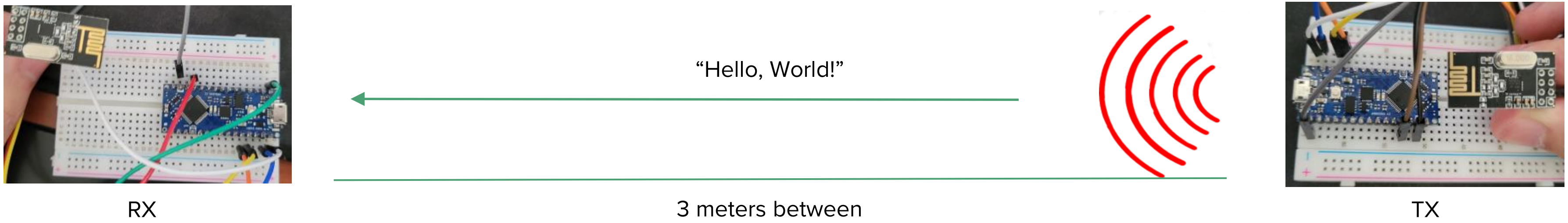
	nRF24L01+	nRF24L01+PA/LNA	FS1000A & XY-MK-5V
Range	100 meters	800+ meters	~50 meters
Cost	$4	$5	$2
Operating Voltage	3.3V	3.3V	TX: 3-12V, RX: 5V
TX/RX interchangeable?	Yes	Yes	No
Antenna	Built on, not changeable	Attachable, changeable	Must be custom made

Between the above components, the nRF24L01+ and nRF24L01+PA/LNA were selected for testing. When testing each module the following was observed:

- nRF24L01+PA/LNA required more precision in aiming in shorter ranges such that the TX & RX could reliably communicate
- nRF24L01+ needed less precision but the range of reliable communication was worse

Given these observations, the nRF24L01+ was selected for continued use for ease of testing

RF Communication Testing



To test latency for communications between TX & RX devices 3 meters apart, the test goes as follows:

1. Create programs for TX to continuously transmit “Hello, World!” string with no delay, RX to accept strings from TX. Upload to respective devices.
2. Set devices 3 meters apart and begin communication between devices.
3. Connect RX to a serial monitor to see what it is receiving and how long it takes for messages to be received. Record times between messages

Not perfect test, but if latency is greater than 100ms than adjustments need to be made.

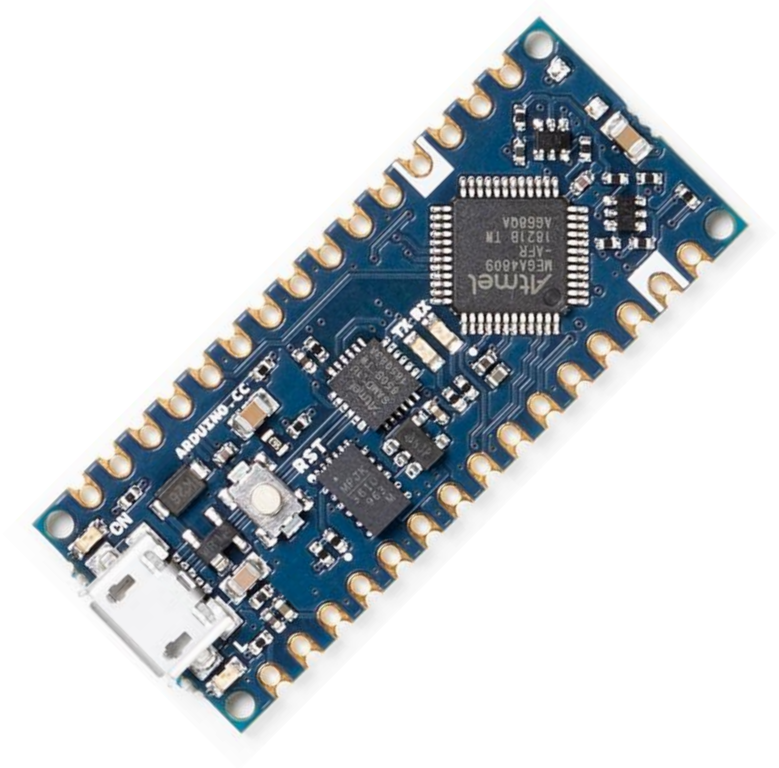
Results:

Minimum Latency	26ms
Maximum Latency	6ms
Average Latency	12ms

Results fall well within system delay parameters. Test conducted at 250kbps transmission speeds and 9600 clock, well below optimal settings for system delay, making results more promising.

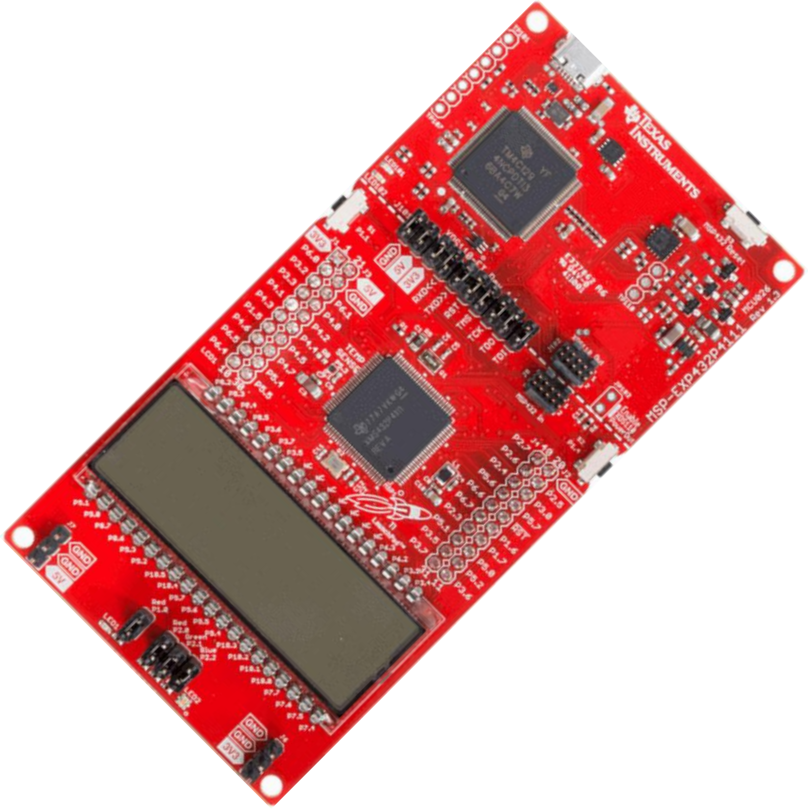
MCU Board: Arduino Nano Every (ATMega 4809)

- C programmable
- Extensive hardware libraries
- Large Support
- Free & open source software
- Inexpensive hardware
    - $28.20 for 3 boards
    - $1.58 for ATMega 4809 MCU



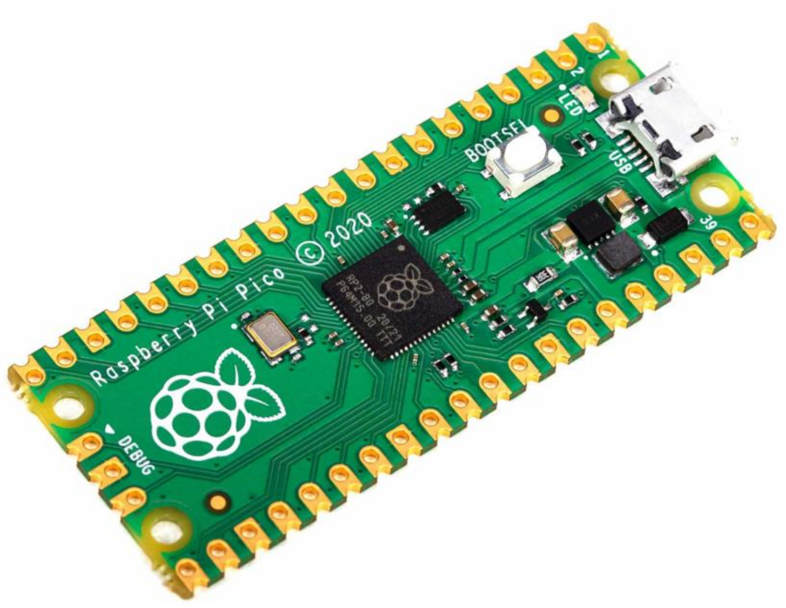
MCU Board: MSP430 family

- C programmable
- Thorough documentation by TI
- Free & open source software
  - Custom boards need enterprise IDE
- Hardware costs vary
  - $10-$20 per board
  - $2-$5 per controller



MCU Board: Raspberry Pi Pico (RP2040)

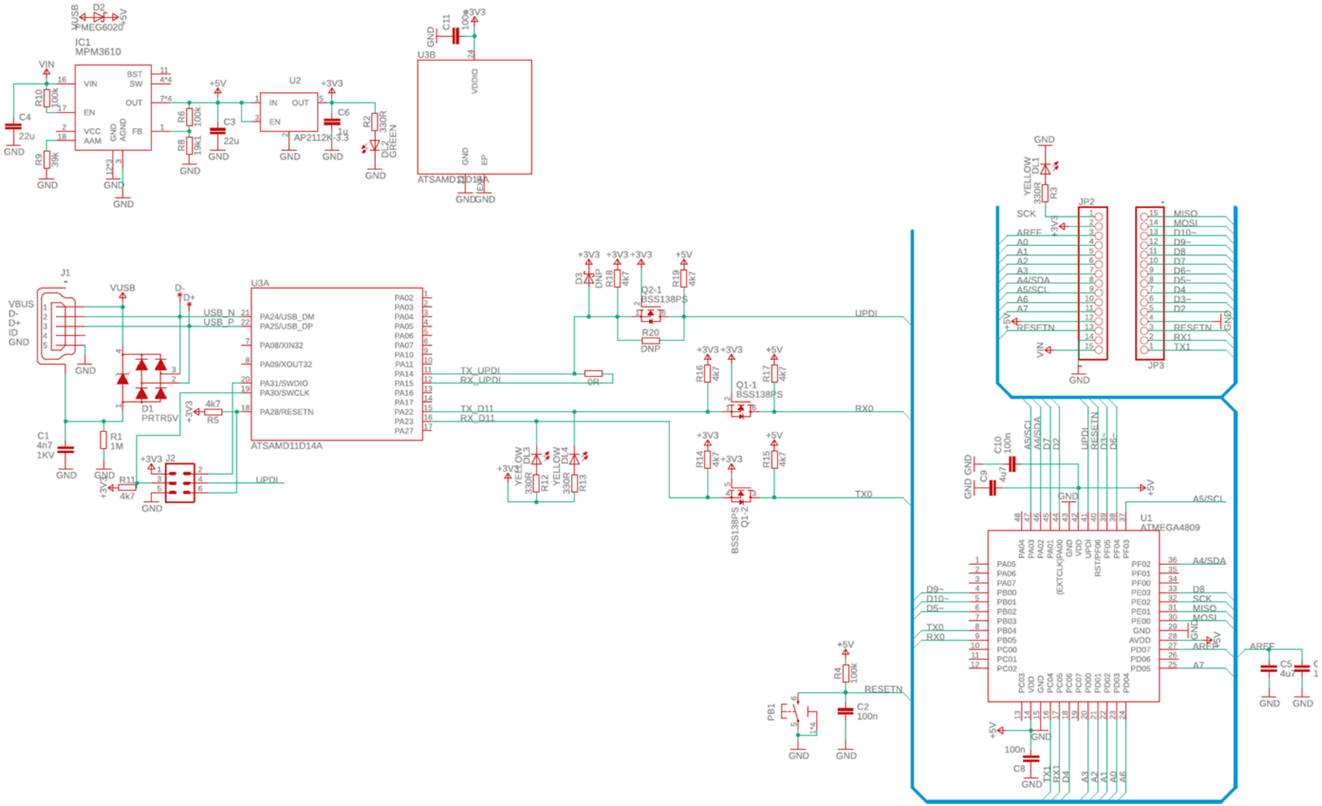
- C and MicroPython programmable
  - Not great implementation for programming in C
- Free & open source software
- Most powerful option
- Inexpensive
  - $4 per board
  - $1 per controller



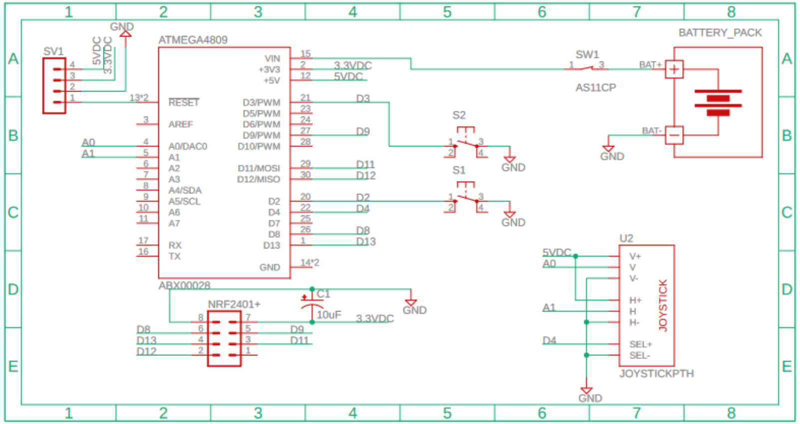
MCU Board: Selection

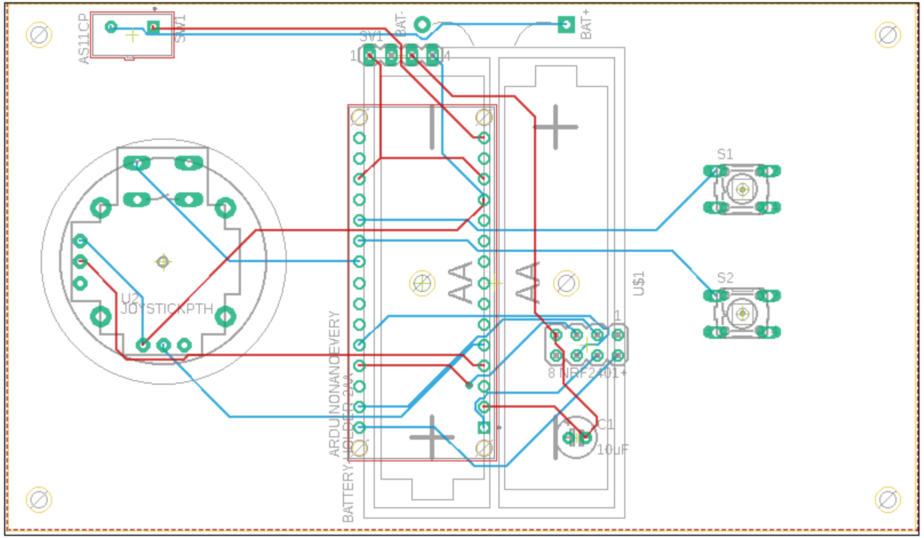
MCU	**Arduino Nano Every ATMega 4809**	**MSP430FR6989**	**Raspberry Pi Pico RP2040**
Architecture	8-bit RISC	16-bit RISC	32-bit RISC (ARM)
Max. Power Consumption (Active)	425µA/MHz	100µA/MHz	718µA/MHz
Low-Power Consumption	15µA/MHz	17.1875µA/MHz	-
I/O pins	41	83	30
Clock	20MHz	16 MHz	133MHz
RAM	6KB (SRAM)	128KB (FRAM)	264KB (SRAM)
Operating voltage	1.8 - 5.5V	1.8 - 3.6V	1.8 - 3.3V
UART, I2C, SPI	1, 1, 1	2, 4, 2	2, 2, 2
Temperature Tolerance	-40 to 125°C	-40 to 80°C	-20 to 85°C

Schematics - Microcontroller

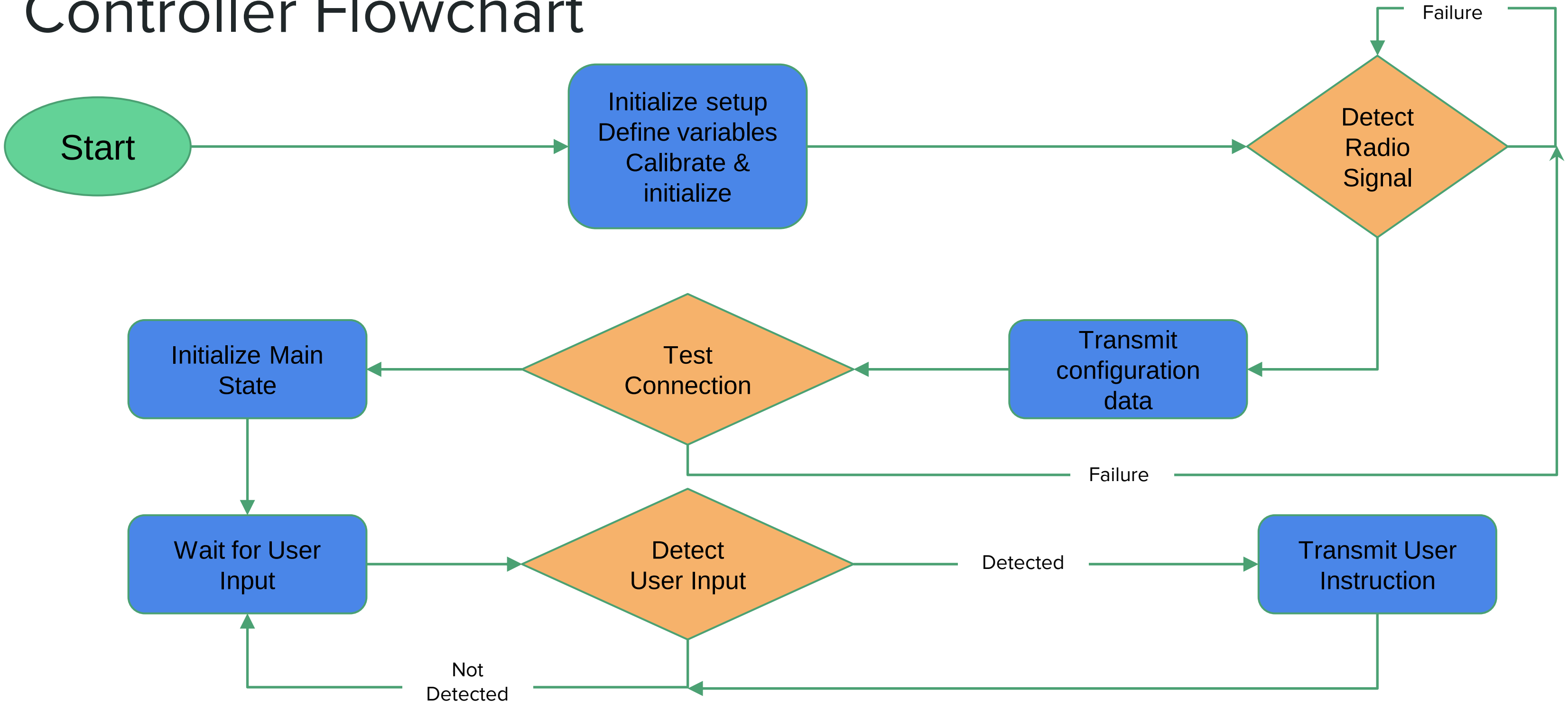


Schematics - Transceiver

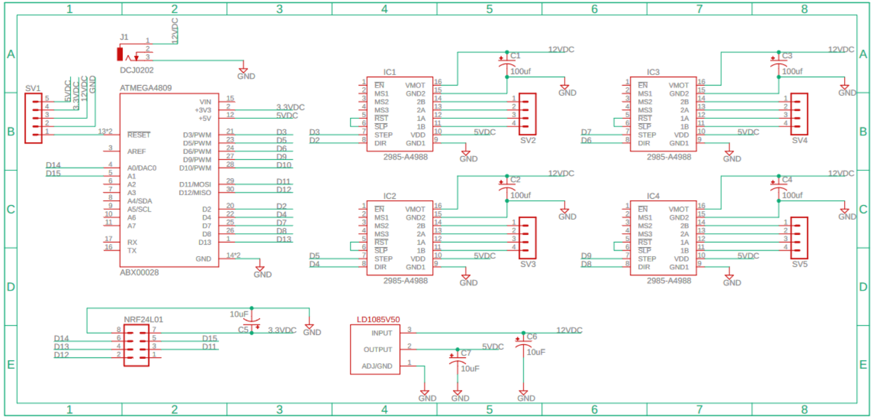


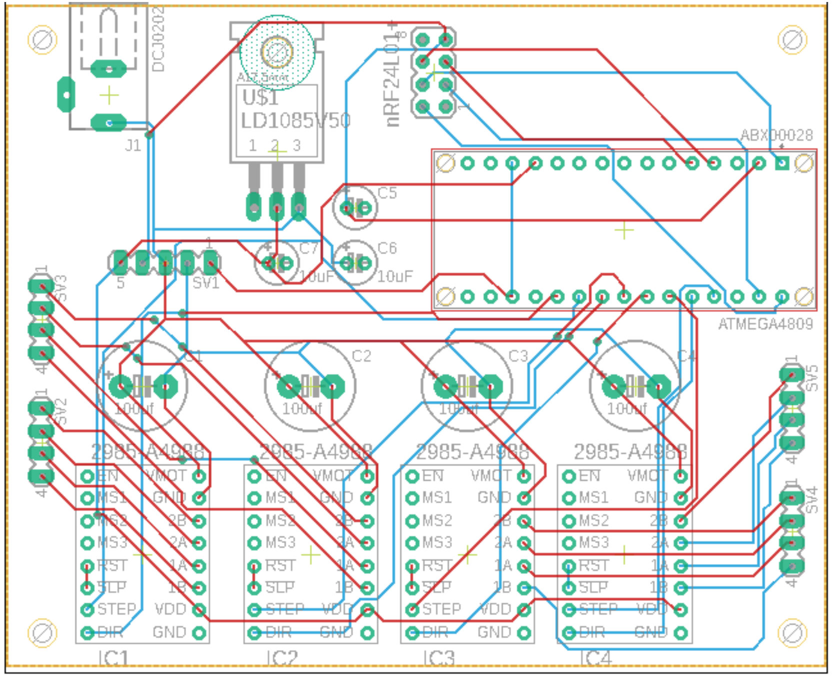


Controller Flowchart

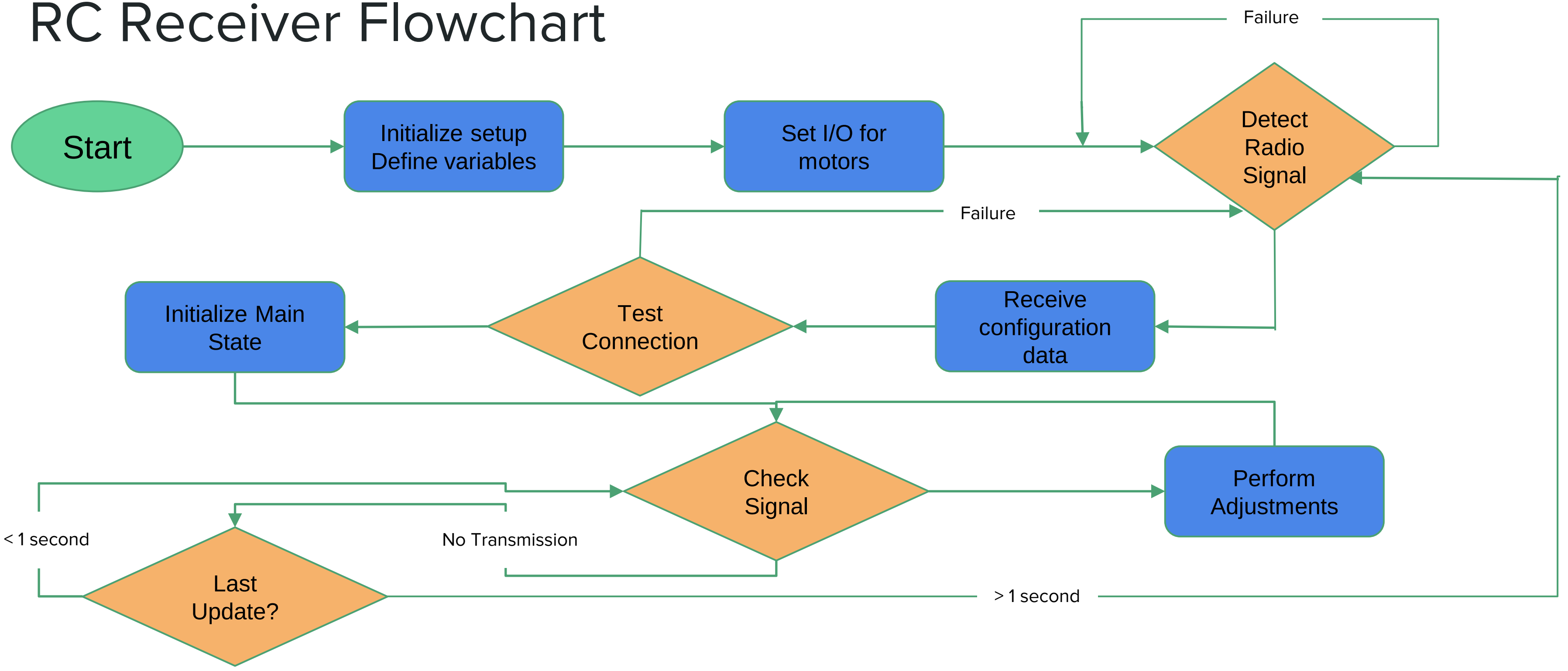


Schematics - Receiver

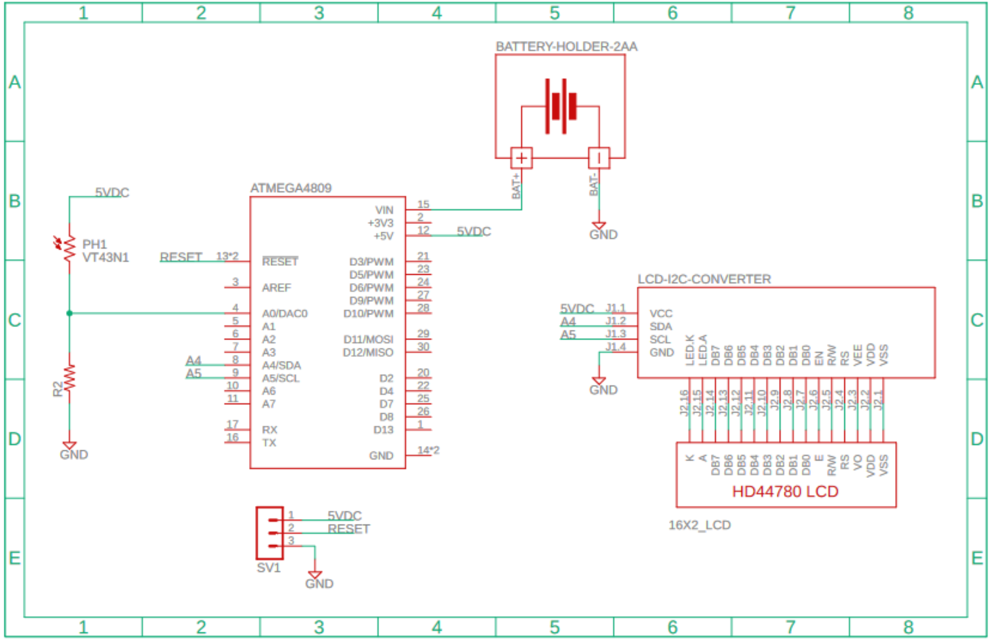




RC Receiver Flowchart

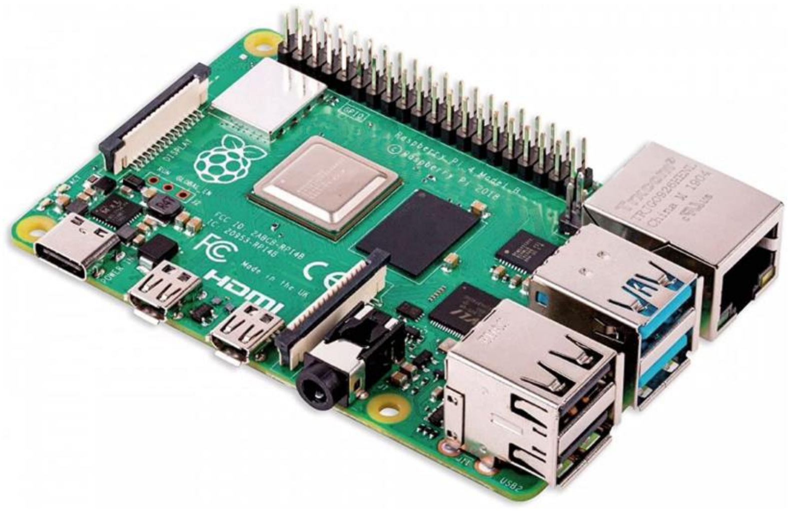


Schematic - LDR



Single Board Computer (SBC) - Raspberry Pi 4B

- Adequate processing power
  - Quad-core ARM, 1.5 GHz clock
  - GPU: VideoCore VI 3D Graphics
  - 8 GB memory
- Extensive documentation from both manufacturers and users
- Generous amount of UART and SPI



Single Board Computer (SBC) - NVIDIA Jetson Nano

- Powerful graphics processing
  - 128-core NVIDIA Maxwell GPU
  - Preferred option for machine learning applications
- Adequate processing
  - Quad-core 64-bit ARM @ 1.43 GHz clock
- Similar GPIO layout

Single Board Computer (SBC) - Comparison & Selection

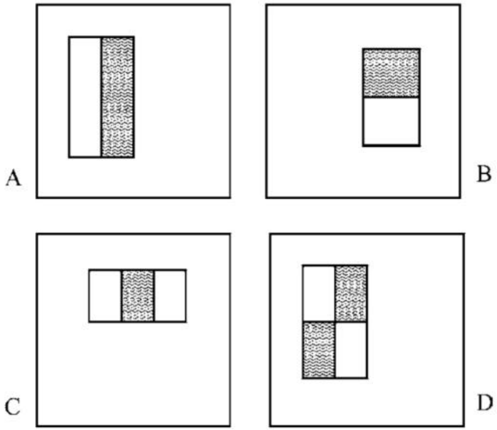
Jetson Nano	Parameter	Raspberry Pi
	Processing Power	✓
✓	Graphics Processing	
✓	Power Consumption	
	GPIO	✓
✓	Temperature Tolerance	
✓	Power Consumption	
	Price	✓ (Free)

Selection: Raspberry Pi

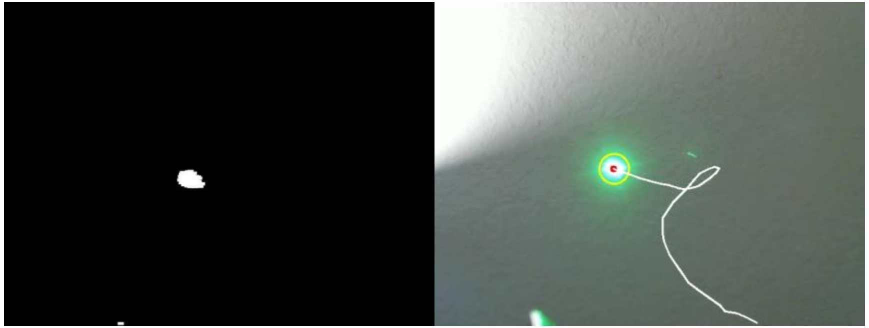
- Already owned
- Possible procurement issues with Jetson Nano

Object Tracking System

- SBC utilizing OpenCV library
- Open source CV and ML library for use in C++ and Python
- Trainable image detection using HAAR features



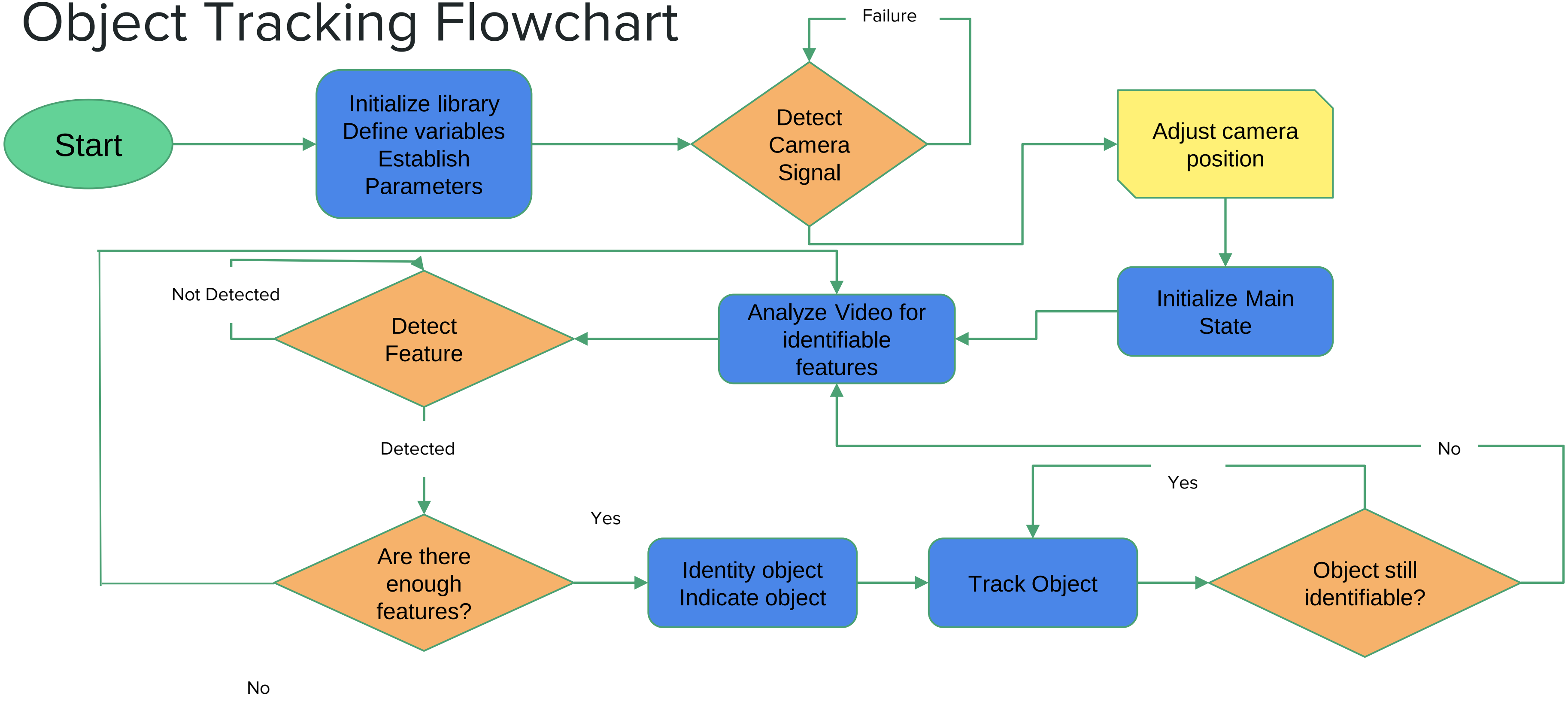
Object Tracking Algorithm



Left: Filtered input indicating which pixels fall within set HSV/HSL parameters
Right: Input frame overlaid with detection indicator and track of object movement

- The Python program used accepts the camera input and filters out which pixels within each frame match set parameters to allow for object detection and tracking over time.
- Filtering algorithm uses the HSV (Hue, Saturation, Luminescence Value) values of each pixel to filter out which pixels fall within the given color parameters.
    - Our program detects green light (H: 0-60), Saturation of any value (S: 0-255), and high Luminance (L: 200-255)
- Tracking determines which part of the part of the frame has the most significant amount of pixels fitting filter criteria and tracks the center point of those pixels. Each position is recorded and the change in position between center points of object in each frame is also tracked.

Object Tracking Flowchart



Work Distribution

	Filter	Lens	Transmitter	Motors	Adjustment Mech.	Tracking	Battery	Camera	Sensor
Madeline		✓						✓	
Devin	✓				✓				✓
Daniel			✓			✓		✓	✓
Miguel				✓	✓		✓		

Financing

Part	Cost	Part (cont.)	Cost (cont.)
Biconcave Lens A	$24.50	Convex Lens	$
Biconcave Lens B	$35.16	MCU	$9.40 (x3)
Biconcave Lens C	$22.92	SBC	$0
Camera	$30.00	RF Modules	$4
Laser Source	$20	Stepper Motor 1	$8.67
LCD/Arduino	$35.00	Stepper Motor 2	$8.67
Band Pass Filter	$160.00	Stepper Motor 3	$8.56
Lux Meter	$30.00	Stepper Motor 4	$8.56
5506 LDR	$20.00 (20)	Battery	$60.32
PCBs	$9.50		
Total Cost:			