Holographic LED Display

ECE 445 Final Report

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Abstract

This semester, our team worked on developing a three-dimensional holographic LED display. Our LED display takes in input from a microcontroller which receives feedback information from a Hall Sensor. We connected a motor to our rotational panel to achieve the holographic effect. One end of the rotational panel features the Hall Sensor and the other end has the LED array. We placed a magnet on the bottom of our device so the Hall Sensor is able to detect information regarding rotational position and relay this back to the microcontroller. Using this information, the microcontroller appropriately delays the LEDs depending on what we aim to show on our LED display. We can remotely program the LED array through a mobile application available on our cell phones. Currently, our display offers support for letters, numbers, words, and animations.

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1 Introduction

1.1 Purpose

Mobile cell phone usage is increasingly common nowadays. The average person spends 3.25 hours on their mobile phone and the average American spends an average of 5.4 hours [1]. Research suggests that there are an array of health risks that are associated with higher rates of mobile phone usage [2]. Aside from consuming media and communicating with friends and family, people use cell phones to look at app notifications and other informational content. We wanted to create an alternative to viewing this content on cell phone screens. Two-dimensional rotational LED displays have already been created and widely implemented; we proposed expanding this idea to three dimensions and allowing user customization of the display content.

Our objective was to create a rotating display of LEDs such that the rotation creates a holographic effect and displays certain three-dimensional characteristics. Some features we have created for our display include the current time, words, the alphabet, numbers, and a few preset visual animations.

1.2 Functionality

- ❖ We can use our mobile application to connect with the microcontroller through the WiFi Module using DHCP protocols and toggle between settings of display functions such as preset animations, time, or specified texts
    - ➢ Purpose: User Customizability
- ❖ Rotated the propeller between 400-500 rpm with center of mass in the middle of the chassis to ensure proper alignment
    - ➢ Purpose: Hologram effect functionality
- ❖ Calculated rpm from the Hall sensor within software to ensure consistency of the hologram and avoid the presence of inaccurate information displaying on LEDs, which should update in under .00075 seconds.
    - ➢ Purpose: Hologram effect stability

1.3 Subsystem overview

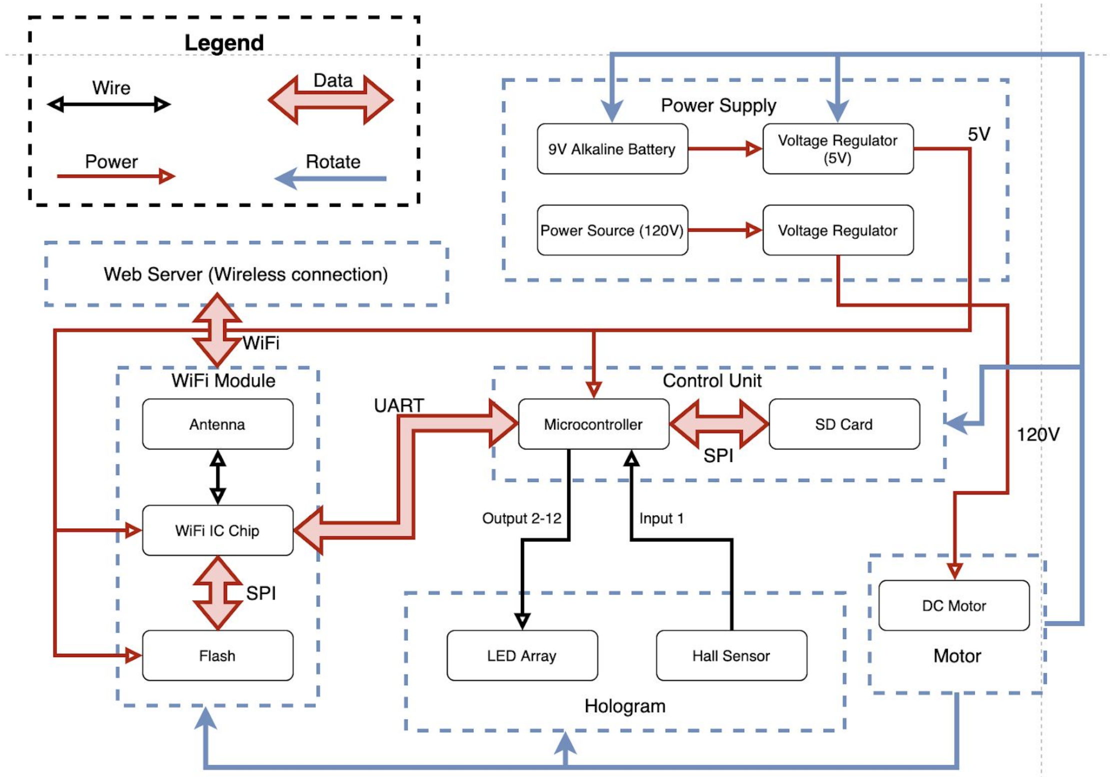


Figure 1.1- Block Diagram.

- WiFi module
  - Connects device and user interface
- Control Unit
  - Contains microcontroller
- Hologram Unit
  - Contains LED array and Hall Sensor
- Motor
  - Receives input from microcontroller
- Power supply
  - Distributes wall supply and battery power

There are several types of connections such as wire, power, and data, as shown in Figure 1.1

The UART protocol will be used for providing the connection between the microcontroller and the WiFi IC chip, and the SPI protocol will be used for providing the linkage between the WiFi chip and flash.

The microcontroller will serve as the crux of our control unit and will dictate what is shown on our LED array and to keep the hall sensor in coordination with our system. There will also be a wireless connection to the web server via the antenna. No physical connection is necessary and is thus not shown on the block diagram.

A motor is sourced from a power source of preferably 120 V that will help power the DC motor. A 9 V Alkaline battery will serve as the main power source for the rest of the system. Since the microcontroller, WiFi module, and LEDs do not take up a lot of power, this will be sufficient enough.

2 Design

2.1 Design Details

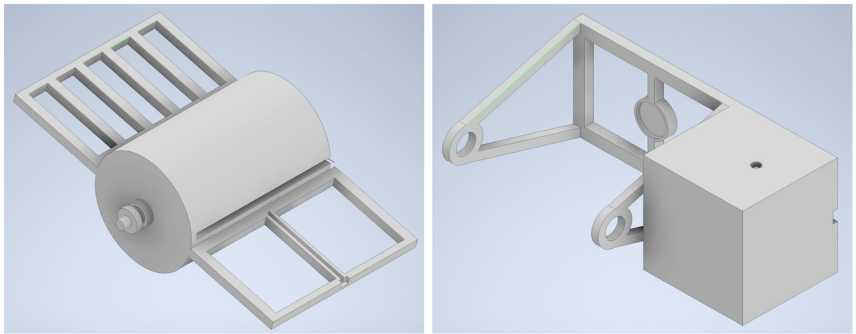


Figure 2.1- Sub-Assembly CAD Drawings

The figure above shows the hardware component of the system, including the propellor that rotates within the holders on the right image. Ball bearings will serve as the main connection between the two parts, so that the propellor can rotate at very high speeds. A motor housed in the cube will connect to the propellor using a belt system. A magnet is fastened on the circular indent in the right image in order to provide accurate readings from the hall sensor. The parts were broken down further in order to 3D print at the proper dimensions.

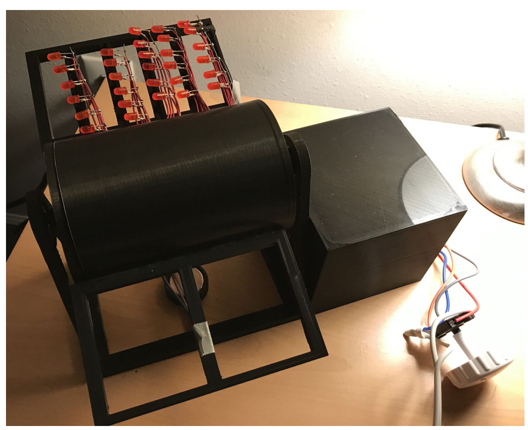


Figure 2.2- Finished Product

Next we have the electrical components, which consist of the microcontroller, WiFi module, LED array, hall sensor, and motor. The motor is detached from the rest of the system because it would be very hard to run wires into the rotating propellor. Because of this, we have two power sources including one from an outlet (120 V) and another from two 9 V batteries in parallel. Figure 2.2 shows the 6x5 LED array coming out of one side of the propellor and the hall sensor (Active LOW) on the other side. Both of these systems are connected to the microcontroller (ATMega328P) and the WiFi module (ESP8266), which is needed in order to toggle between functions from the RemoteXY app.

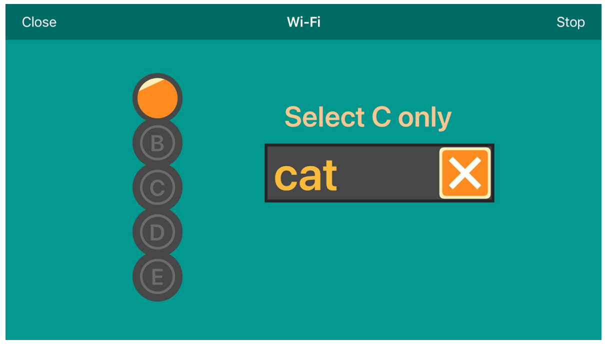
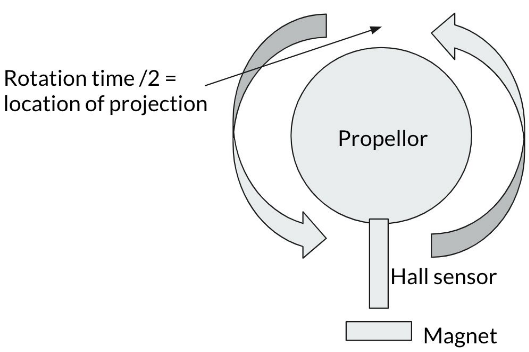


Figure 2.3- RemoteXY Application

The RemoteXY interface is shown in Figure 2.3. We have 5 functions: 2 color animations, alphabet, numbers and customized text input. The ‘Select C only’ tag in the image is customized text that the user can input and have it displayed to the hologram if select C is toggled on. This interface is connected to our ESP8266 board, which sends communication to the microcontroller via TX and RX communication, or UART.




```
ISR(PCINT0_vect){
  current_count = micros();
  ///////////////////////////////////////Chann
  if(PINB & B00100000){
    if(last_IN_state == 0){
      last_IN_state = 1;
      counter_1 = current_count;
    }
  }
  else if(last_IN_state == 1){
    last_IN_state = 0;
    one_rot_time = current_count - counter_1;
    time_per_deg = one_rot_time/360.0;
    previousMillis = micros();
   }
}
```

Figure 2.4- Hall Sensor Functionality

The software portion consists of several things going on at the same time, including writing to the LED array, reading delays from the hall sensor, and toggling between functions from the WiFi module. Figure 2.4 provides an example of how the projection is displayed in the 3D space. The team wanted the letters to display at the peak of each rotation, so we would divide the total time by two and blink the LEDs. We used shift registers to output to 30 LEDs using only 10 outputs (5 latches and 5 data pins). In addition, we used the RemoteXY library in order to obtain input from the mobile application. The code then iterates through the appropriate letters or numbers.

2.2 Design Alternatives

There were several things that we had to change from our original design of the project. The main thing that was included in that was the demultiplexers. After evaluation, the team decided to go with shift registers instead because of the less overall inputs required. The demultiplexers would require three bits as well as the data being read for each demultiplexer and ended up using way too many ports. On the other hand, shift registers only required 2 unique ports for each chip, as well as one shared clock. This put us at a total of 13, which is all the outputs we were allocated. In addition to this, we also decided to limit the color variety of this project for simplicity sake. It would require a lot more wiring and tweaking of the hardware components for adding very little complexity to the overall project.

3 Design Verification

3.1 Power Supply

We verified our power supply branches by using a multimeter to measure the voltages across our major electrical components. This included the microcontroller, WiFi module and LED array. We set our voltage threshold for each of these components to 0.25 V within 5 V. Although these are intermediary components with no use on their own, each component's individual function enables the qualitative success of our three-dimensional hologram effect.

Voltage across microcontroller: 5.04 V
Voltage across LED array: 5.03 V
Voltage across WiFi module: 5.1 V

3.2 WiFi Module

We verified our WiFi module by sending a variety of information from our mobile application. Considering that users will be engaging with the device from a variety of locations, we sent three standard messages from three locations. At distances of five, ten, and fifteen feet away from our device, we sent two preset animations and the sweeping alphabet. All code was deployed on the display within three seconds as measured by an external timer.

3.3 Microcontroller & Software

We verified the microcontroller and software through extensive testing of our LED array component. The microcontroller was able to successfully update LED values with .0075 seconds, a threshold we calculated during initial stages of our project. This verification was qualitative and the presence of the intended image (animation, letter, number, etc.) indicated this component's adept functionality.

3.4 LED Array

Rotations per minute of *motor* (max) - 500 rpm

Rotations per second - $500\ rpm * \frac{1\ minute}{60\ seconds} = 8.33\ rps \rightarrow .12$ seconds per rotation (1)

.12 seconds per rotation → .006 second refresh rate per LED (2)

$4\ sets * \frac{3\ outputs}{set} = \rightarrow 12\ outputs$ (3)

For each set of three outputs:

Three outputs are affecting $2^3 = 8$ LEDs

$\frac{.006\ seconds}{8\ LED} = .00075\ \frac{seconds}{LED}$ (4)

According to Equation 4, the microcontroller updated each output every .00075 seconds for the given rpm. If the microcontroller failed to do so, the system would fail and create an undesirable output. Since a refresh time encompasses time to update the display and hold the output, we held our LEDs below this refresh rate. Anything less than .75 ms was appropriate; we had unintended consequences with a greater refresh rate.

3.5 Hall Sensor

We verified the hall sensor's functionality qualitatively. The purpose of the hall sensor in our project was to appropriately delay LED output depending on the rotational position of the display. The reason we chose to not hardcode this value is due to fluctuations in RPM which may cause the hologram to appear. Through the usage of our hall sensor, our hologram was stable and maintained its position at a certain location in the rotational cycle.

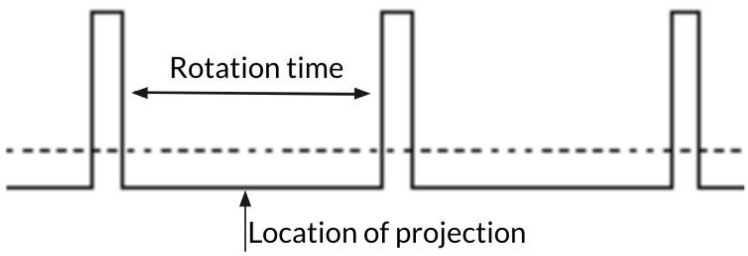


Figure 3.5- Oscilloscope Representation

3.6 Induction Motor

We verified the Induction Motor's functionality by reading the Hall Sensor output from our software. Since our Hall Sensor indicated one rotational pass, we were able to use console output to calculate instantaneous RPM of the motor in all of its three speeds. We used this method to calculate the RPM. On average, our motor rotated at an average angular velocity of 410 RPM when configured at the lowest speed. This is also the speed we performed testing with.

4 Costs

4.1 Labor

Based on Glassdoor [3], the average graduate salary for a software/hardware engineer in Illinois is roughly $78,182. Assuming everyone is working an average of 40 hours a week, we can calculate the per hour average salary.

$$\frac{\$78{,}182}{year} * \frac{1\ year}{52\ weeks} * \frac{1\ week}{40\ hours} = \$37.59/hr\ (hourly\ rate) \tag{5}$$

This averages out to $37.59 an hour. The TA said there would be weeks that we end up working on our projects more than other weeks, but the average amount of time would end up looking at around 10 hours per week. Given that the class is 16 weeks long, and the group consists of 3 people, we can calculate the total amount of labor that it will cost to develop the product.

$$\frac{\$37.59\ dollars}{hour} * \frac{10\ hours}{week} * 16\ \frac{weeks}{person} * 3\ persons = \$18,043.20 \tag{6}$$

$$\frac{\$18{,}043.20}{3\ persons} = \$6014.40\ (per\ person\ expenditure) \tag{7}$$

4.2 Parts

Besides the cost of labor, there is also the cost of our prototype as well as the hypothetical cost of production. There are many things that would change from the prototype level to the manufacturing level, including developing plastic molds of the design for quick, easy, and cheap duplicating of the project. Detailed parts table is available on the next page.

Part	Quantity	Cost (prototype)	Cost (bulk)
LED- 5 mm light emitting diode round	30	$0.79	$0.04
Hall Sensor- A3144 Pin 3 Terminal Sensitive	1	$0.556	$0.15
Motor- brushless DC motor	1	$19.56	$7.83
Microcontroller- ATMega328p IC Chip	1	$5.327	$1.60
WiFi module (ESP826P)	1	$3.245	$0.95
Motor Belt	1	$2.245	$1.80
9 V Alkaline Battery	1	$1.373	$1.20
3-D printed parts	2	$101.74	$39.00
Injection molds	2	$3.49	$3.20
Ball bearings	2	$1.38	$1.02
Magnet- Super strong neodymium disc magnets	1	$1.498	$0.019
PCB print	1	$20	$3.50
Total cost		**$75.97**	**$21.27**

Figure 4.1 - Total Costs Table

Figure 4.1 includes a breakdown of costs for prototype vs. those faced in mass production. Total cost including wage would be $18,043.20 + $75.97 = **$18,119.20.** If we were to mass produce the product, the price per unit would significantly decrease. However, the overall price including labor would not vary significantly ($18,043.20 + $21.27 = **$18,064.50**).

5 Schedule

Week	Rishab	Amar	Sriram
9/27/20	Worked on tolerance analysis and requirements and verification for design document	Worked on schematic, block diagrams and tolerance analysis for design document	Worked on requirements and verification and cost analysis for design document
10/4/20	Worked in Eagle on PCB design iteration 1	Worked in Eagle on PCB design iteration 1	Worked in Eagle on PCB design iteration 1
10/11/20	Print out 3D printed parts, required two iterations	Designed 3D printed parts in CAD software	Purchased shift registers, LEDs and other electronic hardware
10/18/20	Finalized PCB iteration for final order	Finalized PCB iteration for final order	Finalized PCB iteration for final order
10/25/20	Unit tested LEDs at various voltages	Unit tested hall sensor at various distances	Unit tested shift registers and microcontroller i/o
11/1/20	Started constructing LED array layout	Soldered components onto PCB	Constructed motor component
11/8/20	Tested motor speeds' compatibility with hall sensor	Constructed hall sensor component panel and connections	Constructed the motorized housing for the LED array layout
11/15/20	Wrote microcontroller code to work with hall-sensor	Wrote microcontroller code for alphabet and word support	Integrated construction of 3D printed parts and individual subcomponents
11/22/20	**Thanksgiving Break**	**Thanksgiving Break**	**Thanksgiving Break**
11/29/20	Worked on presentation and final paper - Abstract, Introduction and Design Verification	Worked on presentation and final paper - Design Details, Design Alternatives and Editing	Worked on presentation and final paper - Cost of Parts & Labor, Schedule and Conclusion

Figure 5.1 - Schedule

Figure 5.1 shows the weekly schedule for our group and each member's objectives for that week.

6 Conclusion

6.1 Accomplishments

For this project, we were able to successfully meet the high-level requirements set out by the group. We meticulously 3-D printed all of our parts - motor, belt system, LED array panel, hall sensor panel, and a cylindrical storage part. By taking into account safety measures as well as precise detail to measurement, our display was void of any mishaps such as potential for our circuitry to fall apart during rotation. We were able to successfully reach the minimum RPM we needed for the chassi and could get a legible "holographic" display of letters and numbers to show. Furthermore, we were able to control our input through a RemoteXY phone app where users could toggle between preset animations to custom animations free of latency issues and with success.

6.2 Uncertainties

While this project was highly successful in that of our group's high-level requirements being met, there were some uncertainties present that which if solved in the future, can significantly boost the future success of this project. One uncertainty was the structural integrity of our chassi. During the demo, one of our group members had to hold the housing unit for the motor in order to make sure there was not too much frictional movement from the rotating unit and the ground itself. This can be resolved by inserting an additional mass on the other side of the device to offset the imbalance caused by the rotation. Another uncertainty was the belt system in play. For current purposes, rubber bands were used in order to control the torque produced from the motor to the rotating body. These bands were entangled between usages of the device and this could slow down the motor itself if there was a knot that had to be untied before the motor starts. This can be solved by using a stronger material in place of the bands - such as a miniature belt. Another uncertainty was the LED craftsmanship in play. Some of the LED lines in our display were not aligned and were slanted - making it harder to have a clean look. This can be fixed by improving upon the LED panel to hold the LED strips in alignment. While these uncertainties exist, they are good first steps to take in order to improve our product for the future.

6.3 Future Work

There are a lot of exciting directions we would like to take our project into from hardware, software, and mechanical standpoints. From a hardware standpoint, we would like to incorporate support for multiple colors as it would allow the display to be on par with current displays on the market. We would also like to increase the number of LEDs as it can provide more clarity of the hologram itself. This can potentially be done by using more shift registers to expand the number of outputs.

From a software point, we would like to increase support to flash words instead of sequentially going through letter by letter of a user input. This helps make the display easier to understand for a user and more flexible as well. We also want to be able to expand our device by providing compatibility to sync to a phone or a computer to be able to signify the user of a notification. This would make our product more human-friendly as well as beneficial.

Mechanically, we would like to replace our rubber bands with stronger materials to prevent the bands from being entangled between usages of the device. Additionally, if the motor speed used to create the rotational device was increased, then it is possible the display could be crisper and more stable. This could be done by improving our motor efficiency by adding a capacitive element to increase the power factor, or by bringing about a new motor itself. There are a lot of directions our project can take and we know that we are not done yet.

6.4 Ethical Considerations

There are a variety of ethical guidelines and safety measures we took into account for the design and functionality of this project. As with any electromechanical hardware, there are several electrical and mechanical hazards to take into consideration. With regards to safety, we need to mitigate two main attributes of our physical design.

Since our hardware body housing the LED arrangement rotates at a very high RPM, it is important to disclose to potential users that they should not touch the holographic display while it is in operation. Any sort of interaction that involves interacting with the physical display while it is in rotation poses two issues. The first issue is one of functionality. We can not guarantee safe functionality after a user initially mangles with the device. Although users may not get injured from their first use of the device, improper handling of the device can deform and mutilate parts from their intended purpose in our device. Thus, unstable parts pose a hazard for future operation of the device (i.e. parts are loose or electronic components are improperly grounded).

It is imperative that younger children and less attentive audiences not handle the device without appropriate adult supervision so as to not injure themselves or others. Children pose a significantly greater risk to the use of our device since they are inherently less careful than adolescents or adults [9]. Therefore, we intend to restrict the usage of our device to adults for the time being.

Additionally, the flashing LED lights at full brightness have the potential to trigger symptoms in people with epilepsy or elevated seizure risk. Epilepsy can be caused by a variety of hosts but only 3% of epileptic persons are photosensitive (react to flashing lights) [4].

Although one LED’s brightness is relatively low, the combined luminance from our LED array will be rather bright. Those with sensitive eyes or other vision conditions should take caution when operating the device, and should possibly generally refrain from doing so. Overall, we will need to disclose to avoid or closely monitor usage in people that are part of the aforementioned groups or mentioned health risks.

Our project upholds engineering ethical standards and addresses the safety, health and welfare of the public as mentioned in [5] and [6]. This includes designing the rotational component in a manner that upholds safety of all users.

From an ethical standpoint, we took measures to ensure privacy of information for our device. Since we displayed information from a mobile application on our display, there is potentially private and/or sensitive information present on the holographic display at any times. We also need to ensure that the display is not able to have malicious software that pulls other information from the user’s web client. The only information going into the display should be what the user enters on the web client.

We took the appropriate measures to mitigate any security risks that seem inherent since our WiFi module communicates data to the web. We ensured the privacy of our users by making sure that the WiFi module is secured with a WPA2 type connection.

References

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Appendix A Requirement and Verification Table

1 Power Supply

The power will consist of a 9 V alkaline battery for the electronic components in the propellor. Most of the components require less that 9 V to operate at their given capacity so this requires us to use a voltage regulator in order to reduce to 5 V. The microcontroller, the WiFi module, and the LED array are all able to operate at 5 V.

Requirement	Verification
1. Voltage output is 5 V ± 5%	1. Used a multimeter to measure voltages across microcontroller, WiFi module and LED array a. Threshold voltage: (4.75 V, 5.25 V); all voltage points within threshold

2 WiFi Module

The WiFi module will be the main connecting point between our control unit and the web server to toggle between settings. The IC chip that we will be using is the ESP8266 [8], which will be the transceiver that will send the data to the microcontroller.

2.1 Antenna

The antenna in our WiFi module is used to send/receive signals from the WiFi chip itself and the web app.

Requirement	Verification
1. The antenna should be able to send and receive signals between 0-15 feet (0 meters ~ 4.572 meters)	1. Stood at intervals (5, 10, 15) ft. to ensure a strong signal connection from each of these areas a. Connection deemed as strong from each distance; executed code to switch on LEDs from each of the distance intervals b. No data loss in transmission: entire text/animation input into mobile application was present on display

2.2 WiFi IC Chip

The WiFi IC Chip is used to be the logic for our WiFi module. It acts as the middleware between communicating what our objective is from the web server to the microcontroller.

Requirement	Verification
1. Able to connect to web server 2. Convey proper information from the code to a smartphone	1. Verify DHCP protocol IP address from any computer and log in to that address in a web browser a. The content of the code should display there 2. When a button is pressed, a temporary LED should turn on and off in order to determine functionality of the chip

2.3 Flash

The flash is connected to the WiFi IC to store its program memory.

Requirement	Verification

1. The flash is able to operate at least 80 MHz for full capacity
2. The flash must have at least 1 MB of program storage
	1. The flash should be able to run a simple program to switch on an LED at 80 MHz
	    a. Make the flash at 80 MHz and run the simple program and confirm that it works
	2. Have a simple program to turn on LED lights that is at least 1 MB of storage
	    a. Read LED data back and forth using the UART terminal and make sure that there is consistency between the data

3 Control Unit (Microcontroller)

The microcontroller that we are using is called the ATmega328 chip, which is the same chip used in a lot of low level computational devices and will also suffice for our project. It is commonly used in Arduino [7], which is perfect for the scope of our project. The chip operates at 5 V, and has a CPU speed of 16 MHz, which will also be sufficient for our project. The calculations done in our tolerance analysis shows how fast the microcontroller has to send outputs to the LEDs. The rest is up to the speed of our code. For the software component for our microcontroller, this is explained in 2.3.4.

<table>
<tr><th>Requirement</th><th>Verification</th></tr>
<tr><td>
1. Memory is able to store code without reuploading the code to the microcontroller
2. Microcontroller is able to update the values of the LEDs under 0.00075 seconds
</td><td>
1. Turn on and off the microcontroller and see if everything is still functioning properly
a. Execute code that turns on an LED light
b. Unplug the power and then plug it back into the microcontroller and see if it is possible that there is proper functioning of executing the original code of turning on and off an LED light
2. Create a program which is able to run executed code of switching LEDs on and off for within 0.00075 seconds
a. This can be done using a timer library in terms of code and to create code that is able to refresh the LEDs on and off and make sure that the time is satisfied
</td></tr>
</table>

4 Software

The web server will be connected to the microcontroller via the WiFi module. The code for the microcontroller will consist of several components. The first component will be the calculations for the hall sensor. The hall sensor will be used to calculate the time that has elapsed between the rotations of the propellor. Since our motor is not attached to the microcontroller, this is the easiest way to simply calculate the output. The next component would be assigning the LEDs that need to turn on based off of the calculated rpm. The last component would be the web server. Using DHCP protocol, we are going to make HTML code to host a local domain so that the settings can be toggled through any device with internet connection.

Requirement	**Verification**
1. Code should be able to turn on and off all LEDs within our threshold of **.00075 seconds** 2. Be able to gauge the rpm of the motor using the hall sensor on web server client 3. Toggling different settings should change display to desired outcome	1. Unit test each input in series configuration to see if each LED maintains high or low as specified by voltage source a. When voltage is high, each LED should light up at full brightness b. When voltage is low 2. Measure timestamps between repetitive passes by Hall sensor a. Measure time duration between each low input of the hall sensor b. Calculate rotational speed; this speed should match the rpm of the motor at any given time 3. Input a message into the web server client and check that the new message text is appropriately displayed on the LED display a. If previous message is “x”, inputting “y” should instantaneously display “y” on LED display

5 Hologram

The Hologram display consists of the LED array and the hall sensor. The display is able to convey user input as well as preset animations.

5.1 LED Array

The LED array is used for the actual holographic display. The LEDs have to update fast enough for our display, which is more dependent on the microcontroller than the actual LEDs. Nonetheless, there should be a baseline requirement for the LEDs. The LEDs that we bought are standard diodes of a singular color.

Requirement	Verification
1. Refresh rate of LEDs are faster than .00075 seconds, which is fast enough to update with the code	1. Ensure that the refresh rate is below .00075 seconds a. Rotate the propellor at the rated 500 rpm and get the code to update an LED every .00075 seconds b. Granted that there is less than .00075 latency for the LED, the hologram should show 20 points to create a circle based off of our calculations in tolerance

5.2 Hall Sensor

A hall sensor is going to be used to calculate the rpm of the motor. Every time the hall sensor comes in contact with the neodymium magnet, the output voltage will be 0 V, and when it is not, it will be 5 V. We can track this data through the microcontroller. The hall sensor will be used to determine position

Requirement	Verification
1. Hall sensor should send 0 V when next to the magnet and 5 V elsewhere 2. The Hologram should not waver when displaying	1. Ensure output of the hall sensor is Active LOW a. No voltage present when placed next to magnet and 5 V at multiple places 2. Test 45 degree lines with the LEDs and ensure that they do not waver every rotation of the propellor

6 Brushless DC Motor

The motor that we are using for this project is a brushless DC motor. Since we are not worried about the sudden stopping and starting of the motor, a brushless DC motor is the best motor specification for us. The motor is connected to the propellor via a belt system. The motor will be connected to a wall outlet rated at 120 V. The voltage regulator is in place to ensure that the voltage will step down just enough to spin the motor between 400-500 rpm.

Requirement	Verification

1. The propellor is spinning between 400-500 rpm
2. Voltage spikes do not affect the motor speed for safety
3. Hardware body is stable
	1. Calculate gear ratio between spinning motor and propellor (attached to belt) to ensure 400-500 rpm of the propellor
	    a. Use voltage regulator to adjust accordingly if rpm is too high or low
	    b. Voltage and RPM are directly proportional
	2. Create a simulated voltage spike at +12 V, and measure brushless DC motor's speed
	    a. Motor speed should remain unimpacted
	3. Run propeller at overdriven speed (1.5x ~ 600 - 750 RPM) and ensure the hardware body has minimal movement
	    a. Body stability with overdriven speed implies stability with motor being run at regular speeds