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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1 Project Description

1.1 Motivation and Background

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 requires more precision. 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. Being able to track a moving target while the receiver is also mobile would be useful in many different fields, such as robotics, automotive, and aerospace.

1.2 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, without accounting for any parameters or specifications we set by ourselves or our sponsor. They can be summarized as follows:

- Create a beacon with enough power and divergence to be detected by the receiver.
- Detect and track the beacon with the receiver.

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.
- 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 signal 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.

1.3 Requirements and Specifications

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

Table 2.1: Engineering Specifications.

1.4 Hardware and Software
1.4.1 Hardware

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.

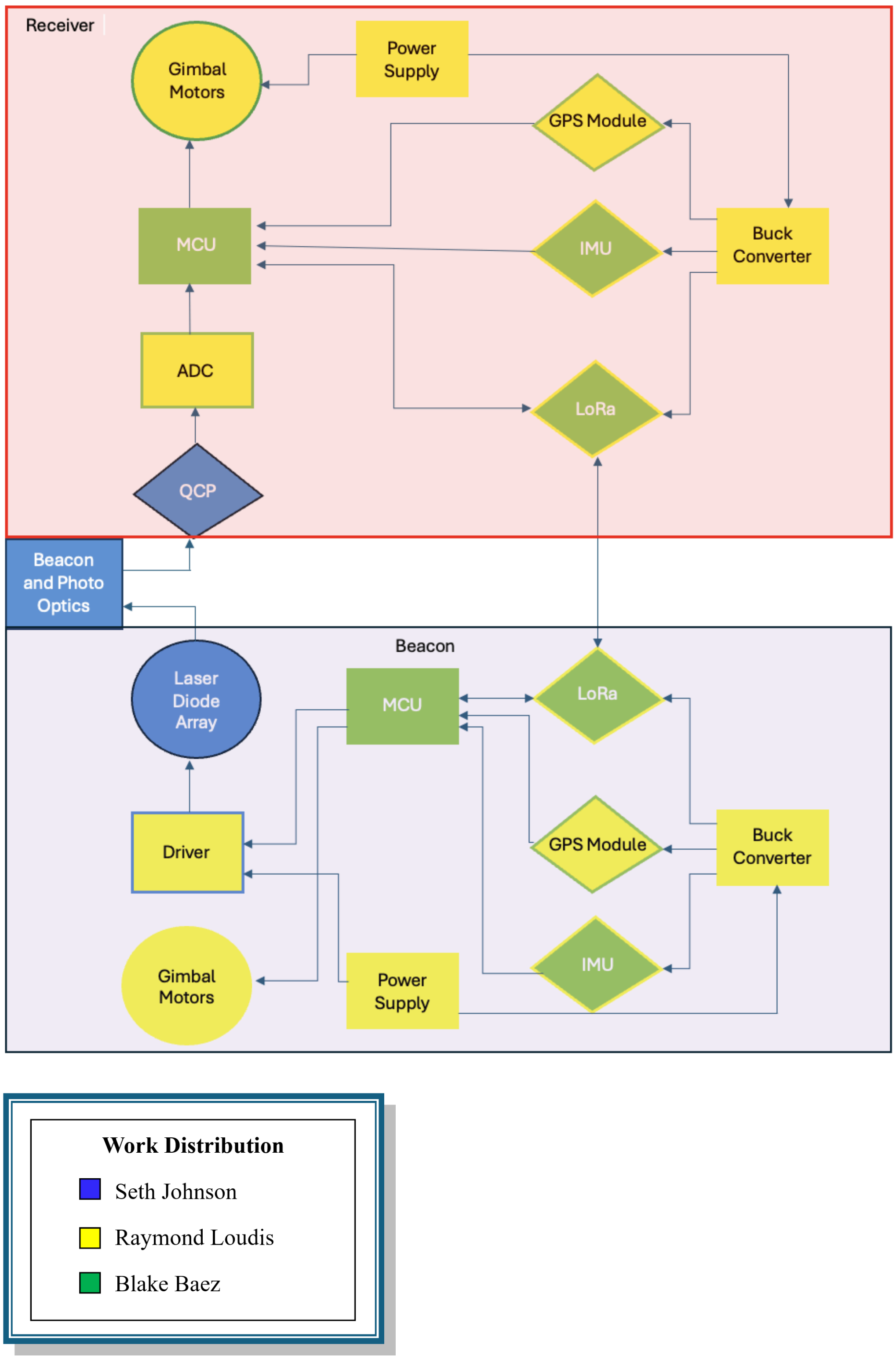

Figure 1.4.1: Hardware block diagram.

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 purpose 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.

1.4.2 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 24 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.

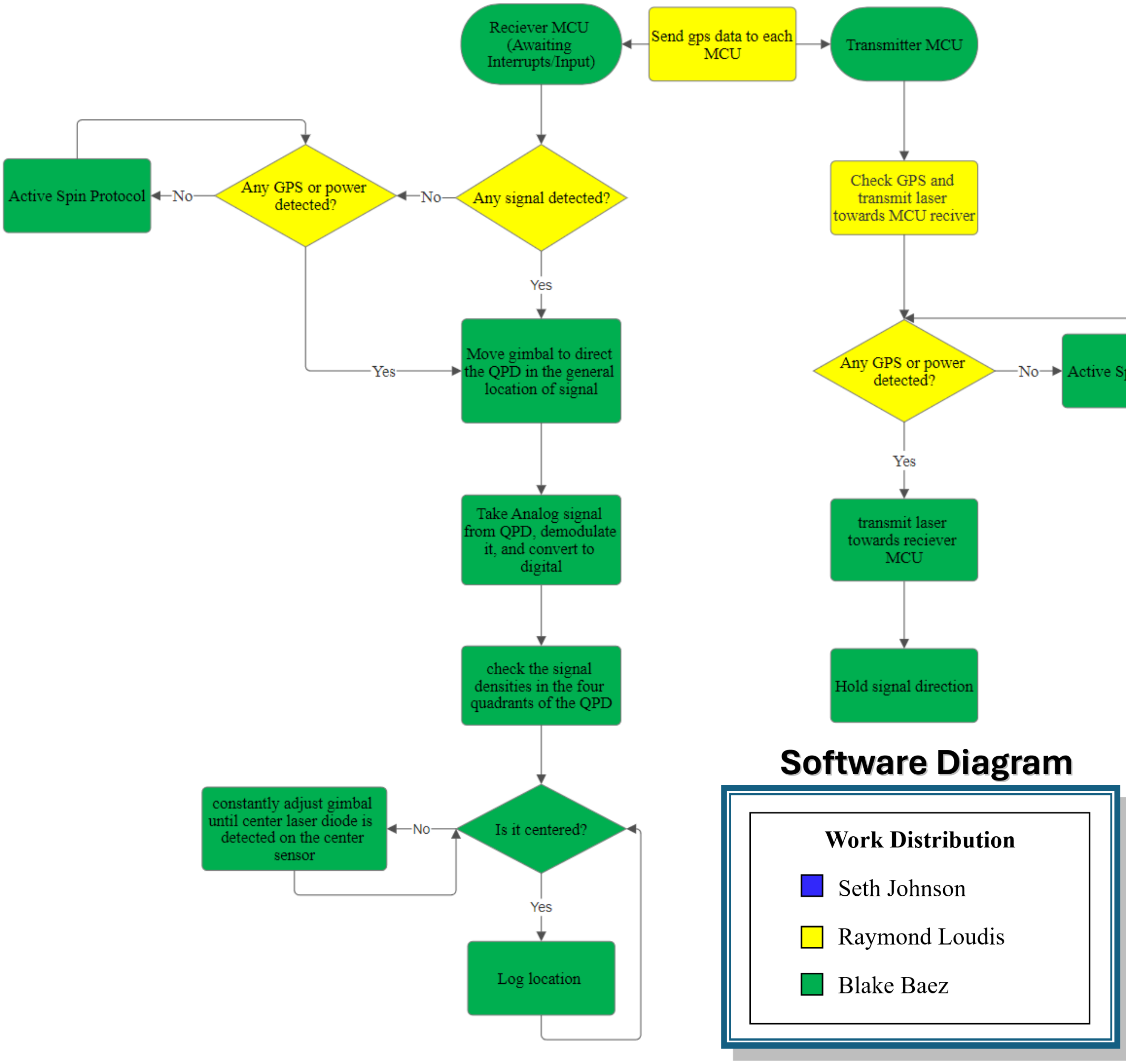

Figure 1.4.2: Software flowchart

1.5 Related Standards.

For this project, it's likely we'll have to abide by the following standards:

- IEEE 802.15 (Bluetooth)
- IEEE 802.11 (WiFi)
- IEEE 802.3 (Ethernet)
- TCP/IP

- SPI
- I2C
- Ardupilot
- NMEA 0183
- GPS Standard Positioning Service (SPS)
- USB
- C/C++
- Arduino

2 Research and Part Selections

The receiver gimbal is one of the most critical pieces of equipment we'll need 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
- Power Supply: 12-52V (3S-12S LiPo battery)
- 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

The Transmitter gimbal was our next priority. 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°

The microcontroller wasn't as much a top priority for a handful of reasons: the kind that are needed are wildly available and they are cheap. We just needed an Arduino that was capable of Wi-Fi/Bluetooth. This was done fairly fast as we picked the cheapest one that met our requirements.

GPS was another cheap addition that was low priority. This was because they can come cheap and most are compatible with arduino and the Gremsy gimbal. The list of potential GPS modules that we considered are the: u-blox NEO-6M, u-blox NEO-M8N, Quectel L80, GY-GPS6MV2, Adafruit Ultimate GPS Breakout, and the SparkFun GPS Breakout - XA1110 (Qwiic). All of them are compatible with arduino via UART and SparkFun can also use I2C. They all can interface with the gimbal via communication ports.

3 Administrative Content

3.1 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	$40	$1000
1550 nm LD	4	$200	$800
Annular Quadrant Photodiode	1	$500	$500
Dual Band Filter	1	$400	$400
Lenses	5	$30	$150
Dichroic Mirror	1	$160	$160
Arduino Nano ESP32	2	$20	$40
Receiver Gimbal	1	$1800	*Acquired
Beacon Gimbal	1	$100	$100
GPS module	2	$30	$60
IMU	2	$30	$60

LoRa Module	2	$20	$40
Li-Ion Power Supply	2	$300	$600
Rough total cost estimate			$3910

Table 3.1 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 3.2.1: 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 3.2.2 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 3.2.3 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.