Interactive Climbing Hold Design Document

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1. Introduction

1.1 Objective:

The primary goal of this project is to introduce interactive climbing holds to improve end-user experience for climbers and climbing gyms.

Climbing gyms normally have set "routes", which are a way of increasing the difficulty and complexity when climbing a wall. These routes only allow certain, selected holds to be used when climbing the wall. Routes are currently set in two different ways. Some climbing gyms use colored tape attached to the holds, where a certain color is a certain route. Also, sometimes there are routes which are marked by the color of the holds themselves.

One of the main problems in climbing gyms is that there is a high density of different colored holds, which can also have several different attached colored tapes. This makes it difficult to determine which holds are on route to use in the current route. Also, tapes often fray and fall off, causing further confusion about the holds on route. Furthermore, the climbing gyms, which only use hold color to indicate routes, suffer from inflexibility. This route marking method limits the holds they can use to create routes. By using holds with RGB LEDs on their surface, we would fix both these issues. Firstly, on route holds would not only be to more visible to climbers but we could also deactivate any off-route holds to eliminate confusion. Secondly, they would offer flexibility by providing ease in setting and changing the color of holds.

Climbing gyms often try to keep their routes exciting and fresh, so they will redesign a wall, every so often, with a different configuration of holds. However, we want to create a system in which the physical holds do not need to be changed due to the immense time sink of the redesigning task. Instead, new routes will be created by simply selecting a configuration of holds already attached to the wall. The holds will have unique identifiers, and a route will be a list of the selected hold IDs. This also means climbers would have a far wider range of routes to climb per wall. The routes will now be based on all the different configurations people can think of, with the same physical setup of holds. This will allow greater periods of time for the gym before having to refresh the wall, and change the physical holds.

Finally, currently gyms do not interact enough with their climbers; thus, new routes may not cater to the core audience of the gym. There are little to no records of what people are climbing, completing or enjoying in many climbing gyms. By adding an electronic aspect to rock climbing, we would be able to provide analytics for both the climbers and gyms. For example, climbers would be able to see their progress over the span of their climbing career. Gyms would be able to better understand what their clients want and in turn could better serve their customer base.

1.2 Background:

All three group members are intermediate climbers and we all felt the same way when climbing at two different locations. We have gone climbing with a wide skill range of climbers, and many feel the same way. The University of Illinois ARC wall is incredibly diverse and has several different routes. However, the route information is limited and vague. It is difficult for any climber, especially new climbers to gauge whether they can attempt a route through only one difficulty rating metric. Often times, route difficulties are misjudged by climbers and end up on both ends of the spectrum, either frustratingly difficult or far too easy.

Furthermore, all three of us have experienced routes where we have struggled due to a missing piece of tape on a hold. This drastically changes the dynamic of the route, often making it much harder. It is frustrating having to try and climb a route with poorly designated markers, and makes the climb take much longer.

Climbing is something that is starting to see an uptick in popularity, and we feel as though by adding a digital element to the sport, it can help climbing become one of the best recreational activities available. The analytics we could provide could also serve to be very interesting for gyms, and highly useful in a commercial and competitive setting.

1.3 High-level requirements list:

- Each climbing hold will have an above 90% detection rate for a climber on each hold. There should also be a false positive rate of less than 1%.
- Each climbing hold will be able to support a weight of at least 400 pounds for climber safety based on the maximum impulse applied by the climber on the hold during a climb[7].
- A selected route on the web interface will be able to illuminate the correct holds and accurately time the climber’s movements to within a one second error range.

2. Design

2.1 Block Diagram:

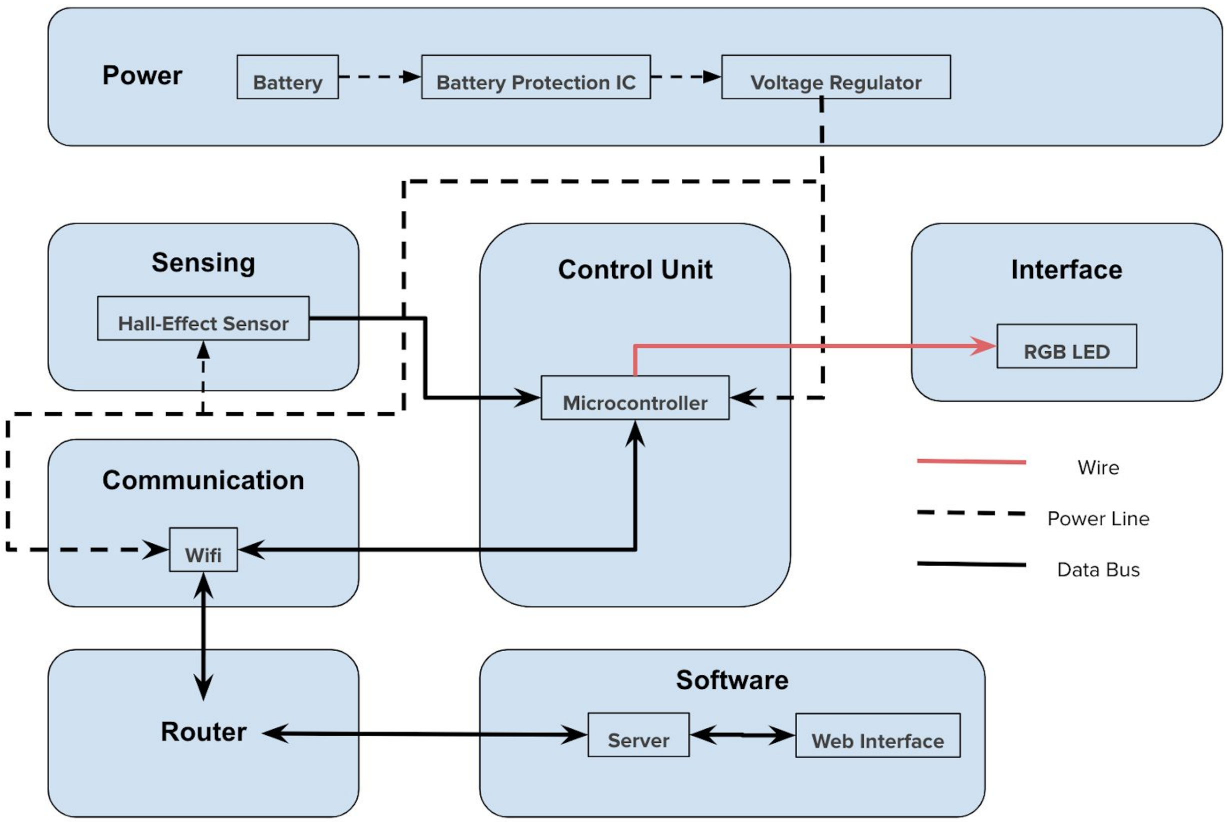

Figure 1: High Level Block Diagram

The block diagram covers the basic modules of our system broken down by purpose, so that each module can be isolated in implementation. One of the main high level requirements is the ability to detect a person on a climbing hold, which will involve mostly the sensing and control unit module of our high level block diagram. To achieve the specified detection rate and robustness to noise, we will rely on DSP methods in the control unit to process the data from the sensing module in order to determine if a climber is using a current hold. Another high level requirement is the ability for the correct holds to light up when a route is selected through our web interface and accurately measure the climber movements. The communication module handles the connection between the web interface and the control unit in order to light up the LED in the interface module as well as notify the server when a climber is on a hold. This two-way communication through the communication module will allow the server to accurately time a climber's ascent.

2.2 Physical Diagram:

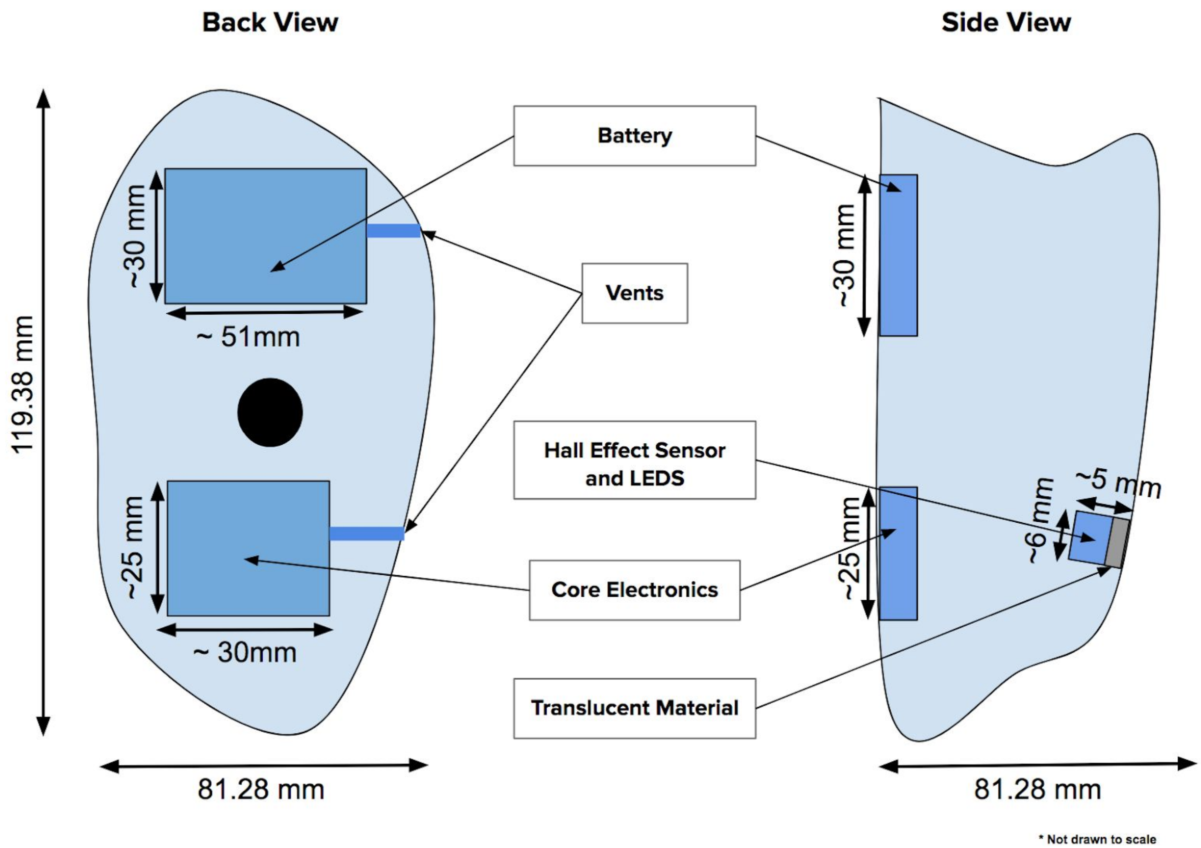

Figure 2: Physical Design Diagram

We are integrating the power, sensing, control unit, interface, and communication module in a climbing hold. Our proposed method is to mill out two sections in the bottom side of hold, a small section in the surface of the hold, and a channel connection between the surface and bottom sections. The two bottom sections in the hold are for storing the core electronics, which includes the microcontroller, wifi module, and battery protection circuit, and the battery. The battery is isolated into its own section to minimize risk to our core electronics. The surface section will contain our hall-effect sensor and RGB LEDs behind a translucent acrylic insert, which will allow the LEDs to shine through the surface of the hold while protecting the electronics. The small channel within the hold is for communication between the core electronics (microcontroller) and the hall-effect sensor/ LEDs.

2.3 Block Design:

2.3.1 Power:

The power module in our block diagram supplies the power to all the electronics in each hold, which will involve a battery, battery protection IC, and a voltage regulator. We are using a Lithium-ion battery that feeds into a BQ2970 battery protection IC, that handles many safety requirements of lithium-ion batteries such as over-voltage, under-voltage, and over-current protection [3]. The output of the battery protection IC will lead into a voltage regulator, which will allow our circuit to provide a steady voltage for our other modules. The localized power from the power module will allow each hold to operate with an independent power supply, which will make our climbing holds easier to install. The power module integrates with the communication, sensing, and control unit modules, which can be seen through the power connections in the high level block diagram.

Requirements	**Verification**
1. Must be able to supply a 4.5 - 5.5 V source voltage with a minimum 300mA current draw. 2. Has to be accessible from the back of the hold for convenient removal. 3. Battery should last for 24 hours with 6 hours in the climb state and 18 hours in the standby state.	A. Apply a resistor to simulate a load to draw a minimum of 300mA and check if we have between a 4.5 - 5.5 V across the battery terminals. B. Confirm that the battery is removable from the back of the hold. C. Run a climbing hold throughout a 24 hour period and manually switch from the climb state into the standby state after 6 hours of testing.

Table 1: Battery Requirements and Verification

Requirements	**Verification**
1. Must be able to safely operate our battery at below 60°C.	A. Apply a resistor to simulate a load to draw a minimum of 300mA and check that the battery does not exceed 60°C.

Table 2: Voltage Regulator Requirements and Verification

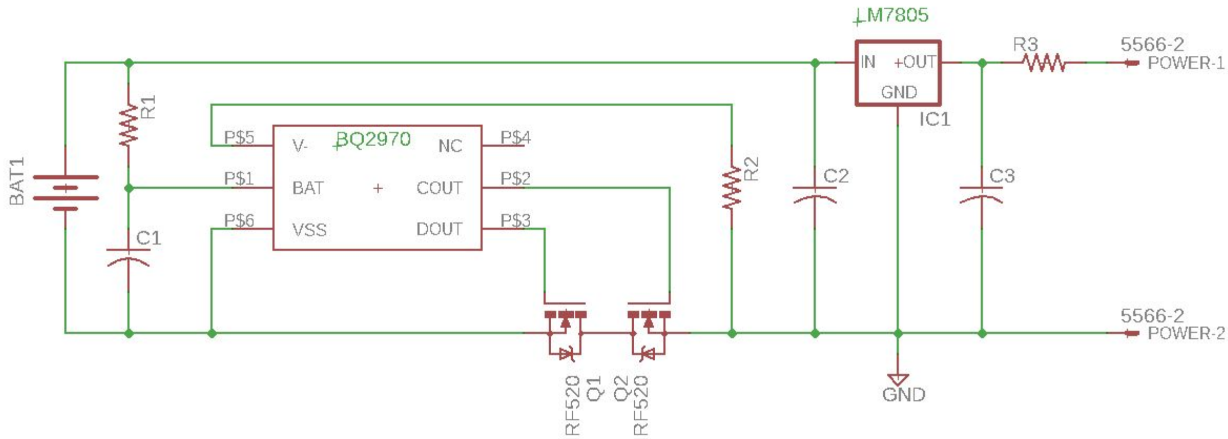

Figure 3: Lithium Battery Control and Regulator Circuit Schematic

2.3.2 Communication:

The communication module links each climbing hold with the server through the router. Since we want to minimize the size of our electronics in each climbing hold, we offload the majority of the more difficult decision making and information storage to the server. Thus, we communicate from each climbing hold to the server using the ESP8266 ESP-01 wifi module, which will communicate to the server through the local intranet [2]. The wifi module will communicate to the microcontroller in the control unit module using the UART protocol. The wifi module will be in a low-power state for the majority of the time, and will wake up to receive and transmit data between the server and the hold. The communication module is powered by the power module and allows data transfer between the control unit and software module.

Requirements	**Verification**
1. Tranceive data with the server at >2 kbps under an IEEE 802.11 b/g/n protocol [9]. 2. Must be able to communicate with the microcontroller using a UART connection. 3. Wake up time from Standby mode should be < 20 ms.	A. a. Transmit 2kb of random data from server to the microcontroller and start timer. b. Echo data back from microcontroller to server. c. Stop the timer after all the data is received from the microcontroller. d. Verify that the data received is identical to the original send data and the time elapsed is under 1 second. B. a. Set climbing hold into standby state. b. Start timer and wake up the climbing hold. c. Verify that the response time of the hold is less than 20 ms.

Table 3: Wifi Module Requirements and Verification

2.3.3 Sensing:

The sensing module's primary purpose is to interface with the climber and detect when the climber has reached that specific hold. We are planning on implementing the sensor through use of a hall effect sensor using the DRV5032 module [8]. By giving climbers magnetic wearables for their hands and feet, this will trigger a threshold breaching event for magnetic flux density in the hall effect sensor when a climber is on a hold, providing a fairly time accurate model as the climber progresses through a route.

The hall effect sensor poses many advantages over other sensors that we considered for this task, such as being much less expensive and minimizing end-user intrusion through the sensing process. However, there are still a fair amount of considerations with regards to the sensing abilities under different magnetic situations from various distances that we must consider at a deeper level in order to accurately apply the sensor. This issue is explored in depth in our tolerance analysis, but in summary we made a design choice to pair the Hall effect in close proximity to the LED close to the surface of the hold. By doing so, we decrease the effective sensing distance needed to actuate the voltage change, while simultaneously improving clarity to the climber as to where the sensor is located should such a situation occur where the magnet is too far away from the sensor. We hypothesize that implementing this strategy will significantly improve both accuracy and precision of our sensing capabilities.

Requirements	**Verification**
1. Sensor must read accurate input signals between 10 - 30°C. 2. Sensor must be able to detect a magnet within 5 cm with a detection rate of 90% within 500 ms.	A. Put climbing hold in cold environment, such as a refrigerator, and verify that the magnet can still be detected reliably as specified in our high level requirements. B. Heat the climbing hold and verify that the magnet can still be detected reliably as specified in our high level requirements. C. Verify with high frame rate camera by identifying the frame when the magnet enters the sensing range, and validating that the LED lights up within 500 ms since the sensing frame.

Table 4: Hall Effect Sensor Requirements and Verification

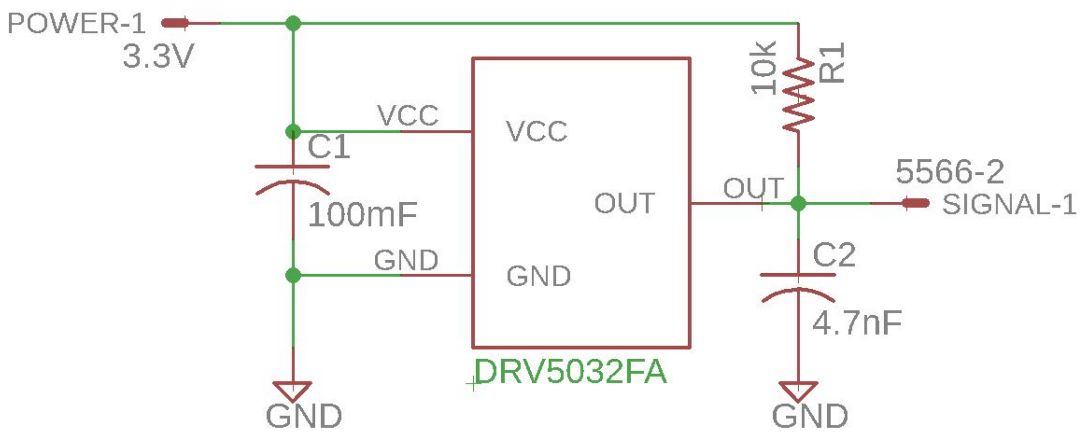

Figure 4: Hall Effect Sensor Circuit Schematic

2.3.4 Interface:

The interface for our project is simply a visual notification via RGB LEDs. This will be used to light up specific routes with different colors and also display other states through other colors/patterns. The interface module is directly controlled by the control unit as there is a direct wired connection between the RGB LEDs and the microcontroller. We are using 3 digital pins and a PWM pin per hold to control the interface. Each digital pin will be connected to an AND gate, and the other input is the PWM pin. The outputs of these three AND gates will go into the R,G and B pins, with the fourth pin being ground on the LED. The physical placement for the LED will be in the PCB with the hall-effect sensor near the surface of the climbing hold under the protection of a translucent acrylic insert, which lets the LED shine through the hold.

This set-up therefore limits our color space to 7 hues: red, green, blue, yellow, cyan, magenta and white. Furthermore, we can also change the brightness using the PWM pin.

Requirements	Verification
1. Specific colors must be visible through the hold in standard room lighting conditions from reasonable distances.	A. Create an eyesight test from 10 meters away where we set half of the holds are randomly selected and lit to a random color and 5 participants must identify which holds are on, and what color they are to a 80% accuracy. Participants will do the test 3 times.

Table 5: RGB LED Requirements and Verification

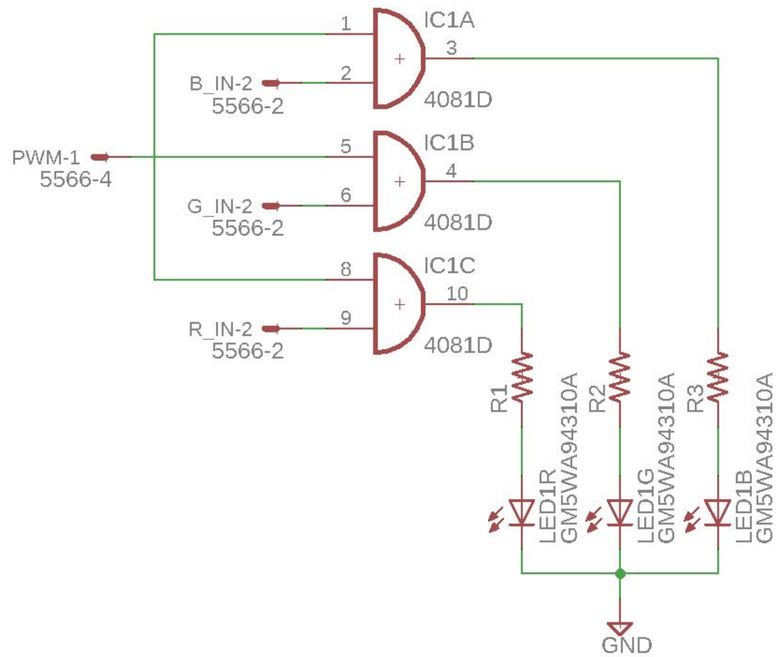

Figure 5: RGB LED Control Circuit Schematic

2.3.5 Control Unit:

The control unit module contains the microcontroller in each climbing hold that locally controls the RGB LED, processes the signal from the hall-effect sensor in the sensing module, and handle requests and responses to/from the server. In this case, we are using a PIC16LF18877 microcontroller so we have UART communication with our wifi module, and digital I/O pins for our RGB LED and hall-effect sensor [5]. We want the climbing holds to have multiple functionalities and therefore designed each hold with several different states in mind. All the high-level state transitions are handled a request from the server, except for the status state. A more detailed description of each state are located in table 6. The state diagram for the state transitions in a more detailed explanation can be found in figure 6.

State	Description
Off	*This state occurs when the battery is out of power*
Standby	*This is a low-power waiting state where the holds are conserving power, but are waiting for a state change command from the server* ● LEDs and hall-effect sensor are off ● Wifi module is in a low-power state waiting for a request from server
Status	*This state is activate by server and replies a status report back to the server with the climbing hold modules: battery level, hall-effect sensor readings/state, and LED state. The climbing hold will return to its previous state once the report is generated and sent back to server*
Display	*This state is used to hold a certain LED color. This can be used to create patterns or animations on the holds.* ● LEDs are on and set to the requested color ● Sensors are off.
Climb	*This state is used for when a route is activated by the server for climbing. The LED lights up in the color of the specified route and the hall-effect notifies the server when a climber is detected.* ● LEDs are set to the route color ● Sensor is on and notifies server when a climber is detected
Route Setting	*This is used with respect to an entire wall of holds. All holds on a wall are initialized as unselected holds, a user can toggle a hold's selection by triggering the hall effect sensor for 5 seconds. The hold notifies the server about its state change and toggles its LED color. This allows the user to create a list of holds for setting climbing routes. The holds will stay in this state until the end route setting request is received.* ● LEDs are either "off route" (red) or "on route" (green) ● Sensors are on, but only activate after a 5 second stimulus to lower false positives (in order to toggle a hold, the route setter has to purposefully trigger the sensor)

Table 6: Climbing Hold State Description Table

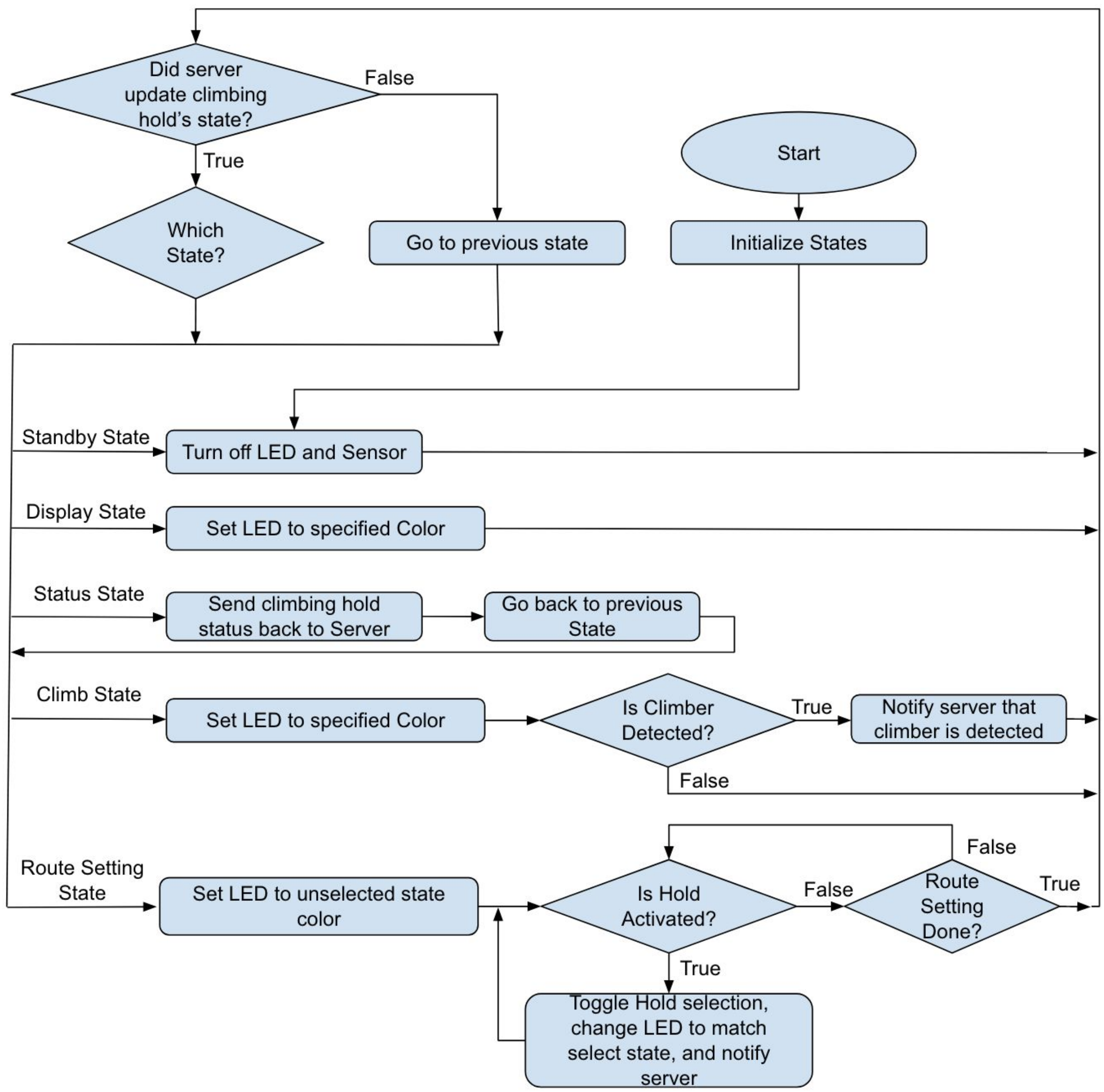

Figure 6: Hold State Diagram

Requirements	Verification
1. Should have enough pins to handle WIFI module, hall-effect sensor, and RGB leads. 2. Should be able to transmit and receive over UART at >2 kbps .	A. Wire all components to the microcontroller and verify that all components operate as expected. a. Verify that data can be echoed back to server through the Wifi module. b. Verify that we can reach all colors with the RGB LED. c. Verify that hall-effect sensor data can be collected.

Table 7: Microcontroller Requirements and Verification

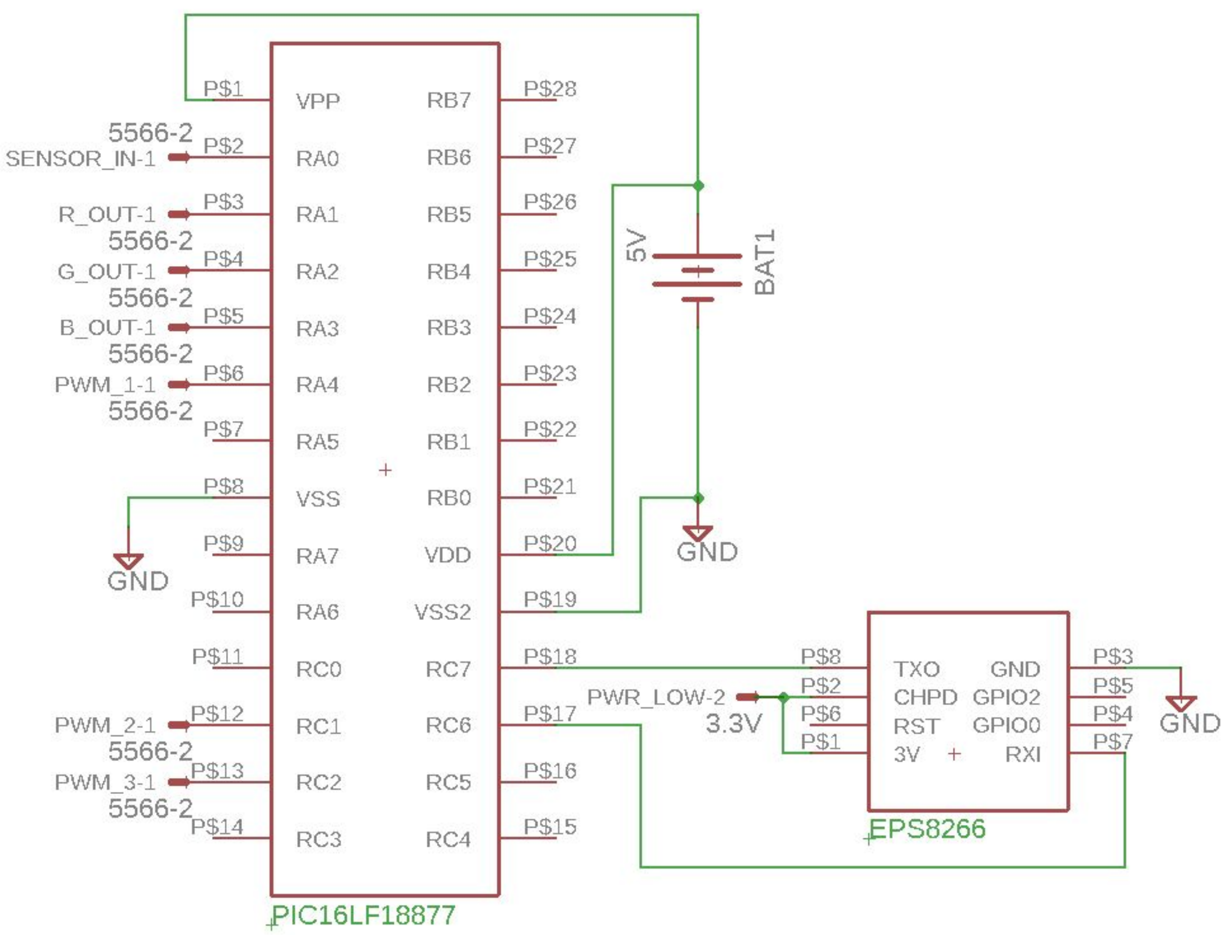

Figure 7: Microcontroller and Wifi Module Circuit Schematic

2.3.6 Software:

Our software module will serve as an interface for users to send and receive data through the communication module. This will consist of a server created using a Raspberry Pi and a router, which will host the web application. The server will communicate directly with both phones of the climbers and the interactive climbing holds. The web-app the server hosts will act as the bridge between the various user intentions and the functions required to carry them out unto the holds. Refer to the Figure 8 to see the state diagram of what users will be able to do on the website. We will use software to allow climbers to store and display various data. For example, climbers will be able to select “created/ saved” routes on the wall using the webapp and prepare them for climbing. Climbers will also be able to view personal climbing statistics on the application. We will create personalized profiles for each climber and gym to track data, and help both groups of users improve their climbing experience. Refer to Figure 9 to see how the software communicates between both parts in the module, and see the state diagram of the server, and how requests from the web-application affect it.

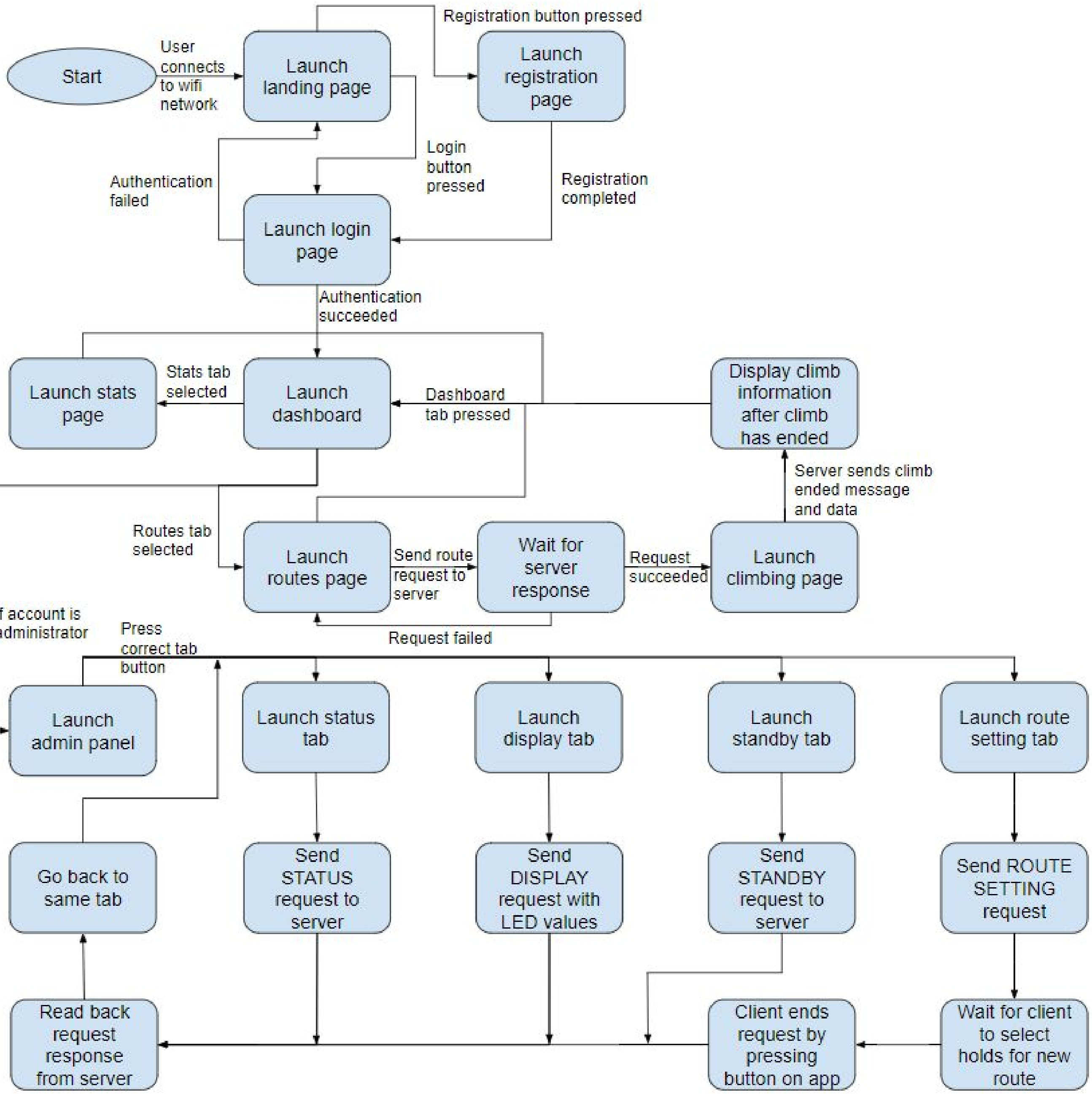

Figure 8: Web Interface Diagram

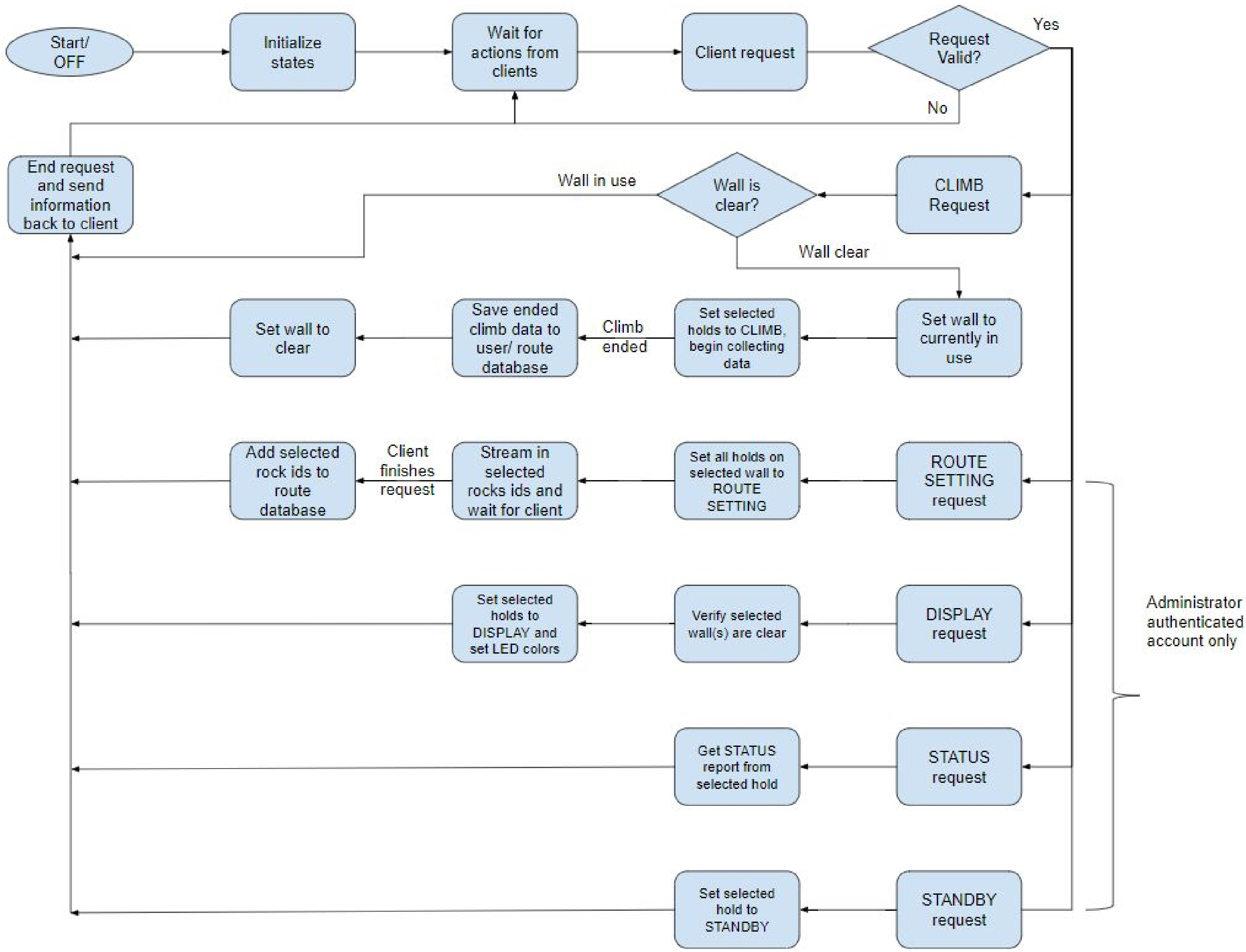

Figure 9: Server State Diagram

Requirements	Verification
1. Displays all possible routes available to climb, with detailed information about the routes. Easily categorizable and filterable to select best routes on certain walls for the climber. 2. Displays statistics to climbers about their progress over time. 3. Displays statistics about a climb after the climb has ended to a climber. 4. Offers route setting screen for inputting hold ids into new/existing routes. 5. Functional admin panel to set holds to a certain color, to turn holds off, to receive information about battery life of holds. 6. Route setting mode to select certain hold ids on a wall and save them as new routes.	A. We will simply identify whether or not, each of these requirements is possible using the software provided. B. To ensure the best possible user experience we will also ask 5 friends to test out these functions and try to complete them. This will let us see how new users interact with our software system, and the ease of completing the requirements without knowing all about how to perform them. We can mark how accurately they complete each task, and will aim to have a task completion rate of over 80% among new users within a 1 hour time frame. C. Finally, we can have a satisfaction survey about the tasks completed for these friends that demo our system. We will aim to have a satisfaction rate of over 7.5/10.

Table 8: Web Interface Requirements and Verification

Requirements	Verification
1. Should be able to handle data from 5 holds. 2. Should be able to serve 3 clients simultaneously.	A. Connect 5 holds and 3 mobiles to the server. Attempt to perform functions normally, and make sure interactions don't overwrite each other and the server goes through functions correctly and quickly.

Table 9: Server Requirements and Verifications

2.3.7 Physical Design:
The physical design is covered in section 2.2; however we have some physical design requirements and verifications that are listed below in table 10.

Requirements	**Verification**
1. All components should be able to fit within the hold. 2. Hold should be durable enough to hold a minimum of 400 lbs of force for at least 1 minute.	A. After the PCB is finished, install into hold and verify that the hold can be installed onto the wall without damaging electronics. B. a. Mount the hold on a small testing wall. b. Attach 400 lbs to the hold and start timer for 1 minute.

Table 10: Physical Requirements and Verifications

2.5 Tolerance Analysis

Our final decision to use a Hall effect sensor was primarily due to several design restrictions concerning pricing, minimizing end-user interference, and clarity in received signals over noise. While the sensor itself provides a relatively elegant way of solving these basic problems, our analysis into the electromagnetic mechanics behind the sensing effect call into question several considerations in terms of magnet and sensor tolerance.

For a project like ours which hinges on not only successful detection when a climber reaches a specific hold but also accurate timing of the route, it is critical that the Hall effect sensor and magnet interact in such a way that guarantees a standard for timing and success. We chose the TI DRV5032FA Hall effect switch sensor to base our design and testing off of. Under the assumption that a cylindrical magnet will be used by the end-user, the mechanics of the Hall effect seen by the sensor from the magnet is given by the following formula [8].

$$B = \frac{B_r}{20}\left(\frac{D+T}{\sqrt{(0.5C)^2 + (D+T)^2}} - \frac{D}{\sqrt{(0.5C)^2 + D^2}}\right)$$

The magnetic flux density, B, is calculated in mT using the remanence B_r of the magnet (in Gauss), for which we will be using a 14000 Gauss magnet. The actual variables that we have a design choice over are D, the distance between the center of the magnet and the face of the sensor, T, the thickness of the magnet, and C, the diameter of the magnet. D will be represented in mm, while T and C are in inches due to ordering standards.

The goal of our tolerance analysis is to determine a combination of magnet dimensions that will reduce the potential for an occurence of flux tolerance as well as the risk posed should such an error occurs. The Hall effect sensor functions by outputting a small voltage when the magnetic flux density threshold, B_{OP}, is exceeded due to the presence of a magnet in its proximity. Due to several physical factors such as surrounding temperature, physical tolerances, magnet approach angle, and applied bias, B_{OP} spans a relevant length between typical performance of 3T and the maximum reported threshold of 4.8mT on the datasheet. For the majority of these phenomenon, the error caused by them on the flux threshold is out of our control. For our tolerance analysis, we will interweave the potential errors with our design choices in order to make an educated and eventually tested conclusion on the magnet dimensions to choose in order to satisfy the guarantees for our sensing system.

Our primary design choices for the sensing system have two dimensions of freedom when it comes to choosing the diameter and thickness of the magnet. We first constrain our variables, taking into mind that a larger magnet will have greater inconvenience for the end user, and state that the magnet will be no thicker than ½” or wider than 1 ½”. From our sensor requirements, we want to be able to sense the magnet from at least 50 cm away from the face of the sensor. Under these constraints, we can simulate the magnetic flux density effect on the Hall effect sensor if we constrain two of the three variables and plot the last one versus the theoretical flux density. Doing so will allow us to formulate tolerance combinations of the magnet dimensions to analyze the distance effects. The two plots below illustrate our simulated magnetic flux densities when one only one variable is unconstrained.

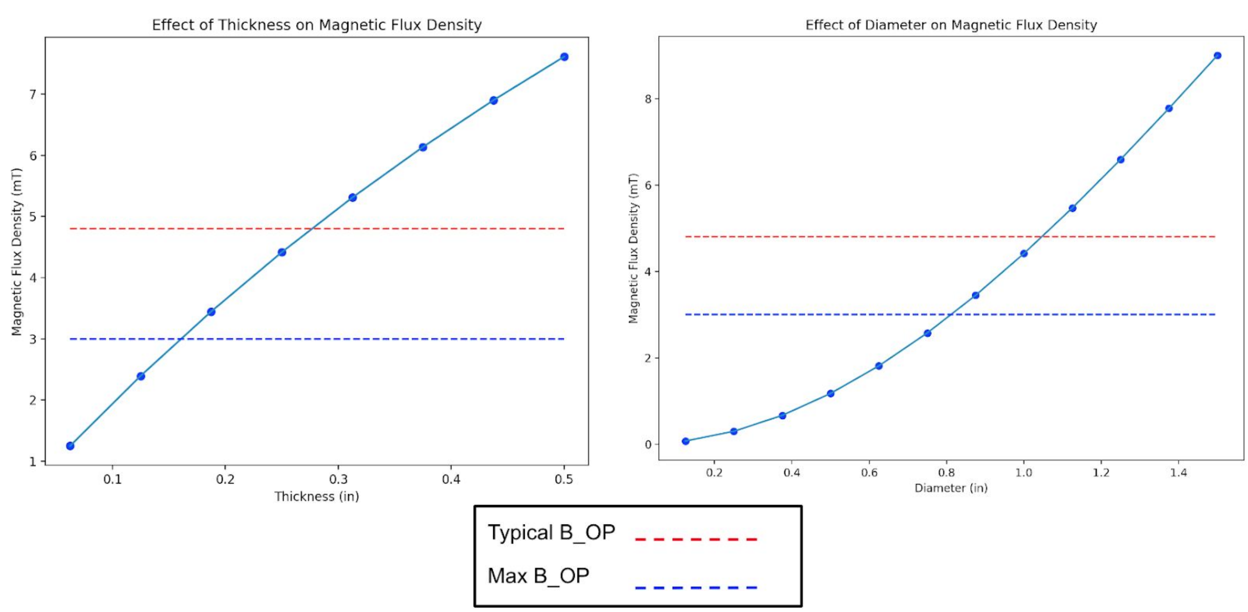

Figure 10: Dimensions of Magnets in Relation to Magnetic Flux Density

The left plot displays the magnetic flux density under the theoretical conditions that the magnet has a diameter of 1”, while the right plot assumes a thickness of ¼”. In both cases, we calculated the flux density under the assumption that the magnet is 5 cm away from the sensor. Furthermore, the blue dotted line represents the typical magnetic threshold, while the red dotted line represents the maximum magnetic threshold. This means that all points above the red dotted line will theoretically have little to no problems switching the sensor at the distance assumed. From these two plots, we can take away key points of information regarding the theoretical behavior of the magnetic flux. For a variable thickness within our tolerance range, changing the thickness has a slightly less than linear effect on the magnetic flux. On the other hand, increasing the diameter has a slightly greater than linear effect up to around 1”, after which we maintain an approximately linear increase. In either case, it makes sense to vary our tolerance decisions based on increasing the diameter to as high as practical, while decreasing the thickness to compensate for the overall size, since diameter will always outscale thickness as a factor in the magnetic flux density

Coming to this conclusion still leaves us with several options in terms of the final magnet densities in our design. Furthermore, we must ultimately make the decision on whether it is admissible to choose a design that may not match the worst-case magnetic flux tolerance threshold in order to compromise magnet size. With regards to the first problem, we narrowed down our design choices into three potential dimensions based on magnets that were cheap and convenient to purchase. The three magnet dimensions are as follows (diameter x thickness): 1.26”x1/4”, 1.26x1/8”, 1”x1/4”. The respective plots for the three tolerance choices are displayed in the plots below.

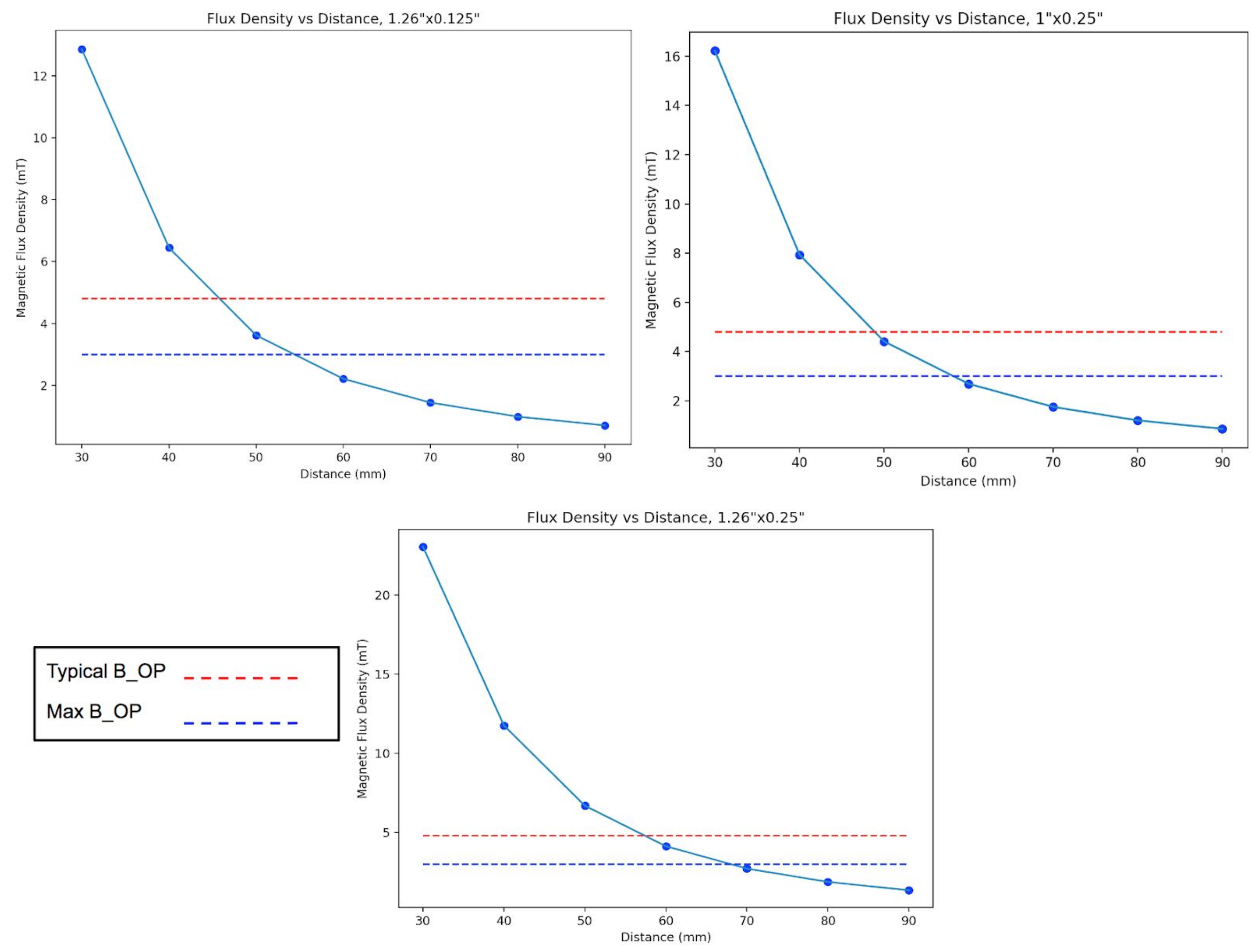

Figure 11: Flux Density Tolerances for Three Magnet Combinations

Of the three configurations, the only one which guarantees a flux density above the maximum threshold at 5 cm is the bottom one, with the dimensions of 1.26”x1/4”. The other two magnet designs sacrifice this worst case error tolerance for a reduction in size, which from our design perspective is just as important if not more. Upon further analysis of our system, however, we came to a final design choice that allows us to satisfy the threshold requirements without compromising room for potential error by our theoretical calculations. Instead of embedding the sensor deep into the hold, we will test configurations that have the sensor near the surface of the hold close to the LED. Doing so will allow us to sense at a lower distance that disregards the error tolerance by a significant degree, and allows us to choose a magnet size that falls more in line with a compact, nonintrusive end-user experience. To this end, looking at the two graphs on the top row, we settled on buying and testing magnets with the more compact dimensions at a slightly closer distance than the tolerance thresholds.

3. Cost and Schedule

3.1 Cost Analysis:
3.1.1 Labor

At 16 weeks, at 10 hours a week, we expect each group member to spend 160 hours on this project. If we estimate our labour at a $35,000 salary, cost per hour (assuming 40 hours per week for 50 weeks per year) comes out to $17.50. This therefore makes our total student labor cost:

$$\frac{\$17.50}{hour*person} * 160\ hours * 3\ people * 2.5 = \$21,000$$

For the machine shop work, we estimate half an hour per hold of work, and two hours discussing and deciding on how to complete the work. There are 10 holds to complete which places the total machine shop work at 8 hours. At a rough estimate of $50/hour of work for the machine shop, this makes total machine shop labor:

$$\frac{\$50.00}{hour} * 8\ hours = \$400$$

The total labor cost is $21,400.

3.1.2 Parts

Our parts are both bought online and borrowed from the lab but we have estimated the overall cost for the entire amount of each part ordered:

Part(s) Name	Quantity	Total Cost
Hall Effect Sensor (DRV5032FADBZR), Texas Instruments	10	$1.80
Wifi Module (ESP8266), Espressif Systems	10	$32.50
Microcontroller (PIC16LF18877-E/PT), Microchip Technology	10	$18.70
RGB LED (YSL-R596CR3G4B5C-C10), China Young Sun Led Technology Company	10	$19.50
Battery Protection IC (BQ2970), Texas Instruments	10	$2.30
Battery (PRT-13813), Shenzhen Data Power Technology Ltd	10	$99.50
Climbing Holds	10	$18.99
Magnets	6	$10.99
Raspberry Pi 3 Model B and PSU, Raspberry Pi Foundation	1	$42.99
Microcontroller Flashing Tool (PICKIT), Microchip Technology	1	$47.95

Table 11: Parts Cost analysis

Total cost of parts is **$295.26**

3.1.3 Final Cost

$$Total\ Cost = Labor + Parts = \$21,695.26$$

3.2 Schedule:

Date	Jishnu	Brian	Daniel
2/19/2018	Decide on/order microcontroller and wifi module	Decide on/order hall effect sensor and associated magnets	Decide on/order Climbing Holds, RGB LEDS, misc electronics (i.e. wires)
2/26/2018	Write front-end first prototype of software	Prototype with PIC and wifi module and finalize order for machine shop	Write front-end and begin back-end prototype of software
3/5/2018	Finish writing climber web-application and begin writing admin panel on web-app	Design PCB for Microcontroller and parts	Prototype with PIC and wifi module
3/12/2018	Test web-application fully and begin prototyping with server and web-application	Test hall effect sensor and magnet strength and try running with the PIC	Test wifi module and the PIC and display connectivity between PIC and server.
3/19/2018	Test server and web-application together and finalize their connecting functions	Test hall effect sensor, LED's and PIC all together. Find a suitable battery to use in project.	Combine/ complete PIC instruction set, flash onto microcontroller and test
3/26/2018	Finalize all functions and test mock software with all hardware	Combine prototype and place into hold, test sensor inside hold.	Test Wifi connectivity inside hold and finalize wifi-connectivity.
4/2/2018	Refine first prototype web-application based on previous test	Refine first prototype of all hardware once inside hold. Potential bug fixes with hardware and PCB.	Refine first prototype of PIC instruction set and wifi connectivity.
4/9/2018	Prototype should be fully functional. Responsible for the software portion of this prototype.	Start soldering parts onto PCB to create embedded system and place into physical hold.	Prototype should be fully functional. Responsible for the wifi connectivity of this prototype.

4/16/2018	Help with and refine integrated system. Software will not change so help with the hardware.	By the end of this week, the prototype should be fully functional. Responsible for the sensor/ microcontroller portion of this prototype.	Begin to do all verification checks for physical requirements, interface. Physical requirements may require building a wall/ contacting the ARC or Urbana Boulders.
4/23/2018	Test and refine integrated system, do all verification checks for wifi module and software.	Test and refine integrated system, do all verification checks for hall effect sensor, microcontroller, and battery.	Test and refine integrated system. Do and complete all verification checks for safety, physical requirements.
4/30/2018	Prepare final presentation	Prepare final demo	Prepare final presentation and some of the final demo

Table 12: Planned Schedule Table by Week

4. Discussion of Ethics and Safety:

4.1 Ethical and Safety Issues:

Rock climbing is already a dangerous activity and so this project must be extensively tested to ensure maximum safety. The power module is a particularly important area of consideration, due to the potential danger posed by the battery under high pressure or puncture situations. In most batteries, several chemicals within the batteries are harmful from contact, while others may be flammable or prone to exploding under extreme pressure [4]. After now working on the design documents, we have realized that a lithium battery would be the best option to supply power, due to its rechargeable nature. However, it is one of the most dangerous out of the options we chose from, and therefore we must take safety very seriously. In order to curb the potential dangers posed by the battery embedded in the climbing hold, there are a couple design choices we can potentially make further down the road. One such choice could be to pad the area around the battery with force absorbing material such that any external pressure would be reduced, but the sacrifice made in doing so is in the space taken up by the power module. All in all, for the power module to pose as small of a threat as possible, we need to take proper consideration in the physical forces that could potentially cause a dangerous situation and make conscious design choices around these situations. From a regulatory perspective, the U.S. Consumer Product Safety Commission recommends the following considerations for embedded battery casings and casts [6]:

- “Battery packs with proper Battery Management Systems, including charge control, short-circuit protection and cell balancing”
- “Cells suitable for intended loads and conditions and manufactured with good quality control”

Furthermore, rock climbing holds are frequently exposed to chalk and sweat which can damage internal circuitry. We therefore would want a way of enclosing our internal circuitry and preventing contact from outside of the mold. We can do this by placing our circuitry as proposed, inside the hold and ensuring any access panels to the internals are in the back of the hold, which is then mounted onto a wall and closed off from the environment.

Although our designs raise very few ethical concerns, we must focus again on the issue of safety. The IEEE code of ethics states to “hold paramount the safety…” and so we must utilize all our resources to maintain this code [1]. It is essential we test these holds in an environment similar to a commercial application of the project, and with human subjects. However, once again, we must be concerned with human safety and so adequate tests must be designed to not only be safe for the test subjects, but also test our devices to ensure they are safe when under extreme factors that can potentially occur in public use. Previously, we had an unrealistic weight amount that the hold should have been able to support. Now, having done research into this area, we have a better estimate for this and as such should also look to test this.

4.2 Documentation of Safety Procedures:

4.2.1 Battery Safety

A safety concern for our project is the inclusion of a battery in each climbing hold. We are using this battery as we want our project to be useful as an out of the box product and not require need for extra wiring or physical architecture to set-up. The battery's are used for their portability, and this is certainly required for climbing holds, which are often moved around in a gym.

We are using a lithium-ion chemistry battery, which has extra safety regulations due to its highly flammable nature. According to the ECE 445 general battery safety document, we must follow a strict set of rules to maximize safety using this device [4]:

- The battery must be placed "in one of the lithium battery bags whenever charging or discharging the battery".
- It must only be used with a TA present after having simulated our circuit and also tested the prototype without a battery.
- If a problem ever occurs we must immediately turn off the circuit and identify the problem.
- If a battery explodes immediately call emergency services.
- If a battery ignites immediately call emergency services, extinguish the fire with a fire extinguisher and call a TA.
- If a battery swells, or feels hot to touch, place it into the lithium battery bags and call a TA to inspect. Never leave this unattended until it has been inspected as this is a potentially severe safety hazard.
- To charge a battery, TAs must first approve of the charger circuit design and TAs must be present during the initial first test of charging.

These are essential when using the lithium battery and must be maintained when both testing and prototyping our design, but also in general use for the finished product afterwards.

4.2.2 Climber Safety

Another primary safety concern is climber safety in a climbing gym. According to the paper "Instrumented climbing holds and performance analysis in sport climbing," they reported the maximum impulse applied to climbing holds during dynamic movement as 1705 Newtons, which converts to 383.3 lbs of force at the applied to a hold. For our design requirement, we have each hold required to withstand 400 lbs of force. However, climber safety extends to the climbing gym that our holds are installed in. The expectation is for each climber to follow the safety regulations specified in the climbing gym that our holds are installed in.

General climbing guidelines should be followed:

1. Follow all directions of climbing gym staff and climbing gym
2. All children should be accompanied by an adult
3. Use proper climbing gear, such as climbing shoes for bouldering and proper belay equipment for top rope/lead rope climbing
4. Only one climber per wall with adequate spacing between each climber

5. Citations:

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