Directed High Frequency Open Air Communication

Ryan Heitz, Sandy Cline, Brian Ascencio, Shane Zweibach

University of Central Florida School of Electrical Engineering and Computer Science, Orlando, FL

***Abstract* — The Directed High Frequency Open Air Communication project sources an electrical audio signal from an auxiliary input and uses this signal to directly modulate a laser. This modulation causes the detector to generate a varying current level to be amplified at the receiver. The amplified signal is then used to drive a speaker. The device also aims to achieve automatic and manual beam tracking through the use of servo movement. A remote control is to be used to manually control the servos, while automatic control of the servos will be based on the accelerometer position of the receiver and the information of that accelerometer would be sent through wireless modules to the transmitter.**

I. Introduction

While there are many different ways to transmit data through air, not all of them are the most secure means of communication. That is what we hope to achieve from our overall project. We want to ensure that data can be sent through the air and delivered both successfully and securely.

II. System Components

During the beginning of this project, we thought of many different components that can be used in this project, but due to the time constraints we had, we picked the few components that we thought would best be able to meet the minimum goals of the project.

A. Microcontroller

The Microcontroller that was selected for this project was the Atmega328p. This microcontroller was chosen for its familiarity with the team and its flexibility to attach and detach from a breadboard during testing. Additionally, the programming language used for this microcontroller is very similar to the C Language which will be very familiar with the group. The microcontroller also has a clock rate of 20 MHz which will be more than enough for our group to work with for the overall project. This microcontroller also has several different connection ports that we would use to connect to our other components such as UART, SPI, and I2C connectivity.

B. Accelerometer

The accelerometer was chosen by our group to try and achieve automatic control of the servos. The particular accelerometer that was chosen for this design was the MPU6050. This accelerometer can operate from 3.3-5V. It also works as a gyroscope.

C. Joystick Module

The group will also be integrating the KY-023 joystick module into the project to be able to manually control the servos holding the laser transmitter. The joystick will be able to take voltages up to 5V in the overall project. Additionally, the joystick module has dimensions of 4.0cm x 2.6 cm x 3.2 cm, which will be an important factor when mounting it on the PCB.

D. Servos

Since we wanted to include beam tracking for our project, one of the components needed to allow that were the servos on the transmitting side. If our receiver was located in a different source, we would use the servos with the laser attached to control where the beam would align itself at the receiver. The particular servos that were used were the Tower Pro Micro Servos, which can move at 180 degrees. Two of them are placed inside a housing to allow them to simulate an arm that can rotate and tilt. This housing does slightly restrict the range of the tilt servo as it can collide with the rotation servo at low values. Thus, it's range has been limited to a minimum of 48 degrees and a maximum of 180 degrees.

E. RF Modules

For our wireless modules, we decided to go with the NRF24L01 RF Modules. We chose these modules for both their compatibility with the Atmega328p software, the low amount of power that is required for it, and its frequency of 2.4 GHz. We want to ensure that the accelerometer data can be set successfully over from the receiving microcontroller to the transmitting microcontroller.

F. Op-amps

The operational amplifier chosen for the receiving circuit is an LM 386. This amplifier was chosen because it is designed for use in audio applications. Other parameters including bias voltage and input bias current were not at the forefront of selection criteria. Initial prototypes proved that this amplifier was capable of accepting an electrical signal from a photodiode and amplifying it. This electrical audio signal is capable of driving a variety of speaker sizes. The capability of accepting a photogenerated current and amplifying the signal to drive a speaker makes it possible for this amplifier to form the only amplification stage in the end product, simplifying electrical design.

The op-amp on the transmitting circuit is the LM 358. This amplifier is used to amplify the audio in signal. The output of this amplifier superimposes the DC power and the audio signal from the auxiliary jack to drive the laser.

G. Optoelectronics

Optoelectronics cover the lasing source, and photodiode chosen to generate and receive the electrical audio signal. The criteria for selecting these components varied throughout the course of the project, as priority of the design changed. Because the transmitting and receiving units will be aligned by human sight, some beam divergence is desired for ease of alignment. The distance of useful operation requested is to cover the area of a "room". This was taken to mean that the sending and receiving units should operate up to 25 ft. in range. Wavelength of the laser is 650 nm. Initially 1550 nm was chosen because of history of use in existing telecom and smaller dispersion through media. The usage scenario currently desired, alignment by human input, marked the change to a visible wavelength to aid in optical alignment.

H. Optics

Optics chosen for the transmitter and receiving units consist only of one lens. The receiving lens chosen is a 25.4 mm diameter lens with a back focal length of 22.2 mm. This particular lens was chosen for its larger size, enabling it to focus more incident light from the transmitter. The transmitting unit's lens is a 12.7 mm diameter lens with an 11.6 mm back focal length. Criteria for choosing the transmitting lens dictated only that the optic be easy to handle, and that the power of the lens produce a desirable beam divergence for ease of alignment.

I. LCD

A 16*2 AdaFruit LCD displays the current angles of both the rotation and tilt servos. In addition, when a user enters in a value on the IR remote, that value is printed on the LCD alongside an arrow pointing to the servo angle to be modified. This LCD was chosen for its simplicity and size, as we were not displaying a large amount of data with it and one of our goals was to shrink the physical footprint as much as possible. A 10k Ohm potentiometer was added to the circuit to calibrate the contrast of the LCD should any conditions change.

J. IR Remote and Transceiver

Infrared communication with a remote has been added to allow the user to adjust the angle of the servos at longer distances, while also allowing for more precision than that given by the joystick. It also has the benefit of not interfering with the RF modules. The part selected was an ELEGOO remote that was simple enough to interface with a Keyes IR receiver through software. The user can use the + layout of the volume and fast-forward/rewind buttons to rotate/tilt the servos. Alternatively, he or she can select a servo with the arrow buttons, enter an angle within range, and press the EQ button to directly set that servo to that angle.

III. System Concept

The system concept is a simple, one-way transmission of an analog light signal. This light signal is modulated by an audio signal from an auxiliary input. When the receiver gets a signal from the transmitter this audio signal is amplified and played back through the onboard speaker. Initially a digital signal transmission was sought after, but in the interest of delivering a more complete project, priority shifted to include a method of beam tracking at the expense of a digital transmission. Attempts were made to automate tracking of the receiver via accelerometer data, but this method required more time than was available to implement. In order to deliver a working version of a way to track the receiver, it was decided to implement a way to manually control the servos via remote.

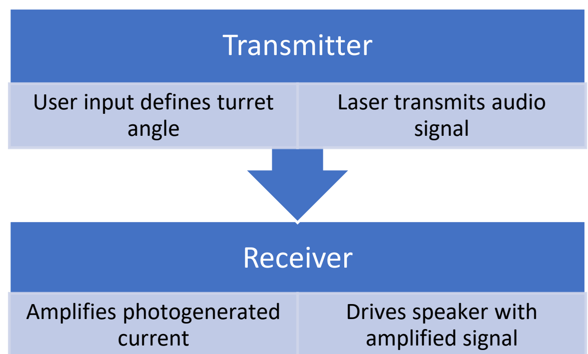

Figure 1: Flow diagram of transmitter and receiver.

IV. Hardware Detail

For the transmitter circuit several of the components require different types of connections and power. As shown in Figure 2, we want to power our whole transmitter through a 9V battery but we want to use a voltage regulator to bring it down to 5V to power certain components. Some of the components that we have will be powered through the microcontroller, such as the servos, the LCD, and the Wi-Fi modules. Some of these components will also require 3.3V instead of 5V, so in our transmitter, we will also want to include another voltage regulator that will output 3.3V.

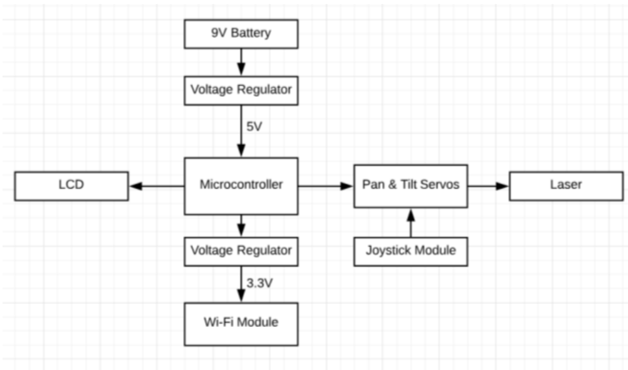

Figure 2: Transmitter block diagram

In the receiver block diagram in Figure 3, it will also be powered by a 9V battery and a voltage regulator will be used to output 5V. Also shown in the diagram, when the photodiode will receive the laser signal, that signal will output in the audio amp as shown below.

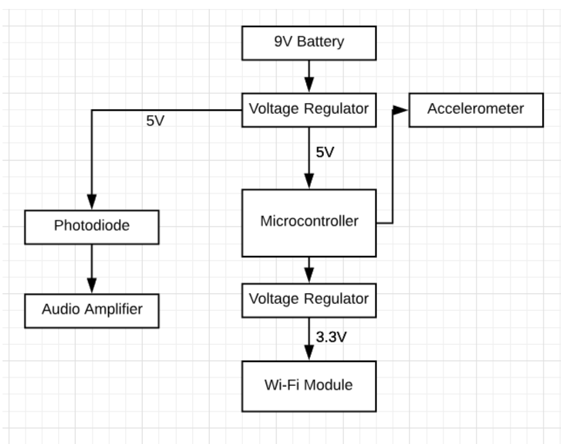

Figure 3: Receiver block diagram

A. Microcontroller

The Atmega328p will require a 5V source to power. Since we will be using a 9V battery to power the overall circuit, we will need to connect the battery to a 5V voltage regulator where we will be able to convert the 9V to 5V. By using the Atmega328p, we will be able to provide functionality to several of the components such as the RF modules, the accelerometer, the LCD, and the servos.

B. Accelerometer

The MPU6050 accelerometer can be powered to 5V. This module can be connected to the microcontroller via an I2C connection. As mentioned earlier this piece of hardware can measure both acceleration and rotation. It can record acceleration up to -16g and 16g. It also can record gyros up to -2000dps and 2000dps. However, there were some issues with both it's accuracy and the use of an accelerometer in general to extrapolate position. As per calculus, if one wishes to obtain position from acceleration, they must integrate twice over a time integral. However, this causes a severe loss of accuracy if the position and velocity at the start of that time interval are not known (or if a new interval is started). The loss of accuracy proved to be too dramatic to reliable track the receiver with this technology.

Additionally, an object that is traveling at 0 cm/s, 4 cm/s, and 400 cm/s will all have an acceleration of 0, even though they are moving at very different speeds and will thus have much different positions at any point in time. It is near impossible to program an accelerometer to fix this issue.

C. Joystick Module

After experimenting with several modes of input, including buttons, we decided that a joystick module should be used for manual alignment. Precise aiming can already be done via the IR remote and the joystick is much simpler to implement, for the most part.

By default, the joystick values directly map to the servo angles through software, meaning that if a user released the joystick, both servos would return to their middle value of 90 degrees. This would require the user to physically hold the joystick in a very specific position while transmitting to avoid disconnects, which would be very frustrating. The software was changed such that the joystick would act more like that of a video game controller, moving the servos in the direction of input and not moving them when released.

D. Servos

As mentioned earlier the Tower Pro Micro servos will be used to perform pan and tilt operations that will be used to perform beam tacking for our device. There will be both a horizontal and vertical servo that will be used to help move the laser. Both the servos will be powered by 5 volts and a PWM signal will be sent over to them.

E. RF Modules

The NRF24L01 RF modules will require a maximum amount of 3.3 volts. These modules will require an SPI connection to the microcontroller. These modules can be program to either listen to incoming data, or writing data to output. Unlike our laser, these modules will use a radio frequency to transmit data to each other. Also the only data that will be sent to these modules will be the accelerometer data, which would be needed to help control the servos of our device.

F. Op-amp

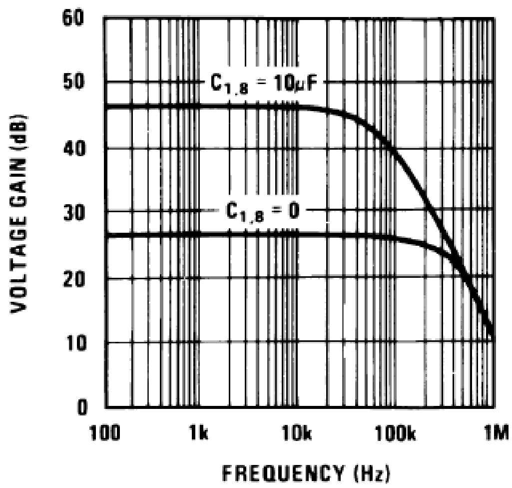

Figure 4: LM386 frequency response chart. [1]

The receiving operational amplifier was not only chosen for its frequency response, but also because of its low current drain. This means lower power consumption and longer battery life. Figure 4 shows a voltage gain for frequencies starting at 100 Hz and this extends well beyond the range of normal human hearing of 20 kHz.

G. Optoelectronics

The optoelectronics chosen consist only of two parts, the laser, and the photodiode. Both parts had to be suitable for use with the existing electronic circuitry and small enough to be portable. Semiconductor diodes were chosen that are housed within TO-style can packaging. This is preferred because of the familiar style of the packaging and small form, allowing for ease of integration. Figure 5 is a plot of the responsivity of the photodiode used in the receiving circuit. Because the laser is 650 nm, the photodiode will produce roughly .75 A/W. The steep slopes of the responsivity are actually a good thing. The responsivity covers the visible spectrum as well as near infrared, but it peaks at about 850 nm. This leaves the receiving circuit susceptible to noise from sources emitting infrared radiation, but tests indoors have not shown this to be much of a problem.

The laser diode will be discussed in more detail in section 5, circuit detail.

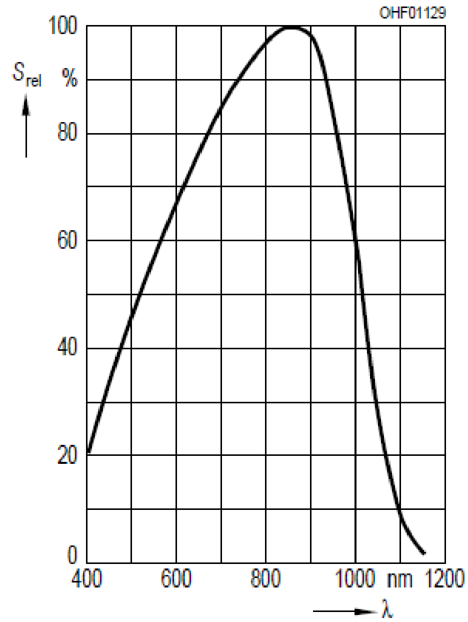

Figure 5: Responsivity of the photodiode as a function of wavelength. [2]

H. Optics

Figure 6 shows the receiving optic and the convergence of incoming parallel rays of light. The photodiode used to generate a photocurrent from incoming light must be situated slightly before the focal point of the lens. The reason for this is twofold. First, the photodiode must not reach saturation as no information can be gathered from a constant signal level. Second, there must be enough tolerance in the change of off-axis rays so that a slight pitch in angle will not cause light to converge while completely missing the photodiode.

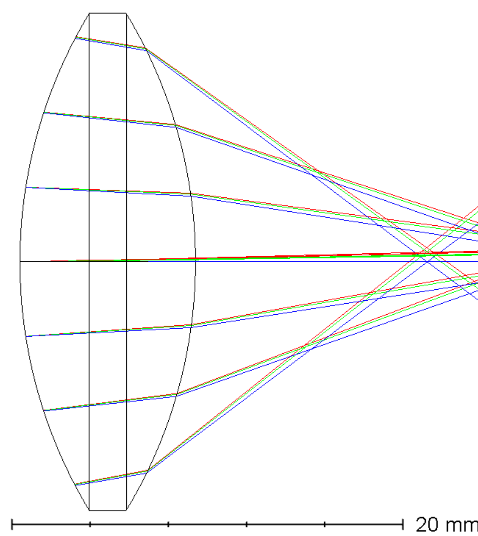

Figure 6: LB1761 Optic

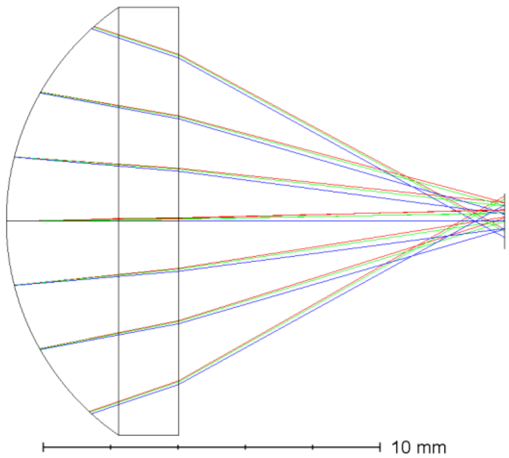

Figure 7: LA1540 Optic

Figure 7 illustrates the transmission optic, behind which the laser is situated. The laser has a built-in collimation optic, simplifying optical design. All incident rays from the lasing source to the transmission optic can be assumed to be parallel, and collimated. This allows for only the transmission lens itself to determine beam divergence.

V. CIRCUIT DETAIL

This section provides the circuit schematics to the receiving and transmitting circuits with brief descriptions of prominent component functionality.

Figure 9 shows a voltage regulator on the top half of the schematic and an op-amp on the bottom half. The VAC symbol is standing in place of the audio signal being fed into the op-amp at the same point as the DC voltage. This is a non-inverting op-amp which is configured to have a gain of 2. The purpose of this configuration is to properly bias the laser diode so that clipping does not occur by saturating, or turning off the laser. This scheme is illustrated in figure 8 below.

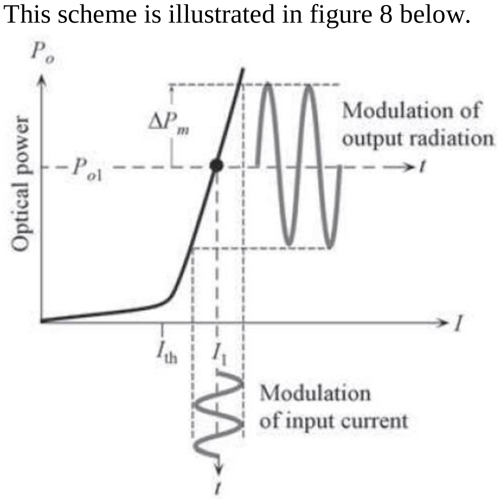

Figure 8: Desired laser bias for transmitting an AM signal. [3]

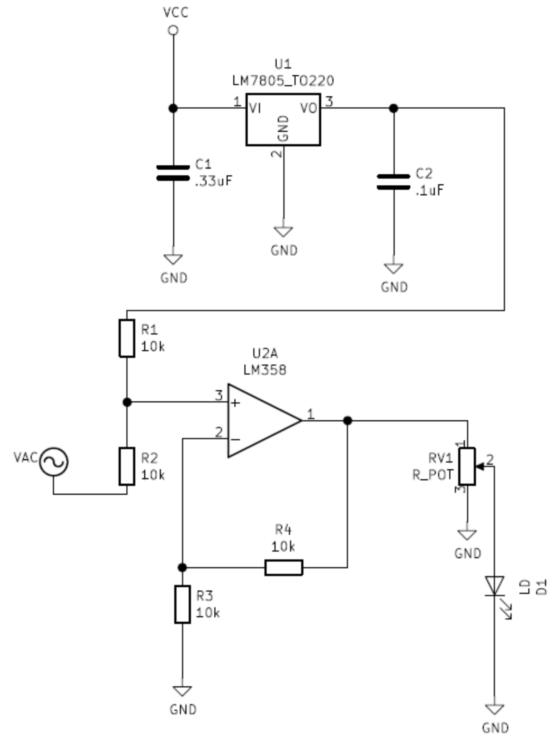

Figure 9: Transmitter circuit

Figure 10 shows a photodiode connected directly to the two inputs of the LM 386. The op-amp reads a change in voltage across the photodiode and amplifies it to drive a speaker. A capacitor is connected across pins 1 and 8 to set the op-amps gain to 200.

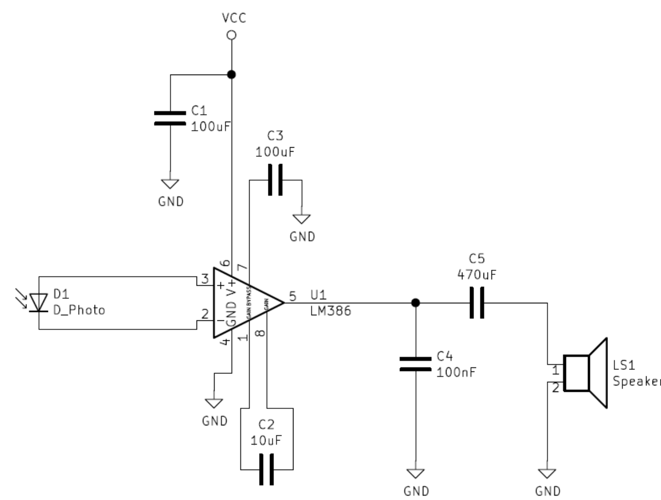

Figure 10: Receiver circuit

VI. SOFTWARE DETAIL

The IDE that will be used to create the software is the Arduino IDE. Since most Atmega based microcontroller chips are compatible with that type of IDE, we believe that the Arduino IDE would be the best development tool used for our software.

The code that will be running will first be operating on the receiving side. The receiver will continuously read in the accelerometer data that is coming in from the microcontroller. Then that data will be sent over to the transmitter via the NRF24L01 modules.

Then on the transmitting side of the microcontroller, the wireless module will read in the data coming in from the other RF module and use that data to control the servos of the transmitting microcontrollers.

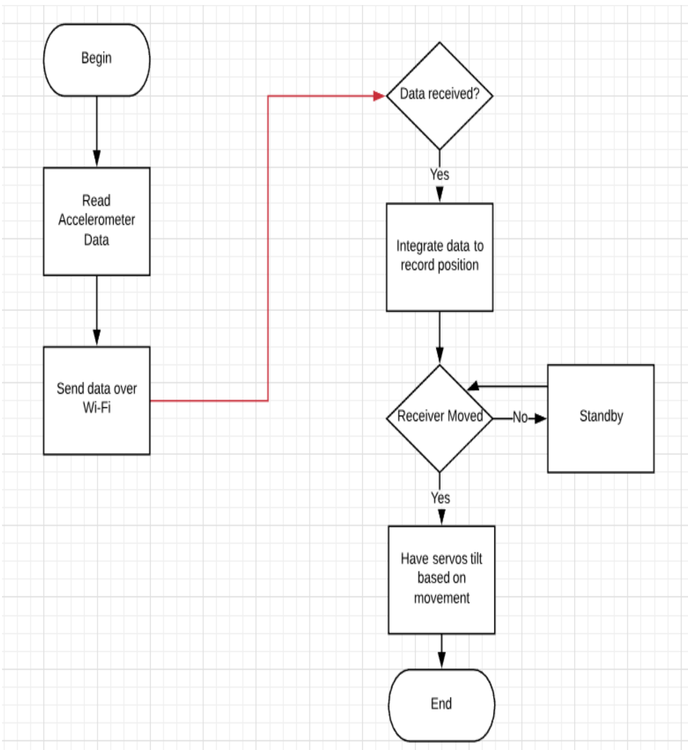

Figure 11: Software flowchart for transceiver-side automatic beam tracking with the MPU 6050 accelerometer and NRF 24L01+ wireless modules.

Another way we plan on controlling the servos will be through a remote control. With the remote control, we can select which servo we want to control and what degree orientation we want the servo to position itself at. As an additional feature, the orientation of the servos will also be displayed on an LCD. The paraphrased code for the IR is below.

The processKeypadEntry() function stores the value in the keypad in a 3-digit array if a number was pressed or multiplies each digit of the array by the appropriate weight and sums into the desired angle value if EQ was passed. It then sets the position variable of the currently selected servo and clears the array for next time (if EQ was pressed).

The lastRes variable stores the value of the last button press

```
void processIRInput() {
  int res = 0;
  if(lastRes >= 5 && lastRes <= 17)
    lastRes = 0; // prevents accidental duplicate numbers
  res = getResFromIRTransmission();
   if(res >= 5 && res <= 15) // EQ or KeyPad
    processKeyPadEntry(res);
  if(res == 1 && xPos < xMax) // FF
    xPos++;
  if(res == 2 && xPos > xMin) // FB
    xPos--;
  if(res == 3 && yPos < yMax) // VOL+
    yPos++;
  if(res == 4 && yPos > yMin) // If VOL-
    yPos--;
  if(res == 16 || res == 17) // UP OR DOWN
    switchSelectedServo(res);
  lastRes = res;
}
```

and sets res to that value if the button is held down. This dramatically increases the usefulness of the "D-Pad" in adjusting the servos. It is cleared if a number is entered to prevent the user from accidently typing in two digits of the desired angle by holding the button slightly too long.

A third option we had for controlling the servos would be through the joystick. With the joy stick we can tilt it in different directions which could allow us to control both servos at the same time. The software diagram for this is below.

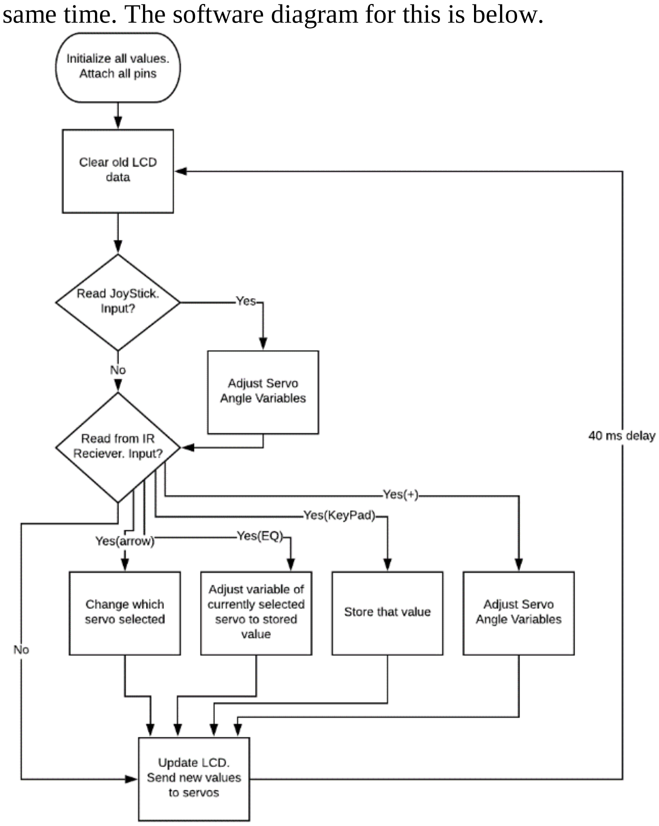

Figure 12: Software flowchart for transceiver-side manual beam tracking with a joystick or remote.

VII. Board Design

A. Software

There were a variety of software's that were at hand, specially as a student in the engineering field, however, the chosen software that the team used was EasyEDA Editor as it is very user friendly and could be used as private or with teams. As Engineering student working in teams, it made it extremely easy for each of to view the progress of the CAD file and share amongst each other to make sure we all agree on what was put into the board and adjust it as needed. In addition, since the corporation has everything for an engineer to make the PCB, it made it extremely easy and time efficient to make schematics, PCB design, manufacture the PCB, and order the components from the company as there's a variety of parts that sizes for the same purpose and there shall not be any error when ordering the PCB, specially for erroneous parts since that is the last thing a project of this magnitude wants.

B. Schematics

The schematics is a huge part of the Board design as which took some time to develop as it took quit some research and development since the project had many stages of development. Each stage had its complication as the best part of designing the schematics is not just make it engineer friendly but also, user and technician friendly for it to be maintain since each and every component that is made has to for sure be exact and to the point for any user to read. However, after many breadboard prototypes and looking over many datasheets to assemble this project so that it can be friendly for anyone, the final product was then done and review by each other to make sure that there are no errors as if there are some errors, then when making the PCB, there are going to be issues. Once the schematics were done and set that it meets standards. It was time for the PCB to be design

C. PCB

Once the schematics was done and ready for the PCB, then, the converting from schematics to PCB was then used to make everything happen so that everyone can see each and every part and with the traces so each component can then interact with each other accordingly. At the beginning, we took the effort to place our components where we wanted and try to adjust the traces to our needs but as time progresses when using the CAD software ad got familiar with it, then we started to use the softwares shortcut which save at the end a large amount of time. This then brought us to a very intriguing part, when changing the layout in the schematics and a couple of parts. Once those parts were change, then the PCB design had its changes which created a couple of movements of parts. This then provoke more work but as kkk as previously mention, the familiarity of the software was the perk since the parts were just place where we wanted them and the software did its magic to change the track and make every connection that is needed according to the schematics.

D. Assembly

There were two ways to develop the Assembly of the PCB board. The first way was to let the company who is building the PCB install them or we engineer install the chips. Since there were a couple of time constrains, the decision was to just order the PCB and the engineers solder the components as that could be a couple of hours of work instead of 2-3 business days. However, as notice when building the schematics, there were many package sizes to the components and to not make any erroneous steps, the decision was to order the parts from the same company so that we have the components that were use when creating the parts. That made it easier since the main goal is to make it as easy as possible for each and every one since each engineer is on a tight schedule and if there were erroneous parts specially base on size, then the PCB could not be assemble and not finish on time.

VIII. BUDGET

The overall budget of the main components is listed as shown in the table below. The most expensive out all the components was the PCB. Overall, each of the group members has purchased their own respective components that they needed for their portion of the project.

Component	Price
Microcontroller	$5.95
Laser	$.60
Amplifier	$.33
Pan and Tilt Servos	$19.42
Accelerometer	$10.99
Wi-Fi Modules	$7.59

Photodiode	$1.13
LCD	$5.99
PCB	$60

Table 1: Expenses

IX. COMPONENT TESTING

In order to ensure that each of our components are working properly, we make sure to test them separately on a breadboard. During the course of development all electrical components were prototyped on an electrical breadboard. At certain points throughout the semester each member had to demonstrate progress with these prototypes. If a feature was too far behind in development, it had to be discontinued so that effort could be directed towards features that could be integrated in time. When a component of the project has been thoroughly tested, the final iteration of the design is finalized so that it could be etched into a PCB. When the PC boards had their components soldered to them they are finally able to be placed into 3D printed housing for protection and portability. The housing also plays a critical role in tying together the electronics into a cohesive unit. Up until assembly, the team had different design requirements which effectively split the team into two sides. One side was responsible for MCU instruction coding, while the other was responsible for the circuitry that controlled the laser, photodiode and audio signal. The assembly of the transmitter combined the teams efforts on servo control and signal transmission.

X. CONCLUSION

The overall project had its successes and difficulties. The experience of researching, designing and developing a working prototype was a new experience for everyone on the team and our overall design had to go through many different revisions. In the end however, we had done our best to create a working prototype that met the minimum goals of the overall project. Conducting research of the project was a challenge from the point of view that there were many different directions we could've taken when building this project and there several different hardware options that we needed to research.

THE ENGINEERS

Sandy Cline is a 28-year old graduating Photonic Science & Engineering student with a background in optics, electronics and computer science.

Ryan Heitz is a 23-year-old senior Computer Engineering student who is graduating on May 2019. Ryan also accepted a job offer at Lockheed Martin in Orlando as a systems engineer

Brian Ascencio-Aleman is a 26-year-old dual Electrical and Computer Engineering student with a minor in Intelligence Robotics System and theoretical Physics who is graduating in August 2019. He will further his career by staying at UCF to continue his education and complete his PhD as a dual degree Engineer with a concentration on signal processing in Control Systems. Also, he is working to move into his career at Universal Creative as a Control System Engineer with the Engineers, CEO, and SVP of Universal Studio, Intern as an recommendation. ElectroAccustical Engineer at Parsound, and upon finishing the degree, the president of Precision Test Solutions wants to have a conference meeting to become a Jr. Engineer.

Shane Zweibach is a 22-year old Computer Engineering student who is graduating in August 2019. He started coding at age 13 by modifying Halo gametypes and continued to code in HTML and CSS throughout high school. In college, he learned to program in C, Java, Go, Python, and Prolog in various classes alongside assembly. He aspires to work at Apple, Google, or Samsung on mobile technology as well as the incoming battery revolution.

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REFERENCES

1. (2017). LM386 Low Voltage Audio Power Amplifier datasheet (Rev. C). https://www.ti.com/product/LM386?qgpn=lm386, Texas Instruments.
2. Kasap, S. O. Optoelectronics and Photonics - Principles and Practices, Pearson.
3. (2015). SFH 203 P Datasheet. https://www.osram.com/media/resource/hires/osram-dam-2496046/SFH%20203%20P.pdf, Osram