UCF Senior Design I

Optical Beacon Tracker for Optical Wireless Communication

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Initial Project Document and Group Identification

Divide and Conquer

Sponsored by the Knight Vision Lab

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***Chapters 1, 4, 5, 6, and 7 will not be in this document version**

2 Project Description

2.1 Motivation and Background

The idea of optical wireless communication (OWC) has existed for decades and comes with many advantages. Signals can be driven by light sources across the electromagnetic spectrum, granting a large range of frequencies to choose from, and the speed of signal transfer is only limited by the pulse width of the light source since the signal travels at the speed of light. Signals also cannot be intercepted unless the potential spy is within the line of sight of the transmitter, which makes OWC one of the most secure ways to send communications. Unfortunately, clear signals require precise alignment and are weak to interference from atmospheric loss [4]. Also, if the transmitter or receiver are mobile then maintaining that precise alignment becomes even more difficult, which is the problem we will try to solve.

The goal of this project is to build a device that can track an optical beacon while both the receiver and the beacon are mobile. When it comes to position tracking, one of the most obvious solutions would be GPS, and in fact we'll even be including GPS in the design for general alignment. However, most GPS systems are only accurate down to a few meters, while optical communications require precision down the centimeter. With a quadrant photodiode (QPD) we can accurately track the position of any light source at a certain wavelength as long as the receiver optics are properly designed. With an array of laser diodes, we can transmit light over long distances with enough optical power to be detected by the QPD and align both the receiver and the beacon. We'll be using a QPD sensitive to 850nm for alignment, and a standard photodiode sensitive to 1550nm to confirm perfect alignment of the system.

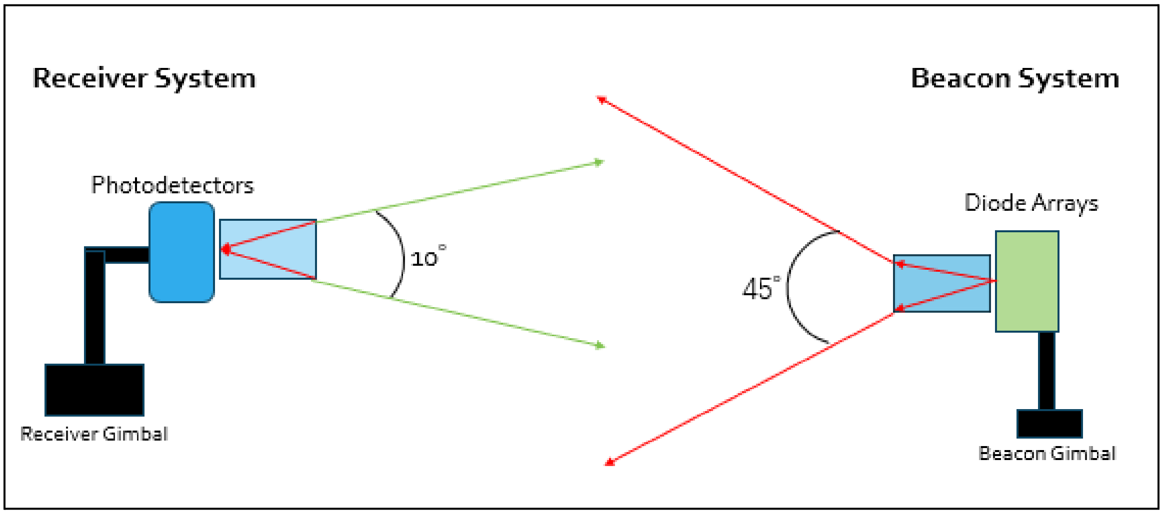

Figure 2.1: System diagram of the optical beacon tracker.

Using two separate wavelengths is essential. If we only used one wavelength, the beacon and the transmitted signal would interfere with each other. By using laser diodes that emit 850nm and 1550nm infrared light, we can avoid loss due to atmospheric interference. The lack of susceptibility to atmospheric loss is also one of the reasons that 1550nm is the most common wavelength for OWC, which is why it's the wavelength we'll use to confirm alignment. We'd like to stress that we are not building a communication system, only a tracker that can be easily integrated into a communication system.

2.2 Goals and Objectives

The goals we have for this project span from immediate basic goals, to advanced and stretch goals. The basic goals define the bare minimum for the project to be successful, and can easily be accomplished by our project deadline. They can be summarized as follows:

- Create a beacon with enough power and divergence to be detected up to 3 meters away whilst indoors
- Create a receiver that can actively track the beacon whilst mobile, up to 3 meters away when indoors

The advance goals for the project will be more difficult and still need to be completed before our allotted time for the project is up, but they are still reasonably achievable. The advance goals are:

- Capable of tracking up to 1 km away whilst outdoors.
- Tracking the beacon with the accuracy stated in the requirements and specifications section.

The stretch goals would only be attainable if we stay very far ahead on this project. Since we only have 3 team members, the second stretch goal in particular would be difficult to achieve during our allotted time. The stretch goals are:

- Capable of tracking up to 10 km away in ideal weather conditions.
- Capable of transmitting and decoding a simple signal (like an SOS) from the beacon.

For now, the goal is simply to be capable of tracking a beacon attached to the object transmitting the signals. To be able to send and decode actual signals from the beacon would reasonably require an extra team member, which makes it a far stretching goal. Tracking the beacon at 10 km should be possible in theory, however proving it in any way other than mathematically would be nearly impossible without the use of drones.

The objectives for this project will all add up to help us accomplish our goals.

- Perform safety calculations so that the 850 nm laser diodes can be safely used indoors.
- Calculate the required optical output power for the beacon to be detectable by the receiver at a given distance.
- Design the focusing, diverging, and collimating lens systems on the beacon and receiver.
- Design a PCB for the beacon and receiver.
- Design a power supply for the beacon and receiver respectively, capable of driving the laser diodes and gimbals/dc motor, as well as biasing the photodiodes.

- Create an algorithm that enables the gimbals/dc motor to use outputs from the QPD, GPS, and IMU as inputs for positioning.

2.3 Requirements and Specifications

Like any engineering project, we'll have to meet certain design specifications by the end of the year. This is a sponsored project, so certain specifications such as outdoor functional distance and track accuracy are set by the sponsor. Other specifications were set by ourselves to ensure we can meet our goals for the project.

No:	Requirement	Specification	Description	Priority
1	Receiver FOV	10 degrees	The viewing angle from the receiver.	Mid
2	Beacon FOV	45 degrees	The divergence angle from the beacon.	Mid
3	Stationary track accuracy	10 µRad	The accuracy of the system when stationary.	High
4	Mobile track accuracy	500 µRad	The accuracy of the system when mobile.	High
5	Track loop without IMU compensation	10 kHz	Signal processing loop without using an IMU	Mid
6	Track loop with IMU compensation	100 Hz	Signal processing loop while using an IMU	Mid
7	Receiver and Beacon Weight	Less than 5 kg each	The receiver and the beacon must both be less than 5 kg respectively.	Low
8	Indoor functionality	3 meters	Functional distance while indoors	High
9	Outdoor functionality	1 kilometer	Functional distance while outdoors	Mid
10	Battery Life	1 hour run-time	How long our system will be able to run on a battery power supply	High
11	Power Consumption	Less than 500 Wh	To ensure the minimum battery life requirement	High

Figure 2.3: Table of engineering specifications.

2.4 Hardware and Software

2.4.1 Hardware

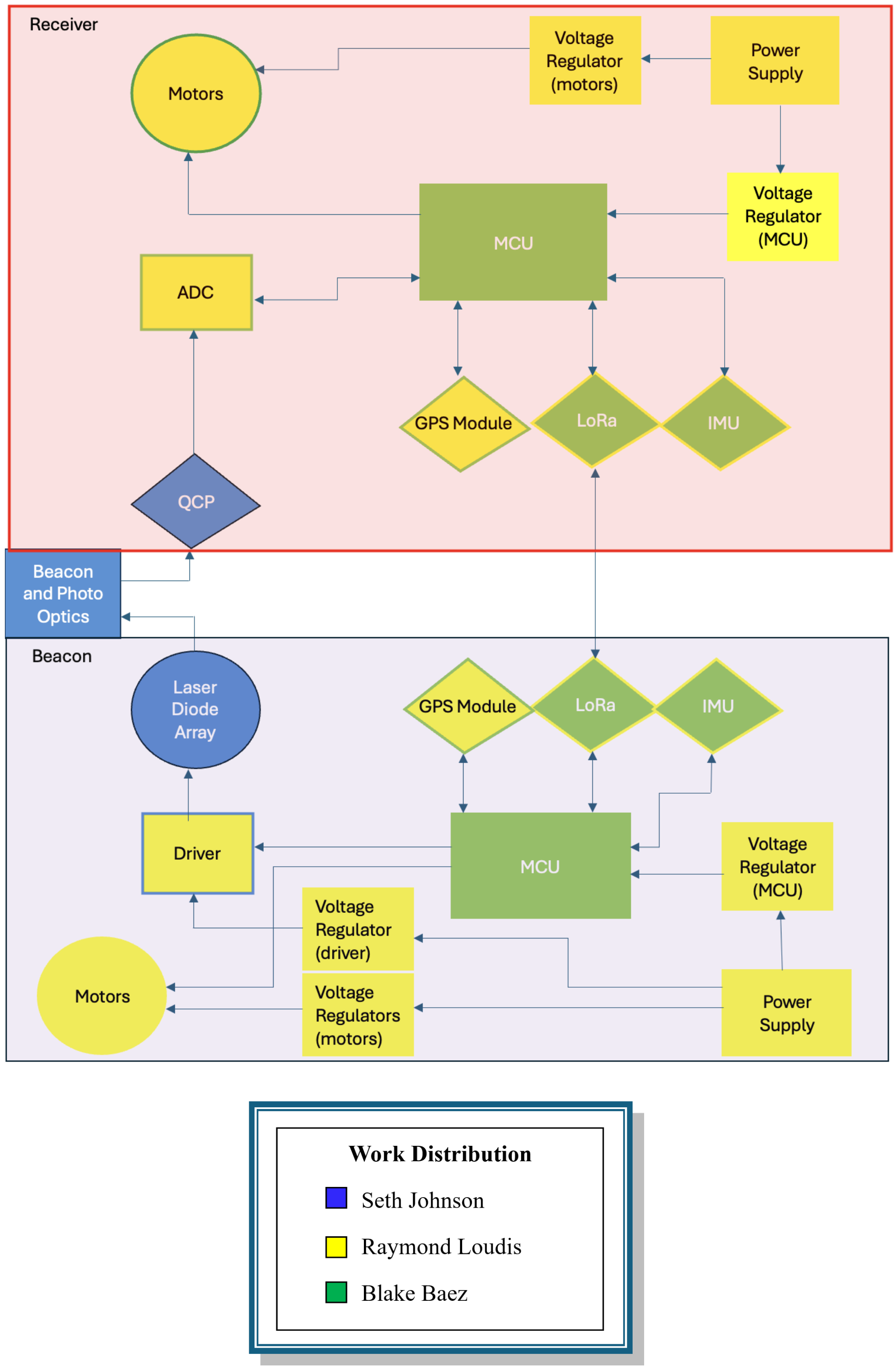

Figure 2.4.1: Hardware block diagram.

A quadrant photodiode consists of four separate photodiode segments or quadrants. When the light source of the beacon illuminates the photodiode each segment generates a current proportional to the light received. By comparing these currents, we hope to determine the position of the light source relative to the photodiode and align it with the beacon's transmitter/laser diode array.

However, to generally align the QPD on the receiver with the laser diodes on the beacon we have two plans of attack, the first and most simple option is to have the receiver gimbal rotate slowly at around 10 RPM while angling the lens up and down until a signal is received from the beacon. Simultaneously, the beacon will be pulsating its laser diodes and be rotating in the opposite direction at half the speed. Once the two intersect the receiver will stop its automatic rotation and via LoRa send a signal to the beacon stopping its rotation as well. The receiver's gimbal will then be controlled by the inputs given by the QPD.

The second solution to general alignment is a bit more complicated but preferable to long range target acquisition. Rather than having the beacon and receiver enter a sort of "search mode" as described above with both gimbals rotating until a signal is received, we propose that both the beacon and the receiver be outfitted with GPS and IMU modules to relay exact position and orientation over LoRa communication (assuming IMU has magnetometer). Although more complicated, having GPS and IMU modules can increase the amount of usable tracking data in addition to quicker alignment. As we continue to conduct more research and price out components, we will reassess which method is better suited for this design project. For now both options are being considered, the first option, which will be called "spin protocol" in the flowchart, will be initiated when neither GPS or light signals are received, acting as a sort of fail safe.

The reason that we are currently researching and leaning towards implementing LoRa communication for positional data is that it yields low power consumption and can transmit over long distances. However, the major drawback is the trade off between power efficiency and throughput. Currently we are in the process of calculating the necessary throughput to relay accurate positional data within 90 seconds.

Our stretch goal is to implement digital modulation drivers so that the user can modulate the laser diodes output via digital signal, which would be useful for pulsating or changing intensity based on user control. However, the assumed drivers in the diagram above are controlled by the MCU and are constant current drivers.

2.4.2 Optical Diagram

The optical design is crucial to this project. We must be able to project the light of our beacon with enough divergence to cover a significant area. We must then be able to collect the light from the beacon so that it illuminates the active cell of our QPD while also focusing onto a separate detector.

Laser diodes naturally diverge unevenly on the horizontal and vertical axis, so both arrays will have to be collimated into smaller, more evenly dispersed beams. They will then both pass through a dichroic mirror and a diffuser plate so that the arrays appear as a single spatially coherent beam, and then diverged upon exiting the beacon aperture. Upon reaching the receiver, the two wavelengths must be separated again so that they can be focused onto their own respective detectors. The diagram below illustrates the necessary optical setup for the beacon and receiver system.

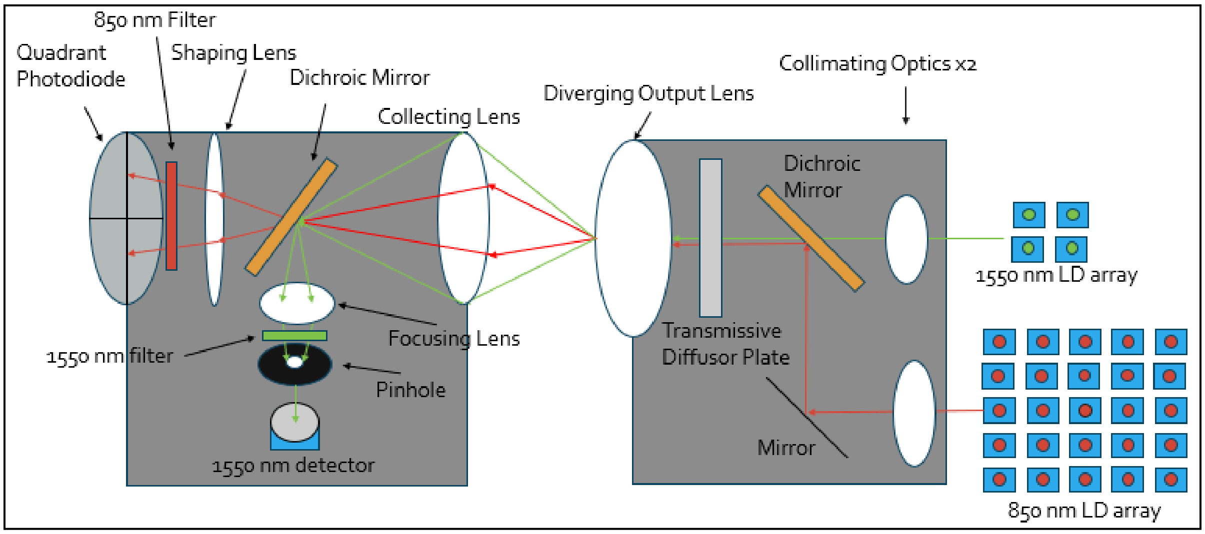

Figure 2.4.2: Diagram of the intended optical design

2.4.3 Software

There will be two programmable MCU's controlling both the beacon side and the receiver side. This will be the bulk of the programmable software in this project. The first step is to initialize all system components, including the microcontroller (MCU), the laser diodes, quadrant photodiode (QPD), gimbals, and communication interfaces. To do this, we need to set up communication protocols (e.g., I2C, SPI), configure the QPD for signal detection, and set up control parameters for the gimbals. The next step is detecting the signals from the 25 lasers diodes (850 nm) and the telecomm tracking lasers (1550 nm).

To accomplish this, the MCU must take the analog signals from the QPD and use ADCs to convert analog signals to digital format. One must implement demodulation techniques to extract the pulsed signals from the noise. Then filter out ambient infrared sources. The software side of that is to apply digital filtering to eliminate remaining ambient IR interference. The tracking algorithm must also only accept the 1550nm, while the 850nm laser input is used for centering from a general location. The way it will be done is by computing the position of the laser beam on the QPD using the differences in signal intensities from the four quadrants. To move the gimbal, The MCU will contain a PID control algorithm to generate gimbal movement commands based on the position data. This PID control algorithm will be done using Ardupilot. It is important that the movement is smooth and precise to avoid signal loss.

As this project goes on, it's important that the code logs critical data and ensures reliable communication. This means logging position data, signal strength, gimbal movements, and system status for debugging and analysis. The system must be able to handle faults effectively to ensure its reliability. This can be done by implementing self-check routines to verify the functionality of all components at startup. It is also somewhat important to efficiently manage power consumption. This system can be used with a battery.

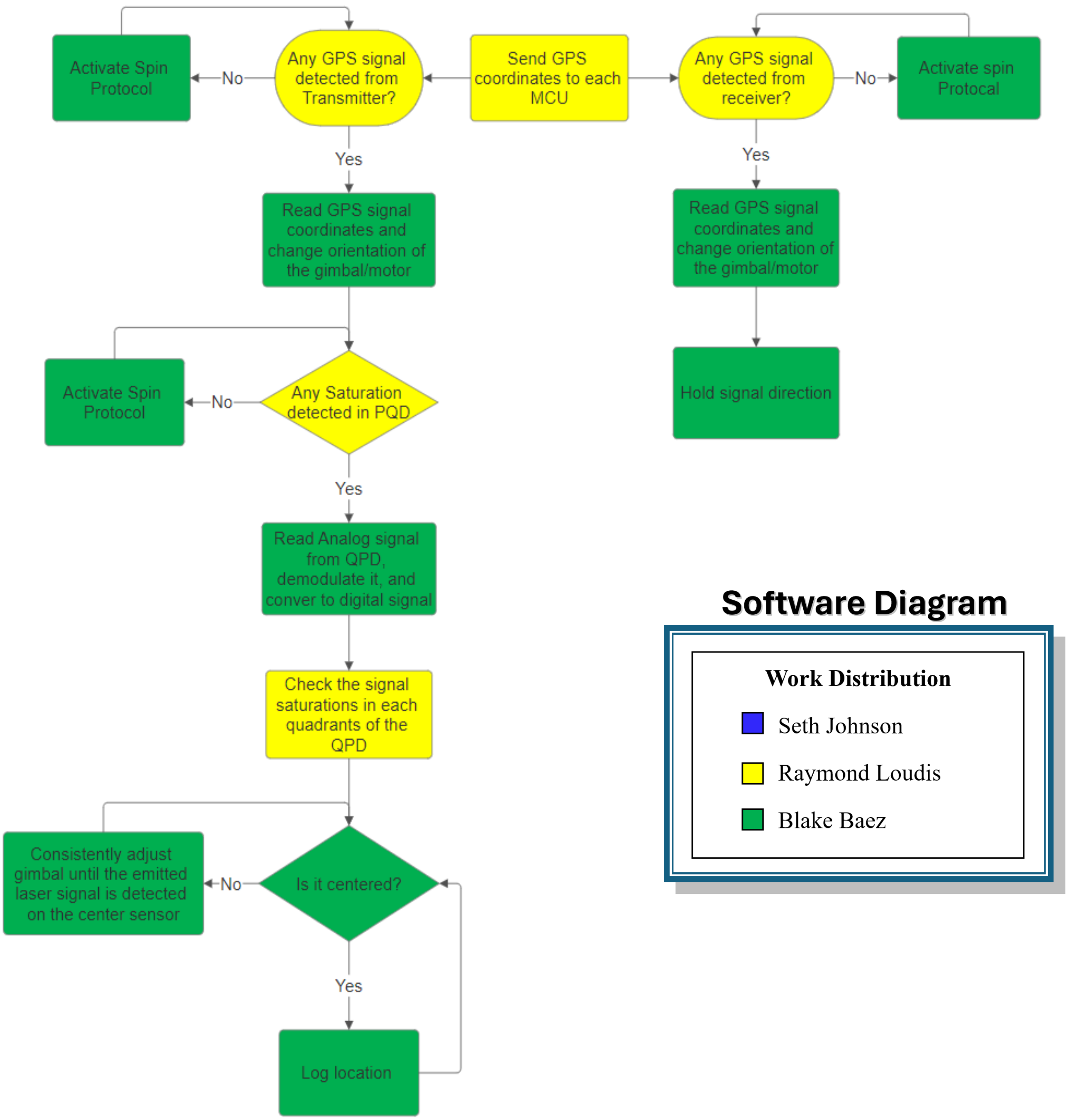

Figure 2.4.2: Software flowchart

2.5 House of Quality

The house of quality diagram is essential for making sure our engineering specifications meet the needs of our clients or sponsors. Our house of quality is shown below.

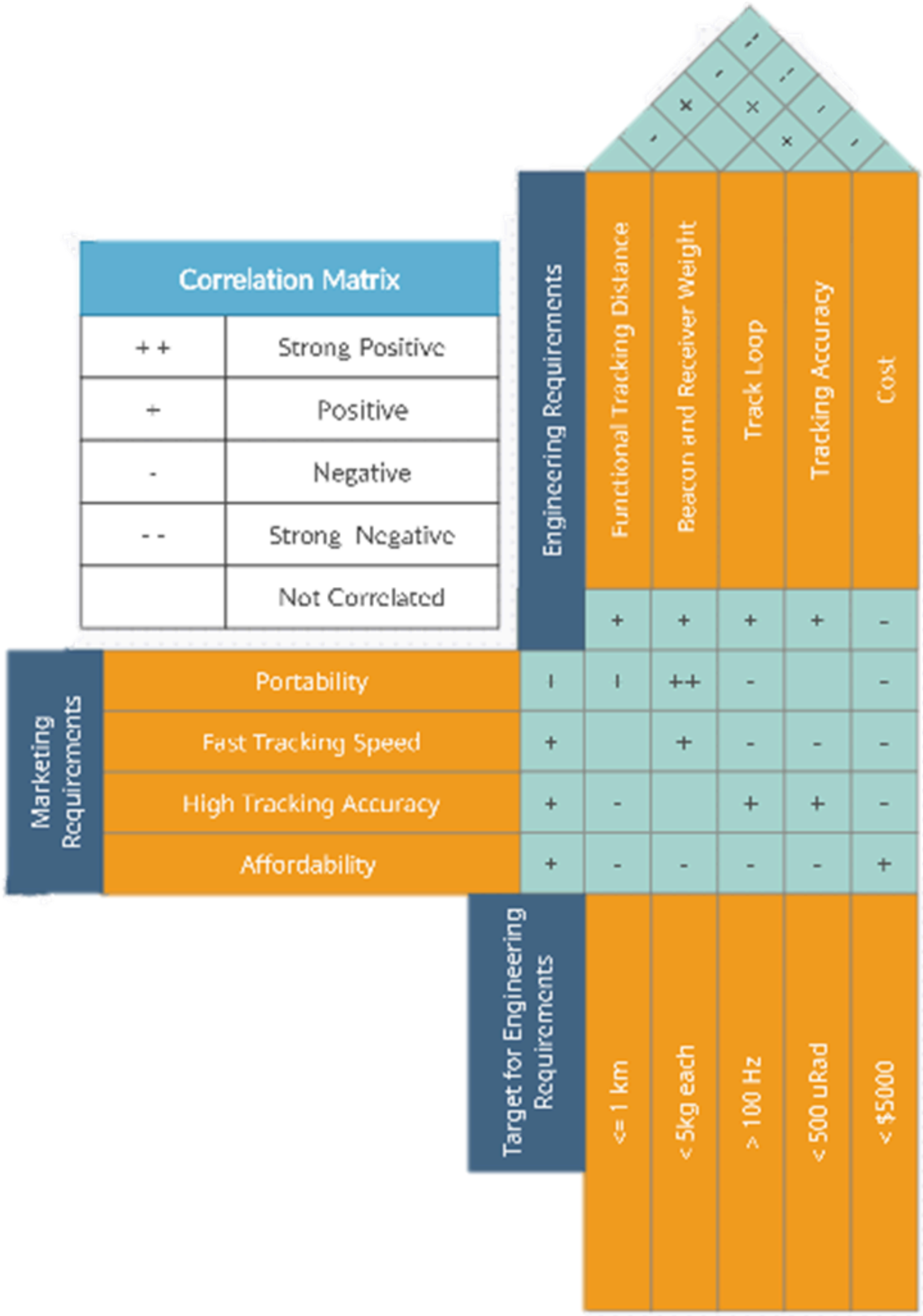

Figure 2.5: House of quality diagram

3 Research and Part Selections
3.1 Similar Projects

There are a total of 3 comparative projects that will be addressed in this section. The fist two share likeness in optical alignment using a QPD while the last one focuses on real time tracking using a 2-axis gimbal such as the Gremsy T3V3 proposed to be used on our receiver.

The first related project that I will be addressing is a study conducted for Free-Space Optical (FSO) communication between a Ground Control Station (FSO) and a UAV [1]. I bring this study up first because it shares likeness in both optical tracking and using a 2-axis gimbal for tracking in real-time. This study proposes, much like our own, that we will be able to use a QPD to align the laser diodes on our beacon. Additionally, the proposal of a circular search pattern to obtain line of sight is similar to our “spin-protocol” listed above in the software flow chart. The experiments conducted in this study show that by using a laser generator, QPD sensor and driving actuators it is possible to control each side of their GCS and UAV independently to achieve perfect optical alignment for FSO communication [1]. However, there are some differences between our approach and the one used in this study. The first key difference is that their design is focused on a communication between a GCS and UAV where our project hopes to be able to achieve this alignment between two UAVs. Another key difference is that we are hoping to reduce the time and increase the range of target acquisition using GPS and LoRa modules. Furthermore, where this study transmitted the positional information received from the GCS photo diode to the UAV, we believe that positioning the beacon with the GPS and IMU will be sufficient for optical alignment and tracking. It should be noted that if our approach lacks the necessary accuracy we may consider a similar solution in both the beacon and receiver utilizing the data obtained from the QPD. Additionally, the distance between the transmitter and receiver for this study were only a distance of 100m, about a tenth of what we hope to demonstrate on our finished product.

The next comparative project that will be addressed is a study to construct a linear closed loop feedback system that compensates for beam wander in medium-range optical link applications or a Laser Beam Stabilization (LBS) system [2]. Unlike the previous study, the distance implemented here is 10km, a bit closer to our desired distance. Issues of longer distance transmission are brought to attention such as beam wander, which is caused as the optical beam propagates through free space and encounters atmospheric interference or turbulence. The turbulent medium consists of large and small scale eddies that act as prisms of varying refractive nature. The LBS system is to compensate for beam wander in a closed loop fashion, the methodology used in their optical alignment are of note and may need to be implemented into later designs for our own project given further testing. This case study shows the implementation of fast steering mirrors mounted onto actuators that reflects the focused beam onto a QPD. Essentially the technique of actuating a mirror for fine tune adjustments could be promising for our attempt of obtaining and maintaining line of sight between our beacon and receiver.

Moving on to our last comparative project, a paper on the development of a gimbal control algorithm for real-time object tracking and location acquisition from a UAV [3]. The algorithm proposed by this paper deals with two scenarios, one offering gimbal pointing at a given coordinate and the other is to align an optically with a certain point in an image plane. This paper covers the implementation of GPS systems with an IMU for position orientation for their first scenario, similar to our own, however their algorithm for tracking is designed around user target selection. Essentially the gimbal is rotated and moved into position until the user has determined line of sight, once the object of interest is selected it is able to control the gimbal to keep the object within a designated camera frame. Although our project aims to be a bit more autonomous, the algorithms used for gimbal tracking control and the use of GPS systems for positional approximation, provide us insight into what lies ahead for our own project.

3.2 Parts Comparison

One of the first and biggest considerations that group had to make is how to move the QPD and the laser diode array. There are many ways we can practically move objects in the x and y plane but there are many complex-mirror based options as well. Some of the options we look at are galvanometer-based systems, voice coil actuators, MEMS (Mirco-Electro-mechanical Systems) mirrors, stepper motor systems with precision stages, piezoelectric actuators, electro-optical deflectors (EOD), rotary encoders with DC motors, and gimbals.

The Galvanometer-based system, although highly precise with extremely fast response times, was immediately out due to complexity and cost. We believed it would put us over budget when looking up parts. Even if we could fit it into our budget, the online support and complexity of these would hinder the development of our project. Even without the high cost, they would not be practical. They work based on mirrors, motors, and the servo. The problem is if one wants to have a wider range of motion, you must have more motors and mirrors. This would just be impractical. The electro-optical deflector is similar in the sense that it uses mirrors as well. However, it uses electro-optic effects instead to deflect the light beam without moving parts. This cannot work because of several reasons: it is too expensive, complex, and it can only move the laser from specific predetermined angles.

Voice coil actuators are used for other applications besides sound. They provide high precision and fast response times as well. Their biggest downside is limited range of motion. The average range of motion for a small VCA is in the millimeter range. That will not work for this project. Somewhat similar is the Piezoelectric actuator. Piezoelectric actuators are a device that use piezoelectric effect to provide small, precise movements. These are also in the microscopic effective range and would not meet the needs of this project.

Another mirror-based system is the MEMS. This was another method that was immediately dismissed. The degree of motion was exceedingly small and for much more precise movement that was what we needed. There are no ways for the average person to even build this machine for an application such as this.

The last two options are the ones this group has settled on, gimbals and rotary encoder with DC motors. They both meet the requirements for this project. They are both affordable, have the right amount of precision we need, and are far less complex than most of these options. The gimbal would be ready as is, but the difficult part would be coding the algorithm to use it. DC motors are simpler in nature, but they would need some work. They only spin on one axis so two are needed. It is a matter of hooking them up together and being able to maintain that precision.

For the receiver rotary encoder with DC motor, the group came up with several different brands that could work with this project. The brands are as follows: Maxon Motor, Faulhaber, Oriental Motor, Dynomotion, Pololu, and US Digital. The ones with high precision are the US digital, Faulhaber, and Maxon Motor. The Oriental Motor has some models that are precise but generally laws only the less precise but cheaper. Same with the dynomotion and Pololu.

For the receiver rotary encoder with DC motor, we have chosen two options, the Maxon Motor and the Faulhaber. The reason we didn't pick US digital is because they generally don't sell motors on the level we need for the receiver, just the encoders that they can be paired with. We have picked two motors from the Maxon motor and Faulhaber Motor companies that we think would suit our needs. The rotary encoder with motor we picked from Maxon Motor is the DCX series with encoder (specifically the Maxon DCX 22 S with Encoder (High Precision Version)). Here are the following specifications:

- **Motor Type:** DCX 22 S
- **Nominal Voltage:** 24 V
- **No Load Speed:** 10,000 rpm
- **No Load Current:** 27 mA
- **Max. Continuous Torque:** 23.1 mNm
- **Max. Efficiency:** 86%
- **Torque Constant:** 13.6 mNm/A
- **Speed/Torque Gradient:** 438 rpm/mNm
- **Rotor Inertia:** 4.29 gcm^2
- **Weight:** 56 g

The corresponding encoder has the following specifications:

- **Encoder Type**: ENX 16 EASY Absolute

- **Resolution**: 4096 steps per revolution (12-bit)
- **Output Type**: SSI (Synchronous Serial Interface) or BiSS-C
- **Max. Speed**: 12,000 rpm
- **Operating Temperature**: -40°C to +100°C
- **Supply Voltage**: 3.3 V or 5 V

This is in a price range from $700 to $1,500 depending on the configuration. The Faulhaber Motor - series 3242 with encoder (specifically the Faulhaber 3242 BX4 with Encoder (High Precision Version)) is about $800 to $1200 depending on configuration. Here are the following specifications:

- **Motor Type**: 3242 BX4
- **Nominal Voltage**: 24 V
- **No Load Speed**: 8,700 rpm
- **No Load Current**: 19 mA
- **Max. Continuous Torque**: 72 mNm
- **Max. Efficiency**: 88%
- **Torque Constant**: 28.6 mNm/A
- **Speed/Torque Gradient**: 120 rpm/mNm
- **Rotor Inertia**: 6.6 gcm^2
- **Weight**: 140 g

The corresponding encoder has the following specifications:

- **Encoder Type**: IE3-1024
- **Resolution**: 1024 pulses per revolution (4,096 counts per revolution in quadrature mode)
- **Output Type**: Line Driver
- **Max. Speed**: 10,000 rpm
- **Operating Temperature**: -30°C to +100°C
- **Supply Voltage**: 5 V

It is important to note that this project needs two of these motors since it needs to be able to rotate in the x-plane and y-plane. It is highly unlikely that these motors need anything but the base configurations so they are both within our budget.

The transmitter rotary encoder with a DC motor could be much cheaper and less precise. For that reason, we picked motors from Pololu and Oriental Motor. The rotary encoder with motor that we pick from Pololu is the 37D gearmotor with encoder (specifically the Pololu 37D 12V 50:1 Metal Gearmotor with Encoder). Here are the following specs for the motor:

- **Motor Type**: Brushed DC Motor
- **Nominal Voltage**: 12 V
- **No Load Speed**: 180 rpm
- **No Load Current**: 300 mA
- **Stall Torque**: 24 kg·cm (2.35 Nm)
- **Stall Current**: 5 A
- **Gear Ratio**: 50:1
- **Shaft Diameter**: 6 mm
- **Weight**: 300 g

The corresponding encoder has the following specifications:

- **Encoder Type**: Magnetic Encoder
- **Resolution**: 64 counts per revolution (CPR) (256 counts per revolution with quadrature encoding)
- **Output Type**: Quadrature (A/B) channels
- **Supply Voltage**: 3.5 V to 20 V
- **Current Consumption**: 10 mA per channel

This motor is much more affordable, at $50 to $70, The precision is fairly low but that should not be a problem. WIth further testing, we will know for sure if this is sufficient or not over long distances. The rotary encoder with motor we chose from Oriental Motor is the BMU series with encoder (specifically the Oriental Motor BMU Series (BMU60-A2) with Encoder). Here are the motors specifications:

- **Motor Type**: Brushless DC Motor
- **Nominal Voltage**: 24 V
- **Rated Speed**: 3000 rpm
- **Rated Torque**: 0.64 Nm
- **Rated Current**: 3.4 A
- **Gear Ratio**: Various options available (standard 5:1, 10:1, etc.)
- **Shaft Diameter**: 8 mm
- **Weight**: 1.4 kg

The corresponding encoder has the following specifications:

- **Encoder Type**: Incremental Encoder
- **Resolution**: 1000 pulses per revolution (PPR) (4000 counts per revolution with quadrature encoding)
- **Output Type**: Differential Line Driver
- **Supply Voltage**: 5 V
- **Current Consumption**: 50 mA

The price range is $200 to $400 considerably more expensive, however much more precise. If we find that the Pololu motor is not sufficient enough precision wise, we will switch to this motor.

The receiver gimbal is one of the more practical options that we are considering in order to reach our specifications. It's important that the gimbal has high precision and stability. It also needs to have the necessary connections to support the microcontroller and other necessary parts. The top 6 viable brands that came up were: Gremsy, DJI, Freefly Systems, Moza Zhiyun, and FreiyuTech. The Gremsy not only had the most precise control, but it was also compact. It comes with direct drive motors, high-resolution encoders, and many attachment points. These features contribute to the gimbal's ability to quickly and accurately adjust its orientation in response to commands derived from the QPD data. It also comes with various software support. Some of the specifications that Gremsy T3V3 met are:

- **Control:** PWM, S.BUS, CAN, and Bluetooth
- **Input Power:** 12-52V
- **Operating Temperature:** -20°C to 50°C
- **Stabilization Accuracy:** ±0.02°
- **Angular Vibration Range:** ±0.02° to ±0.03°
- **Tilt Range:** -135° to +90°
- **Roll Range:** ±45°
- **Pan Range:** 360° continuous
- **Communication Ports:** USB, CAN, UART, S.BUS
- **Software Support:** Gremsy Tuning App, SDK available

For the transmitter gimbal, the top picks between 100-200 dollars are as follows: Yes, the gimbals listed typically fall within the $100-$200 range. Here's a brief confirmation of their price range: Zhiyun Smooth 4, Hohem iSteady Mobile Plus, FeiyuTech Vimble 2S, MOZA Mini-S, DJI OM 4 SE, and Snoppa Atom. The gimbal on the transmitter side does not have to be accurate, unlike the receiver side. It just needs to be able to have good mounting and be able to steadily hold a position. Out of these picks, it was decided that the DJI OM 4 SE suited this projects needs the most. Not only did it meet our budget constraints (can be bought for as low as $100), it is a gimbal well known for its 3-axis stabilization system. The weight capacity is a recommended 300g but is able to carry more. This is plenty for what we need as the laser array does not weigh much. Its mechanical range is:

- **Pan:** -161.2° to 171.95°
- **Roll:** -136.7° to 198°
- **Tilt:** -106.54° to 235.5°
- **Voltage:** 7.2 V
- **Maximum package weight:** 230 +/- 60g

The next step for this project was to find a suitable IMU and MCU. Our employer wanted a reliable setup. Some of the models we considered are as follows: the Pixhawk 4, Holybro Durandal, InvenSense MPU-9250, Drotek Sirius RTK GNSS, and the Cube Orange+ Standard Set ADS-B. All of these are separate MCU and IMU except for the cube Orange. That comes at a cost however as the Cube orange is more expensive. The first two are MCUs. The specifications of the Pixhawk 4 are as follows:

- **MCU:** STM32F765 (ARM Cortex-M7, 216MHz)
- **RAM:** 512KB
- **Flash Memory:** 2MB
- **IMU:** Dual IMU (ICM-20689, BMI055)
- **Barometer:** MS5611
- **Magnetometer:** IST8310
- **Connectivity:** CAN, I2C, UART, SPI, USB
- **Power Supply:** Redundant power supply
- **Price:** ~$200

Here are the specifications for the Holybro Durandal:

- **MCU:** STM32H743 (ARM Cortex-M7, 400MHz)
- **RAM:** 1MB
- **Flash Memory:** 2MB
- **IMU:** Dual IMU (ICM-20602, ICM-20948)
- **Barometer:** MS5611
- **Magnetometer:** IST8310
- **Connectivity:** CAN, I2C, UART, SPI, USB
- **Power Supply:** Redundant power supply
- **Price:** ~$220

The first of the two IMUs is the InvenSense MPU-9250. Here are its specifications (due note that it's just a chip so if it is chosen, it will need to be accompanied by some pcb):

- **Gyroscope:** 3-axis
- **Accelerometer:** 3-axis
- **Magnetometer:** 3-axis
- **Price:** ~$45

The other IMU is the Drotek Sirius RTK GNSS. Here are its specifications:

- **Gyroscope:** 3-axis (included in integrated IMU)
- **Accelerometer:** 3-axis (included in integrated IMU)
- **Magnetometer:** IST8310
- **GNSS:** RTK-enabled GNSS
- **Price:** ~$275

The final option is the Cube Orange+ Standard Set ADS-B. We don't have to worry about connecting the IMU and MCU as they both come integrated. In fact this model has multiple IMUs (triple redundancy). It is fully compatible with Ardupilot, which is ideal in controlling a gimbal. It contains many connectivity options (CAN, I2C, UART, SPI, USB) and a Here3 GNSS module. This provides precise positioning data. Here are some of the specifications:

- **MCU:** STM32H743 (ARM Cortex-M7, 400MHz)
- **RAM:** 1MB
- **Flash Memory:** 2MB
- **IMU:** Triple Redundant IMUs (ICM-20948, BMI055, LSM303D)
- **Gyroscope/Accelerometer:** 32-bit, high-speed data capture
- **Barometer:** MS5611
- **Magnetometer:** IST8310
- **ADS-B Receiver:** Integrated, uAvionix ADS-B IN
- **Connectivity:** CAN, I2C, UART, SPI, USB
- **GNSS:** Here3 GNSS (UAVCAN)
- **Power Supply:** Redundant power supply
- **Dimensions:** 38.5 x 38.5 x 22.0 mm
- **Weight:** 33g
- **Software Compatibility:** ArduPilot, PX4

This module is priced at $350 dollars. This is actually cheaper than most of the other parts excluding the Invensense when pairing up both MCU and IMU. We included it as a backup just in case we did not need all the features that the other products provide.

GPS was another secondary addition as it will be used to support the precise tracking. Nonetheless, the GPS must be accurate enough so that the receiver side does not have trouble locating the laser signal. GNSS RTK (Real-Time Kinematic) products seem to be ideal for this purpose. Some of the products the group considered were Emlid Reach RS2 and Reach M2, Ublox C099-F9P Application Board, ArduSimple SimpleRTK2B, Here3+ & Here+ RTK Base (M8P) Combo, and Tersus GNSS BX306. The problem with some of these selections is price. If the budget is there, it would be nice to have them, but at a price of the EMlid Reach RS2 (not the M2 model) and Tersus GNSS are expensive (at around $1000+). The Emlid Reach M2, at a cheaper price of $500 to $600 compared to some of its adversaries is a great deal. Here are its specifications:

- **Constellations Supported**: GPS/QZSS L1C/A, L2C; GLONASS L1OF, L2OF; BeiDou B1I, B2I; Galileo E1-B/C, E5b; SBAS L1C/A
- **Channels**: 184 channels
- **RTK Accuracy**: Horizontal 7 mm + 1 ppm, Vertical 14 mm + 1 ppm
- **Update Rate**: 1 Hz, 5 Hz, 10 Hz, 14 Hz, 20 Hz
- **Communication**: UART, USB, Bluetooth 4.0, Wi-Fi 802.11 b/g/n
- **Power Consumption**: 1.5 W
- **Weight**: 36 g

The Ublox C099-F9P Application Board has similar specifications:

- **Constellations Supported**: GPS L1C/A, L2C; GLONASS L1OF, L2OF; Galileo E1-B/C, E5b; BeiDou B1I, B2I; QZSS L1C/A, L2C; SBAS L1C/A
- **Channels**: 184 channels

- **RTK Accuracy**: Horizontal 10 mm + 1 ppm, Vertical 20 mm + 1 ppm
- **Update Rate**: Up to 20 Hz
- **Communication**: USB, UART, I2C, SPI
- **Power Consumption**: 0.9 W

Here are the ArduSimple SimpleRTK2B Specifications:

- **Constellations Supported**: GPS L1C/A, L2C; GLONASS L1OF, L2OF; Galileo E1-B/C, E5b; BeiDou B1I, B2I; QZSS L1C/A, L2C
- **Channels**: 184 channels
- **RTK Accuracy**: Horizontal 10 mm + 1 ppm, Vertical 20 mm + 1 ppm
- **Update Rate**: Up to 20 Hz
- **Communication**: UART, USB, Bluetooth, Wi-Fi (via expansion)
- **Power Consumption**: 0.6 W

Here are the Tersus GNSS BX306 Specifications:

- **Constellations Supported**: GPS L1/L2, GLONASS G1/G2, BeiDou B1/B2, Galileo E1/E5b
- **Channels**: 384 channels
- **RTK Accuracy**: Horizontal 8 mm + 1 ppm, Vertical 15 mm + 1 ppm
- **Update Rate**: Up to 20 Hz
- **Communication**: RS-232, USB, CAN
- **Power Consumption**: 1.6 W
- **Weight**: 57 g

Here is the Here3+ & Here+ RTK Base (M8P) Combo specifications:

- **Constellations Supported:**GPS L1C/A, L2C, GLONASS L1OF, L2OFGalileo, E1-B/C, E5b, BeiDou B1I, B2I, QZSS L1C/A, L2C, SBAS L1C/A
- **Channels:** 184 channels
- **RTK Accuracy:** Horizontal: 10 mm + 1 ppm, Vertical: 20 mm + 1 ppm
- **Update Rate: Up to 10 Hz**
- **Communication:** CAN, UART, USB
- **Power Consumption:** Typically 0.6 W
- **Weight:** 200 grams

With only a significant addition of weight (as far as this project is considered it should not matter). We believe the Here3+ & Here+ RTK Base (M8P) Combo is ideal. It is considerably cheaper than most of the options (it is priced at $305) and it meets our known specifications. We left the other options open if the project runs into complications and different modules are required.

8 Administrative Content

8.1 Budget Estimates and Funding

Our team is sponsored by the Knight Vision Lab (KVL), a research group at CREOL, and they will be providing the budget for this project. Our limit for the project is $5000. Luckily the KVL will provide certain components, such as the receiver gimbal, so they won't come out of our budget. The table below consists of very rough cost estimates of the most critical components we'll need for the project.

Item	Quantity	Unit cost	Total cost
850 nm LD	25	$10	$250
1550 nm LD	4	$200	$800
SI Quadrant Photodiode	1	$100	$100
InGaAs Photodiode	1	$65	$65
Optical Bandpass Filters	2	$165	$330
Engineered Optical Diffuser	1	$280	$280
Lenses	6	$35	$210
Dichroic Mirror	2	$160	$320
Arduino Nano	2	$20	$40
Receiver Gimbal	1	$1800	*Acquired
Beacon Gimbal	1	$100	$100
GPS modules	2	$30	$60
IMU modules	2	$30	$60
LoRa Modules	2	$20	$40
Li-Ion Power Supplies	2	$300	$600
Rough total cost estimate			$3,255

Table 8.1 Rough estimate of project cost

8.2 Project Milestones

There are several milestones and deadlines we'll have to meet in order to finish the project. The tables below roughly encompass these milestones.

Task	Start Date	Anticipated End Date	Duration
Project Brainstorming	Spring Semester	Spring Semester	10 weeks
Project details worked out (some optimizations)	05/13/2024	05/23/2024	1.5 week
Individual Research Delegations and Assessments	08/16/24	09/23/24	1 weeks
Initial Design Document (Based upon the D&C documents)	05/21/24	05/31/24	1.5 weeks
20-Page D&C (improvements made, more research done, and any recommended changes through consultation)	5/31/24	06/7/24	1 week
Meet and Discuss with Sponsor/mentor (seek guidance)	06/7/24	06/21/24	2 weeks
60-Page Milestone (improvements made, more research done, and any recommended changes through consultation)	06/21/24	07/5/24	2 weeks
Group Review: Final Draft (90 pages)	07/5/24	07/23/24	2.5 weeks

Table 8.2.1: Senior Design 1 deadlines

Task	Start Date	Anticipated End Date	Duration
Final Selection of components and Ordering the Parts	05/24/24	06/7/24	2 weeks
System Design (designing schematics for PCB, filters, etc.)	05/27/24	06/17/24	3 weeks
PCB Design	06/07/24	06/17/24	2.5 weeks
Testing components, arrays, and filters	06/17/24	07/5/24	2.5 weeks
PCB and MCU Testing	06/17/24	07/5/24	2.5 weeks
Develop prototypes for Mini Demo Video	07/5/24	07/23/24	2.5 weeks

Table 8.2.2 Senior Design I Project Design Milestones

Task	Start Date	Anticipated End Date	Duration
PCB and Other Design Testing (improving on prototype)	08/21/24	09/11/24	3 weeks
Assembling Parts/System Integration for final prototype	09/11/24	09/23/24	3 weeks
Prototype testing for final product	09/23/24	11/15/24	7 weeks
Finalize the Documentation	11/1/24	11/15/24	2 weeks
Practice Final Presentation	11/15/24	11/22/24	1 weeks
Final Presentation	TBA	TBA	TBA

Table 8.2.3 Senior Design II Project Design & Documentation Milestones

3.3 Work Distributions

There are three members of our team, each from a different discipline. The PSE, Seth, will handle the design and assembly of all optical components in the system. As the team leader, Seth will also be responsible for the administrative content and relaying information between the team and the sponsor. The EE, Raymond, will be in charge of designing the necessary power supply and integrating the GPS, IMU and LoRa modules into usable PCBs for both the receiver and beacon. Other responsibilities will be to support Blake with software implementation and Seth in properly driving the laser diodes. The CPE, Blake, will be responsible for most of the software work required for the project. This includes demodulating the signals from the QDP, as well as using those signals to give directions to the gimbal.

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