iSPY, Image Surveillance and Protection Yielder

Group 5

Our Team

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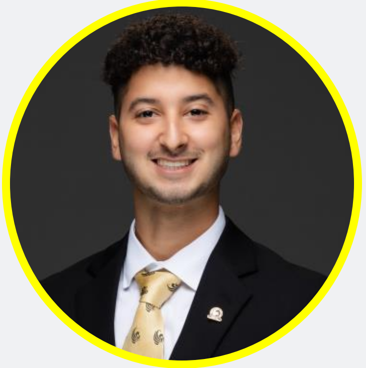
Introduction

- iSPY is a surveillance system that utilizes Free-Space-Optical (FSO) communication and body recognition.
- By transmitting data from a live video feed using FSO, iSPY minimizes the interception risks associated with most wireless surveillance systems.
- iSPY's body recognition allows for precise monitoring, making it perfect for urban and military security.

One could visualize the future of the system like this

Motivation and Background



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- **Current surveillance and telecommunication systems are susceptible to hacking when not integrated within a secure network.**
  - + Dangerous when considering proliferation of products like the Ring Doorbell Camera and peripherals.
  - + If systems are not under a secure network, hardware is in danger of being tapped!
  - + Private home and military installation surveillance systems are susceptible.
- **Electromagnetic carrying capacity is narrowing every day.**
  - + Proliferation of RF tech uses up necessary EMF real estate.
  - + The spectrum must expand towards optical frequencies to meet demand.
- **Optical wireless communication (OWC) is a solution.**
  - + Has picked up momentum recently.
  - + Common for TV controllers…but now also for LiFi and on satellites.

"iSPY addresses these needs and paves the way for other technologies benefiting from OWC."

– iSPY Team

Priority Goals and Objectives

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Goals

Basic

- Transmit and receive a laser pulse.
- Detect objects with the use of computer vision algorithm in video feed.
- Capture faint images of the environment.

Advanced

- Transmit and receive usable optical signals using integrated circuits at 1Gbps.
- Capture recognition of people as well as count the number of individuals recognized from video feed.
- Capture a clear image of the surrounding environment with 80° FOV.

Stretch

- Ultra-fast transmission speeds using high-speed FSO transceivers.
- Tracking movement of individuals in video feed with confidence scoring and enhancing recognition of people to determine gender and age.
- Aberration-corrected, high-resolution, 120° FOV images.

Objectives

Basic

- Turn laser on/off and measure pulse.
- Utilize an object detection algorithm.
- Create a two-lens imaging system.

Advanced

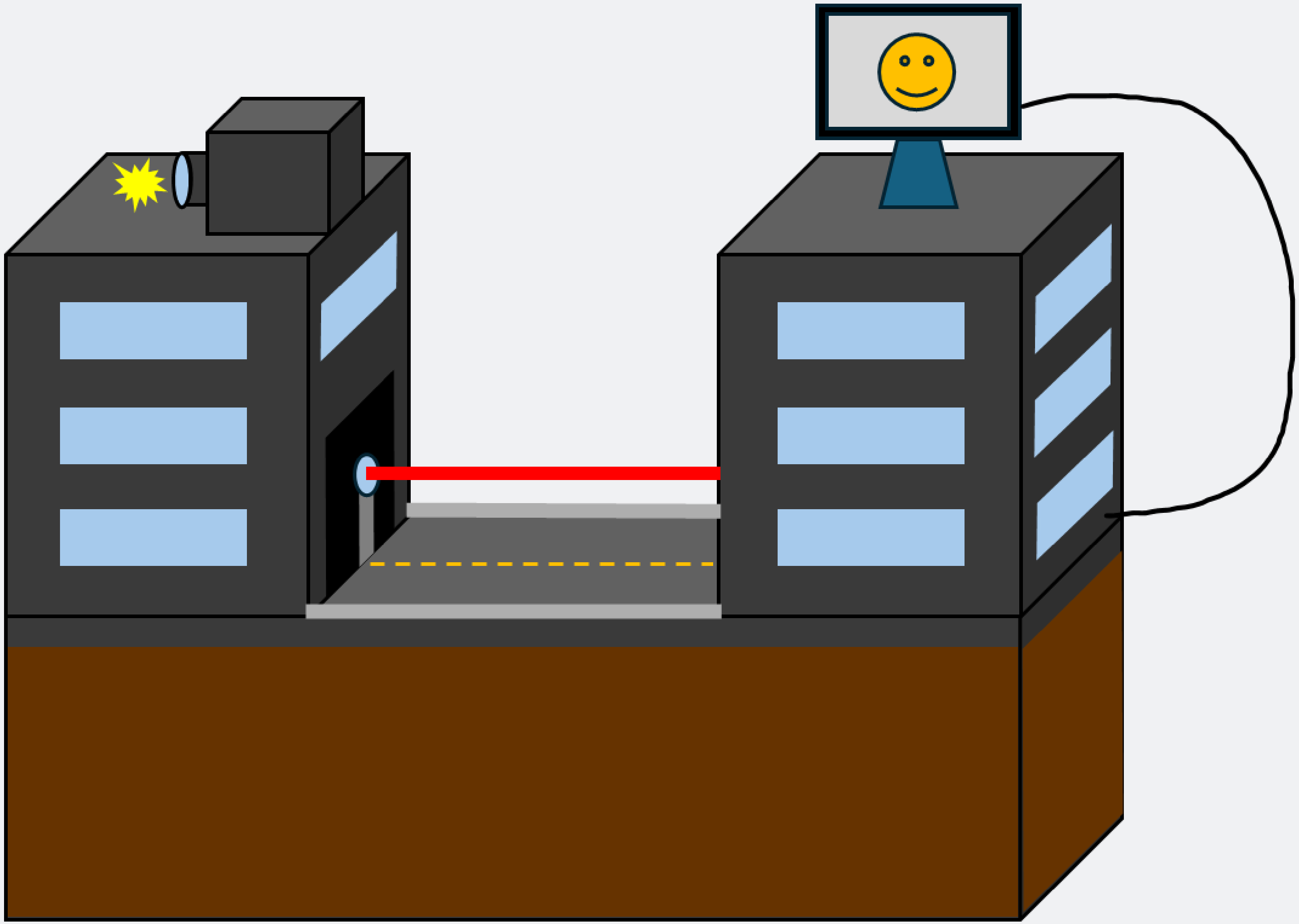
- Utilize optical transceiver to transmit and receive laser pulses.
- Edit a body detection library to detect a human body with ≥75% confidence.
- Create a wide field of view imaging system to capture a continuous image feed.

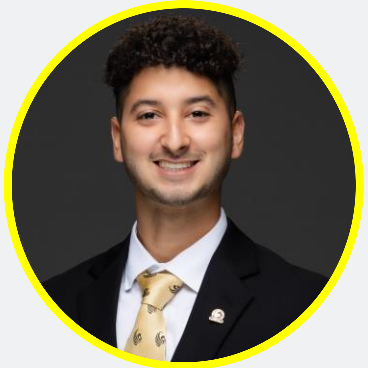
Stretch

- Create an ultra-fast laser/receiver system with adaptive optics capabilities.
- Write object tracking algorithms to enhance body detection algorithms' abilities with high confidence scores.
- Design a wide field of view lens system capable of resolving aberration-free and well-detailed images.

● FSO system ● Body Detection ● Image Acquisition

Prototype Schematic





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Prototype Engineering Specifications

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Sub-System	Parameter	Specifications
Imaging	Field of view	80 degrees (horizontally) 50 degrees (vertically)
Computer Vision	Accuracy of detection	75%
Communication	Emulated Distance	> 10 km
Communication	Optical Link Length	0.25 meter
Image Processing	Clock Speed	16 MHz
Imaging	Framerate	30 frames per second
Power	Voltage Output	3.3V DC regulated

Hardware Design – High Level Overview

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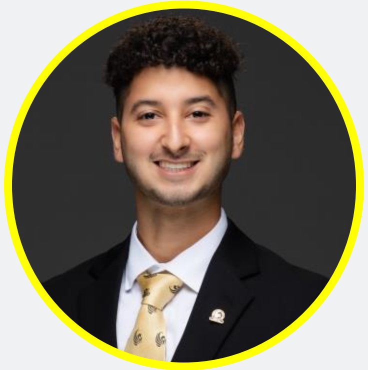


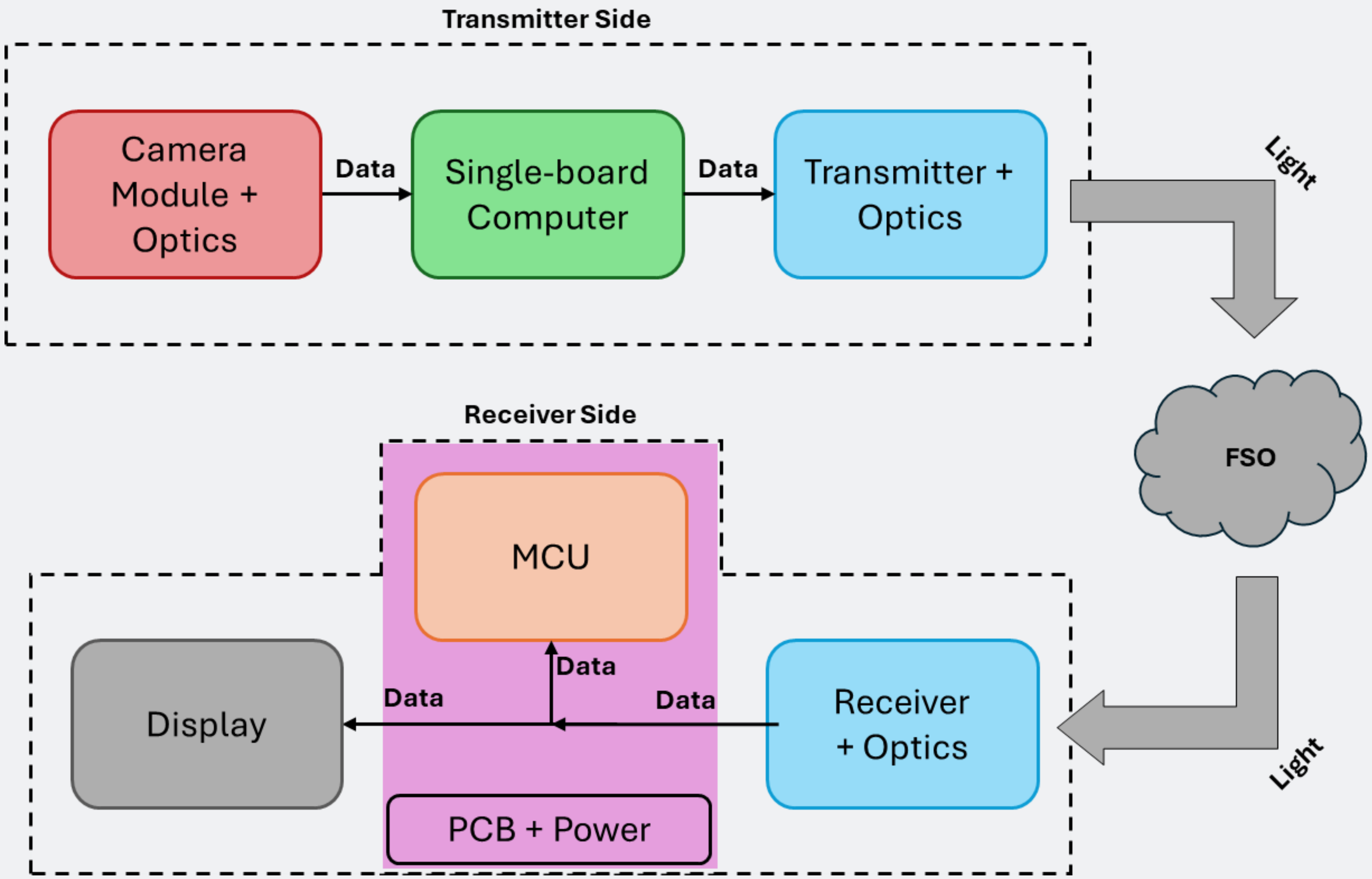
Luke

Alejandro

Armani

Gaby

Robert



Software Design – High Level Overview

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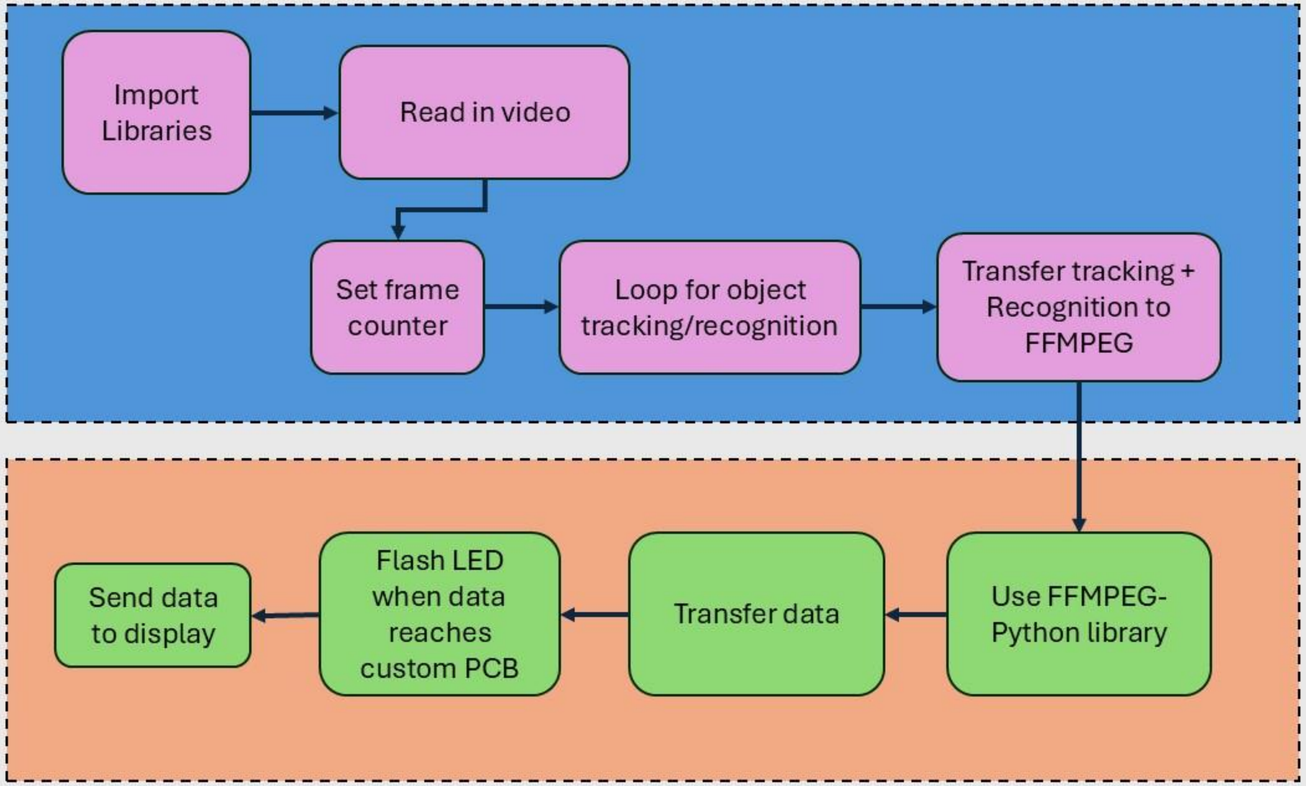
CPE

Robert

Luke



Hardware – Image Acquisition System – Design Calculation

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What?

An imaging system with a wide field of view.

How?

Using less than 4 lenses with a short effective focal length.

Why?

To reduce cost and size.

Task

To achieve comparable results with less materials.

Components

Pinhole (Noise filter)

Lenses

CMOS Sensor

Calculations for EFL

$$\tan(\mathrm{FoV}/2) = (D/2)/\mathrm{EFL},$$

$$\mathrm{EFL} = D/[2\tan(\mathrm{FoV}/2)].$$

EFL = 4.41 mm for 80° FOV

EFL = 3.14 mm for 100° FOV

Calculations for EPD

$$F\# = \frac{\text{focal length}}{\text{entrance pupil diameter [EPD]}}$$

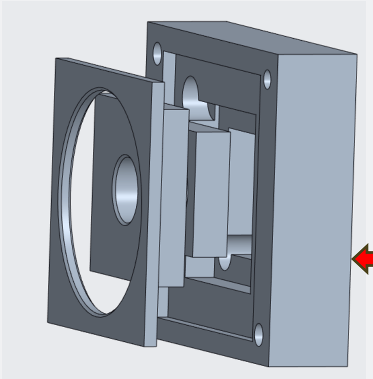
$$EPD = \frac{\text{focal length}}{F\#}$$

F# desired range: 6 to 8

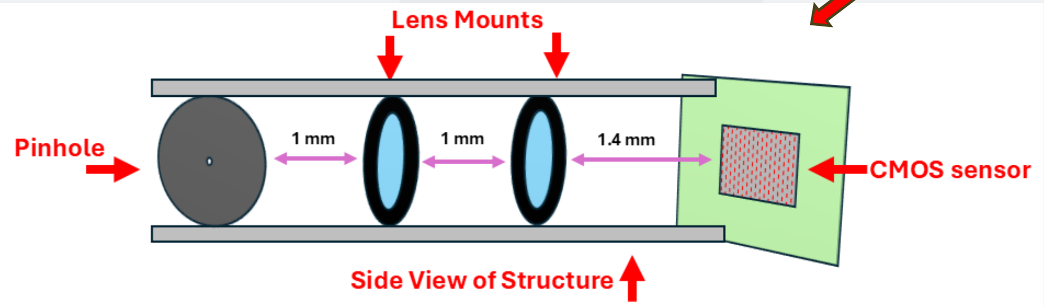
$$EPD = \frac{4.41\text{ mm}}{6 \text{ to } 8} \Rightarrow 0.735\text{ mm to } 0.55\text{ mm}$$

$$EPD = \frac{3.14\text{ mm}}{6 \text{ to } 8} \Rightarrow 0.523\text{ mm to } 0.3925\text{ mm}$$

Schematic



The structure and what is inside



Comparison and Selection of Hardware

Image Acquisition System - Overall

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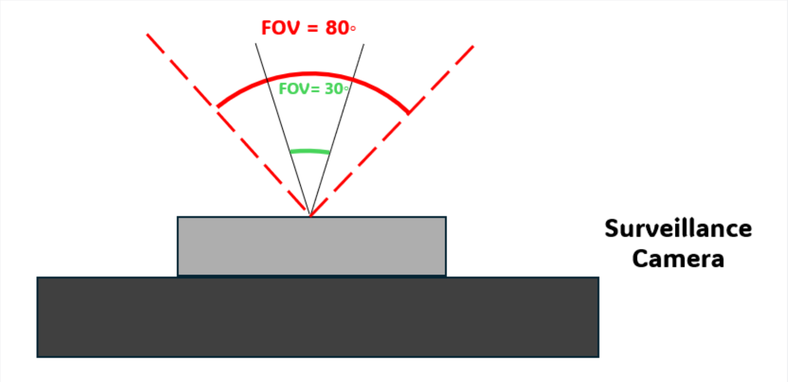
- For our surveillance system we wanted a camera with a wide field of view.
- Field of view (FOV) is an angle measurement of how much of a scene one can see.
- A wide field of view give us a “big picture” of a scenario rather than a detailed focus in one part.
- Our plan is to build our own camera with the goal of reducing size and cost.
- Off-the-shelf cameras have around 4 lenses. We want to reduce that number.



FOV (field of view) representation

Lenses from an off-the-shelf surveillance camera

Comparison and Selection of Hardware

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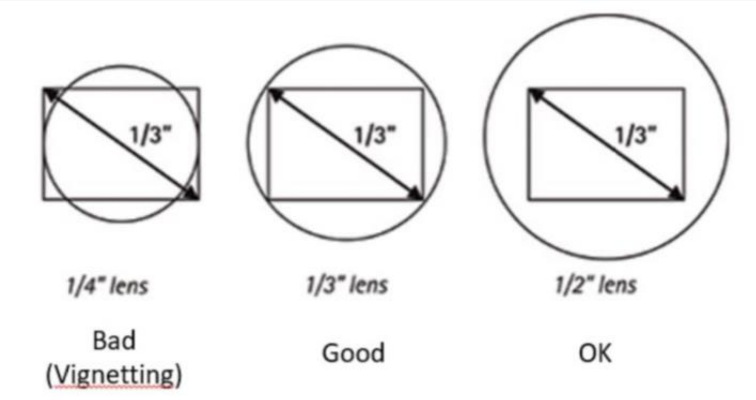
Image Acquisition System - Sensor

- The optical design of the image acquisition system starts with the choice of the sensor.
- The sensor size dictates the size of the lenses.
- Failure in matching sensor size with the lenses will cause vignetting.



Lens optical format (circle) vs sensor size (rectangle)

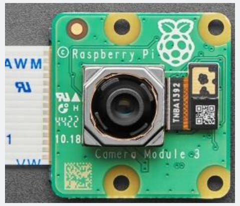
- Size and price of the sensor and lenses increase proportionally.
- FPS (frames per second)
- CMOS vs. CCD
- Shutter type
- Connection to PCB / Interface

Comparison and Selection of Hardware

Image Acquisition System - Sensor

Camera Module A				
Model	**Frame rate (fps)**	**Sensor size**	**Interface**	**Shutter Type**
daA3840-45uc	45	1/1.8’’	USB 3.0	Rolling
Brand	**Pixel size (H x V)**	**Resolution**	**Weight**	**Price**
Basler	2.0 x 2.0 µm	8.3 MP	< 15g	$199

Camera Module B				
Model	**Frame rate (fps)**	**Sensor size**	**Interface**	**Shutter Type**
Pi Camera Module 3	30	1/2.43’’	MIPI CSI-2	Rolling
Brand	**Pixel size (H x V)**	**Resolution**	**Weight**	**Price**
Raspberry Pi	1.4 x 1.4 µm	11.9 MP	4g	$25



Camera Module C				
Model	**Frame rate (fps)**	**Sensor size**	**Interface**	**Shutter Type**
IMX519	30	1/2.53’’	-	Rolling
Brand	**Pixel size (H x V)**	**Resolution**	**Weight**	**Price**
ArduCam	1.22 x 1.22 µm	16 MP	8.5g	$37.99

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Comparison and Selection of Hardware

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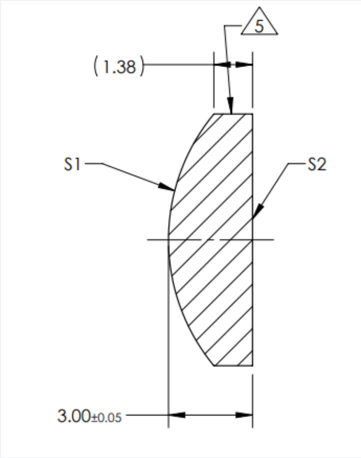
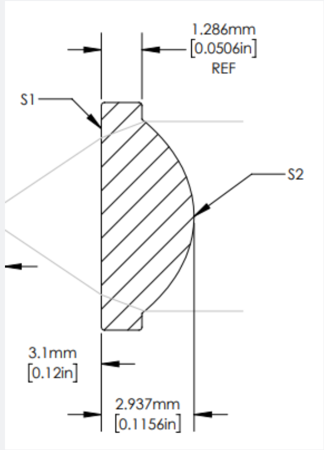
Image Acquisition System – Lens Design

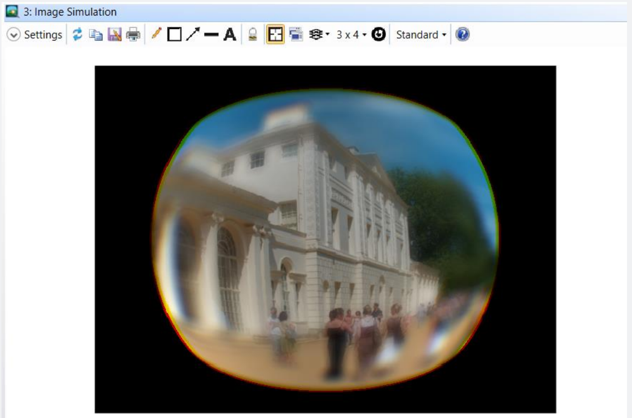
- Short focal length
- Wide FOV and aberrations
- Coating
- Aspheric lenses
- Fixed focal length/focus
- Illumination
- F# and Aperture stop

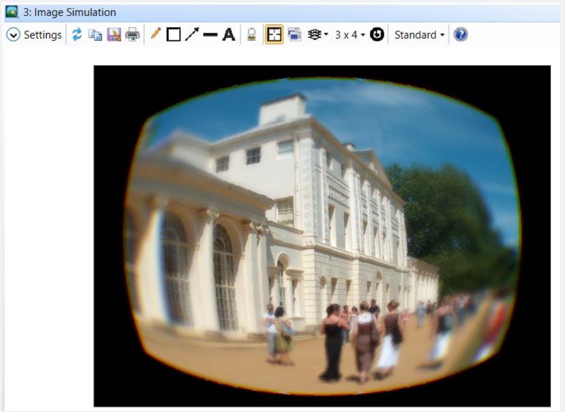
Regular lens vs. Aspheric lens





Aberration examples





Comparison and Selection of Hardware

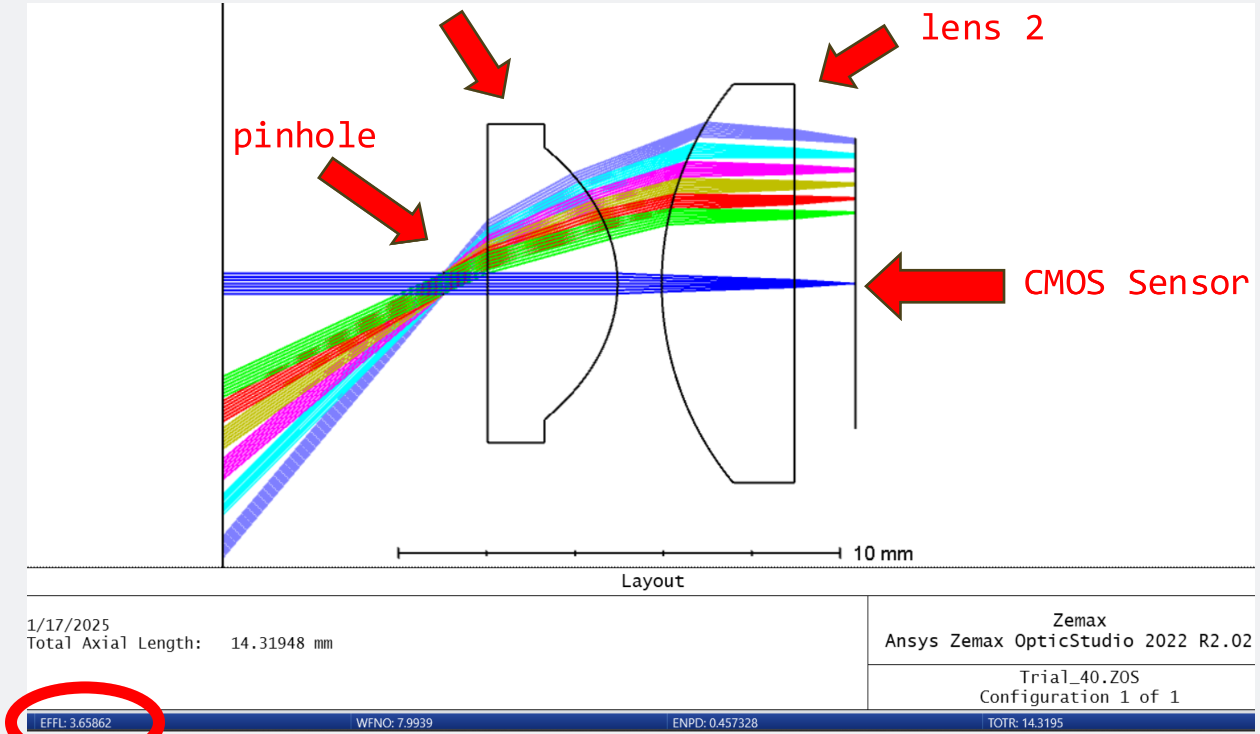
Image Acquisition System – Simulation

lens 1

lens 2

pinhole

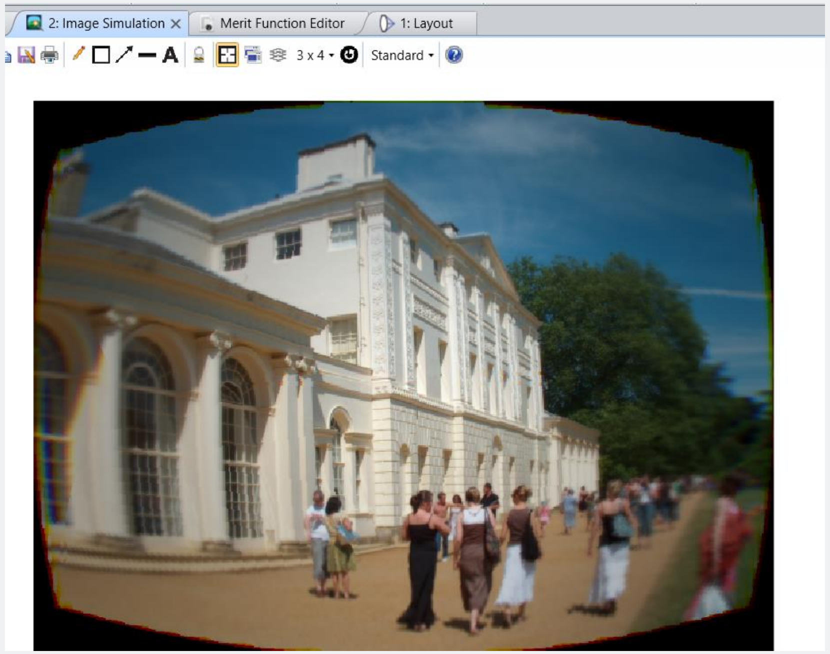
CMOS Sensor



EFFL: 3.65862

Effective Focal Length

*The aspheric lens helps to reduce aberration, and the convex-plano lens assists on focusing the light onto the sensor and reducing the effective focal length.



- 400 microns pinhole – entrance pupil / aperture stop
- Aspheric (lens 1)*
- Convex-plano (lens 2)*
- CMOS sensor

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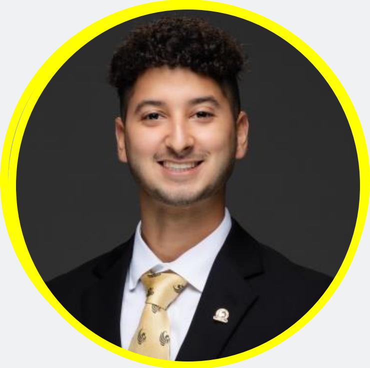
Further image enhancement will come from post-processing.

Comparison and Selection of Hardware



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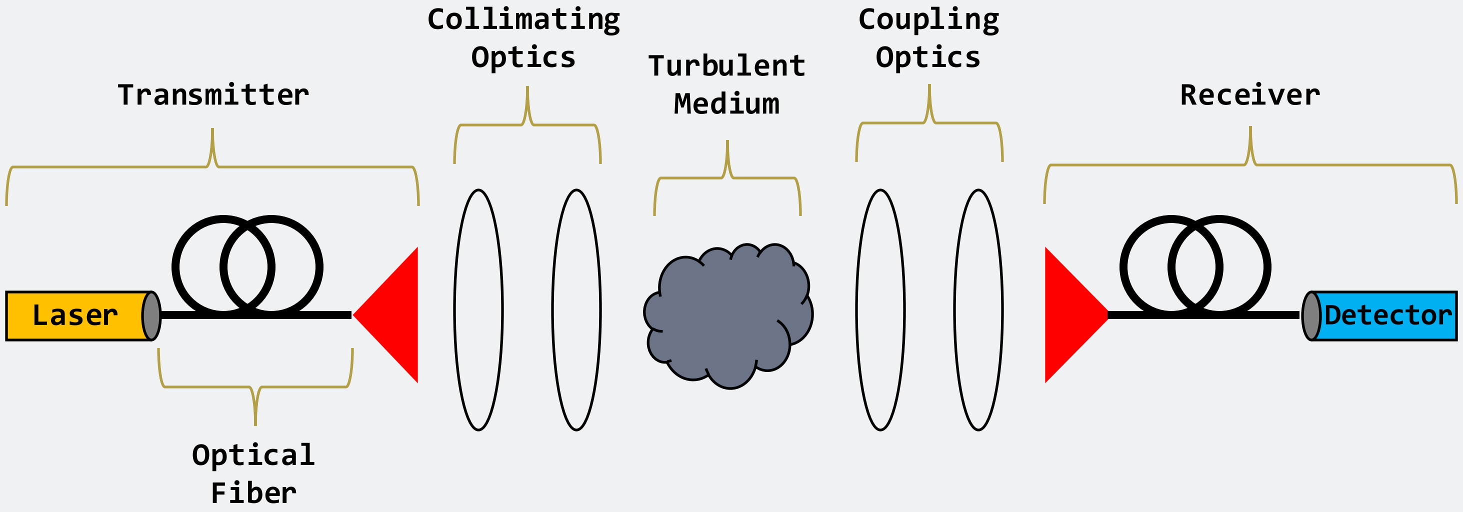
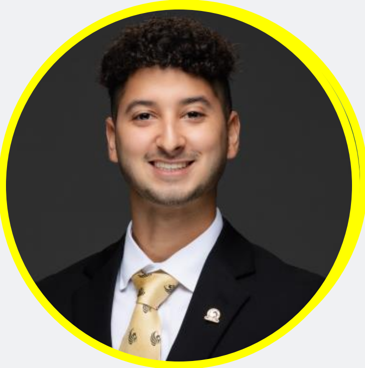
Free-Space Optical Communications System - Overall

General Design:



- To facilitate OWC, the transmitter and receiver are housed inside optical transceivers.
- Optical transceivers necessitate optical fibers to deliver light signals.
- To send optical signals, twin collimating/coupling optics are also necessary.

Free-Space Optical Communications System - Transceivers



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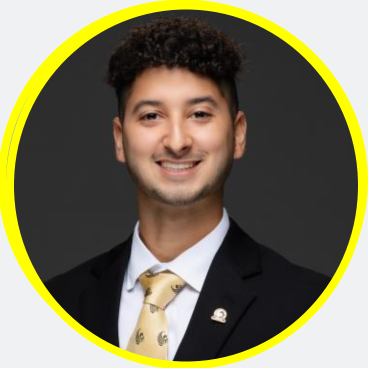
Transceiver	Cisco GLC-SX-MMD	Cisco GLC-EX-SMD	FS SFP1G-EX-55
Fiber Type	Multimode	Single Mode	Single Mode
Power Budget (dBm)	8	17	20
Wavelength (nm)	850	1310	1550
Cost	$12.00	$28.00	$27.00

- Tx/Rx systems are readily available and are known as optical transceivers.
- Transmitting high quality video in near real-time necessitates fast speeds.
- Optical components are lossy. Larger power budgets give more optical wiggle room.

[Transceiver]

Free-Space Optical Communications System - Media Converters



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Converter Type	SFP to RJ45	Integrated SFP to RJ45
Swappable SFP? (Yes/No)	Yes	No
Power Consumption	4.3 W	5 W
Cost	$18.99	$19.99

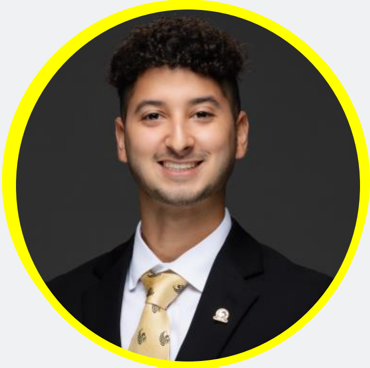
- Optical (SFP) to Ethernet (RJ45) media converters are ubiquitous.
- Open-SFP formats enable different SFP modules to be used on the same converter.
- Integrated-SFP formats have built-in Tx/Rx systems.

[Open-SFP to RJ45]

[Integrated-SFP to RJ45]

Free-Space Optical Communications System - Fiber

Fiber Name	Corning ClearCurve (OM3)	Corning SMF-28e (OS2)
Fiber Type	Multimode	Single Mode
Numerical Aperture	0.215	0.14
Modal Bandwidth (MHz·km)	2000	N/A
Wavelength (nm)	850	1550
Loss (dB/km)	2.3	0.20
Cost	$10.79	$5.93



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- Optical fibers are optical waveguides.
- Transceivers are built for and used with optical fibers.
- Optical fibers are very low loss. Choice comes down to other parameters like numerical aperture, loss, and wavelength.

[ClearCuve]

[SMF28e]

Free-Space Optical Communications System - Lenses

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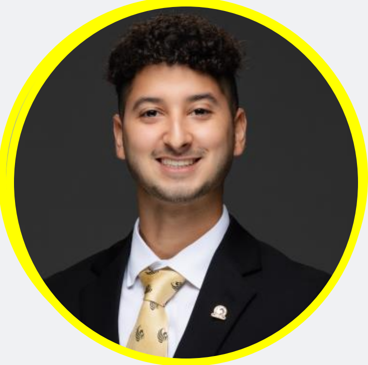
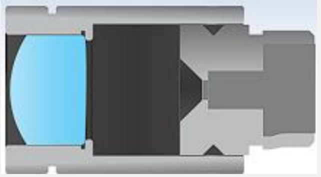
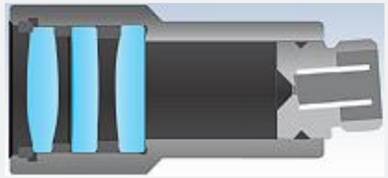


Collimating Lens Type	Achromatic Doublet	Pigtailed Fiber	Single Lens	Air-space Triplet
Numerical Aperture	0.54	0.125	0.15	0.28
Losses	N/A	< 1 dB/km (fiber loss)	N/A	N/A
Spot Size (mm)	0.17	5	3.6	3.3
Coated Type	B	C	C	C
Cost	$240.98	$226.14	$181.00	$488.23

- Lenses enable effective free-space optical links for communications.
- Lenses must match the fiber NA and coated according to working λ.
- The more lenses, the more divergence is controlled…but the more it costs.
- Chosen lens yields low loss.



[Singlet]



[Triplet]

[Doublet]

Comparison and Selection of Hardware

MCU - Overall

Armani
Garcia
EE

- Adequate Performance
- Low Power Consumption
- Cost Effective
- Compact Design
- Flexibility for system integration

Parameters	MCUs		
Model	ESP32-S3-WROOM-1-N16R8	STM32H753VIT6	Raspberry Pi CM4
Clock	240MHz	480MHz	1.5GHz
RAM	512KB of SRAM + 8MB PSRAM	1MB SRAM	Up to 8GB LPDDR4 SRAM
Operating Voltage	3.3V	1.7 - 3.6V	5V
Operating Temp.	-40°C to 85°C	-40°C to 125°C	0°C to 80°C
Cost	~$4	~$17	~$30

Comparison and Selection of Hardware

Power Supply

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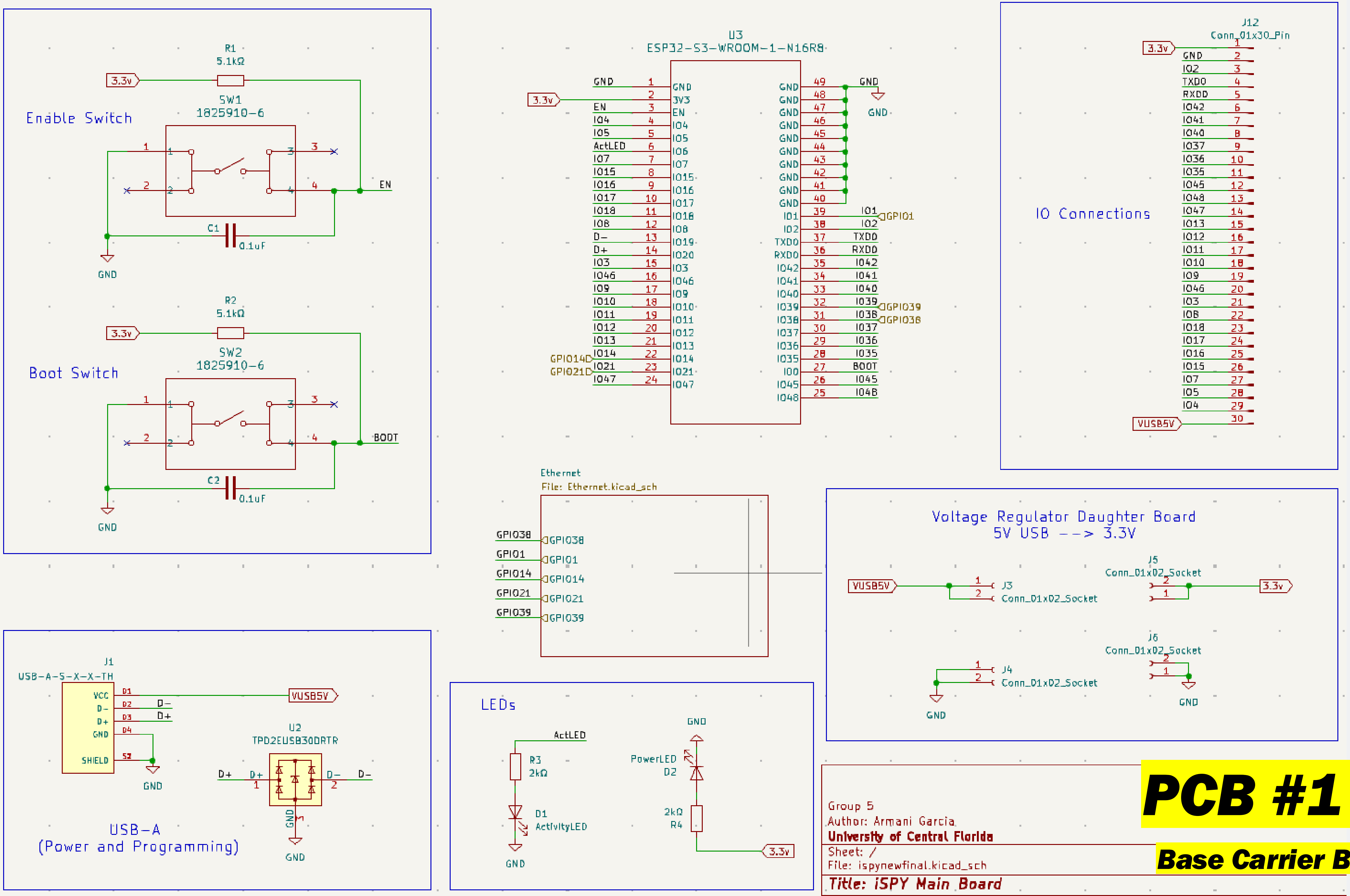
Based on the comparisons, the Mean Well LRS-50-5 meets the requirements set by the project:

- Reliable 5V Output
- Sufficient Current Capacity
- Compact and Efficient
- Protection Features

[Mean Well LRS-50-5]

Parameters	Power Supply Units			
Brand	Mean Well	RS Pro	CUI Inc.	Mean Well
MFG. P/N	LRS-50-5	777-6171	SWI5-5-N-P5	RS-15-5
Output Voltage	5V DC	5V DC	5V DC	5V DC
Output Current	10A	7A	1A	3A
Output Power	50W	35W	5W	15W
Efficiency	Up to 90%	Up to 82%	Up to 85%	~77%
Operating Temperature	-30°C to +70°C	0°C to +45°C	0°C to 40°C	-20°C to +70°C
Form Factor	Enclosed	Enclosed	Wall Plug Mount Adaptor	Enclosed
Size	99x82x30mm	99x82x30mm	22.6x36x47.7mm 1.5m Cord	62.5x51x28mm
MTBF Min. (Hrs)	645K	N/A	50K	108.8K
Price	~$15-$20	~$10-15	~$10	~$10-15



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PCB #1 Design

Base Carrier Board Schematic

PCB #1 Design

Base Carrier Board

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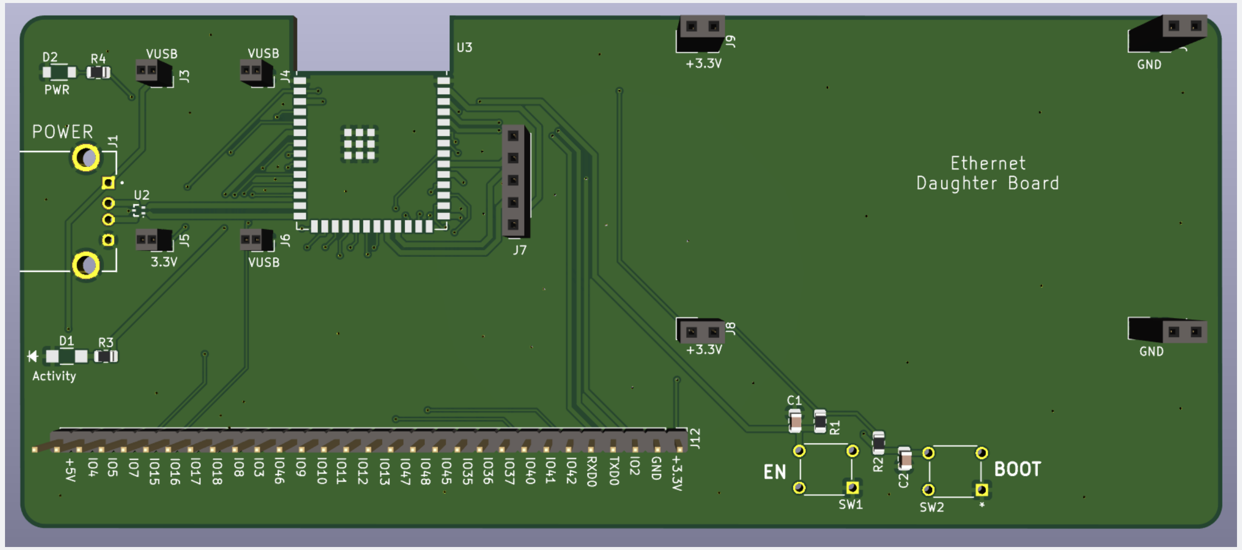

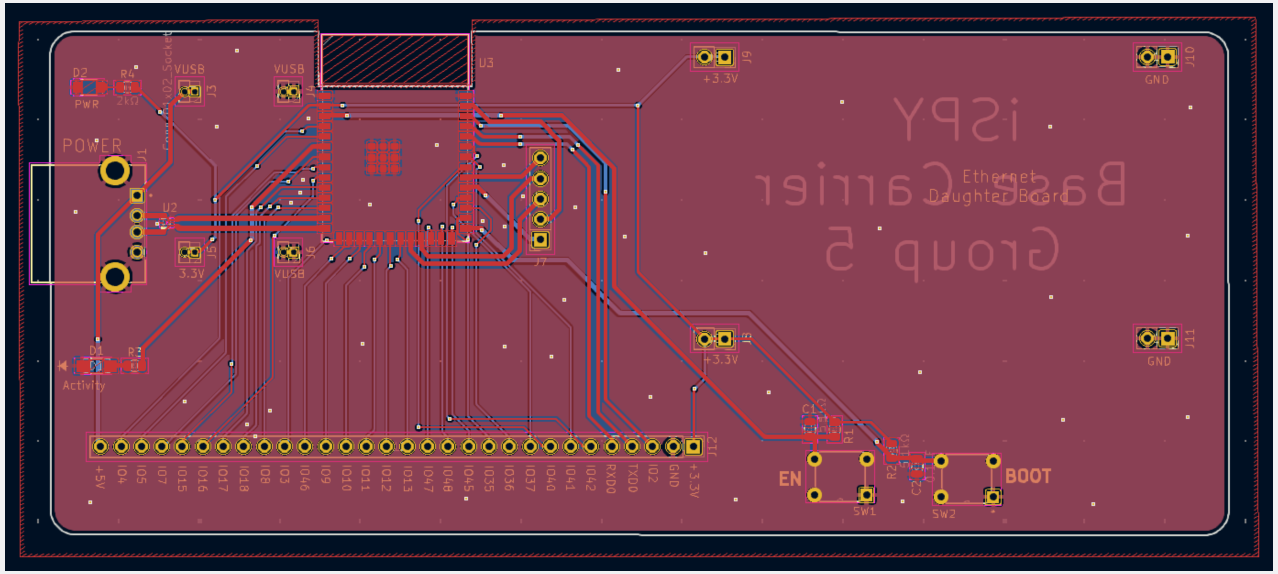

PCB #2 Design

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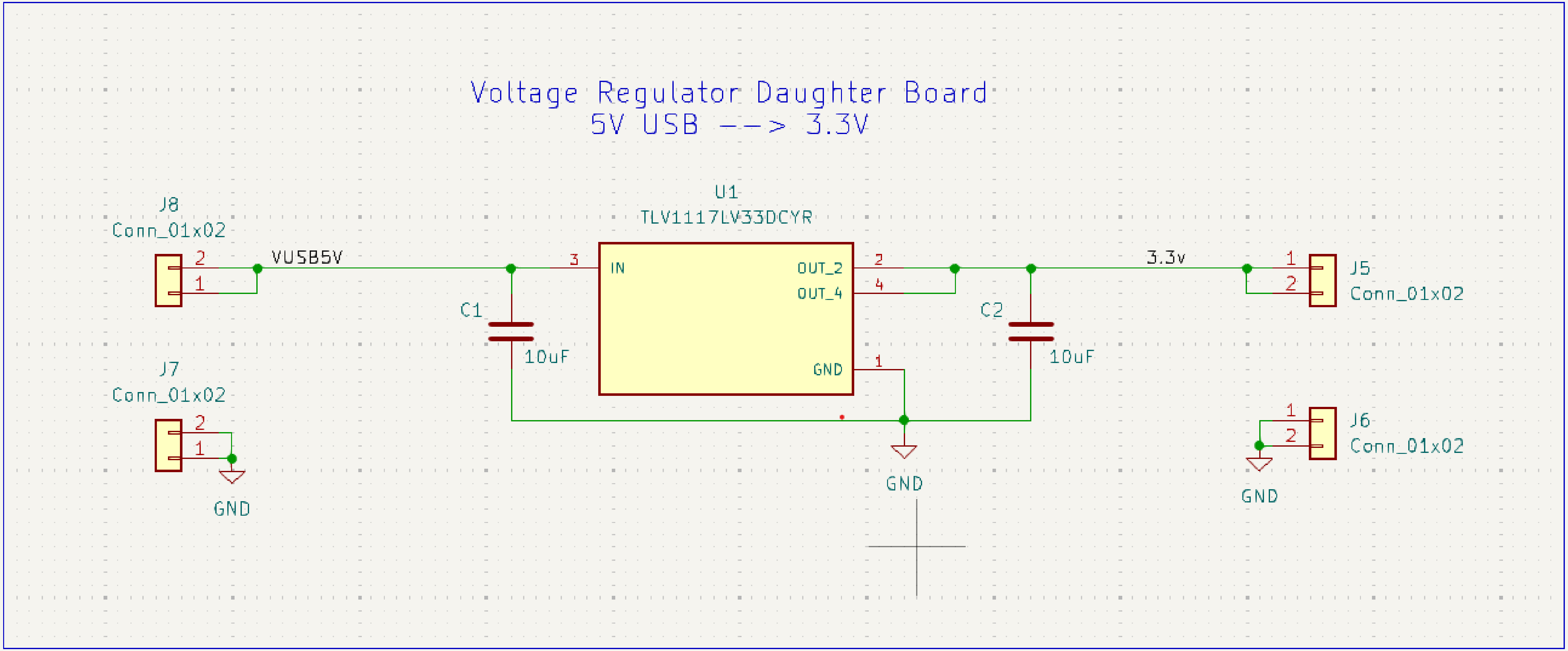
Voltage Regulator Daughter Board Schematic – as per Datasheet



PCB#2 Design

Voltage Regulator Daughter Board

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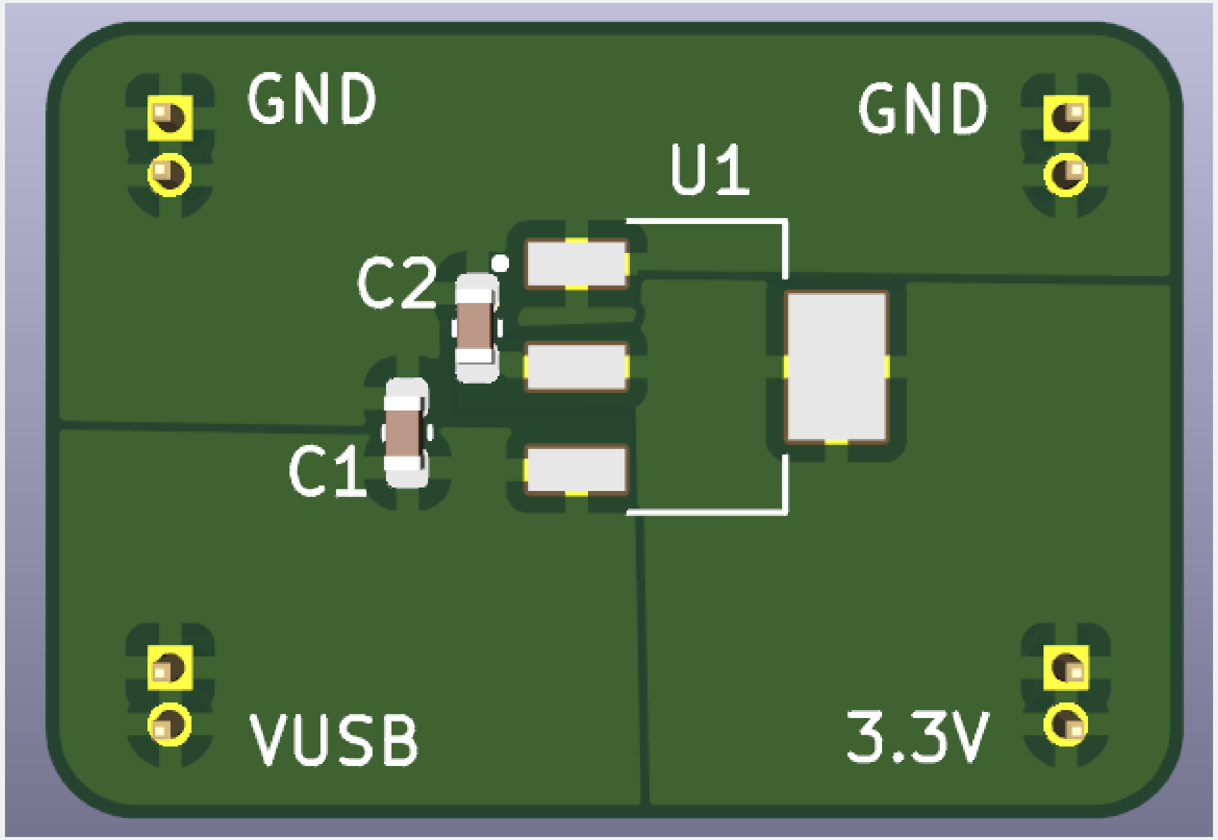

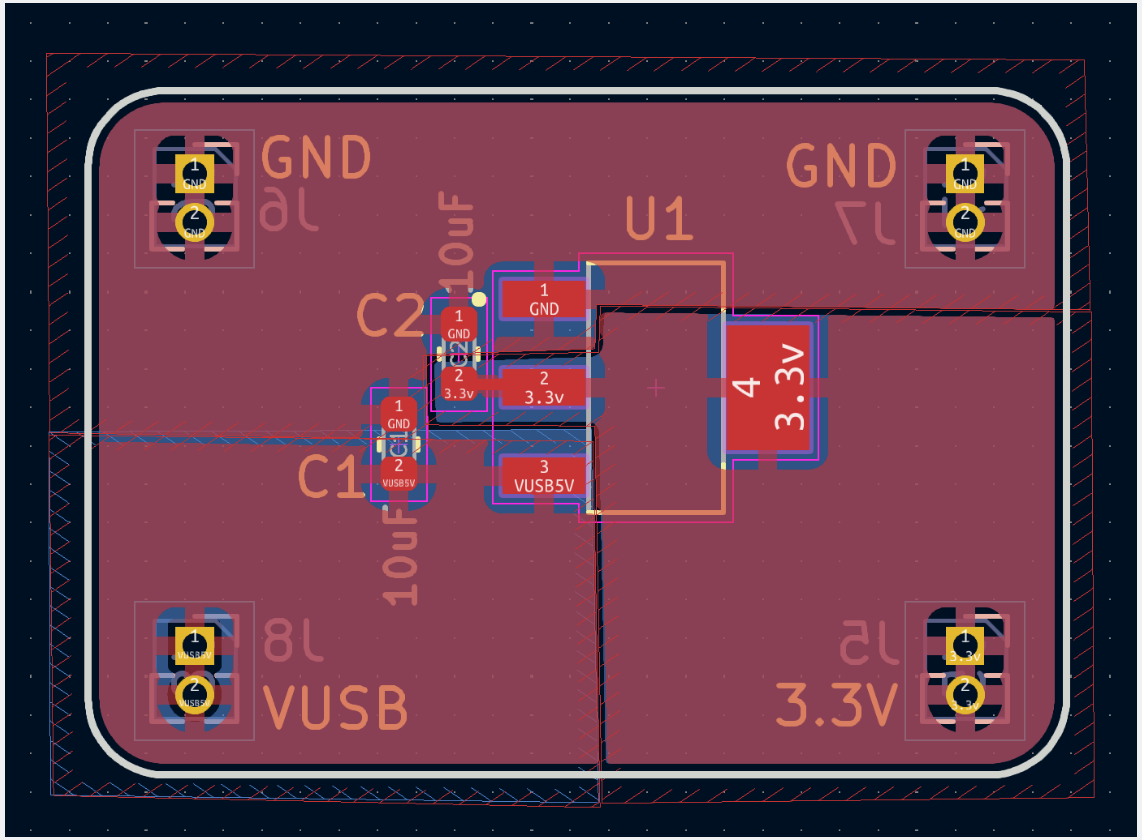

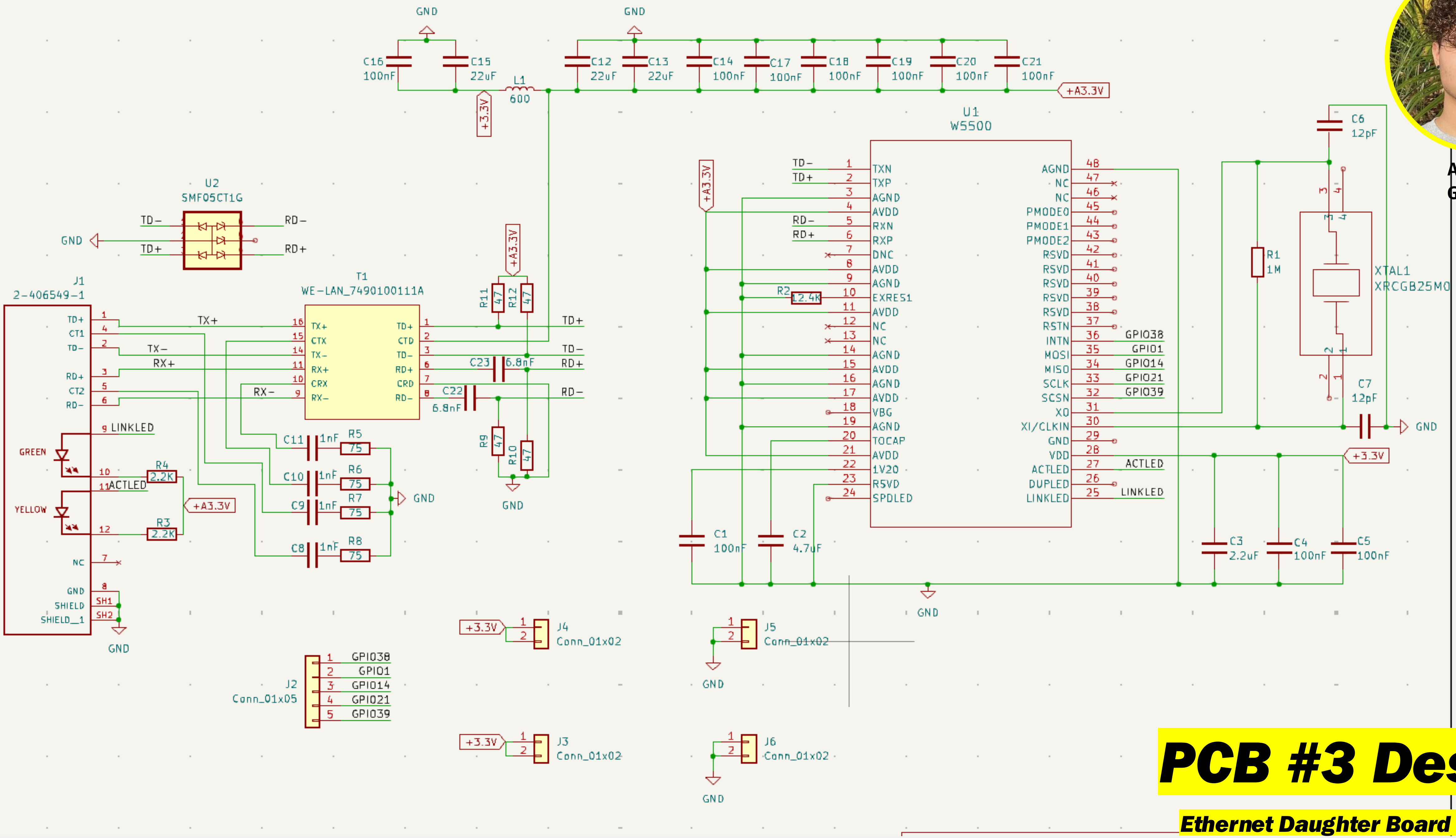

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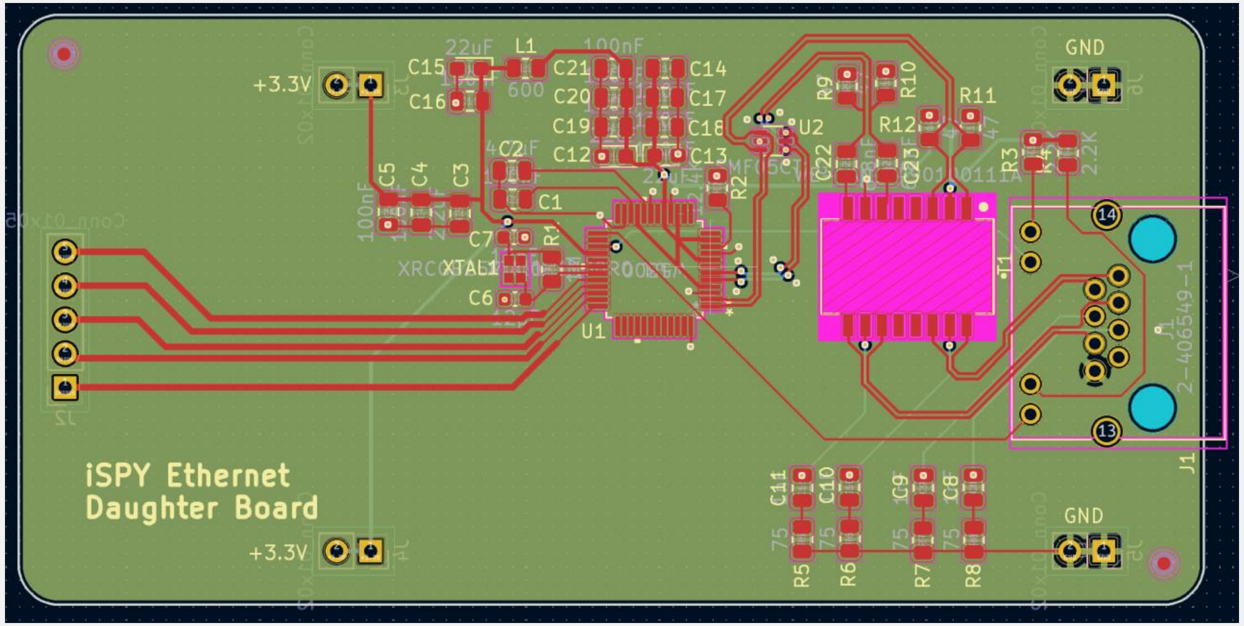
PCB #3 Design

Ethernet Daughter Board Schematic

PCB #3 Design

Ethernet Daughter Board



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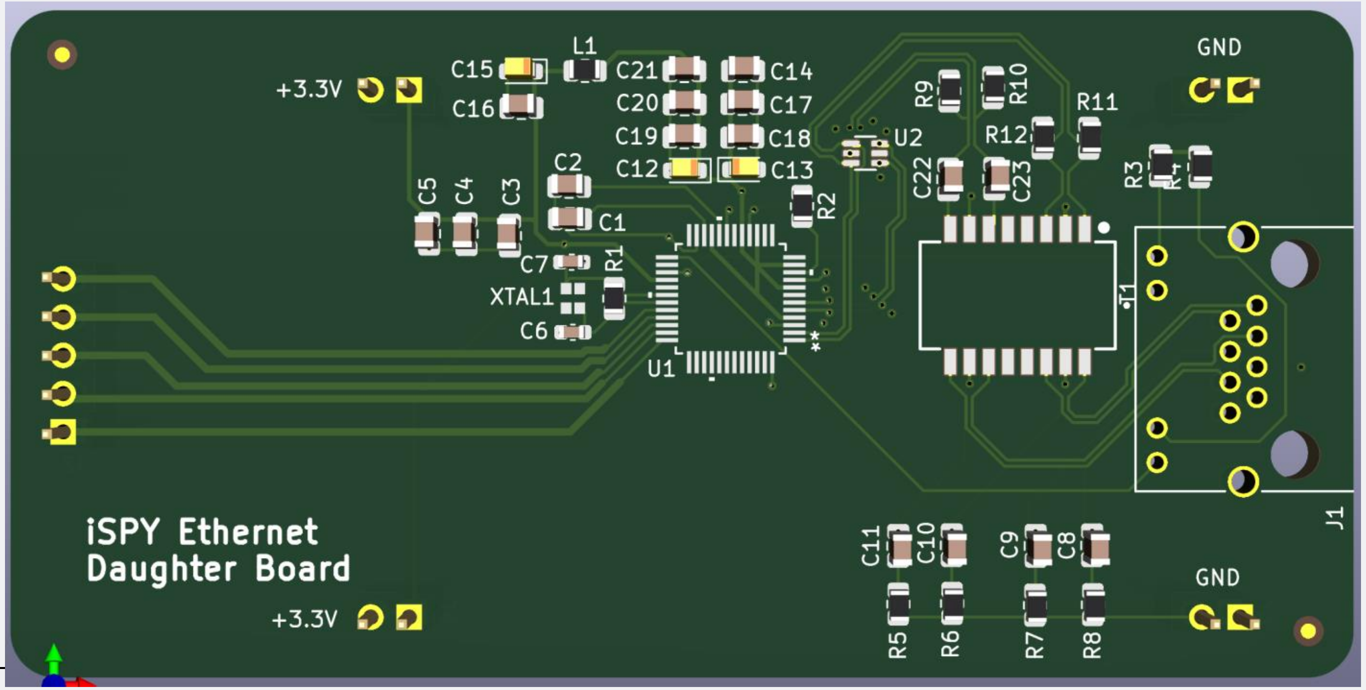
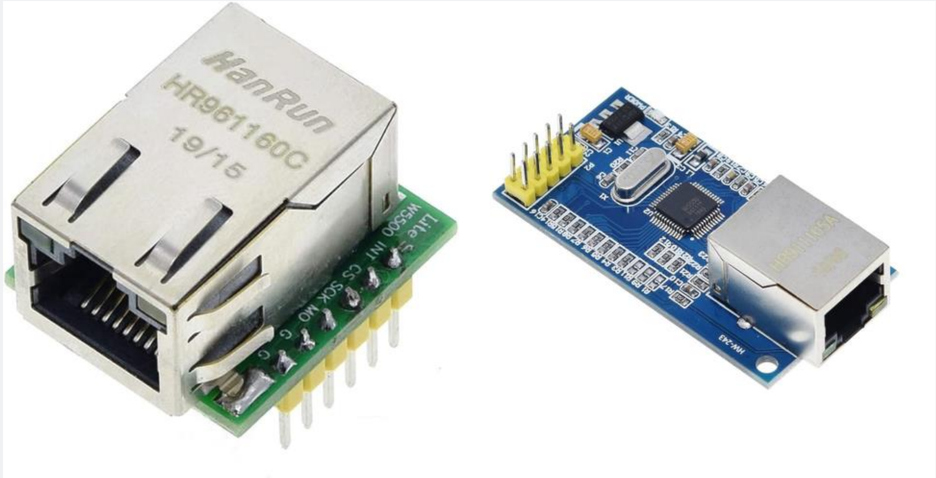
↓ Designed PCB →

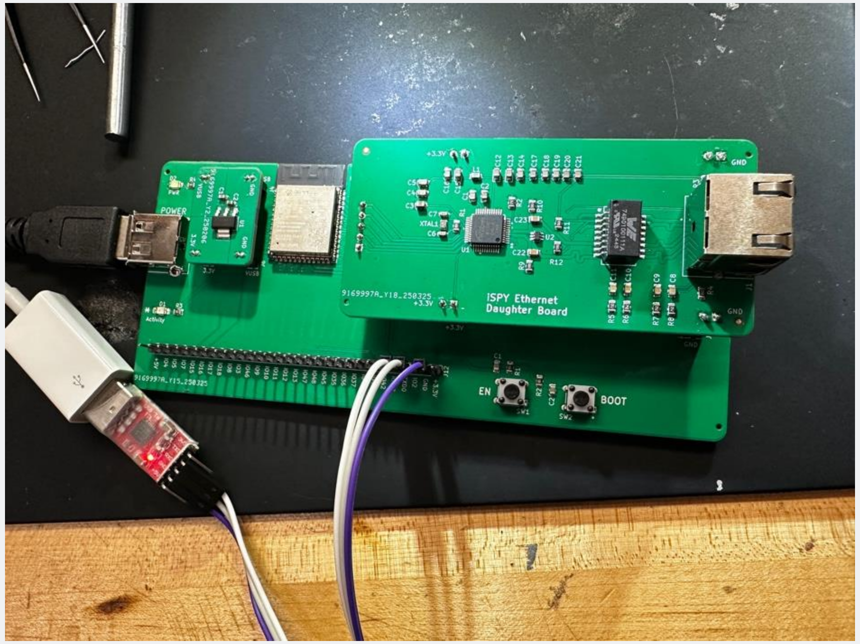




↑ Bought from Amazon ↑

PCB Design

Changes and Solutions



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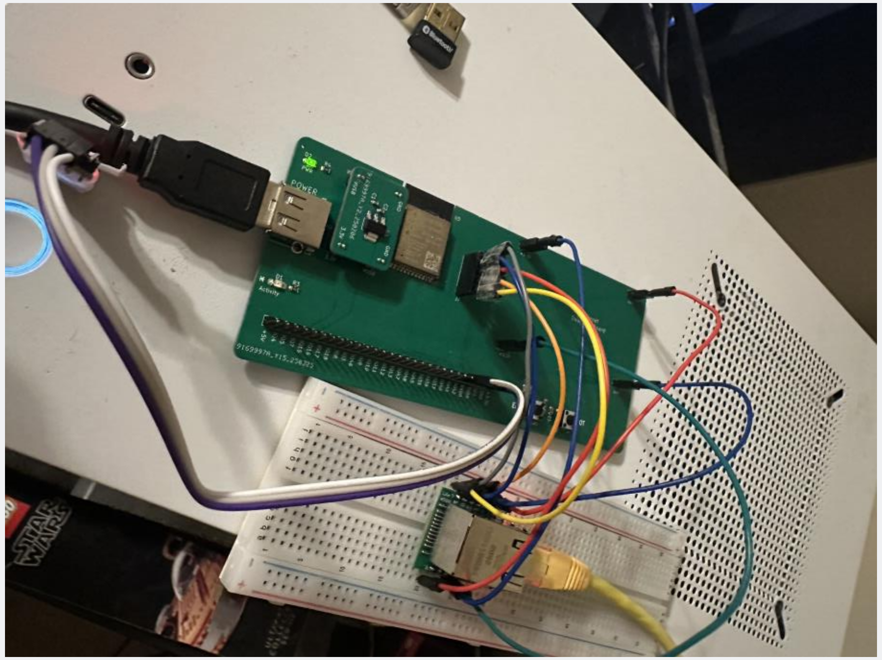
PCB #1:

- Standard Header Size
- GPIO Header
- Incorrect Diode
- Cut HDMI



PCB #3:

- Compatible IC (W5500)
- More efficient trace routing
- Controlled impedance techniques

Comparison and Selection of Software

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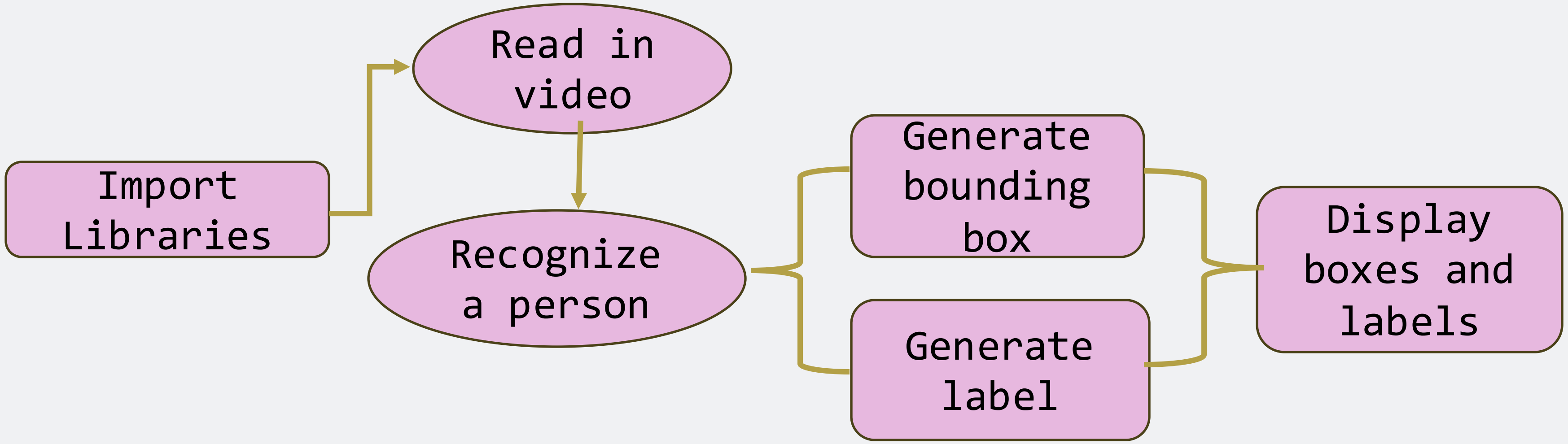
Computer Vision Recognition Program - Overall



- To begin the Computer Vision Recognition Program certain libraries are imported for usage of pretrained models and data
- Looping through frames to recognize people
- To display the result, the program shows the live video feed which includes the bounding boxes and labels

Computer Vision Recognition Program - Computer Vision Algorithm

Robert Josephson
CPE

- When it comes to the computer vision algorithm, we wanted it to be able to handle real time recognition
- The algorithm used had to meet certain parameters such as response time and fluent recognition
- YOLOv11 algorithm was able to meet requirements as specified

Model 1		
Model	mAP	Latency (ms)
YOLOv10 N	38.5	1.84
YOLOv10 S	46.3	2.49
YOLOv10 M	51.1	4.74
YOLOv10 L	53.2	7.28
YOLOv10 X	54.4	10.70

Model 2		
Model	mAP	Latency (ms)
YOLOv11 N	39.5	1.55
YOLOv11 S	47.0	2.46
YOLOv11 M	51.5	4.70
YOLOv11 L	53.4	6.16
YOLOv11 X	54.7	11.31

Model 3		
Model	mAP	Latency (ms)
YOLO-NAS S	47.5	3.21
YOLO-NAS S INT8	47.03	2.36
YOLO-NAS M	51.55	5.85
YOLO-NAS M INT8	51.0	3.78
YOLO-NAS L	52.22	7.87
YOLO-NAS L INT8	52.1	4.78

Computer Vision Recognition Program - Computer Vision Model

Robert
Josephson
CPE

- Accuracy and speed are factors in real time recognition
- We focused on three YOLO algorithm models: YOLOv10N,YOLOv11N and YOLO-NAS S
- YOLOv11N model was used due to its accuracy and latency

Model	Model 1	Model 2	Model 3
Algorithm + Model	YOLOv10N	YOLOv11N	YOLO-NAS S
Precision	38.5	39.5	47.5
Latency (ms)	1.84	1.55	3.21

Comparison and Selection of Software

Luke Reyes
CPE

Compression Requirements

- A codec must be selected that will suit our system's needs.
- Image quality must be maintained to a certain point as to not lose too much detail during compression and transmission.
- It must be efficient as to reduce latency on the receiving side of the system.

An example of different levels of compression. We want to keep as much detail as possible while avoiding blurring or distortion.

Comparison and Selection of Software

Luke Reyes
CPE

Codec Selection

- The codec should be compatible with the Raspberry Pi 4 Model B.
- The codec should be efficient and preferably use a lower amount of computational power due to the lower power of the Raspberry Pi 4 Model B.
- H.264 is a good choice because of how widely used it is and how efficient it is.

Parameter	Codecs				
Brand	H.264	H.265	VP8/9	AV1	FFV1
Type	Lossy/Lossless	Lossy/Lossless	Lossy	Lossy	Lossless
Efficiency	High	Very High	High	Very High	High
Pros	Widely used and compatible with most devices	Better version of H.264	Open source and efficient on web	Open source and very efficient	No data loss during compression, open source, efficient
Cons	Not the best for higher resolutions	More computational power and not as widely used	Not as widely used	Requires more computational power	Not typically used for live transmission

Comparison and Selection of Software

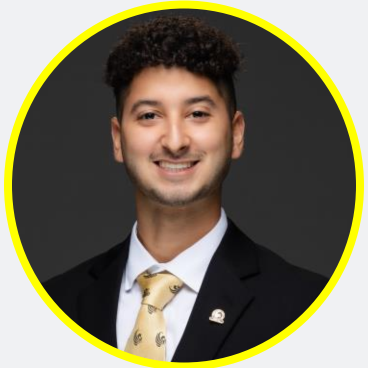
Luke Reyes
CPE

Library Comparison

- A library must be selected to utilize H.264 for compression of the video stream.
- The coding language used in this project is python so the library will be chosen from select python libraries.
- FFmpeg was selected as most other python libraries utilize Ffmpeg already.

Parameter	Libraries		
Library	PyAV	MoviePy	FFmpeg-Python
Performance	High	High	High
Supports Multiple Codecs?	Yes	No (mainly a video editing tool)	Yes
Well documented?	Yes	Yes	Yes
Optimized For Live Feed?	Yes	No (Mainly a video editing tool)	Yes

Hardware Design – Low-Level Overview



Alejandro
Lopez Zelaya
PSE

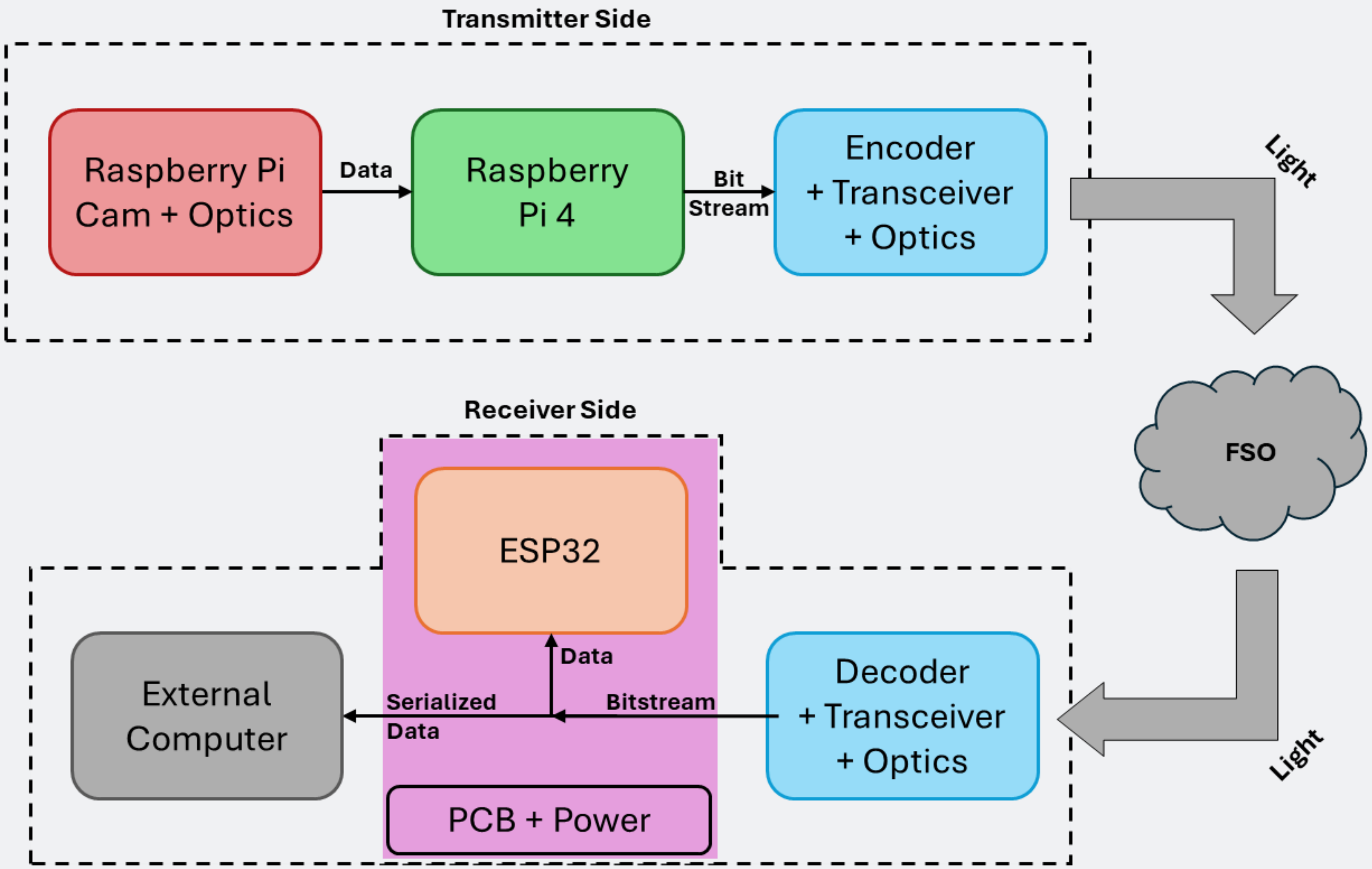
Luke

Alejandro

Armani

Gaby

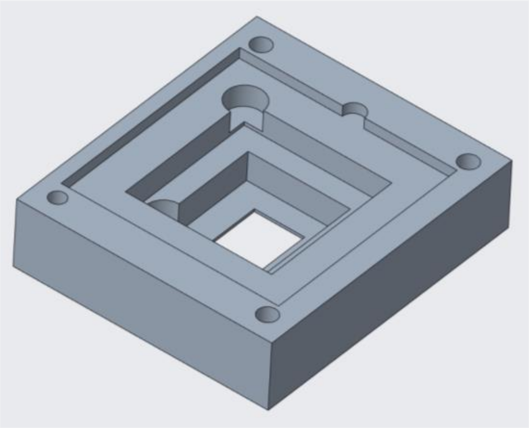
Robert

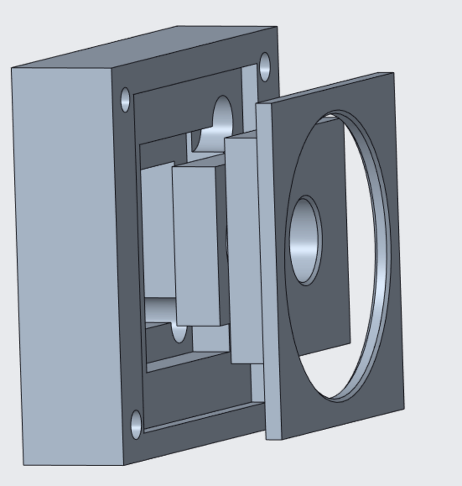


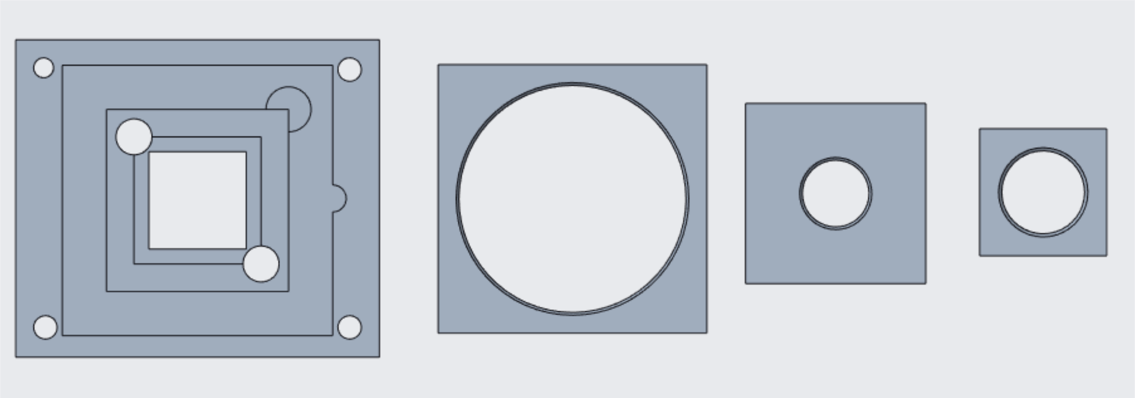
Prototyping and Testing

Gabryella Baldaci
PSE

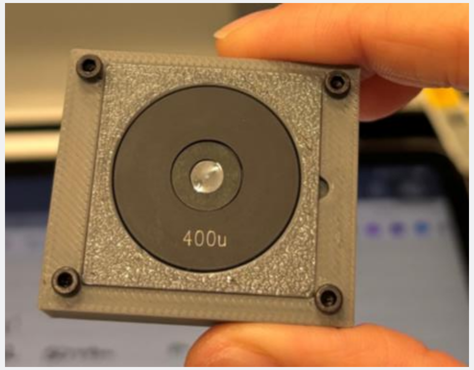
CAD model

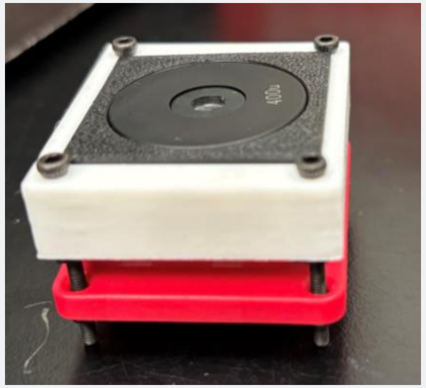


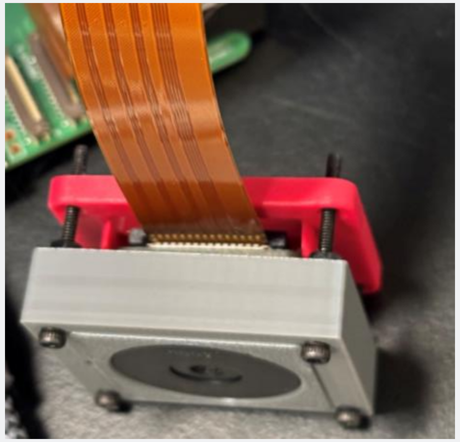


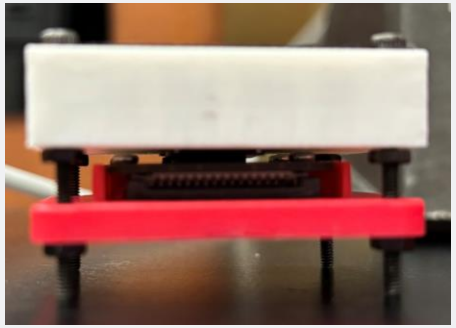


Prototype





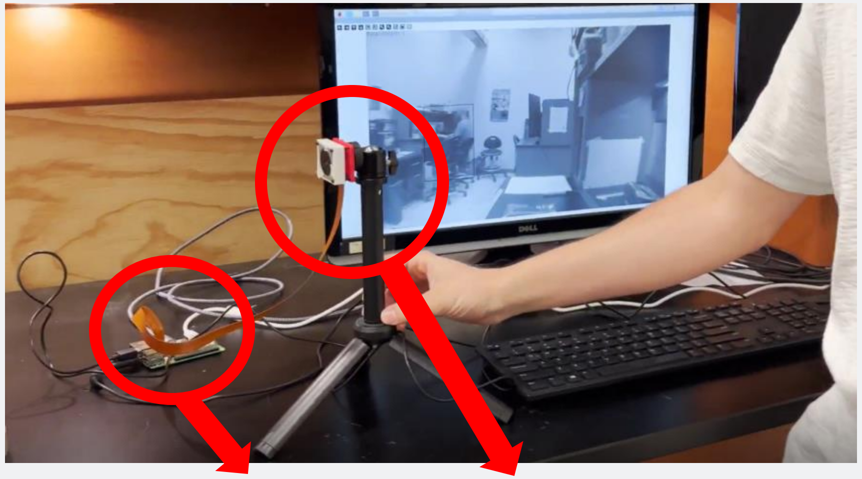




Prototyping and Testing

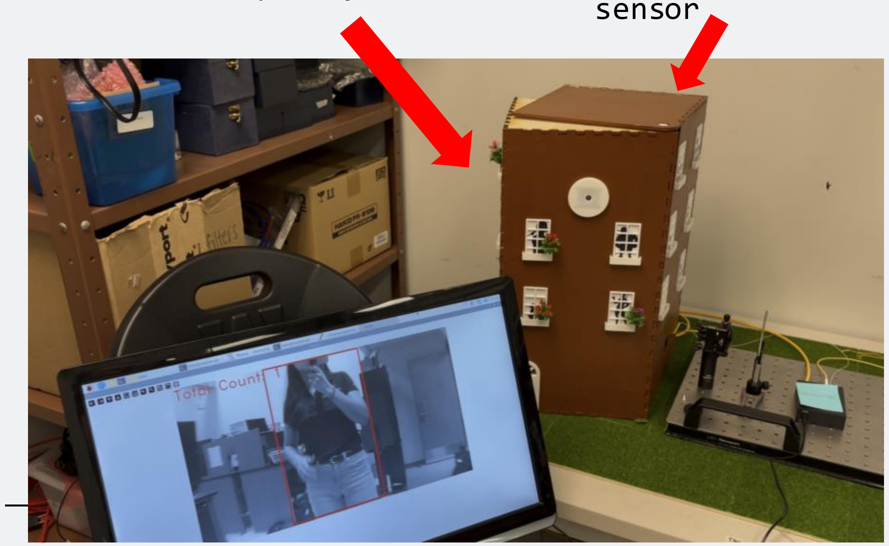
Gabryella
Baldaci
PSE

Setup



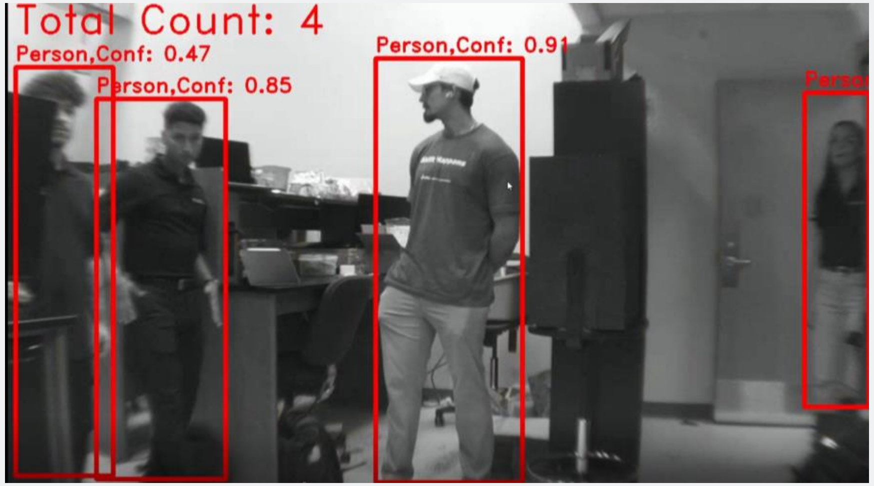
Raspberry Pi

Optics mounted with sensor



Optics and raspberry pi are housed inside the building

Results – Camera Capture



Screenshots of camera display

Prototyping and Testing

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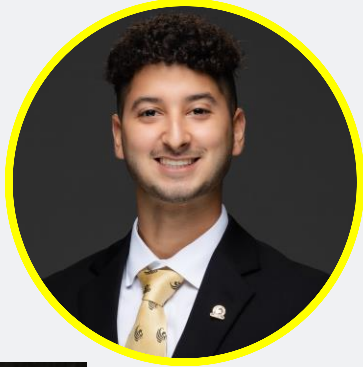
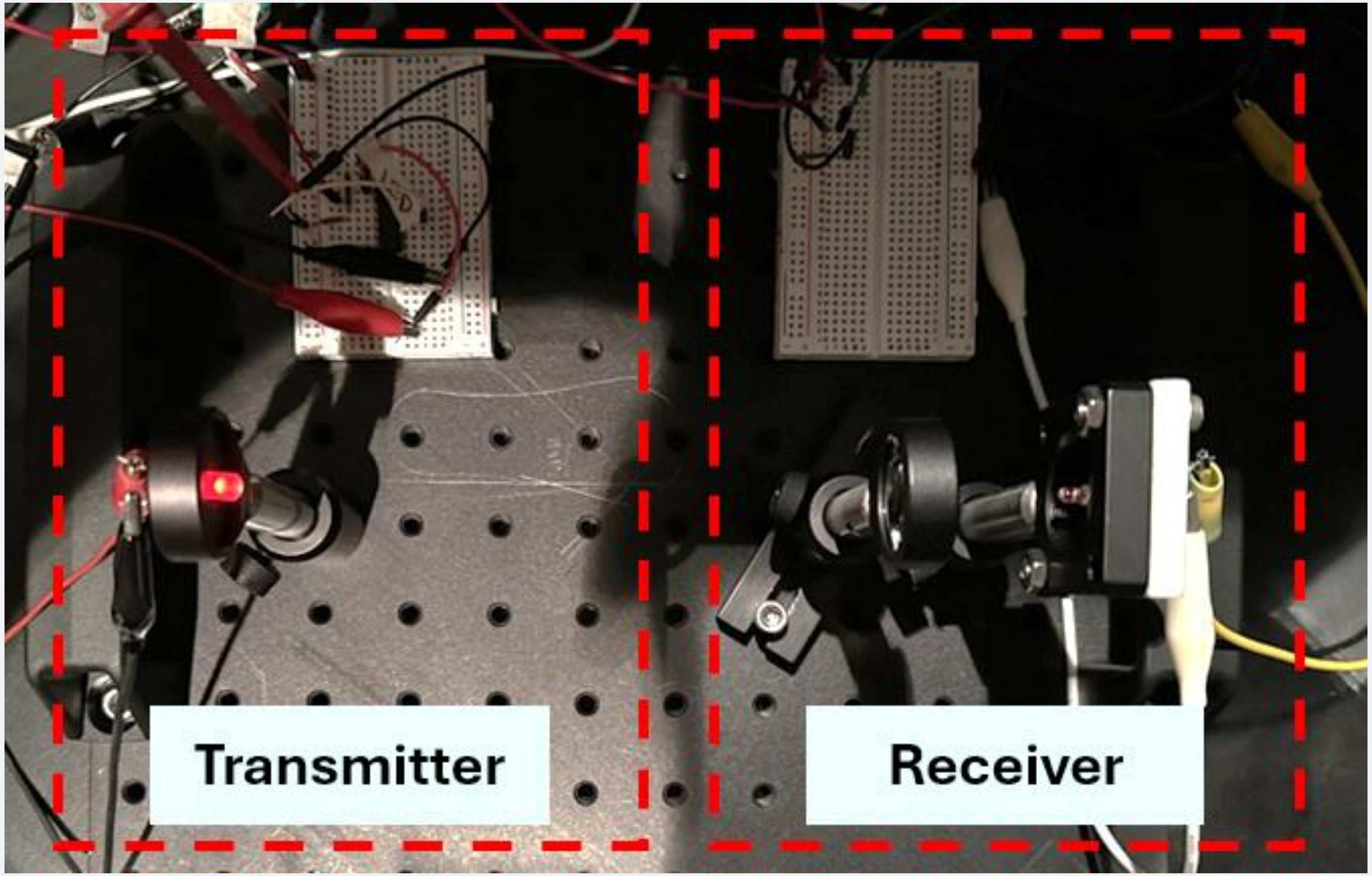
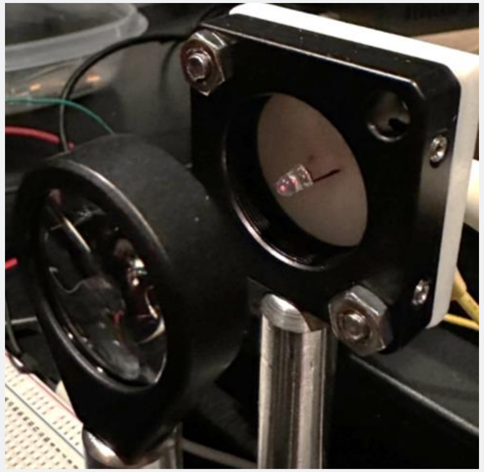
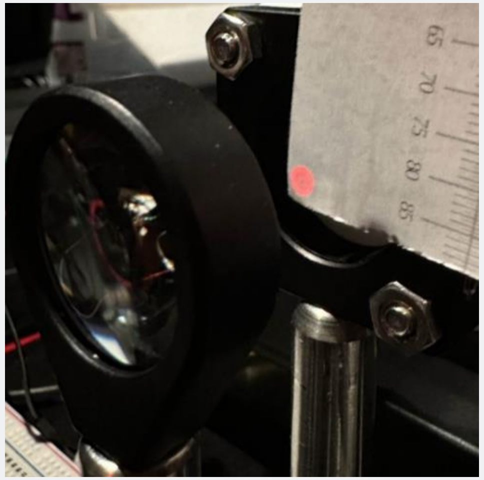
Lopez Zelaya
PSE



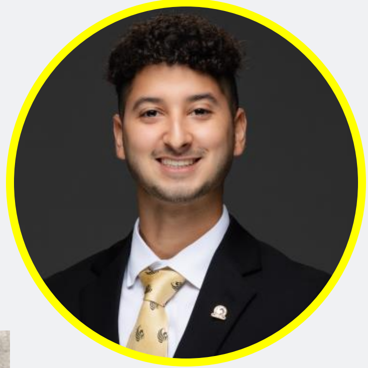
Early Free-space Audio Communications Prototype







Prototyping and Testing



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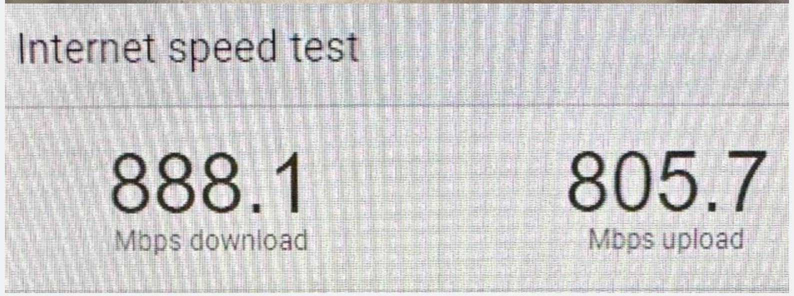
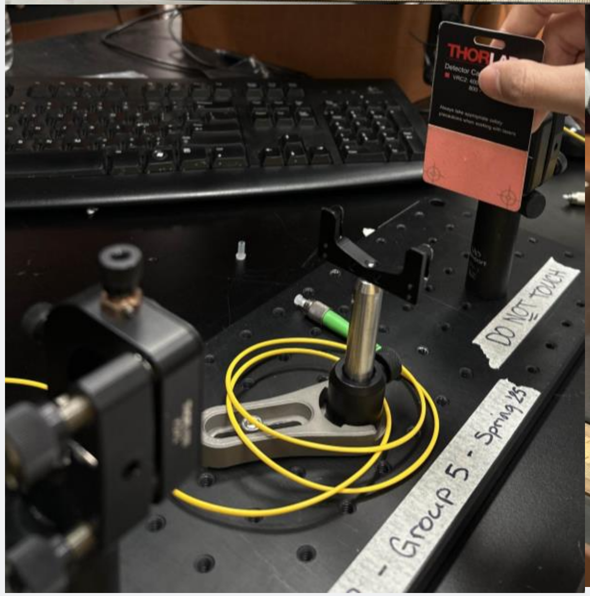
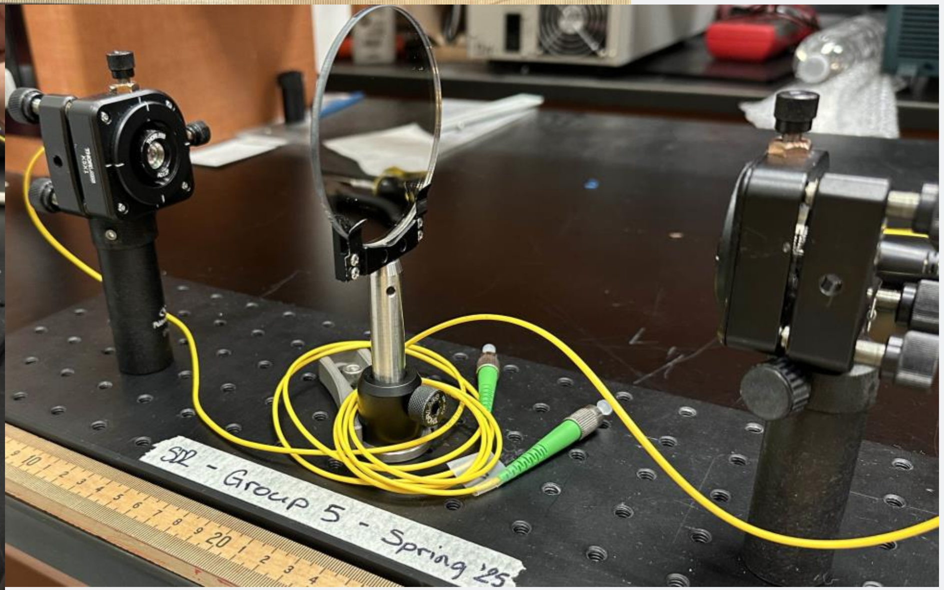
All-in Fiber Prototype

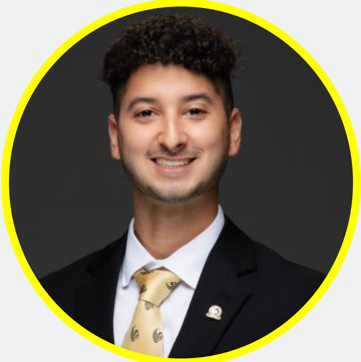


Free-space Alignment Prototype





Prototyping and Testing



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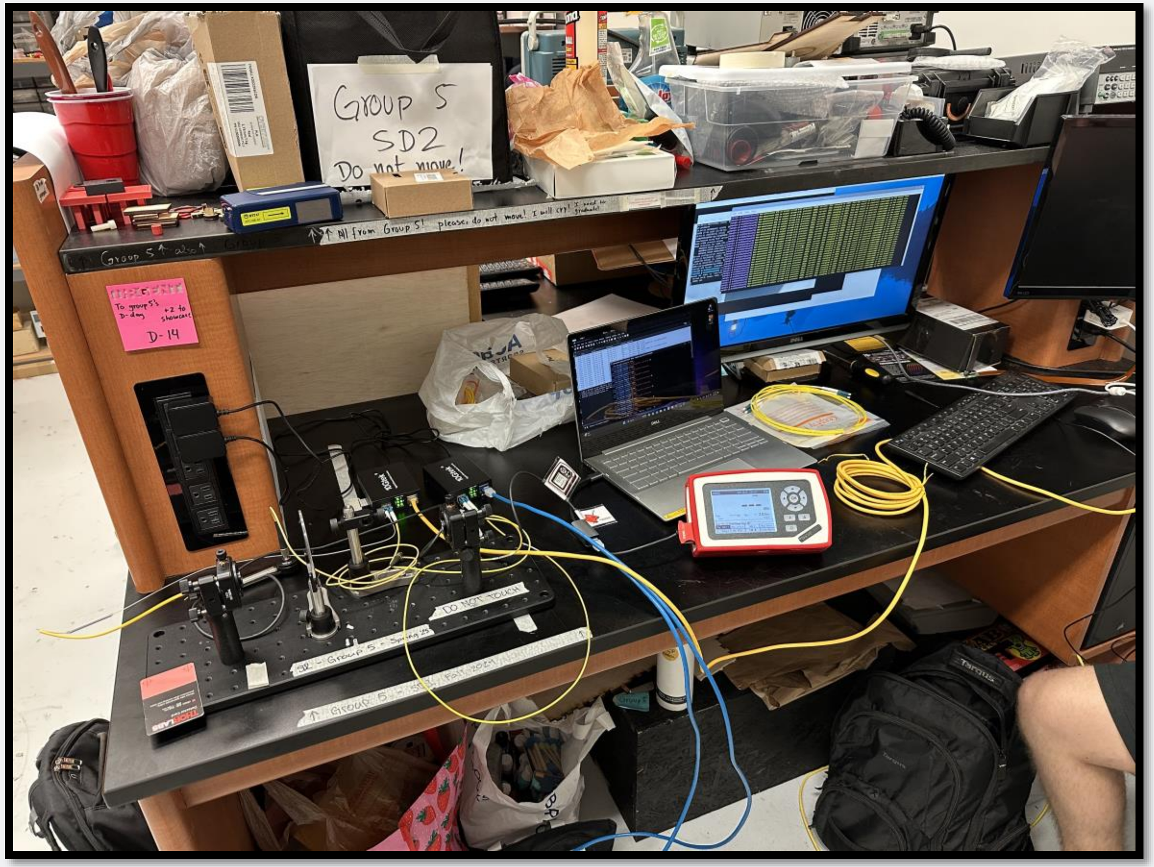
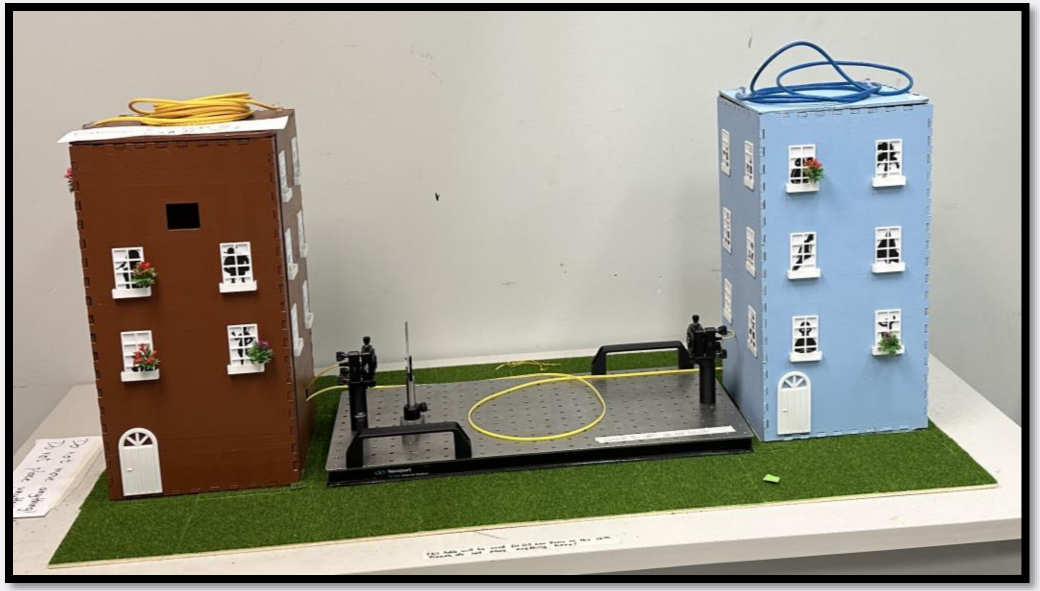
FSO Communication Testing



Final Prototype

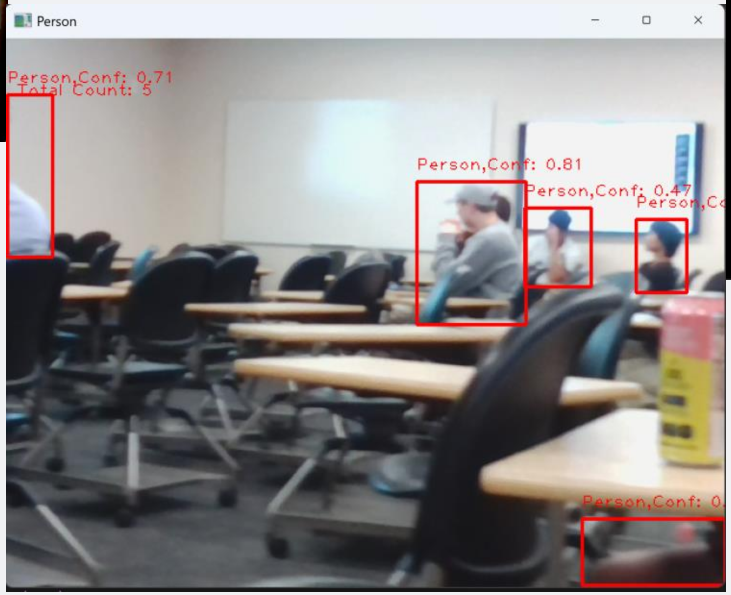


Prototyping and Testing

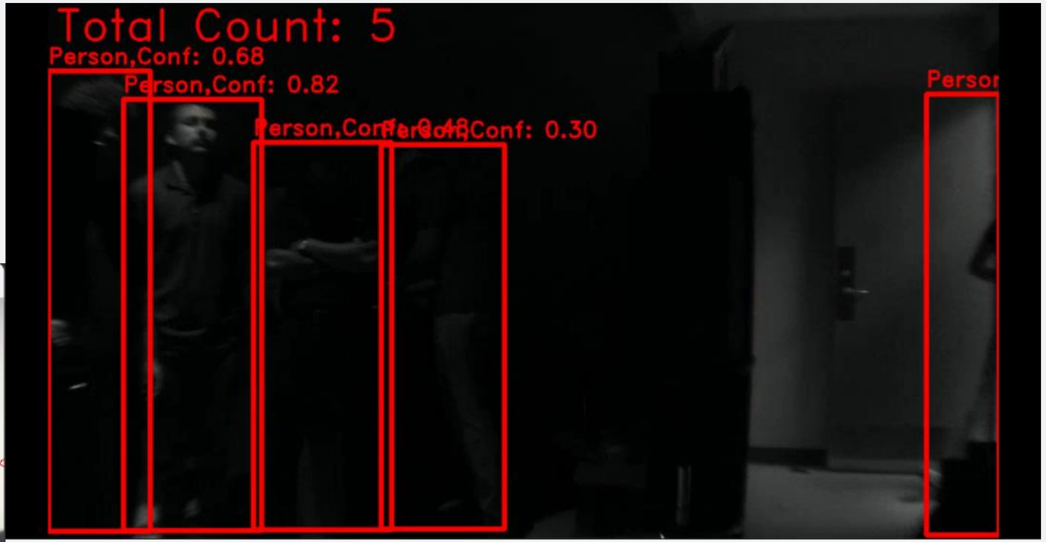
Robert
Josephson
CPE

First Prototype

Second Prototype



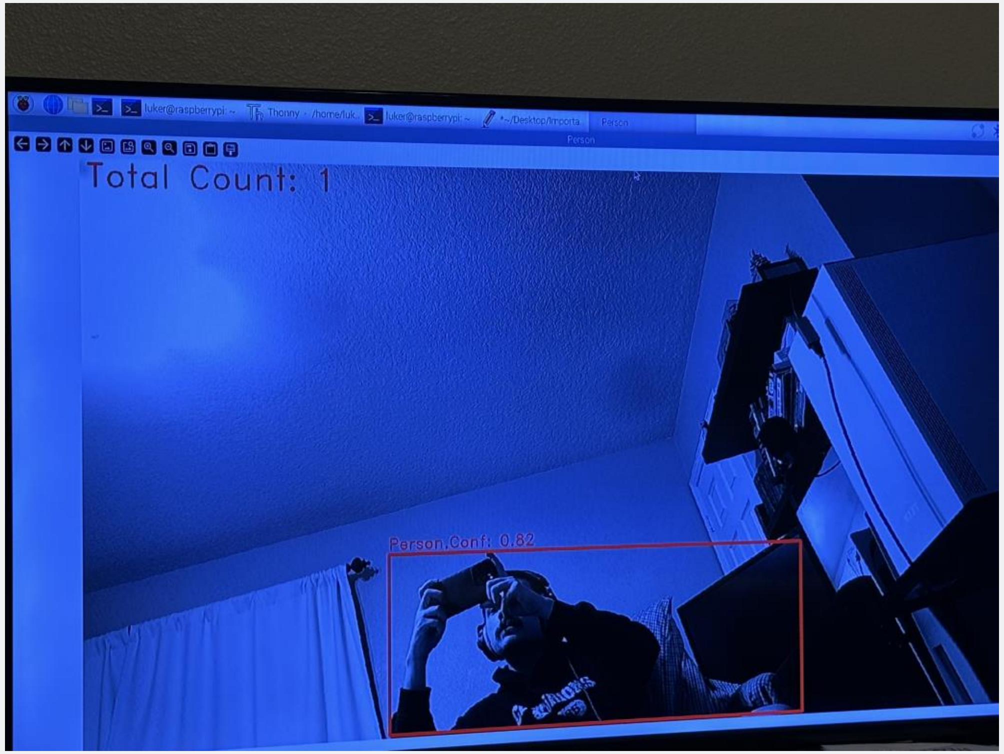
Final Prototype



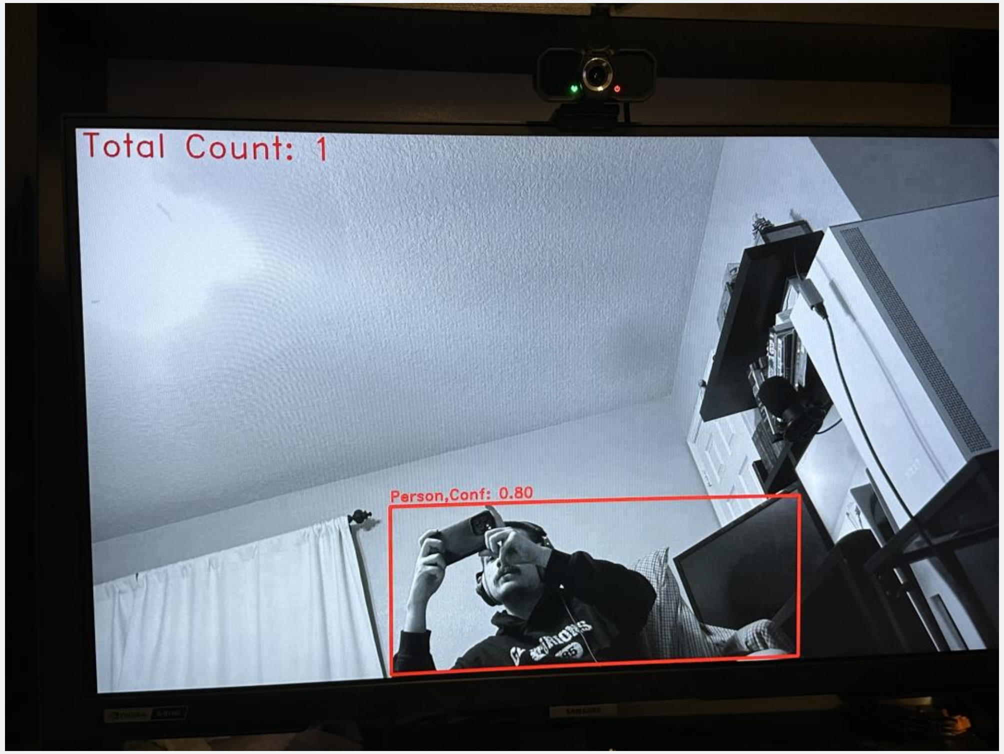
Prototyping and Testing

Luke Reyes
CPE

Raspberry Pi Display
Before Transmission



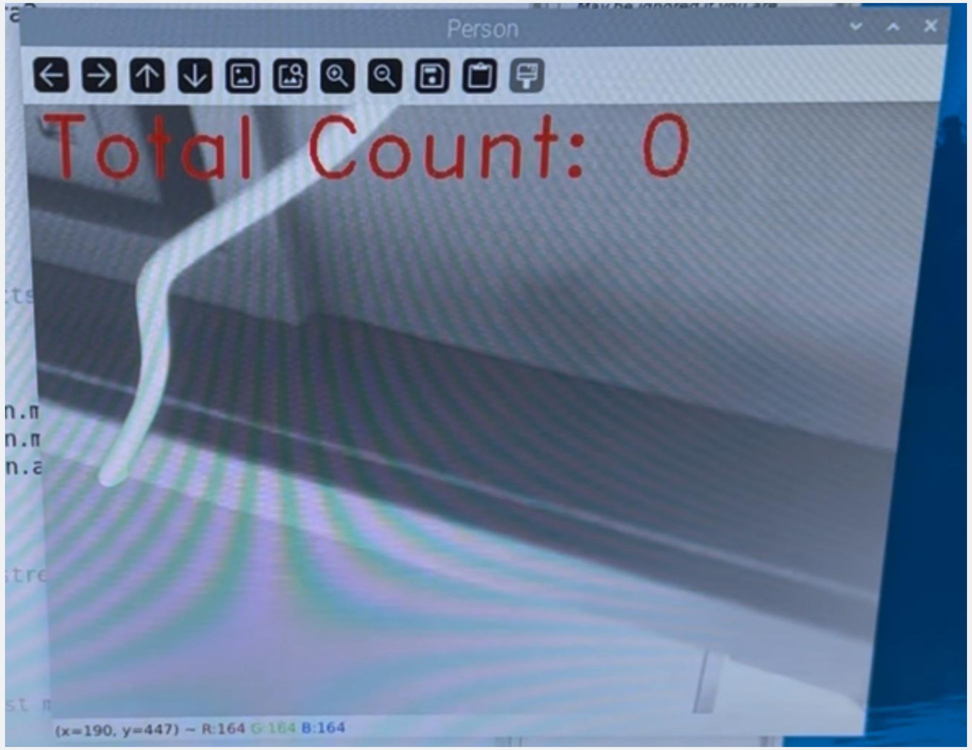
Computer Display
After Transmission



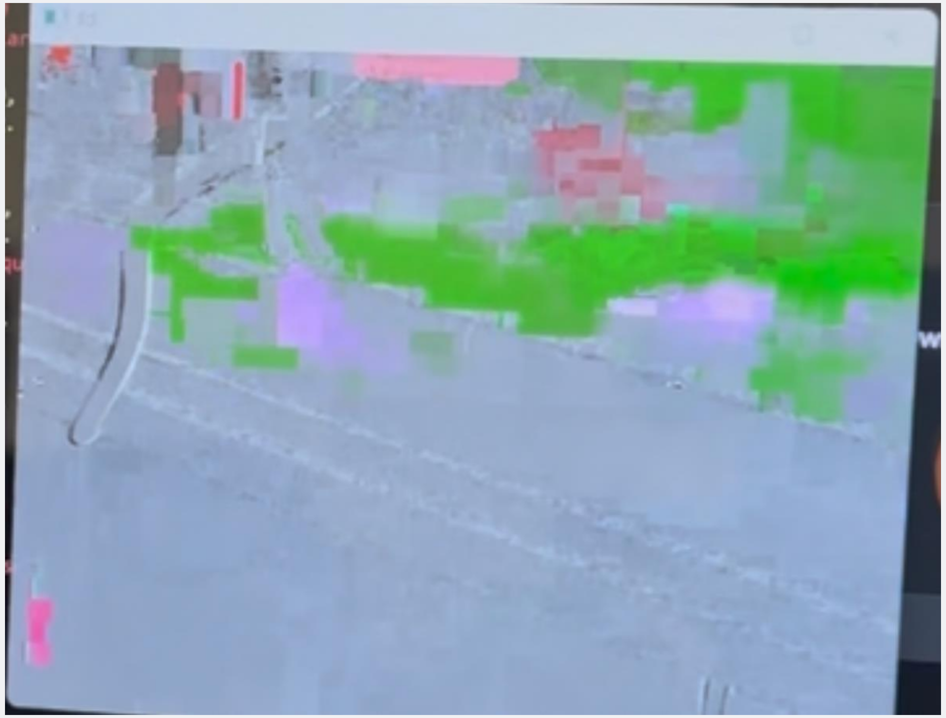
Prototyping and Testing

Luke Reyes
CPE

Raspberry Pi Display
Before Transmission



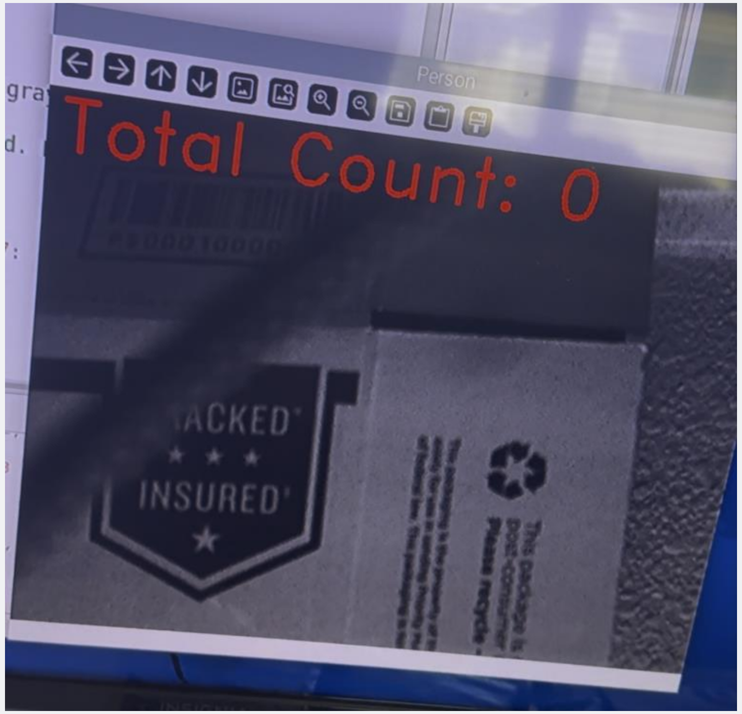
Computer Display From
PCB After Transmission



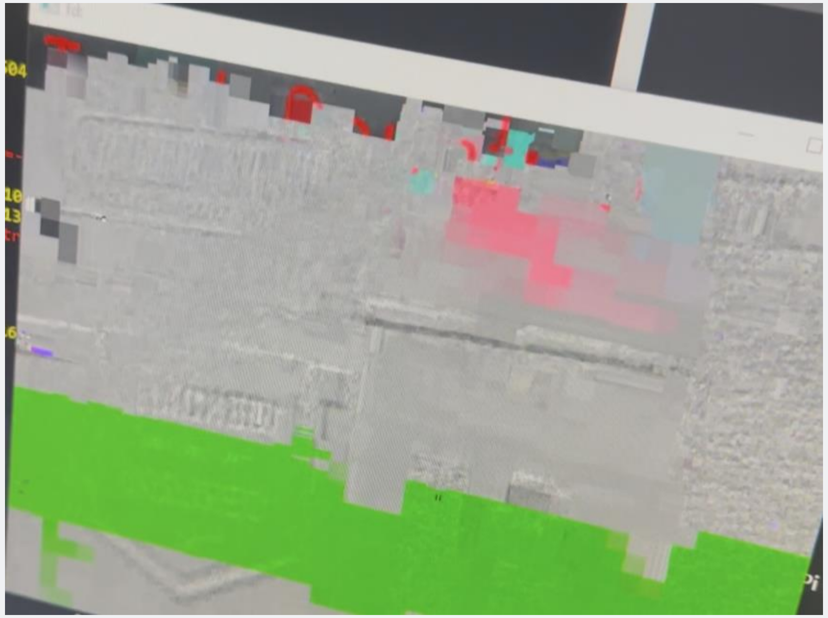
Prototyping and Testing

Luke Reyes
CPE

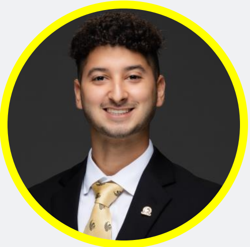
Raspberry Pi Display
Before Transmission



Computer Display From
PCB After Transmission



Work Distribution

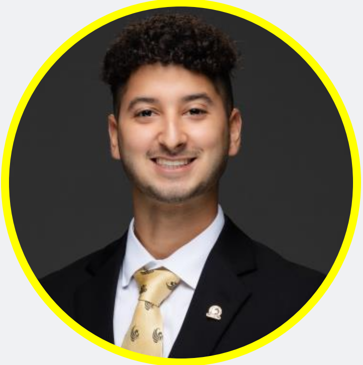


Alejandro
Lopez Zelaya
PSE

Sub-System	Task	Primary Contributor	Secondary Contributor
PCB	1. PCB design 2. High speed trace calculations 3. Daughter PCB boards design and integration	Armani	Luke
Power	1. PSU design with voltage regulator 2. Interface with and house MCU	Armani	Luke
Communication	1. FSO lens selection 2. Tx/Rx component integration 3. Optical alignment	Alejandro	Gabryella
Imaging	1. Design and alignment of lens system 2. Sensor selection and integration	Gabryella	Alejandro
Computer Vision	1. Software design, testing, and implementation 2. Single-board computer and MCU selection 3. Object tracking and confidence training	Robert	Luke
Image Processing	1. Output video processing 2. Back-end image processing and corrections 3. MCU interfacing for data conversion	Luke	Alejandro
Website	1. Update project information on the website	Luke	Robert

Bill of Materials – Optics

Sub-System	Component	Part Name	Budget	Quantity	Per Unit Cost	Real Cost
Imaging	Camera Module	Raspberry Pi Camera Module 3	$80.00	2	$31.77	$63.54
	Imaging Optics	Pinhole	$300.00	1	$78.00	$0
		Aspheric Lens		1	$139.92	$0
		Spherical Lens		1	$35.00	$0
Communication	Tx/Rx Components	Brocade E1MG-EZX-100	$100.00	2	$48.00	$96.00
	Media Converter	Open-SFP to RJ45	$50.00	2	$18.99	$1.00
	Collimating Optics	F280FC-1550	$300.00	2	$181.00	$0.00
	Optical Fiber	SMF-28e	$25.00	2	$6.65	$13.3



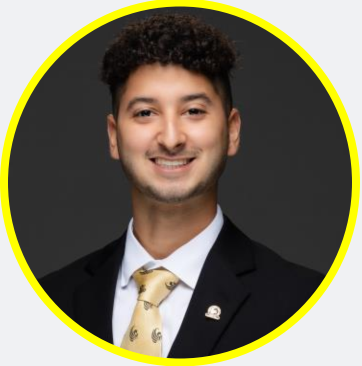
Alejandro Lopez Zelaya
PSE

Bill of Materials – Electronics

Armani Garcia
EE

Sub-System	Component	Part Name	Budget	Quantity	Price per Item	Real Cost
PCBs	Base Carrier	iSPY	$60	5	$17	$17
	Daughter Boards	HDMI		5	$52.15	$52.15
		Ethernet		5	$40.25	$40.25
		Voltage Regulator		5	$10.20	$10.20
Power	Ext. Power Supply	Meanwell LRS-50-5	$30	2	$17.01	$34.02
PCB Components	Misc	~	~	90	$115	$115

Progress and Future Milestones



Alejandro Lopez Zelaya
PSE

Current Status of Hardware and Software

Acquired: part has been acquired, and it is now on testing phase.

Under review: hardware/software is being reviewed to optimize results.

On the way: part has been purchased, and it is on the way.

- CMOS sensor
- Lenses (for Image Acquisition System)
- Lens Mount/Case
- Evaluation Board
- PCB
- Lenses (collimation)
- Transceivers
- Code

Future Milestones

Task	Status	Deadline
Prototype Development	Completed	Week 6
Testing*	Completed	Week 1 – Week 13
Troubleshooting*	Completed	Week 1 – Week 13
Optimizing*	Completed	Week 1 – Week 13
CDR	Completed	February 5, 2025
Senior Design Showcase Project Summary Form Submission	Completed	February 21, 2025
Midterm Demo Group Meeting	Completed	February 7, 2025
Conference Paper	Completed	March 28,2025
Live Demo	Standby	April 15,2025
CREOL Showcase	Standby	April 17, 2025
ECE Showcase	Standby	April 18, 2025

Thank you!