# Mappa Signa

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***Abstract*—Throughout many homes, offices, and buildings the consistency of wifi signal strength wavers significantly. In order to reinforce weak wifi signal strength users can place signal boosters around the building, however many times the placement of wifi signal boosters is simply done by guessing or approximations based on previous experiences. One way to determine optimal signal booster placement is done through signal strength heatmap visualization. By creating a wifi signal strength heatmap of the room(s), users can strategically place signal boosters that optimize their wifi signal strength throughout an area. Earlier approaches to this issue require users to have a pre-made map or blueprint in addition to copious user input as they traverse the room. To make the process of heatmap generation and signal booster placement easier, Mappa Signa provides a handheld device which simultaneously maps the room, marks the user's location, and measures the wifi signal strength at the user's current location. The data collected by the handheld device is then offloaded to an external PC nearby which generates the heatmap while also recommending the optimal placement for a wifi signal booster.**

## I. Introduction

The Internet has changed the way users interact with technology and in order to take advantage of the Internet, many households and offices require strong WiFi connections on a daily basis. In 2015, 77% of households reported having broadband Internet subscriptions [1] and just one year later the number of households increased to 81% [2]. For many Internet users, WiFi presents the quickest and simplest solution for connecting online without the need for laying physical wires. Wifi is a wireless technology that uses radio waves to provide high-speed network and Internet connections. Although users benefit from wireless connections in various environments, WiFi has physical limitations that hinder its convenience and usability. For instance, a single wireless router or access point might be feasible for a single-family household, however, businesses and establishments serving a large office building require grids of access points. Furthermore, WiFi routers operating on the 2.4 GHz bandwidth can theoretically reach distances up to 46 meters indoors and those on the 5 GHz bands achieve approximately one-third of that distance [3], however implementing routers in environments with physical obstructions such as brick walls or metal frames significantly reduces the usability range of WiFi by 25% or more [3]. Additionally, as the distance from a router or access point increases, the power of the WiFi signal strength declines rapidly, especially when physical obstacles are introduced into the environment.

Currently, users can remedy weak WiFi signal strength and dead spots by distributing WiFi signal boosters throughout a building. Although signal boosters can potentially reinforce signal strength of a wireless network, typically booster placement is blindly executed through guessing and approximations which can inadvertently raise costs while not fully optimizing. Our solution, Mappa Signa, is a device that accurately represents the WiFi signal strength throughout a room or building by generating a heatmap. After the heatmap is created, Mappa Signa performs analysis on the map and recommends the optimal locations for signal booster placement based on the apparent weak or dead spots within the generated heatmap.

Applications with a similar premise exist for laptops and mobile devices, however, these devices require the input of a pre-existing map or blueprint of the area and rely heavily on user input in order to plot your current location. One example of such software includes the *Ekahau HeatMapper* [13]. The *Ekahau HeatMapper* is a Wi-Fi Site Survey Software which allows the user to see Wi-Fi coverage on a map, locate access points, and find available networks. The problem with the *Ekahau HeatMapper* is the requirement of constant user input to mark position and travelled path in addition to providing a pre-existing blueprint/map of the area. Due to the need for continuous user input, preceding alternatives inaccurately represent the WiFi strength within the specified area and inconvenience the user by forcing them to manually provide a map and individually mark their current location. Unlike previous existing products, Mappa Signa requires little to no user input and the final result is a more accurate representation of the WiFi strength throughout the traversed environment. Using LIDAR [14] and a WiFi breakout board(s), our device creates a true map of a room, tracks the user's position in the room, and records the WiFi strength at the user's current location. After recording the data and performing SLAM [15], the device transmits the map, trajectory, and WiFi signal strength data to an external PC that generates a WiFi signal strength heatmap of the traversed area and suggests the optimal placement for additional signal boosters.

Mappa Signa benefits both home and business users by providing accurate representations of their current WiFi signal strength distributions. Moreover, providing factual WiFi signal heatmaps and signal booster placement recommendations can potentially save building managers, such as homeowners and contractors, money by only allocating signal boosters in necessary locations as opposed to aimlessly placing signal boosters without prior assessment.

## II. Design

### A. Overview

Our project, Mappa Signa, combines three main components: SLAM, accurate WiFi signal strength measurement, and image processing . Mappa Signa generates a heatmap by aggregating a map, user trajectory, and series of measured WiFi points along the trajectory. Before generating the heatmap, Mappa Signa uses Hector SLAM, a form of

LIDAR-based SLAM discussed in Section II(B), which creates a map and estimates the path traveled by the user. While the position of the user is estimated through LIDAR scans, Mappa Signa simultaneously measures the current WiFi signal strength of the user in their current position using a WiFi-breakout board with a modified antenna. As the user traverses the environment, an LCD display attached to the device advertises the current status of the handheld device in addition to the current WiFi signal strength being measured. After recording the WiFi signal data and calculating the map and trajectory, the data is offloaded to an external PC which proceeds to generate a signal strength heatmap and determine optimal signal booster placement. Refer to the block diagram in Figure 1 which includes the general flow of information and connections of Mappa Signa.

In order for Mappa Signa to be a successful product, our design must satisfy a set of system requirements shown in Table 1: Portability, Power Consumption, Battery Life, Speed, and Convenience. Since Mappa Signa aims to replace pre-existing computer and phone applications, the device must provide more accurate results than preceding applications while also affording portability and convenience for the user.

Satisfying multiple system specifications required compromises and tradeoffs to our overall design. Regarding portability, Mappa Signa should be a relatively lightweight, handheld device weighing less than 4 pounds. The heaviest component in the device is the lithium-ion battery which provides enough power for three or more hours of runtime between charges. We chose the lithium-ion battery, despite its weight, because the battery is compact enough to be stored in a small device but large enough that a user could create a heatmap of an entire building complex. Furthermore, the user should not be expected to walk at a certain speed, therefore our design must perform acceptably for a wide range of walking paces. Finally, the encasement for the device must be compact and lightweight so that using the tool is convenient and benefits the user experience. Overall, creating a portable device with enduring battery life which requires little to no user input makes Mappa Signa worthy of being considered convenient and reliable for the purpose of measuring WiFi signal strength throughout many different building structures.

TABLE I
List of System Requirements and Specifications

| System Requirements | System Specifications |
|---|---|
| Portability | Easily maneuverable, lightweight system weighing < 4lb |
| Battery Life | Lasts up to 3 hrs between charges |
| Speed | System performs at speed adequate for a fast walking pace |
| Convenience | Operates with minimal user input |

*B. Mapping and Localization*

A major component of our design entails creating a map of the environment while also performing user localization so that the measured WiFi signal strength corresponds to the appropriate location in the traversed area. In our design, we employ a LIDAR which records data about the environment and then sends the data to a SLAM algorithm which creates a map and trajectory based on the path traveled by the user.

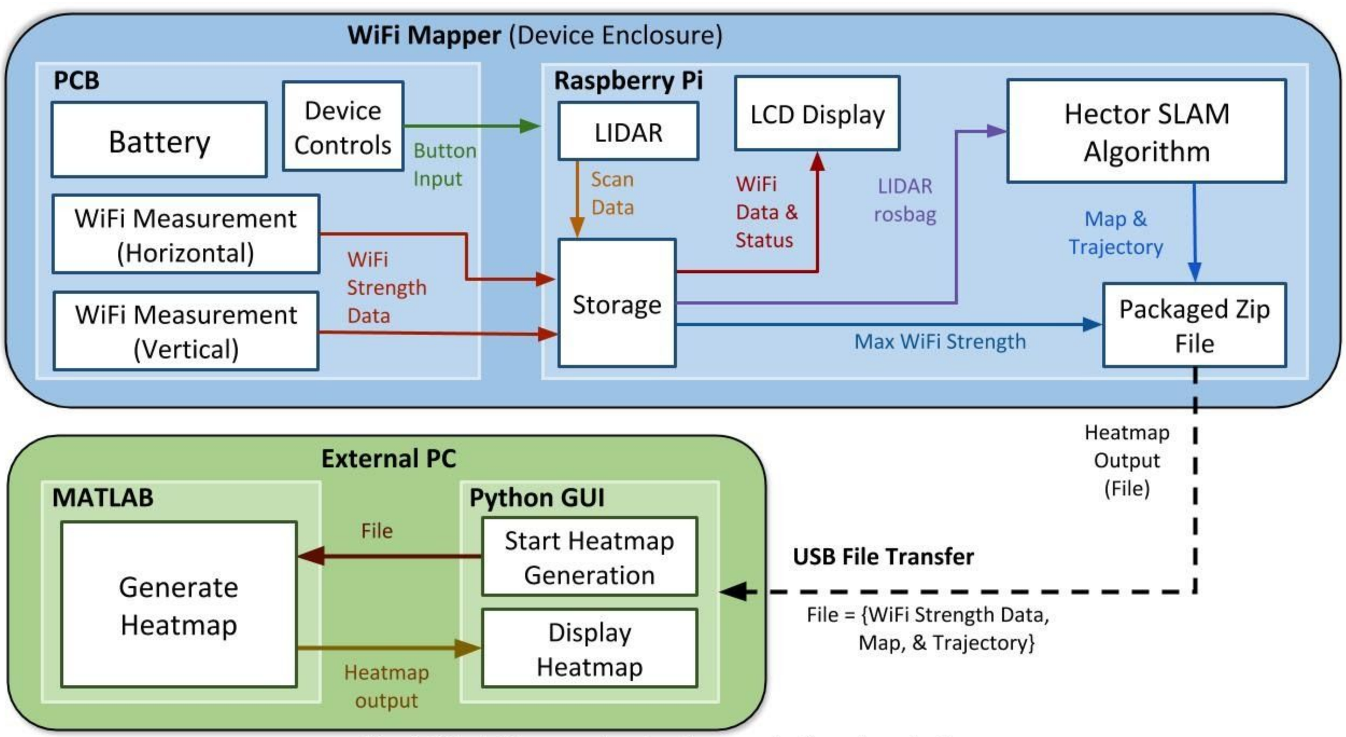

Fig. 1: Block Diagram showing the organization of our design

Specifically, for this purpose we have chosen the RPLIDAR A2M8 [4] and Hector SLAM [7].

The RPLIDAR A2M8 is a 360º 2D LIDAR capable of taking more than 4000 samples of laser ranging per second (4000 Hz) within a range of 0.15 to 12 meters with a distance accuracy of roughly 1% [4]. Furthermore, the RPLIDAR A2 series adopts a low-cost laser triangulation measurement system which makes the LIDAR perform in a wide range of indoor environments with varying light exposures. The LIDAR's laser triangulation ranging method [4] allows the device to perform high-speed distance acquisition by emitting modulated infrared laser signals during every ranging process. As a result of the triangulation method, the LIDAR can accurately and quickly measure distances from objects and obstacles without the need of conventional measuring apparatuses such as rulers or measuring tapes. LIDAR's triangulation method provides a room measurement technique which requires little to no strain on the user while also supplying quicker results in a visibly pleasing format. Once the laser signal reflects off an object and returns back to the LIDAR, the vision acquisition system processes the sample data and outputs the distance and angle value between the detected object and the LIDAR. Refer to Figure 2 for a visualization of the laser triangulation ranging method used by the RPLIDAR. When driven by the motor system, the LIDAR rotates clockwise in order to perform a 360º scan of the surrounding environment.

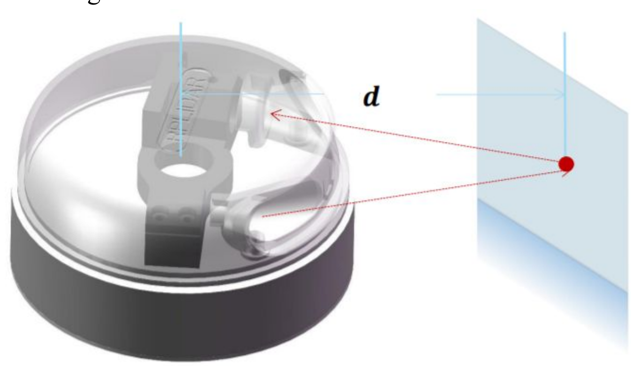


Figure 2: LIDAR laser triangulation process.

For our project, we feed the LIDAR data to a Raspberry Pi 3B+ [16] which handles the processing required to successfully operate the RPLIDAR A2M8, however, due to the Raspberry Pi's low processing power we must record the data from the LIDAR before performing any additional processing on the results. In order to activate, operate, and record data from the RPLIDAR, we use the Robot Operating System (ROS) framework which is available as open-source software for Linux. ROS is a framework used for writing robot software and includes a collection of tools, libraries, and conventions used to create complex and robust robot behavior [5]. For our purposes, we required the rplidar_ros package [6] which provides basic device handling for the 2D laser scanner in addition to the hector_slam package [7] which is used for creating a map and localizing the user. Through ROS, we can precisely control the start, stop, and recording time of the LIDAR.

After recording LIDAR data, we can then perform SLAM on the data by playing back the recorded laser scans in simulated time, similar to playing back a video recording at a later time. SLAM, or Simultaneous Localization and Mapping, is a type of algorithm used to create maps for robot navigation in addition to robot localization within maps. For this purpose, we chose the Hector SLAM algorithm. Hector SLAM is a computationally lower costing SLAM algorithm compared to other algorithms that performs the same function while only requiring the input of laser scan data. Typically, SLAM algorithms operating on LIDAR data require an additional source of odometry, such as wheel rotation, however since our device is handheld we lack a source of odometry which is why Hector SLAM is ideal for Mappa Signa's design.

In Hector SLAM, a map is represented by a 2D occupancy grid based on a collected series of LIDAR scans. In order to build a map of the environment, Hector SLAM incrementally processes the incoming lidar scans and then builds a pose graph which links each scan. A pose graph is a series of nodes connected by edges which define the relative pose between nodes and the uncertainty on the measurement between the nodes [8]. If the SLAM algorithm recognizes a previously-visited location through scan matching, the algorithm tries to establish loop closures as the LIDAR traverses along a path. Once the recorded data finishes playing back, the resulting map and trajectory can be extracted from Hector SLAM and then saved until offloaded to the external PC for heatmap generation with the WiFi signal strength data. Below, Figure 3 shows a map and trajectory extracted from the results of Hector SLAM during testing.

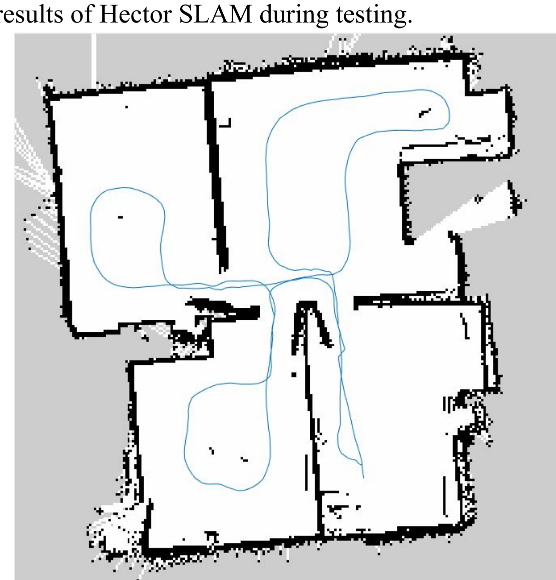

Figure 3: Hector SLAM Map and Trajectory results from a Cliffside Apartment.

### C. *Measuring WiFi Signal Strength*

To measure the WiFi signal strength we needed a device which had the ability to connect to the desired WiFi network, as well as to report its Received Signal Strength Indicator (RSSI). There are many such devices, ranging from full laptop computers to small add-on boards built for arduino projects. For our project, we wanted something that would be very minimalist in size and function, so that it wouldn't be too unwieldy and also to reduce the complexity of the device. With this in mind, we decided the NodeMCU Amica [17] would be a good board for our use case because of its simplistic design, small form factor, and ability to scan networks and report their RSSI.

A network's RSSI is a measurement of the power with which a client receives the access point's broadcast. In our situation, the client would be Mappa Signa, and the access point would be the router(s) which we are measuring [11]. In our project, when we say RSSI we are actually referencing the signal strength in units of dBm. The difference is that RSSI normally is a measurement that is relative. The values used by different manufacturers of Access Points (APs) vary based on the manufacturer's preference. dBm is an absolute unit, referenced with milli-Watts. Therefore, no matter what AP is used, we will be able to measure the strength in a meaningful way. [12]

The device we've chosen for our implementation is the NodeMCU Amica. It has built-in Universal Asynchronous Receiver/Transmitter (UART) which can be used to transmit the RSSI data to the Raspberry Pi, and has a small form factor which is very valuable in compact devices like ours. Figure 4 shows an image of a NodeMCU Amica in its stock form.

Figure 4: Stock NodeMCU Amica

We've decided, however, to customize the board a bit because the built-in PCB antenna was not consistent enough for us. We cut the PCB antenna off and added an external omnidirectional antenna to ensure consistent readings. This modification can be seen in Figure 5.

Figure 5: Modded NodeMCU Amica

We also decided that to further improve consistency and accuracy, we should have two perpendicular antennas. The only way to achieve this setup was to add a second NodeMCU Amica board, and orient the antennas of each perpendicular to the other. With these modifications in place we've experienced far more consistent and accurate results in measuring the signal strength. In order to store the readings in a way that would correlate to a location on the generated map, we have the devices send both the RSSI and the time elapsed in milliseconds since the start of the recording over UART to the Raspberry Pi. The time elapsed matches up with the SLAM data, because that also uses time elapsed to create the map.

*D. LCD Display*

To give the user meaningful and easy to use feedback from the device, we added a 16x2 LCD display. On startup, once our script begins running on the RPi, it tells the user that it's started and is ready to record. Then, for each action it prints different information. On recording, it will print the RSSI in real time. When recording is finished, it will alert the user that it is still working on the map, until it is finished and then it will advise the user to either transfer the mapping data, or re-record it. When transferring data, it prints that the data is transferring, and then updates when the transfer is complete, alerting the user to the ability to remove the drive.

*E. Power and PCB*

To power our system we are using a 7.2V 6500mAH lithium-ion battery [18]. Lithium-ion was chosen over other types of batteries due to its high capacity, high voltage while simultaneously having a small form factor and being relatively light. This was necessary for our project, in order to meet our system specifications we needed a relatively portable device while also having a power-intensive system. The battery needed to be light while simultaneously delivering a lot of power. For these same reasons, Lithium-ion batteries are used in mobile phones, laptops, e-readers, and other types of portable electronic devices.

The components that need to be powered in our system are the Raspberry PI, LIDAR, and WiFi board. Thankfully, all three components run at 5V. Since this is a portable device we could not rely on wall power. Therefore we had to turn to mobile battery sources. Making a rough estimate using datasheets an average 1500mA current draw through the system was calculated. Knowing that our system specifications stated it needed to be capable of mapping an entire building something that could last for a couple of hours without issue was chosen.

Due to the chemical nature of lithium-ion batteries, their voltage goes up in increments of two. For our project, we would either have to use a 3.6V battery and step up the voltage or use a 7.2V battery and step down the voltage.

In order to step down the voltage, we would need a Buck converter. The buck converter works in a similar way to the boost converter. The only difference in circuit layout is that the inductor is on the right side of the diode, whereas on the boost converter is it on the left side of the transistor. The transistor turns on and off very fast keeping the capacitor charged at a specific voltage lower than that of the power source. The circuit diagram can be seen below in Figure 6. [9]

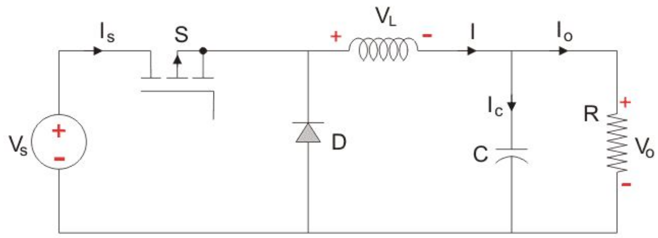


Figure 6: Circuit Diagram of Buck Converter

In order to waste as little power as possible, we ended up choosing the buck converter. In a boost converter, in order to generate the voltage spike that turns on the diode, the inductor must be charged up. The current that goes to ground when charging the inductor is completely wasted. Whereas in a buck converter, it is used to supply the output current until the output voltage drops again. Therefore, a buck converter was chosen for our system. As can be seen in Figure 7, the constructed buck converter is on the bottom left side of the breadboard.

Testing has already been done on the buck converter using a multimeter to ensure that it outputs a steady 5 volts. Further testing needs to be done with the circuit connected to the rest of the system to ensure it still outputs a steady 5 volts. As well as handle the amperage needed to power the entire system.

Our current implementation on the breadboard is very close to what we will have on our final PCB design. The only thing missing from what can be seen in Figure 1 is the LCD display for displaying signal strength and a second WiFi board. The PCB will provide data transfer from the WiFi boards to the Raspberry PI, regulation of power, and signal strength display.

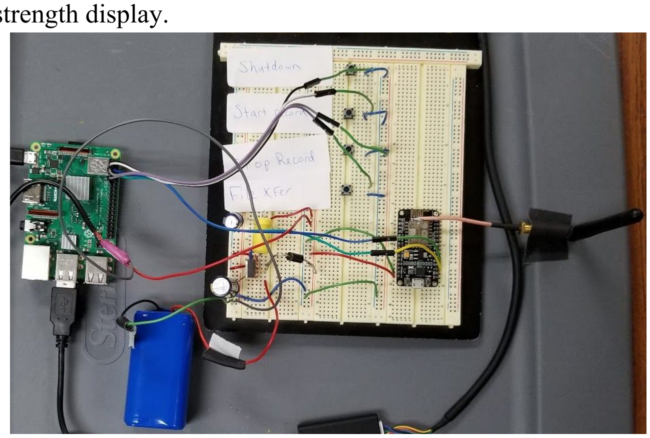

Figure 7: PCB Prototype constructed on breadboard.

*F. External PC*

The external PC is the link that combines all of the data into a final product heatmap. Trajectory points, WiFi strength, and a Hector_SLAM generated map are transferred to the external PC via USB. All of the data is formatted in various text files that are input to the MATLAB program. MATLAB is used in the background of our computer application. We also have a basic Graphical User Interface written in python that displaces all output images and takes an input from the user for wireless extender data.

The Python based application is the central hub for all external PC computations. The application uses scripts to run the MATLAB code in the background to make it simple for the end-user. The GUI currently runs and displays the generated heatmap, displays the calculated signal strength range and color scheme, and takes input for the number of wireless extenders. The number of extenders will be used after heatmap generation to determine low areas i.e. if a user inputs two extenders, the lowest two areas will be highlighted.

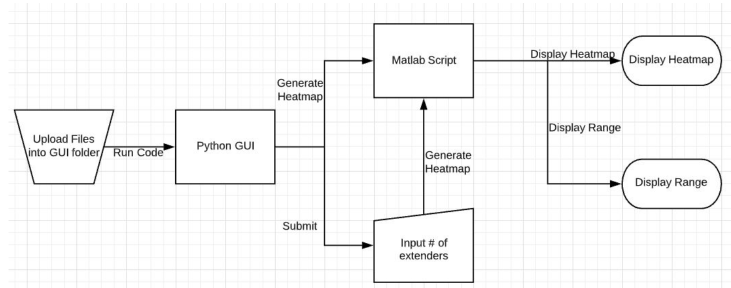


Figure 8: Flowchart of Python Application.

Once the data is input to the PC, the user triggers a button to run the MATLAB program. MATLAB takes the trajectory, WiFi data and matches the signal to the trajectory point based on the time in nanoseconds. This is necessary because we measure more trajectory points than WiFi points, so we must match the signal to the appropriate location.

Once the points are matched, the Wifi data is interpolated so each trajectory point has a WiFi signal. Then the heatmap matrix is created by placing the signal strength in matching X and Y trajectory values. The matrix is then converted to a heatmap using the given MATLAB function, and this heatmap is then saved as an image. This saved heatmap image is then overlaid with the Hector_SLAM generated map of the space. The resulting map can be seen in Figure 10 below.

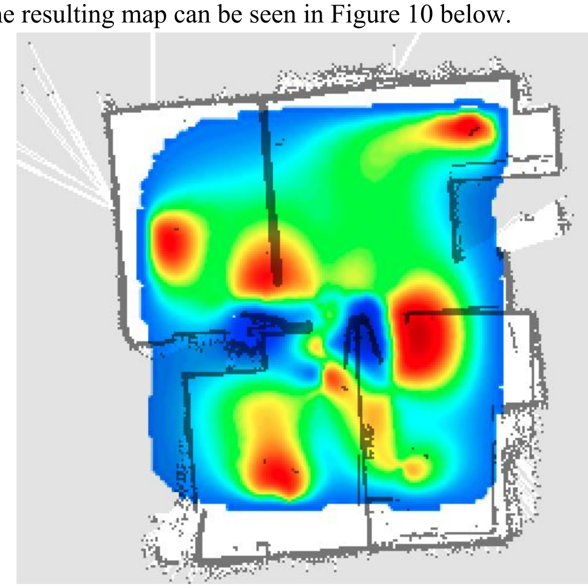

Figure 10: MATLAB generated heatmap and signal range.

## III. The Product

### *A. Product Overview*

At the conclusion of the hands-on, prototyping, fabricating, and productizing portion of SDP20 we managed to produce many of the physical components of our design to the extent that our product was nearly complete. After making several changes to our original design, showcased in the initial product sketch shown in Figure 11, our nearly-final product was fully assembled and ready for use, as can be seen in Figure 12 below.

Using Figure 12 as a reference, all the components described in the block diagram in Figure 1 are included in our final product. From the block diagram, the PCB block, Raspberry Pi block, and all the components contained in those blocks are contained within the main 3D printed body of the product.

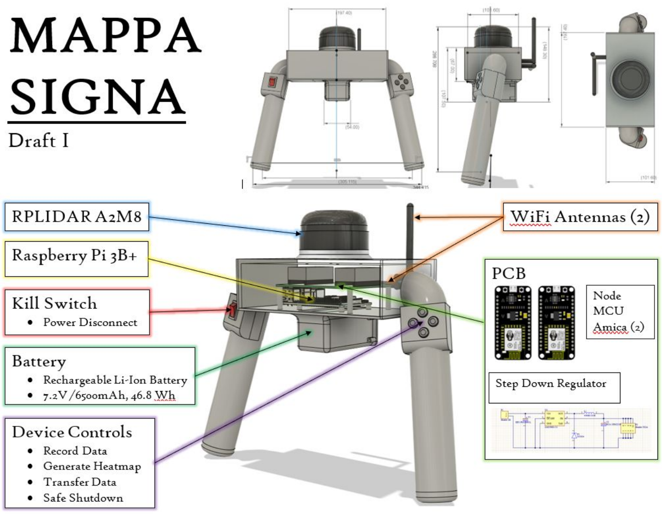


Figure 11: Original product sketch.

Within the encasement, the battery rests at the lowest portion of the device's body in a compartment designed only for the battery. Above the battery in the main box, the Raspberry Pi is mounted to the box using 3D printed mounting pegs and mounting screws. Using mounting points raised above the Raspberry Pi, the PCB is mounted to the device and connected to the battery, LCD, Raspberry Pi, and device controls, and LIDAR. The two WiFi boards are mounted directly on top of the PCB while their antennas are firmly fastened to the outside of the box with one antenna facing vertically and the other aligned horizontally. Mounted to the front of the device is an LCD display which displays the current status of our WiFi Mapping process and live WiFi strength readings. On top of the main lid of the device's body the LiDAR is mounted with the device's cable feeding directly into the encasement. Once the LiDAR cable reaches the inside of the encasement, the cable splits such that the power cable feeds directly into the PCB while the USB data cable, with the power lead removed, connects directly to the Raspberry Pi. This cabling arrangement guarantees that the LIDAR does not drain power from the Raspberry Pi and reduces the chances of low voltage errors in the microcontroller. On the right handle there are three different buttons which trigger the device to record data, generate the heatmap, and transfer data to a connected USB drive. On the left handle there is a small button which triggers a safe shutdown and a larger rocker switch which fully disconnects the power supplied by the battery from all the other components.

Although the external computer used for the heatmap generation is not included in Figure 12, the results produced by the external PC can be seen in Figure 10.

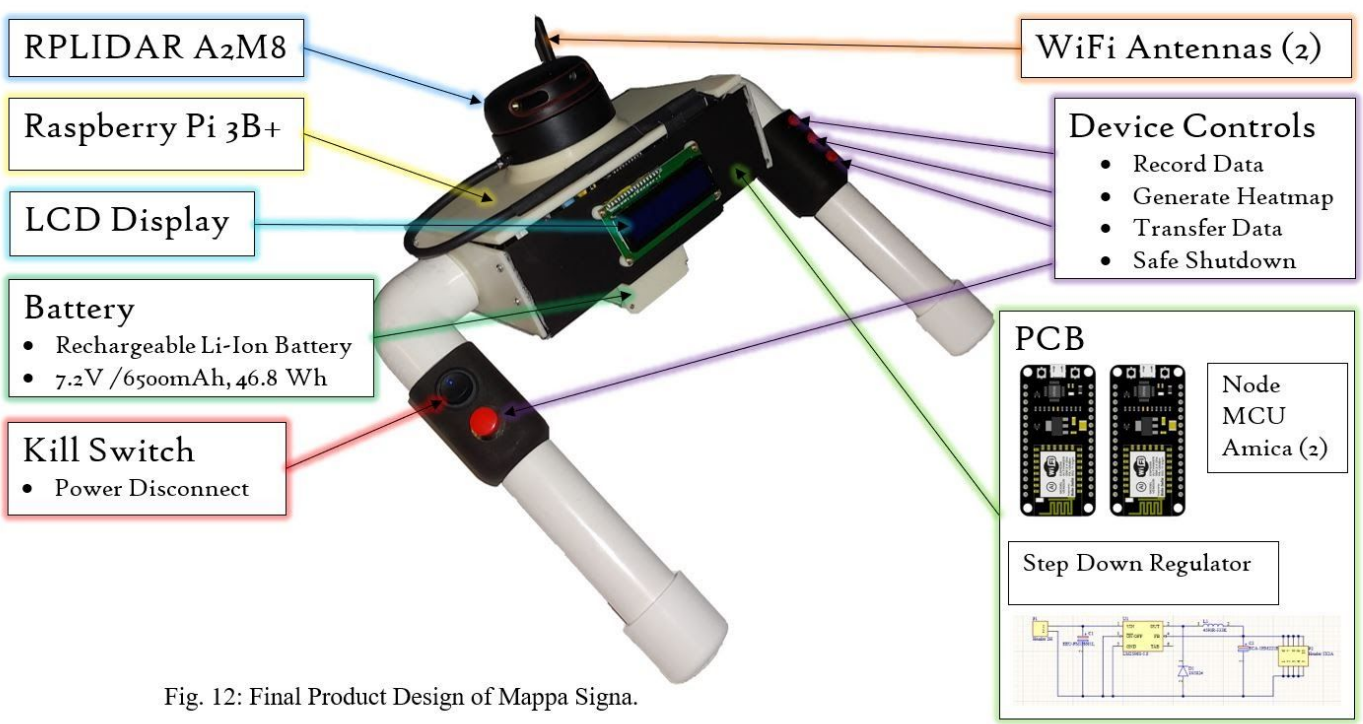


Fig. 12: Final Product Design of Mappa Signa.

*B. Electronic Hardware Component*

The majority of the design and testing for the PCB was done in the Fall semester when working on powering the system through the 7.2V lithium ion battery. This information is found in Section 2.E. Altium Designer was used to move the design from breadboard to something that could actually be fabricated. Before moving to Altium the design was moved to a protoboard, soldered, and tested. Unfortunately no pictures exist of the hand-soldered protoboard. In addition to the buck converter, the PCB included a mounting place for two NodeMCU Amica boards, an outgoing power rail for LiDAR, LCD display, and Raspberry Pi. A second power input was added in parallel with the battery for a charger that would be able to charge the system when powered off.

Each NodeMCU Amica board plugged into the PCB via two 15-pin headers that were soldered directly on to the PCB. Only four pins on each board actually had traces, Vin, GND, RX, and TX. Vin and GND were to power the boards. These pins were connected directly to the Vout for the buck regulator via trace. RX and TX were for data transfer between the Raspberry Pi and WiFi board.

The design of the PCB was entangled with the design of the 3-D printed enclosure. We had to be certain the PCB would be able to fit in the enclosure as well as fit everything that needed to be on PCB. The two WiFi boards also needed to be positioned on the board so that their antennae would be able to reach the outside of the enclosure. Additionally, heat needed to be taken into account. The LM2596 voltage regulator is known to have overheating issues and the PCB layout provided in the datasheet needed to be adhered to to avoid these issues. The PCB was also raised above the bottom of the enclosure to better dissipate heat. The final PCB design was 3x4 inches which fit nicely in the enclosure while also fulfilling the requirements set above. Drill holes were made in the PCB design to match the size of the holes in the enclosure design. Figure 13, below, shows the final circuit diagram for the PCB design. Figure 14, right, shows the final PCB layout with all the top and bottom layer tracing.

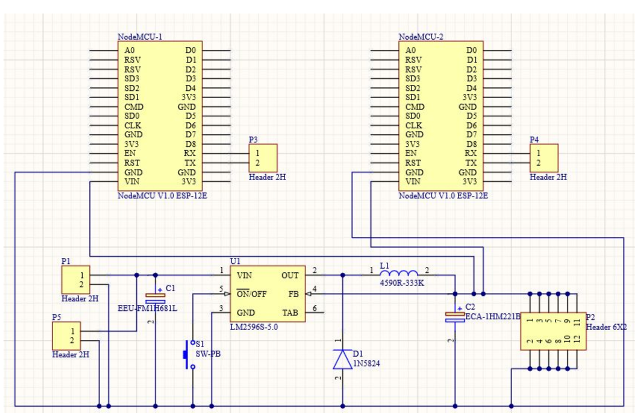


Figure 13: PCB Circuit Diagram

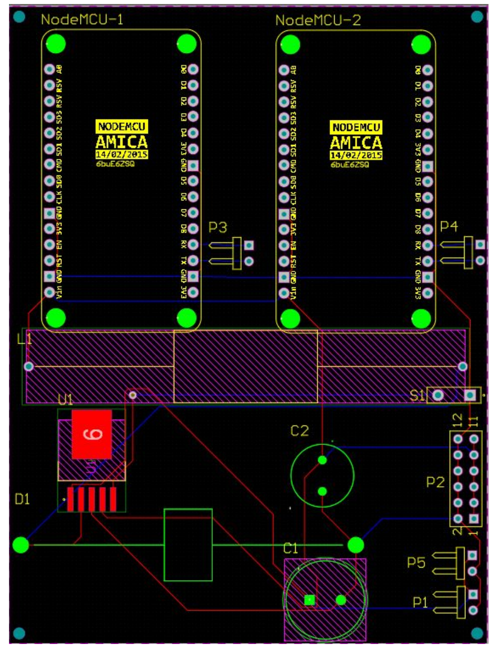


Figure 14: Final PCB layout

After the design and the tracing was double and tripled checked for correctness it was sent off to be fabricated through JLCPCB. Five units were ordered in case there was any issue soldering or with the board itself. The PCB arrived about a week after sending in the fabrication files. The components were then soldered and the PCB was tested. The components were a combination of surface mount and through hole soldering. Two boards were put together in case one of them failed for any reason and both outputted a correct 5V. The PCB was then tested under load with all the components drawing power through it and it performed well. Then the PCB was tested with the charger plugged in and the battery was being charged successfully through the PCB. The voltage on the battery was tested to make sure it was increasing as it was being charged. Then the PCB was tested with the ON/OFF switch routed through it and the switch successfully cut off the battery from the buck regulator. Then all of these things were tested together. The charger and ON/OFF switch with all components plugged in and the PCB again was still working correctly.

In order to connect the LiDAR, Raspberry Pi, buttons, and LCD to the power rail a 2-pin header was soldered onto the rail for each device. Each device could then just plug the power and ground wires directly into the board. Later on, it was decided that this was not the optimal way to safely provide power. The metal in some wires would show even after being plugged in leading to the worry of a short. Also some of the pin headers were not as secure as others and wires could pop out easily. With more time this problem would have been fixed but by Spring Break this was the system the PCB was using. Figure 15, below, shows the PCB with the components soldered on. There is also one WiFi board plugged in as well as the pin headers. Figure 16, below, shows the PCB in its final form in the enclosure with everything plugged in.

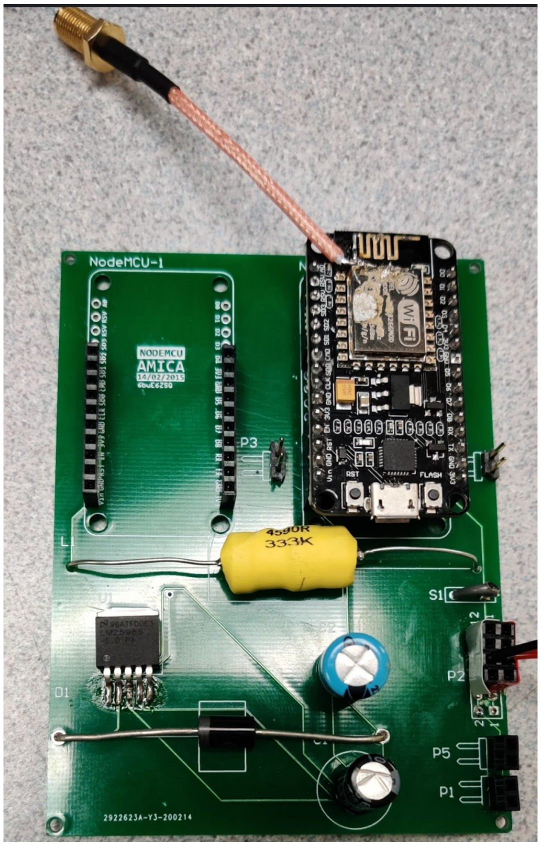
Figure 15: PCB with component soldered

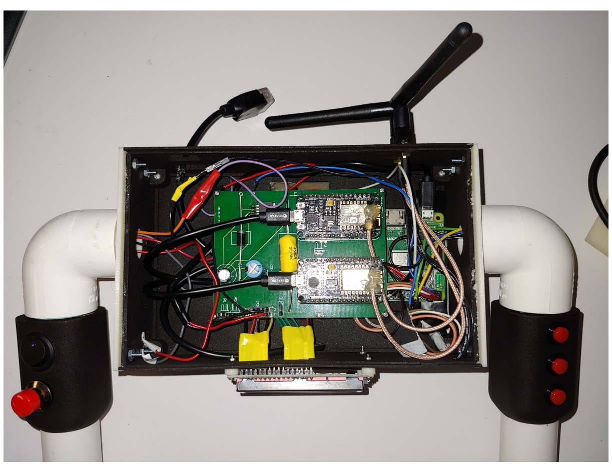
Figure 16: PCB in enclosure

*C. Product Functionality*

After the production period of Mappa Signa ended, our device possessed much of the functionality we had intended to achieve in our final product for Demo Day. Using the block diagram in Figure 1 as a reference, all the physical components of the device included in PCB, Raspberry Pi, and External PC blocks functioned properly at the time of CDR and we managed to perform a successful demonstration of our device during our CDR presentation.

Based on the block diagram, our device was physically complete and the only necessary future changes included adding more air ventilation to the device's encasement and fine tuning the MATLAB program so that the resulting heatmap provides the most accurate and repeatable reading possible. Evidence supporting the functionality of our device includes the resulting heatmap shown in Figure 10, while evidence of our physical device is shown in Figure 12. We were unable to produce a video of our final product before the University shut down.

*D. Product Performance*

Mappa Signa successfully satisfied 75% of our system requirements and specifications mentioned above in Table 1. Our product was sufficiently portable and lightweight. While the final weight of the product is unknown, the final device was easy to hold and maneuver with. The device can be seen in Figure 16. The materials used such as pvc pipe and a lighter 3D printing material helped make the design sturdy without being heavy.

Throughout the design process, we tested multiple speeds for both the LiDAR and Hector Slam algorithm. We found that slowing down Hector Slam caused our map generation time to skyrocket, and decreasing the LiDAR RPMs resulted in skewed data. With both increased, we are able to produce a readable map at a normal walking pace. This successfully meets our product requirement and allows the user to map a room without altering their daily pace.

Our product also successfully operates with minimal user input. The buttons located on the device handle everything from startup to copying data onto the USB. Once transferred to the external PC, the user is only required to input the number of extenders they would like to be placed on the map. This makes it easy for any user to operate with little to no training.

We were unable to conduct a test on how long the battery life will last, so we cannot determine if it will successfully meet our desired specification of three hours. Based on the battery life throughout the tests we've done, we believe that it would be able to last through a long mapping, but we have no data to support this claim.

Overall, the product is operating as we expected. With more time we would be able to complete all the requirements set and have a successful, fully functioning product.

## IV. Conclusion

Just before Midway Design Review (MDR) our system finally came together into a single unit, however going forward we need to properly test our device, analyze which components must be improved, and create baselines of each specification. For instance, the three hour battery life is only a calculation and we must properly run the device from full charge to depletion several times to verify the average battery life the user would experience from rigorous usage.

Additionally, we are still currently researching better methods for measuring WiFi signal strength so that the measurements made are as accurate as possible. At the moment we only have a single WiFi breakout board with an omni-directional antenna, however after testing the device and analyzing the collected data we found that there were still instances of fluctuations between measurements. In order to improve our WiFi signal strength measurements we are looking into algorithms used to accurately distinguish correct signal strength readings in addition to implementations which utilize several antennas and average the measured values of that moment.

For the LIDAR, we aim to decrease the power consumption of the device which hinders the performance of our main processing unit. In order to decrease the power, we will first route all power to the LIDAR directly from the PCB voltage regulator as opposed to syphoning power from the Raspberry Pi. Next, we will test the lowest possible rotation speed of the LIDAR's 360º mechanism. By decreasing the rotation speed of the LIDAR, we can decrease the amount of power required by the LIDAR. Furthermore, decreasing the rotation speed also decreases the sampling rate, causing a trade off between the necessary sampling rate and power consumption decrease. After modifying the configuration files and ROS code for the LIDAR and Hector SLAM to decrease the rotation speed, we must determine the minimum rotation speed necessary for creating accurate maps and trajectories.

In the future, we also must fabricate the PCB but this also requires the finalization of our circuit. Additional components must be implemented into our circuit before fabrication, including an LCD display, LIDAR I/O, and the possibility of additional antennas and WiFi breakout boards. Furthermore, we must design and create a smooth and form fitting encapsulation for our device which is handheld and lightweight using CAD and 3D printing. In addition, we must improve upon and refine the process for generating a heatmap in our computer application. The major obstacle in our path is finding the best possible method for measuring WiFi strength accurately and consistently. Through in-depth research and trial and error, we hope that we can determine a solution which can be applied to our desired form factor and processing capabilities.

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## Appendix

### *A. Design Alternative I: Power Configuration*

Originally a boost converter was going to be used to deliver 5 volts to the system. In the end, a buck converter was used as there is less power lost to heat. A boost converter uses a transistor to turn the circuit on and off very quickly. When the circuit is on, the power supply charges up an inductor increasing the current. When the transistor is turned off the inductor needs to transfer the stored energy to the circuit. The current flows through the other side of the circuit slowly charging up the capacitor on the right side of the circuit. The right side of the circuit is cut off by a diode which only lets current through when the voltage spike from turning off the transistor occurs. The circuit diagram can be seen below in Figure 17 [10]

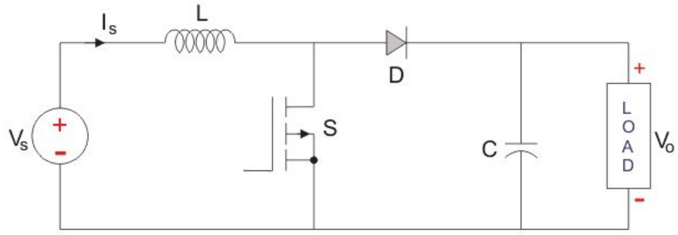


Figure 17: Circuit Diagram of Boost Converter

*B. Design Alternative II: Visual SLAM*

In our original design, we planned on using visual SLAM as opposed to LIDAR SLAM. Visual SLAM performs a similar algorithm to LIDAR SLAM algorithms, however, instead of comparing the pose graphs of LIDAR scans, a video recording is used and the individual frames of the video are compared to establish a robots pose. The hope with using visual SLAM would be the future application of our product with mobile phones, however visual SLAM is much more computationally intensive than LIDAR SLAM and the Raspberry Pi would not be able to adequately perform the visual SLAM. While experimenting with LIDAR SLAM, we found that the Raspberry Pi had trouble keeping up the SLAM computations at times, therefore a more computationally intensive version of SLAM would have been infeasible for our handheld design.

*C. Technical Standards*

Mappa Signa uses a number of standardized hardware and software components. Mappa Signa uses WiFi to capture signal strength through our NodeMCU Amica boards which adheres to IEEE standard 802.11. Mappa Signa uses Ubuntu installed on a Raspberry Pi to run a combination of bash scripts, C, C++, and Python programs. The use of a command interpreter and the C programming language adheres to IEEE standard 1003. Mappa Signa uses universal serial bus for real-time data transfer between NodeMCU Amica boards, Raspberry Pi, and external PC. This adheres to IEEE standard 1394.

*D. Testing Methods*

For the WiFi measurement, we began by testing the stock NodeMCU Amica in spot and rotating it in all directions to see if the orientation would significantly impact the strength reading. We also tested the repeatability by walking a predetermined path and testing if the reading was the same in each location each time around. With the stock board, the results were unsatisfactory prompting us to pursue other methods of measuring. That is how we decided on an external omnidirectional antenna. With this modification we repeated the tests and were satisfied with the results. Future tests

For the mapping and localization, we tested our data on the Raspberry Pi running at different speeds in order to find out how fast we could make the map without sacrificing quality. In the future, we will be testing how changing the sampling rate of the LIDAR affects our ability to increase the mapping speed on the Raspberry Pi.

In order to test our device's ability to last the amount of time on battery power as indicated, we will conduct about 3 battery drain tests, where we will run all the devices in their normal operating modes- for LIDAR, that means spinning and recording, for the WiFi, that means recording and sending the data, and for the Raspberry Pi, that means looping a map creation. Even though during normal operation the recording and map creation wouldn't happen at the same time, we know that if they happen at the same time for the battery test and the test is a success, we know the device would pass during normal operating circumstances as there would be less power draw on the battery.

To test the speed requirement, we will perform about 3 tests of the whole device while walking at a normal/slightly quickened pace and ensuring the resulting map with heatmap is usable.

*E. Team Organization*

All team members have contributed to the functionality and design of the project. Sam has focused mostly on Hector_SLAM and environment mapping. Nick worked on recording WiFi strength accurately with repeatability. Ethan worked on providing power to all devices. Heather worked on the computer application and heatmap generation. Teamwork has yet to be a concern for Team 22. Communication has been consistent and the team meets weekly to discuss issues and next steps.

*F. Beyond the Classroom*

Our senior design project has helped us connect ideas and design concepts we researched with real-world applications. Throughout our design process, we have relied on intuitive researching through IEEE papers, published journals, datasheets, and open-source material from others in the industry. As a result of our education through the ECE Department at UMass Amherst, we carefully assessed and reasoned the plausibility and integrity of external resources and research materials.

SLAM algorithms and the LIDAR system were initially foreign to us so these aspects of our project required extensive research to grasp a basic understanding of the system. Additionally, a hefty load of research has been conducted to determine the optimal approach to measuring WiFi signals accurately with repeatability, although the research in this field will continue moving forward. Overall, measuring WiFi signal strength required us to learn more about antennas and signals, requiring us to dig deeper into our basic understandings of signals and systems. Connecting and powering multiple systems only using one power source also increased our knowledge and comfortability about power consumption and regulation. Finally, writing a computer application for our senior design project has given us the freedom to program using all the tools and techniques learned throughout our undergrad careers. Without guidelines and directions like most programming assignments, creating a computer application has honed our problem solving abilities and allowed us to discover new algorithms and programming techniques which are beyond the scope of introductory programming classes. Being able to focus on one code project throughout the whole semester has resulted in a well thought out application that takes usability into concern.