New Implementation

Of

Hide and Seek

Project 21 Final Paper
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Abstract

This paper documents and explains the design process and outcome of a new implementation of hide and seek. It is a game that uses radio frequency and infrared communications to give the original game of hide and seek a new and updated look. This document outlines the costs and procedures necessary to get a functional proof of concept working in the span of 13 weeks. Even though the final product of this project was not completely functional, there are many verifications to show the inter-workings of specific components and how future work can be pursued to make for an even more successful product.

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1 Introduction

1.1 Objective

One of the biggest pushes in today's technology is a push for virtual, augmented, and merged reality in everyday life. A major problem for this focus on these new forms of realities is the ability to know what the user is looking at in front of them in an easy and efficient way. Currently a few ways to notify a user what objects or locations are in front of them requires the use of various forms of computer vision. This requires clear view of the object and fails when the vision system fails, also computer vision requires a high degree of computing power. Another way of identifying targets to computers is the use of QR codes, but again that requires the QR code to be seen by the user.

We hope to create a non-computationally intense way for a device to determine when a user is facing a target and then be able to give that user information on what they are seeing. The key here is the user won't actually have to be looking at the target to know the information is available. Our proposed solution is to use a mixture of RF and IR communications. This way we can have much lower computing power than most forms of computer vision that are currently out. We plan to use the RF side of the project to determine when a device is in front of the user. Using RSSI a user will be informed when there is a target near them that can be accessed without actually having to be looking at the target. Once the user is given this notification then they can choose to pursue this information or continue with what they were doing. The IR system will function as the way to send information between the user and the target once the target is in the users' field of view.

Just implementing some sort of device described above seemed a little boring so we decided to implement this same sort of technology in the format of a hide and seek game. Instead of a target described above we will have a hider and instead of the user described above we will have a seeker. Using RSSI we plan to notify both parties when they are close together or in range. Then the point would be for the seeker to tag the hider using an IR signal. The games dynamic is explained in more detail in section 2.1. Simply put, we notify a user when there is a target near and then send information back and forth once close enough. Our solution of creating this game clearly still retains the fundamentals necessary to combat the problem described.

1.2 Background

We are in a world where the want and need for information quickly and efficiently is a fast-growing market. Now there are many products out currently which can do this in a pretty effective way. For example, you can verbally ask your phone just about anything and information on the topic will be right at your fingertips. However, what if you have a question about something you are currently looking at. It seems a bit repetitive to look at it and then type the name of it in on your phone or say it out loud. What if we can cut out that step all together? Merely being near something in front of you is enough to get you to a plethora of information if you so choose. Now there are some similar products that use computer vision to do similar tasks however the amount of computing power and cost of these products are very high. Our project will focus on being a proof of concept for this idea of being able to be notified and receive information on anything near you as quickly if not more quickly than say, looking it up on your phone.

This ease of access will encourage people to ask questions and learn more about what they see. We believe the biggest reason people don't pursue questions they have about what's in front of them is not because they don't have the resources to do so. We think it's because the ease of access is just not quite where our audience would like it. A product that solves this problem and makes it so easy that it virtually requires no effort or time will be a product people will want.

1.3 High-Level Requirements

- Device must be able to notify the user when the target is in their field of view.
- Device must be able to send and receive data over IR channel.
- Device must be able communicate with user via LED's, Bluetooth, and tactile vibration.

2 Design

2.1 Block Diagram

We propose to make a proof-of-concept in the form of a merged reality hide-and-seek game that will be based on a mixture of radio frequency and infrared communications. The game will be played by two users. The first user will be referred to as the "Seeker". Their goal is to try and find the second user. The second user will be referred to as the "Hider". The hider's goal is to remain out of face-to-face contact with the Seeker. We hope to use a directional antenna radio frequency system to allow the Seeker to be notified when the Hider is generally in front of them and use RSSI to approximate the distance between them. This will work up to 100 meters. LED's will help the seeker know just how far away they are and an IR system will allow the seeker to tag the hider once they are close enough together. This distance will be no further than about 2 meters. It should be noted if we wanted to commercialize this product we would want each user the capability to be either the hider or the seeker. However, we believe it is outside the scope of this course to implement such a design.

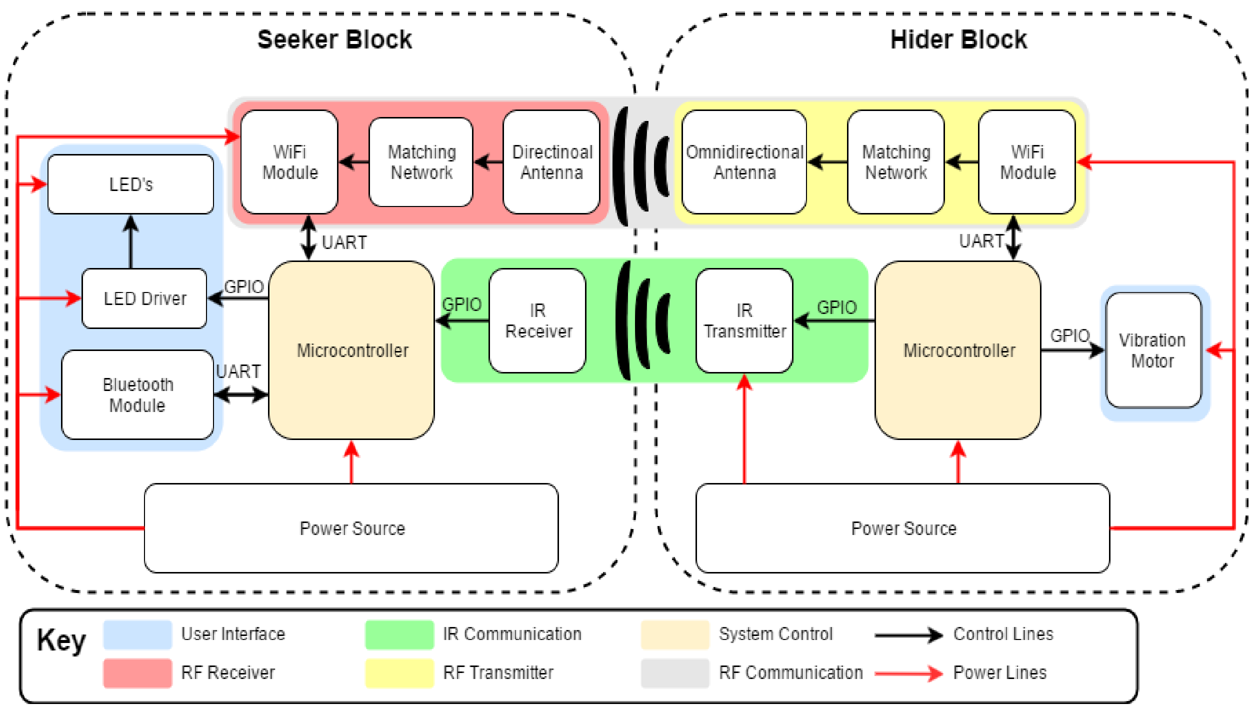

Figure 1: High-level block diagram of seeker block circuit (left) and hider block circuit (right).

2.2 Physical Design

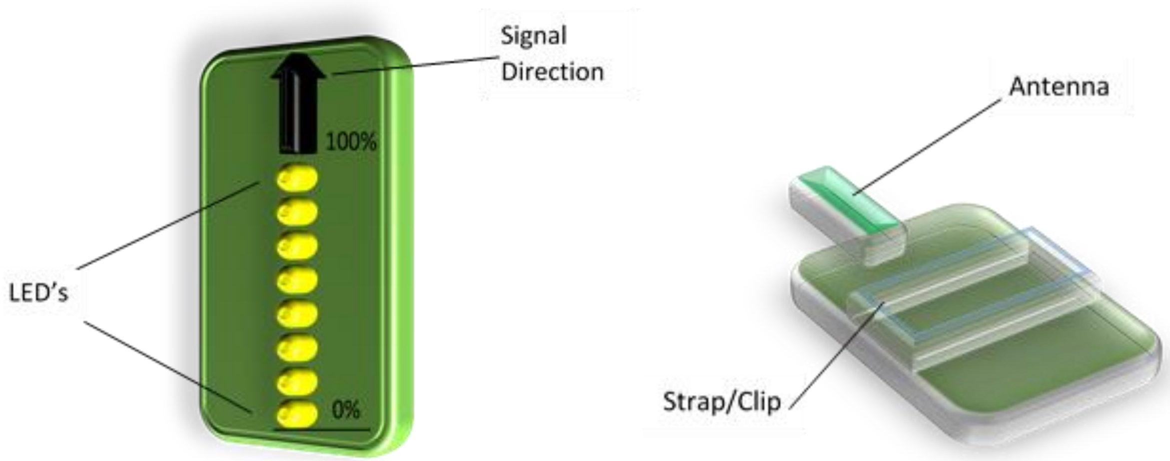

Figure 2: Physical designs of seeker device (left) and hider device (right).

By looking at the block diagram we have two separate circuits, one for the hider block and one for the seeker block. As mentioned earlier, if we wanted to commercialize this product we would make sure to give one user the functionality to be a hider and a seeker to let them pick and switch between the two easily. Due to the limited time, we have during this course we decided to have two separate devices. The seeker's portion will be a handheld device about the size of a phone with LED's on the front indicating the received signal strength of how close the hider is and an arrow pointing in the direction the antenna is receiving. The hider's device will be about the same size except it won't have any external lights. It will be able to clip to the strap of a backpack to make it easy to carry without having to hold it. Prototype images of the devices can be seen above.

2.3 Functional Overview & Block Requirements

2.3.1 Matching Networks

The matching networks are used to transfer the most efficient power between the antenna and the RF blocks. These will be implemented once we can measure our antennas' parameters.

Table 1: Requirements and Verification for Matching Networks

Requirement	Verification
Be able to impedance match the antenna to 50 ohms +/-5% with a bandwidth of the ISM band (2.400GHz-2.4835GHz) [6].	1. Use network analyzer to sweep frequency of 2.400GHz and 2.4835GHz and ensure measured impedance is within +/-5% of 50 Ohms. 2. Also, ensure the transmitted signal does not attenuate more than 3 dBs

2.3.2 Power Sources

Our project will be powered by multiple outputs voltages from our test bench to power each circuit. Note that there are two power supplies (one for the hider and one for the seeker). This is because the hider and the seeker will need to be able to separate in the validation portion of our project. This might require portable power supplies. However, if we were to commercialize this product we would power our device with batteries to make the devices sleek and not bulky.

Table 2: Requirements and Verification for Power Sources

Requirement	Verification
The power sources must be able to supply a steady 3.3 V and 5 V at a tolerance of +/- 5% for a current draw up to 200 mA.	1. Connect the 3.3 V power source to a 16 Ω resistor. 2. Connect an oscilloscope across the load ensuring the voltage stays at 3.3 V +/-5%. 3. Do steps 1-2 with a new load resistor of 25 Ω.

2.3.3 Wi-Fi Modules

The RF receiving block will act as the receiver for the directional antenna so that it knows how far away the hider is. It will use RSSI to determine this and will communicate this information to the microcontroller.

Table 3: Requirements and Verification for Wi-Fi Modules

Requirement	Verification
Must have RSSI capabilities that maintain connection up to 60 m +/- 10%.	1. Use 2 working Wi-Fi modules and start with both devices oriented pointing at each other 0 m away. 2. Record the RSSI values in dB for every reading. 3. Using a tape measurer continually move back 5 m at a time 4. Record the RSSI value for each 5 m increment until loss of connection.
Ability to receive Wi-Fi signals on ISM band(2.400GHz-2.835GHz) [6].	1. Use a spectrum analyzer that can emulate a Wi-Fi transmitter and broadcast beacon packets on every Wi-Fi channel. 2. Ensure module receives packets.
Ability to transmit Wi-Fi signal on ISM band 2.400-2.4835 GHz [6].	1. Measure the output of the module with a spectrum analyzer that can emulate a Wi-Fi receiver. 2. Sweep through all the W-Fi transmitting channels. 3. Ensure that the spectrum analyzer can receive packets on all W-Fi channels.

2.3.4 LEDs

The LED's will be an array of LED's in a line that will communicate to the user how strong their signal is based on direction and proximity to the hider. The more LED's that are lit up will correspond to the stronger the signal and therefore the closer the seeker is to the hider.

Table 4: Requirements and Verification for LEDs

Requirement	Verification
Diffused LED easily viewed by user from an arm length away (approximately 1m) in daylight.	1. Bring device outside on a well-lit day in 110,000 lx. Make sure the sunlight is > 110,000 lux using a photoresistor with a 1% tolerance [4]. 2. Hold device > 1m away from face. 3. Sweep device through 360 degrees around while also covering angles from perpendicular to ground, to parallel with ground. This process is for trying to find the worst viewing angle. 4. Give the device to another user to hold the device at the decided-on angle and have the user say how many / which LED's are powered on. 5. Randomly light a number of different LED's for user and record their accuracy. 6. If the user gets 100% correct, then the LED's are bright enough.

2.3.5 Vibration Motor

The vibration motor must take in input form the microcontroller that controls what vibration pattern is operated and when it is operated. When the signal comes in from the microcontroller the vibration motor turns on effectively shaking the hider device strong enough to effectively tell the user what just happened in the game.

Table 5: Requirements and Verification for Vibration Motor

Requirement	Verification
Must have 2 different vibration patterns that can be easily distinguished while device is attached to a backpack strap on chest.	1. Place device as specified on a test subject. 2. Randomly drive the vibration motor with the 2 different patterns. 3. Have the test subject clarify which vibration pattern is being driven. 4. Record the accuracy of the test subject and make sure it is 100%.
Each vibration pattern must be strong enough to be noticed by the hider while device is attached to a backpack strap on chest.	1. Place device as specified on a test subject. 2. Randomly drive one vibration pattern without telling the test subject. 3. Have the test subject say when they feel a vibration. 4. Record the accuracy of the test subject and make sure it is 100%. 5. Repeat steps 2 through 4 with the other vibration patter.

2.3.6 LED Driver

The LED driver will be powered by 3.3 volts from the power supply and will get information from the microcontroller on which LED's to light up. The driver will be a shift latch register.

Table 6: Requirements and Verification for LED Driver

Requirement	Verification
Drive LED's independently.	1. Run a light up sequence, where we can illuminate each led alone. This sequence should light up one LED at a time until all LED's have been cycled through. 2. Ensure that no other LEDs except for the chosen led turns on.
Output a voltage of 5 volts +/- 10% (LED's forward voltage drop).	1. Light up 1 LED. 2. Measure the output voltage on every output pin that is powered using a multimeter. 3. Increment the number of LED's by one (i.e. light up one more LED) and then repeat step 2. 4. Make sure to note the output pin voltages are within the specified values.

2.3.7 Omnidirectional Antenna

The omnidirectional antenna will take information from the RF transmitter (through the matching network) in the hider block and transmit this information in all directions so the seeker can pick up on this signal in all directions.

Table 7: Requirements and Verification for Omnidirectional Antenna

Requirement	Verification
Tuned for the 2.4-2.4385 GHz (ISM band).	1. Measure output power in anechoic chamber by connecting to a spectrum analyzer recording the power output. 2. Sweep the frequency range given to ensure normalized gain does not dip below 3 dBs
Beam pattern should be omnidirectional such that the signal power is within 3 dB in all directions, at the same radial distance, on the same plane. This should hold true for our required range of 0 m to 60 m.	1. Give seeker device to one user and the hider device to the other. 2. Make sure the users stay at a constant distance starting at 10m. 3. Have one user walk radially 360 degrees around and make sure the signal strength remains within 3 dB the entire time. 4. Increment the distance by 5 meters and repeat step 3-4 until 60 m is reached.

2.3.8 Bluetooth Module

This module is used to provide communication between our system and a cell phone app. The app would allow for additional functionality in gameplay such as score, random matchmaking, and rankings.

Table 8: Requirements and Verification for Bluetooth Module

Requirement	Verification
Must be able to create an open network and connect to other Bluetooth devices and transfer data back and forth.	1. Power Bluetooth module and have it produce an open network with known device name. 2. Use phone app "SmartData" to connect with known device and try sending data back and forth. 3. Record connection and data transfer.

2.3.9 IR Receiver

The IR receiver will allow the seeker to "tag" the hider within a certain distance. It will do this by receiving a signal from the directional antenna through the matching network and send the information to the microcontroller once this occurs.

Table 9: Requirements and Verification for IR Receiver

Requirement	Verification
The IR receiver must be able to receive IR signals from a transmitter at distances between 2 meters and 10 meters.	1. Place the IR receiver on a direct line of site with a transmitter. 2. Start at 2 meters and observe whether the receiving device picks up the signal by probing the output pin with an oscilloscope (note the output is an active low pin). 3. Increase the distance in 1 meter intervals until 10 meters is reached and record the data observing if the transmitted signal is received.

2.3.10 IR Transmitter

The IR transmitter will continually transmit an IR signal so when the hider is close enough and the seeker is pointing their device at the hider, the seeker will be able to "tag" the hider and the game will be finished.

Table 10: Requirements and Verification for IR Transmitter

Requirement	Verification
The IR transmitter must be able to transmit IR light greater than 2 meters and less than 10 meters.	1. Place the IR transmitter on a direct line of site with a receiver. 2. Start at 2 meters and observe whether the receiving device picks up the signal by probing the output pin on the receiving device. 3. Increase the distance in 1 meter intervals until 10 meters is reached using a tape measurer and record the data concerning if the signal is received.

2.3.11 Directional Antenna

The directional antenna will pick up a signal from the omnidirectional antenna in the hider block if the antenna is oriented towards the hider. It will then pass this information on to the RF receiver through the matching network.

Table 11: Requirements and Verification for Directional Antenna

Requirement	Verification
Tuned for the 2.4-2.4835 GHz (ISM band).	1. Measure output power in anechoic chamber by connecting to a spectrum analyzer recording the power output. 2. Sweep the frequency range given to ensure normalized gain does not dip below 3 dbs.
Physically small enough for commercialization and not too bulky for user to hold and carry on person (less than 150 mm x 80 mm).	1. Using a tape measurer with millimeter units measure the dimensions of the antenna. 2. Measurements less than the ones noted for commercialization passes this test.
Single main lobe with no side lobes greater than -3dB, with an effective angle less than or equal to 2.75 sr (a human's focused field of view).	1. Take seeker device and place flat in one direction. 2. Place hider device directly in front of the seeker device about 20 m away using tape measurer. 3. Using compass from original position have hider walk radially in one direction and stop when the received signal strength has dropped dramatically (less than -10 dB). 4. Note the angle that this happens and multiply by two. 5. Make sure this result is less than the noted requirement.

2.3.12 Microcontrollers

The microcontroller provides overall control for the system. This includes managing RF, IR, Bluetooth, and the LED driver.

Table 12: Requirements and Verification for Microcontrollers

Requirement	Verification
Should be able to control the number of LED's powered on through the LED driver, via serial interface, based on the RSSI value from the Wi-Fi module.	1. Program the microcontroller with the code to control the LED's using input from the Wi-Fi module. 2. Push a range of serial signals to the microcontroller to sweep the entire range of RSSI values expected as specified in the documentation. 3. Check to see if the LED's light up in a uniform and incremental fashion.
Should be able to receive serial input from the IR receiver and send a serial signal to the LED's via the LED driver to flash the LED's.	1. Program the microcontroller with the code to control the LED's using input from the IR receiver. 2. Push a serial signal to the microcontroller that mimics a signal from the IR receiver. 3. Check to see if the LED's flash on and off as to notify the user they have been tagged.
Should be able to receive a serial input signal from the Wi-Fi module based on the RSSI value and should send a serial signal to the vibration motor to turn on (should be different vibration pattern than the requirement below) (long less intense pulses).	1. Program the microcontroller with the code to control the LED's using input from the Wi-Fi module. 2. Push a serial signal to the microcontroller that mimics an RSSI signal from the Wi-Fi module. 3. Check to see if the vibration motor vibrates.
Should be able to receive serial input from the Wi-Fi module which comes from other devices Wi-Fi module and send a serial signal to the vibration motor to vibrate (Should be different vibration pattern than the requirement above) (short quick pulses).	1. Program the microcontroller with the code to control the vibration motor using input from the Wi-Fi module. 2. Push a serial signal to the microcontroller that mimics a signal from the Wi-Fi module. 3. Check to see if the vibration motor vibrates.

2.4 Schematics

2.4.1 Seeker Controller

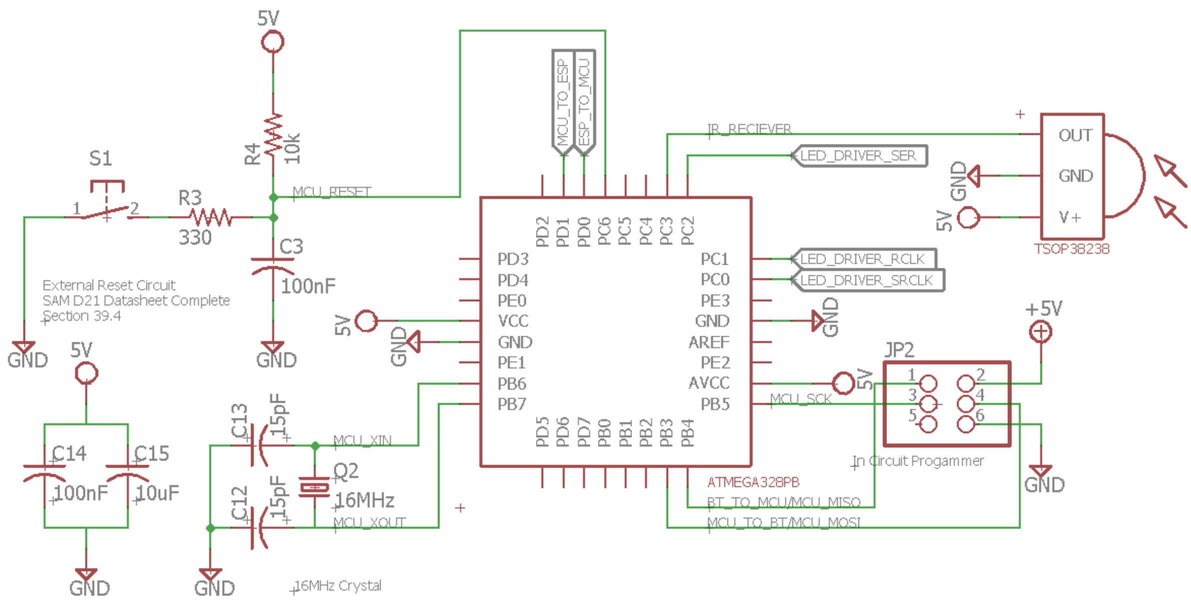

Figure 3: Seeker Controller Schematic

2.4.2 LED Driver

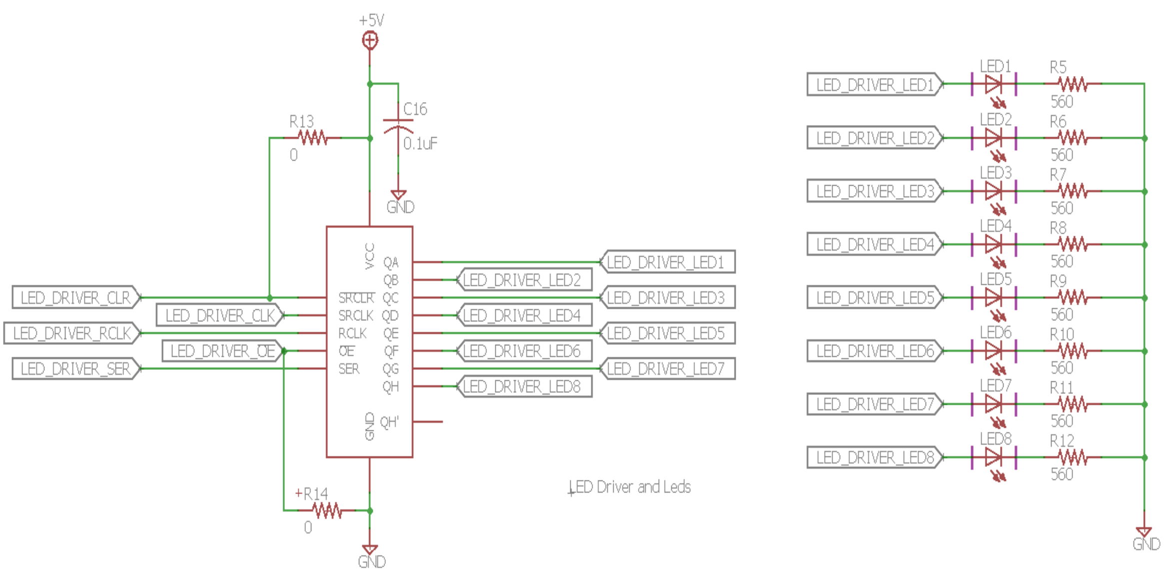

Figure 4: LED Driver Schematic

2.4.3 Wi-Fi Module

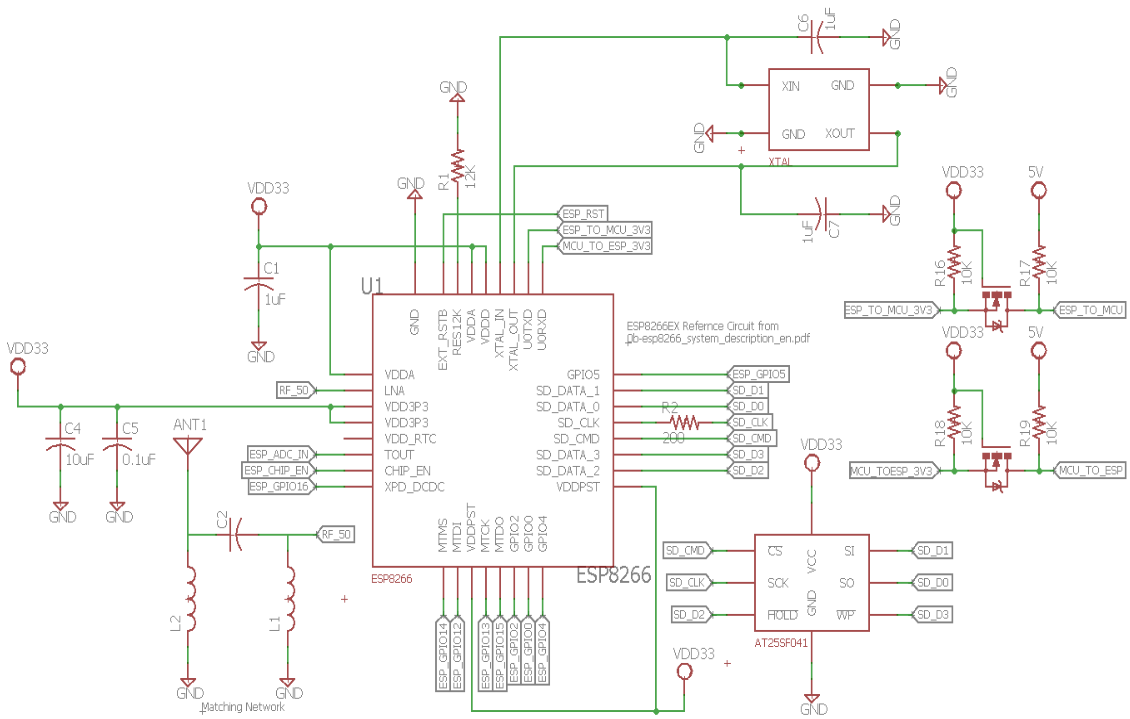

Figure 5: Wi-Fi Module Schematic

2.5 Hider Controller

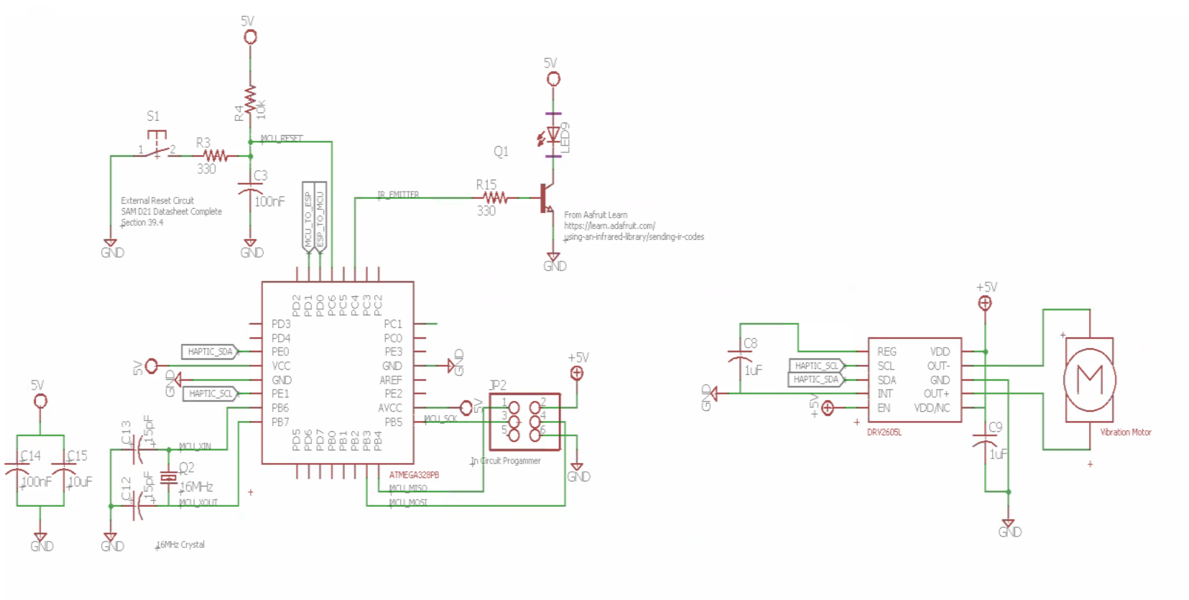

Figure 6: Hider Controller Schematic

2.5 Tolerance Analysis

The most critical component of this system would be the directional antenna. The successful design and implementation of this antenna, such that it closely meets our intended requirements, allows for our device to operate as intended. This component is used to detect when the target is it front of them, which is the ultimate goal of the project.

The intended operation of this component is that it will have the most gain in front of the user, with as close to a null as possible that wraps around and behind the user's side. This allows the device to sense that it is facing the target. If the antenna fails to meet this requirement the users may get false positives that the target is in front of them. This failure will derail the intent of the project, and cause stress to users during operation. This will be combatted by testing prior to releasing the product during verification.

We will use design software to simulate our design to ensure that it should theoretically work as intended. This part of the design will require a majority of our time and resources. We will need to design it such that it can be implemented on a PCB microstrip board. This imposes certain requirements on the materials used for the PCB, such as good dielectric materials and low resistivity of the metal. Having a bad dielectric layer will cause the antenna to deviate further from the simulated results. The more resistive the PCB the more loss the antenna will experience, and the more heat the antenna will produce.

To accurately measure the directivity and gain of the antenna requires the use of a pair of calibrated testing antennas, and an anechoic chamber. Our antenna will transmit a specific amount of power and we will measure the power received from the prior calibrated antenna while slowly changing the orientation of the antenna with respect to receiving antenna. Using the measured radiated power, we can create and model the radiation pattern as a function of orientation, the normalized intensity pattern will be defined as F in Eq. 1-1.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} |F(\theta,\phi)|^2 \, sin(\theta) d\theta d\phi \qquad \text{[Eq. 1]}$$

We can use Eq. 1-1 to ensure that our beam solid angle, the angle where of equal power if all transmitted power was transmitted uniformly, is approximately that of the field of view of a human. We can also note at what orientation F in Eq. 1-1 is maximized, so we can ensure to orient our antenna such that is orientation is pointing away from out user.

Another risk stated was the need to reduce false positives from connection with devices that are close yet behind the user. Using the previously measured and normalized model, we can define a radiation intensity as in Eq. 1-2. Then we can ensure significant attenuation of signals coming from behind the user, as shown by the test in Eq. 1-3.

$$D(\theta,\phi) = |F(\theta,\phi)|^2 \qquad \text{[Eq. 2]}$$

$$D(\theta,\phi)|_{\phi \subset \pi, 2\pi} \ll -10\text{dBi} \qquad \text{[Eq. 3]}$$

3 Cost Analysis

We estimate a reasonable salary for someone in this line of work to produce the product that we set out to make during this 14-week period is about $37/hour. This time period does not include the first two weeks of classes due to it being a brainstorming period that was not specifically beneficial to our project. We figure each of us will spend around 12hours/week on this project to meet all our deadlines. Even though we will have a functional product at the end of the semester we believe about 40% of a fully commercial product will be complete by the end of the semester. However, this does not factor into our cost calculation because we would need to spend a considerably larger amount of time working to fully complete the product. The cost analysis below only considers the time needed to get 40% of the product finished. The portion of the product that will need to be completed for a fully commercial product include: a rechargeable in-device battery power source, creating a phone app for more dynamic gameplay to communicate with the Bluetooth module, the physical housing for the device, and circuit design for making each device capable of being a hider or a seeker (instead of two separate devices). The following equation describes the above logic and calculations.

$$2 \cdot \frac{\$37}{hr} \cdot \frac{12hr}{wk} \cdot 14wks \cdot 2.5 = \$31,080$$

[Eq. 4]

Table 13: Parts Cost Sheet

Description	Part #	Cost	Qty.	Total
LED Driver: IC 8BIT SHIFT REG 3ST-OUT 16SOIC	296-14857-1-ND	0.54	1	0.54
Microcontroller: IC MCU 8BIT 32KB FLASH 32TQFP	ATMEGA328PB	$1.38	2	$2.76
Wi-Fi Module: ESP8 266EX Tiny Wireless 802.11 b/g/n Chip	GC-ESP8266EX	1.75	2	3.50
SPI Flash: IC FLASH 4MBIT 104MHZ 8SOIC	SST26WF040B-104I/SN-ND	0.80	2	1.60
Crystal Oscillator (Wi-Fi Module): XTAL 26MHz - CRYSTAL 26.00 MHZ 9.0PF	SER4105CT-ND	0.56	2	1.12
Crystal Oscillator (Microcontroller): XTAL 16MHz - CRYSTAL 16.00 MHZ 9PF SMD	SER4069CT-ND	0.56	2	1.12
IR MCU: IC MCU 8BIT 8KB FLASH 32TQFP	ATMEGA88PA-AURCT-ND	1.49	2	2.98
Bluetooth: BLUETOOTH 4.2 BLE MODULE, SHIELD	RN4870-V/RM118-ND	7.24	1	7.24
IR Rx: IC IR RCVR MOD 38KHZ DOME RADIAL	751-1227-ND	1.12	1	1.12
IR Tx Transistor: TRANS NPN 40V 0.6A SOT23	MMBT2222ALT1GOSCT-ND	0.10	1	0.10
Haptic Feedback: NEXT GEN DRV260X LRA/ERM DRIVER	296-38481-1-ND	4.79	1	4.79
Vibration Motor: VIBRATION MOTOR 11000 RPM 5VDC	1528-1177-ND	1.95	1	1.95
Omni Antenna: ANTENNA 2.4GHZ 1/2 WAVE WHIP SMA	ANT-2.4-CW-CT-SMA-ND	7.34	1	7.34
IR Emitter: EMITTER IR 940NM 100MA RADIAL	1080-1080-ND	0.44	1	0.44
LED: LED RED DIFF 5MM ROUND T/H	160-1127-ND	0.36	8	2.88
TOTAL				**43.16**

Adding these parts expenses to the labor expenses we can come up with a reasonable estimate for how much the full project would cost an investor. The math can be seen below.

$$GrandTotal = \$31,080 + \$43.16 = \$31,123.16 \quad \text{[Eq. 5]}$$

It should be noted that this schedule is flexible based on uncontrollable and unforeseen events such as which parts come in first and other hiccups in the design process. We have tried to mitigate most of these issues however we have tried to build some time in the schedule for areas where we think could cause more problems than others.

4 Ethics and Safety

With any product that is intended to be released to the public, there comes certain set of hazards that could harm people or other devices. Ultimately, we would want our product to work as intended and in a way that when used properly will not cause harm.

Since this project has a large RF component, we must be sure to adhere to FCC regulations. The radio spectrum is a natural resource that needs to be used responsibly so that all may be able to benefit from it. We need to ensure we don't cause harm by radiating unintentional energy into the atmosphere. This could cause unintended affects, such as jamming other devices on the ISM band, which could interrupt services running on the band that could be critical to people's health and safety. This would violate the IEEE Code of Ethics which includes the responsibility "to avoid injuring others" [3]. Another safety concern that will have to be addressed is the RF radiation of our product. We will need to ensure that being in close proximity to our device for extended periods of time does not cause any discomfort or harm to people or their property. We will design our project to provide safe amounts of RF radiation, based on current information on the topic of RF exposure.

This device also may create an ethical dilemma when used inappropriately. The purpose of the device is to allow a user to track a consenting target. It could be possible to slip our device on an unknowing victim, allowing said victim to be tracked without their knowledge. We know this risk; we would need to devise a way to keep non-consenting parties from being tracked. Upon releasing of this product to the public, we would inform the users of this inappropriate use, such that they may combat it. We see this as a way of disclosing "factors that might endanger the public", as it pertains to the first IEEE Code of Ethics [3]. Also, to avoid this irresponsible use of our product we plan on making sure the vibration motor on our product is strong enough to where if the product were slipped on an unsuspecting victim, the vibrations from the device would be felt by said user.

On the user's side of the device, we would oppose selling histories and logs of what the users device has sensed was in front of them. This information could be sold to create a profit at the user's expense of privacy. Upon commercialization we would notify the public of such risks, and oppose implementing any way of storing user's data. We see this as a means to "rejecting bribery" as stated in the 4th point of the IEEE Code of Ethics [3].

5 Conclusion

While we set out to design a fully integrated proof of concept we did run into certain design obstacles that hindered our production of a full-fledged system. Many of our design blocks we were able to verify modularly however, we had particular trouble integrating them together.

One of the major problems we had was with our microcontroller. While it was compatible with the Arduino environment, the Arduino libraries did not allow us to access the additional hardware on our chip, such as the second serial and the second I2C busses. This limited the functionality and required us to rework our boards so we may use only the Arduino accessible hardware blocks. The outcome of this was that our microcontroller was unable to read data from our Wi-Fi module while sending data via Bluetooth at the same time.

Another module we had considerable trouble with was the Wi-Fi module stability and failure rate. For our boards, we had designed it so that the reset pin was left floating which ended up needing to be pulled high to keep it stable. To fix this we had to solder a break out wire directly to one of the very small pads. This proved to be very difficult and we were only able to get our Wi-Fi module working for brief moments at a time. Our recommendation for future work would be to first, design the PCBs so the reset pin wasn't left floating. Additionally, to decrease our failure rate while soldering we would switch over to a solder paste stencil and a reflow oven. This would help mitigate the overheating of the chip since we would have greater control of the solder temperature in a reflow oven as opposed to an air gun.

Thirdly, we would like to improve on our directional antenna. We settled on a 2-element patch array being fed by a 50-Ohm network. Due to an impedance mismatch, this design required a matching network. After further testing on our prototype antenna we would use our measured impedances to build a microstrip impedance transformer rather than relying on a matching network for our RF feed.

Future work for this project would be focused on preparing this proof-of-concept for commercialization. This includes powering the devices off a battery, merging the two separate devices into a single hybrid device with all the functionality, creating a software application for cell phones to enhance gameplay, and implementing an enclosure that would add durability and an aesthetic appeal to our design.

6 References

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