Antenna Pointer

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Abstract:

The Alaska Satellite Telecommunication Infrastructure (ASTI) team within the FAA is responsible for setting up antennas. These are critical for communication and airway traffic control purposes. Currently, they use a compass and plumb bob to orient these antennas. The FAA has stated that they would like a digital measurement device to simplify this process. The purpose of this project is to create said device, ensure that it is accurate enough for antenna orientation, and guarantee that it can reliably withstand the harsh Alaskan climate. The device is modeled using the CAD program, SOLIDWORKS. To program the device, a microcontroller is used to read data from a sensor. The sensor determines the orientation of the device and can be used as a reference to install the antenna. The device prototype has been 3D printed, and corrections are being made so that the electrical components fit. The electrical components are currently being programmed to allow for the input of latitude, longitude, antenna offset, and the date and in turn return an output of magnetic declination, magnetic azimuth, true azimuth, device elevation, and adjusted elevation. This device will save both time and money when orienting antennas in the field.

Introduction:

The ASTI team's primary responsibility is to replace and upgrade critical system components required to achieve system-wide NAS inter-facility telecommunications throughout Alaska (*FAAXX255*). Due to the remoteness of Alaska as well as the sensitive information the FAA is handling, most of the communication is done via antennas and satellites. A key distinction we want to make about this project is that the antennas that the FAA are using are pointed to geostationary satellites. The benefit of using geostationary satellites is that their position relative to Earth is static. This is due to the orbital speed of the satellite matching the Earth's rotation speed. This means that an antenna can be pointed to a specific point towards a geostationary satellite in space without having to track it. This allows the FAA to communicate across the world on a closed and secure system.

The main issue that the ASTI team is currently facing is that their methods for antenna installation are archaic. Currently, they rely on a magnetic compass and a plumb bob or a clinometer to orient these antennas. While this method does work, it is time consuming and tedious. Not only this, but flights can cost the FAA nearly ten thousand dollars per trip. This means that setting up the antenna correctly the first time is critical. This is important because the communication systems that the ASTI team are responsible for are critical for infrastructure and any downtime of these systems can create a safety hazard. Pilots need critical information that the antenna's provide such as air traffic control procedures, weather data, and any other potential hazards.

There are various apps on the market available via Android or IOS to determine antenna orientation, however, most of these are inaccurate and require an internet connection to determine magnetic declination. Once again, due to the sensitive information the FAA is dealing with, the device was requested not to include any Wi-Fi, GPS, or Bluetooth capabilities. The primary benefit of having a dedicated device is that the antennas can be oriented accurately, decrease critical communication infrastructure downtime, improve overall safety, and save time and money.

Proposed Solution:

Our proposed solution is to create a digital device that accepts user input for given variables, determine antenna orientation via an inertial measurement unit, and output the desired angles necessary for the antenna to be directed at the geostationary satellite. The device will also need to withstand various mechanical conditions to ensure the device does not get damaged. Ideally, the measurement readings from the device can be used as a reference to point the antenna to the proper azimuth and elevation. Azimuth is the horizontal angle relative to the northern clockwise direction and elevation is the angle relative to the objects horizon in a spherical coordinate system.

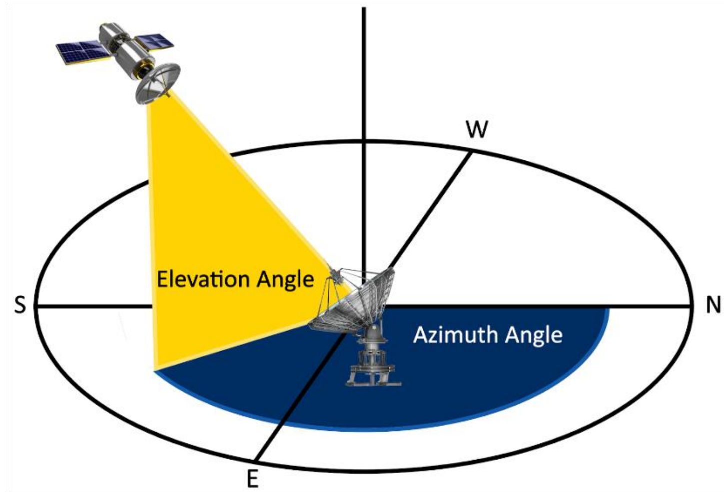

Fig. 1 Orientation of an Antenna in a Spherical Coordinate System

To get these antennas accurately pointed to a geostationary satellite, we have to account for two different offsets. The two offsets are magnetic declination and antenna offset. Magnetic declination is the difference between magnetic north and true north from any specific location on earth. Antenna offset is the difference between the elevation of the antenna and the incoming signal. These offsets need to be accounted for when adjusting the raw data from the inertial measurement unit and this corrected data will then be displayed to the device's screen. Aside from the offsets, we also have a few other limitations that must be accounted for by the FAA. The device cannot rely on the internet due to the remote installation locations and the inherent sensitive information transmitted. The FAA is dealing with very sensitive data, so they require that the device does not have WIFI, Bluetooth or GPS capabilities.

The physical portion of the device needs to be able to withstand the harsh Alaskan climate. Two temperature conditions arise from the parameters of needing to operate in Alaska; cold temperature due to being carried around by the user in potentially sub-zero temperatures, and hot temperatures due to the user in this climate typically carries a heat gun to directly apply heat to their equipment to unfreeze them. The device must be properly insulated from these temperatures to ensure neither extremity affects the device's functionality. From the potential temperature range the device may undergo, as well as being surrounded by snow and ice, the potential for condensation or humidity getting within the device is high, therefore, the device must also be water resistant to prevent moisture contamination. To make the device optimal for the user, we must also consider some of the visual or physical aspects of the device for this convenience. One of those aspects being that the screen must be bright enough to be seen without light from the sun or reflections from the snow hindering the user's ability to read from the device. The user, in this case, must also wear large gloves to protect their hands, in which the device cannot be touchscreen or the buttons too small, therefore the keypad must be large and waterproof.

To test the devices' ability to properly allow input, read sensor data, and deliver an output, a model antenna was created which displays elevation and azimuth on its own LED screen. By using the device with the model antenna, we can verify this way that the device operates as desired. To ensure proper accuracy, the device will be taken to the FAA site in which they have an antenna and follow the same procedure to verify. To verify the mechanical properties of the device, a variety of tests can be performed such as submerging it in water to ensure the inside of the device remains dry (removing the electrical within the device first as to not ruin the electrical components), or applying heat through a heat gun to ensure the device does not melt or alter in any way. Other tests can be ran; however, these tests are the main concern.

In-Progress Design and Fabrication:

Design Plan/Process: Electrical

Regarding the abstract given, the initial problem statement was not clearly phrased, therefore unfortunately, some time was spent trying to get clarification on the problem. The project proposal that the FAA gave us had the required inputs as latitude, longitude, and antenna offset, and the outputs were supposed to be the antenna azimuth and elevation. Our team thought that the main goal was to calculate the antenna azimuth and elevation from a point on Earth to a satellite in space and to create a mechanical device that would automatically orient the antennas. However, this was not the case. After setting up a meeting with the team members, Dr. Tej, and Jonathan Adams from the FAA, we clarified the actual problem. The FAA already has the required information to set up the satellites, they just need a tool to replace the compass and plumb bob they currently use. We were then able to start coming up with ideas to solve that problem.

As stated in the proposed solution, we needed to create a digital device to orient antennas. This can be thought of as a digital level that a field technician can use to either install a new satellite or adjust previous ones. The most common way to create a digital level is to use an inertial measurement unit (IMU).

The IMU sensor includes three degrees of freedom for each component: the accelerometer, gyroscope, and magnetometer. These individual components are commonly used in navigations systems, phones, and various other devices to determine orientation. We can then use the data received from the IMU to determine the device orientation, attach the device to the antenna's backplate as a reference, then use that reference to point for orientating the antenna.

There are seven overall components to the Antenna Pointer. This includes the IMU, the microcontroller, the keypad, display, battery management system, World Magnetic Model, and physical shell. Shown below in *Figure 2*, the block diagram shows that all the components were selected due to their compatibility with one another, availability, and widespread support.

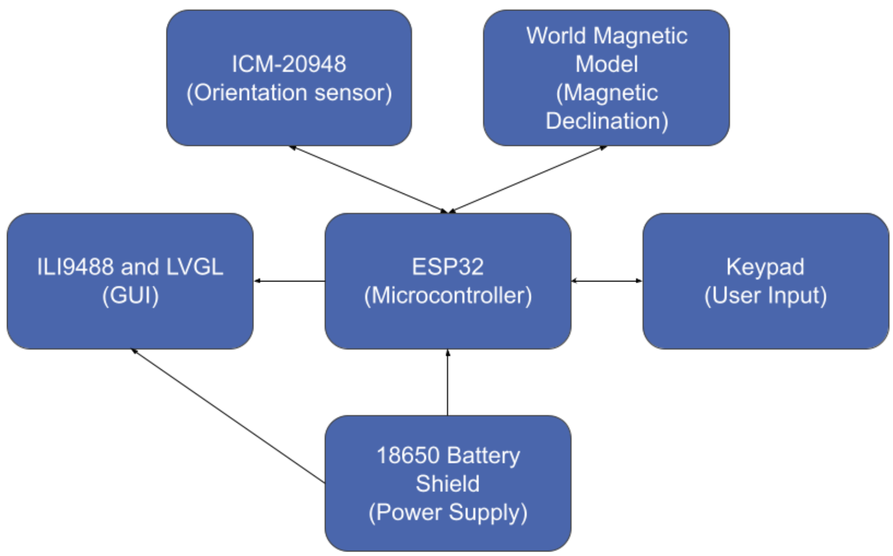

Fig. 2 Digital Components

MICROCONTROLLER

At the heart of our project lies the microcontroller. Initially, we planned on using a Raspberry Pi to drive all our computational needs. We chose this due to our team's previous experience with it, its widespread online support and community, and its ability to easily create a user interface. Unfortunately, this was quickly overshadowed by Raspberry Pi's terrible battery life. The Raspberry Pi is an entire computer, not just a microcontroller. This means it draws a lot more power than expected which makes creating a battery powered device unfeasible. It would have been a viable option if we were to have additional features, but we felt that a smaller microcontroller that did exactly what we wanted was best.

Our second solution considered was the Espressif's ESP32 microcontroller. The ESP32 is only a microcontroller, which solves the issue of battery life while being well supported through Espressif's proprietary development framework called ESP-IDF. The ESP-IDF is similar to how the Arduino microcontrollers work with Arduino IDE, but it is much more extensive and better suited to bigger and more complex projects such as our Antenna Pointer Device that we are creating. Since it is at the heart of our electrical design, we chose each component moving forward based on its compatibility with the ESP32.

ORIENTATION SENSOR

For the inertial measurement unit, we chose the ICM-20948 by TDK InvenSense. This includes the accelerometer, gyroscope, and magnetometer in one package. The accelerometer and gyroscope use the piezoelectric effect to determine the direction of gravity and angular velocity. The magnetometer uses the Hall Effect to determine the Earth's magnetic field direction. The data from each component is measured and then transferred to the ESP32. Most of the software was created from a previously existing library; however, the magnetometer software was not written and had to be created. *Figure* 3 below is a block diagram of the ICM-20948 and it will be beneficial to reference when explaining how the software was modified to account for the magnetometer.

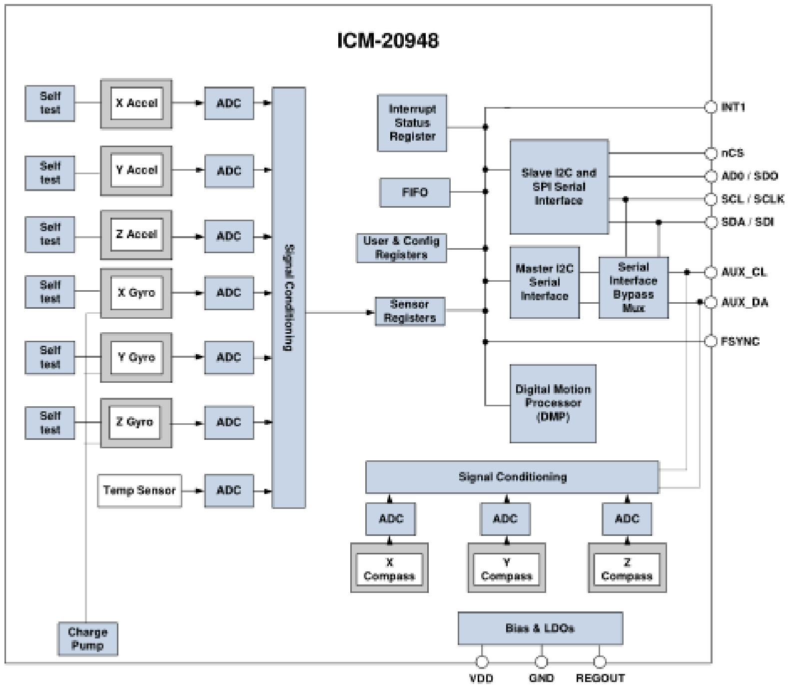

Fig. 3 ICM-20948 Block Diagram

The IMU communicates the data from each component to the ESP32 via I2C. I2C is a serial communication protocol that allows multiple devices to communicate with one another via the same two wire bus. This is possible due to each device having its own I2C address that is communicated at the beginning of data transmission. The reason this is important is that while the ICM-20948 integrates the accelerometer, gyroscope, and magnetometer in one package, the magnetometer is another chip within the ICM-20948 called the AK09916. This leaves two options to communicate with the magnetometer. Either you can treat it like a separate I2C device and communicate directly to the ESP32 or use the onboard registers that the ICM-20948 must access the data. To keep things simple, the pre-existing registers were used and only one I2C device had to be initialized. Luckily, the pre-existing library had enough code setup to access the other registers, and the magnetometer registers were easily accessed with some modification. All the XYZ axes were read via the ESP32, and some trigonometry was done to convert the XYZ axes output to an azimuth and elevation. Collected data and calculations to determine azimuth and elevation will be explained in the Design Simulation and Preliminary Data section of this report.

WORLD MAGNETIC MODEL

As stated previously, the device needs to determine the azimuth heading via the magnetometer. The issue with this is that magnetic declination (the difference between true north and magnetic north) varies over time and depends upon where the user is on the Earth. Many of the systems worldwide that depend upon compass headings use something called the World Magnetic Model (WMM). The WMM is a model of the Earth's magnetic field and is updated every five years. The WMM is maintained by the National Geospatial-Intelligence Agency (NGA) and is distributed by the National Centers for Environmental Information (NCEI), information provided by *World Magnetic Model.* They also distribute software designed for embedded applications. Currently, the code has been downloaded from their website and works.

DISPLAY

As with all digital devices, the display is vital to our device as it is required to create the user interface and to output all the relevant data. The display chosen is a 3.5-inch TFT LCD display. It uses an ILI9488 driver, and LVGL to create the user interface. The ILI9488 driver is responsible for low level functions such as initializing the display and drawing pixels to it. LVGL is an open-source library for embedded devices to create user interfaces. While the driver draws pixels, LVGL communicates with the driver to create much more complex objects called Widgets that can be interacted with either touchscreen or keypad inputs. This naturally seemed like the best course of action due to both the driver and LVGL being created for embedded devices. The current progress will be explained in the Design Simulation and Preliminary Data section.

KEYPAD

The keypad selected is a simple matrix keypad. This works by creating an array of switches, and by looking at which column and row is high, a key press can be determined. This is beneficial as the number of pins it requires is equal to the number of columns and rows, instead of the number of overall buttons. The software has been written to interface with this keypad but next semester we will focus on creating a custom PCB and key button design to fit the physical shell.

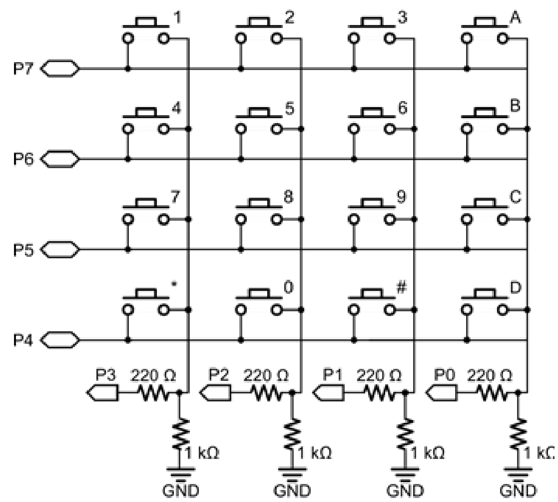

Fig. 4 Simple Button Switch Circuit

BATTERIES AND MANAGEMENT

To power the device, we selected to go with two lithium ion 18650 batteries. These batteries have a nominal voltage of 3.7 volts and capacity of 3500 mAh. In parallel, a total of 7000 mAh is achieved. For the battery management system, the Diymore 18650 battery shield was selected. This is a proven off-the-shelf solution that provides short circuit protection, over/undercharging protection, and the required circuitry for charging all in one. The shield also converts the 3.7 nominal voltage to both 3.3 volts and 5 volts necessary to power the ESP32 and the display. These choices allow us to have a long-lasting battery life for the device while providing the proper protection to the rest of the electrical components.

Design Plan/Process: Mechanical

PHYSICAL SHELL

The one thing that became clear when looking at ways in which to protect the electrical components from the Alaskan climate is that the device's packaging needed to be durable and insulating. Batteries tend to not work well when they are introduced to massive temperature differences to that in which the manufacture recommends. Alaska has recorded temperatures as low as -62.2°C and batteries have been known to stop working at 0.0°C (*Osborn*). This is why most people in Alaska use engine block heaters but for their electrical devices, they use a heat gun. Your average heat gun can go up to 650°C so the shell's material must be insulated to prevent both extremes (*Hutzly*). The battery is the most important electrical component that we look for to protect so the wall of the device was designed to be larger than most handheld devices for this reason.

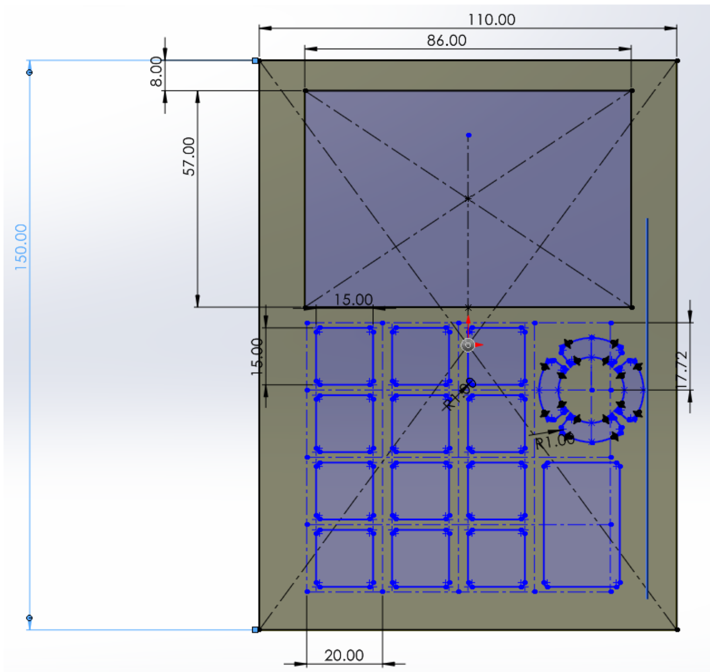

Fig. 5 Device Front Shell

The front of the shell was modeled in the CAD modeling software, SolidWorks, to be 10mm thick with the side walls being 8mm. The back shell is also 10mm to increase the batteries chances of being protected from the elements. The height of the device is 150mm and the width is 110mm due to the screen's size and the wall insulation space needed. For the depth, we currently have it at 54mm so that we can have enough space for the electrical components. This will most likely decrease upon a redesign to reduce space and increase thermal resistance. To ensure that the shell does not interfere with the IMU sensor, we decided that the shell cannot be made from ferromagnetic metals. This creates another problem for us as we need to find another material solution which will be expanded in the Future Works section of this report. The spacing for the screen was made to just narrowly allow for clearance so that we can minimize the amount of air that can enter the system. The buttons were spaced out in such a way to allow clear presses and so that there would still be structurally sound. If the space is too close, then the material can crack as it can create weak spots.

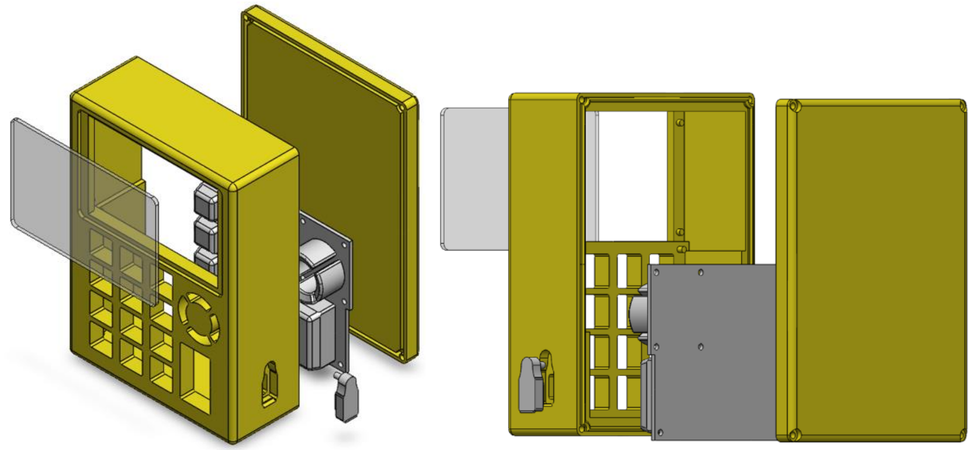

Fig. 6 [**Left**] Front Exploded View and [**Right**] Rear Exploded View of Shell

As with most designs made, the edges were rounded off as much as possible to prevent chipping that can lead to a loss of structural integrity. To make the device waterproof, we created channels in which we can add silicon seals between the front and back shell. A port hole is needed to access the battery for charging, so a silicon seal was added to prevent water from getting in. A 2mm plexiglass that is glued to the front was designed so that we can fully seal all areas. The buttons at this point are designed more for functionality but we will redesign them so that they can be waterproof as well since we plan on creating these from silicon.

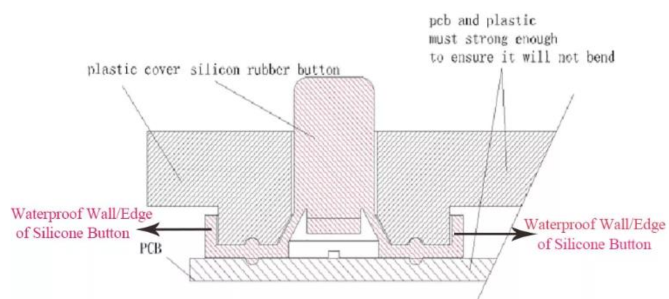

Fig. 7 Waterproof Button Design

For the silicon button and seals, we plan on creating our own so we can familiarize ourselves not only with the process but so that we can also get the desired dimensions. In the Maker's Space here at UCO, we have a Formlabs 3D printer that can take multiple materials not just PLA, so we plan on using it to print out the desired parts. The silicon that Formlabs carries is the Silicone 40A Resin which has a temperature range of -25°C to 110°C (*Formlabs*). Although this is not ideal for our desires range of -80°C to 650°C, there is not a silicon made in the market that we can have access to that can come close to those numbers. As mentioned above, we will need to redesign the rubber button pad that goes over the keypad switchboard, and we plan on making it similar to the other sealed buttons seen in *Figure 7* (*Xiamen*). To attach the device to the back of the antenna, we will look at making a clamp large enough that can wrap around the back without being magnetic.

To verify that our device is functioning to specifications needed, we will need to recreate similar weather conditions and point to a close satellite, as we would in Alaska. We can verify our results by using one of the various satellite finder apps out on the market. These apps use the most up to date World Magnetic Model data and GPS to get the coordinates and the declination. Our modern smart phones internally house their own gyroscopes and accelerometers so they can orientate antenna's relatively well. Since we are not able to use WIFI, Bluetooth, or GPS, we can compare the apps results to our own. We will also use a compass, plumb bob, and a protractor for elevation and azimuth so that we can compare it to the two real world results.

The outer shell will be water pressure tested to ensure the seals work. We plan on running these tests with the electrical components out of the device, just in the event it fails, we don't want to ruin the electrical components should there be a leak in the seals. To cold test it, we plan on finding a cold walk-in freezer or leaving it in cold storage, in which using the device after removing from that environment to see if the insulation works. For the heat, we have access to a heat gun in the Maker's Space at UCO and plan on only pointing it towards the battery access port since that is the part that mainly needs to be warm. In the device's current iteration, it is made from PLA which cannot withstand either temperature extremity, but the plan is to create it out of ceramic coated fabric that will be stress tested to ensure that all requirements are met.

Fig. 8 Current Device Shell Iteration

The World Magnetic Model as we know it today has been around since 1990 and is updated every five years. Early magnetic mapping can be dated as far as 1701 so there are more than enough data points in which we can compare our data to (*Brown*). Specifically, we can backdate the device so that we can compare to a known point close to us. For the last 20 years they have gathered data on the degree error from one WMM to the next so we can see if our data lies within the same error as seen in *Figure 9*. The reason the spikes is that the model becomes less accurate as it approaches five years but even then, it has less than 1 degree or error.

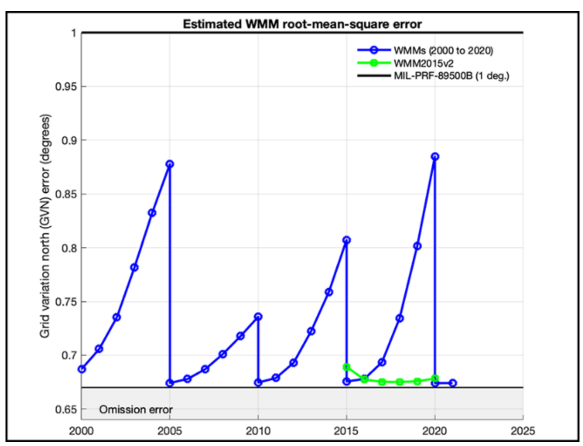

Fig. 9 The Time Evolution of the Global RMS Grid Variation Error in the Northern Hemisphere for All WMMs Since 2000 (*Brown*)

Organizational Structure and Schedule:

For the start of the project, we had each of us come up with a way to solve the problem. For the first time we met, we outlined the advantages and disadvantages of each idea and came up with one cohesive idea. Unfortunately, this was changed as stated above due to the actual needs of the FAA. We knew that the beginning portion of the project would be where we do most of the planning, so pivoting here was not so much of a time loss. When we finally agreed on a plan, we then divided the main tasks into our respective groups while leaving the broad things to the whole group. All of the members needed to do literature review and team meetings as well as input on the administrative side of things. This, of course, includes the progress presentations, forms, the poster, and final report as well as the weekly meeting logs. Since we understand that each of our time is valuable, we made sure to have great communication, as it is key to keeping a good, working relationship. We did not use punishment as a tactic reinforcement as we felt that it was not necessary. There were times when some of the members were unable to meet, but they made it up at a later time.

Regarding the individual task, we tailored them to the person's area of expertise while allowing the others to give input when needed. The electrical aspects were handled mainly by Nathaniel Blair as he is our Electrical Engineer, and the Mechanical aspects were handled by Joshua Nutter and Cesar Vasquez. For this first semester, there is not as much mechanical design as we would have liked but the second semester will more than make up for that as we will be doing material testing in both stress and strain. We will also be making theoretical calculations of heat transfer and testing them in the field to ensure accurate data is given. The Device Shell and the Antenna Model were modeled by the mechanical Engineering team and was a joint effort. To ensure that we stayed on task, every week we met at least 3 times and caught up with one another's progress. We also used the productivity software Notion to hold the occasional meeting and used Zoom when possible.

For the milestones of this semester, we mainly stuck to ones provided by the professor. This includes the Literature review, team presentations, when we got the parts, and the final presentation and poster seen below in *Figure 10*. For a more detailed chart, see *Figure 18*.

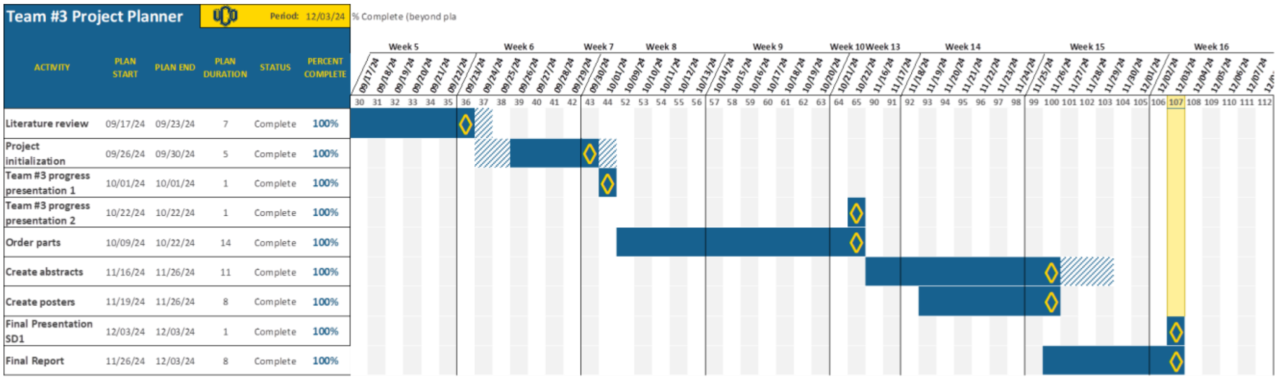

Fig 10. Partial Gantt Chart to Show Milestones

Design Simulation and Preliminary Data:

Given the parameters of the project, we determined it would be best to complete most of the electrical aspects of this project prior to finalizing any of the mechanical aspects. This consideration came across mainly due to the physical dimensions of the device relying partially on the space necessary for the electrical components, however, the mechanical was not halted to a stop.

Electrical:

From the designs of the electrical circuit shown below in *Figure 11*, we assembled the circuit and wrote code for each component individually to begin creating the device. This was a design choice, as we wanted to make sure each component did what was required before integrating them with one another. The main goal was to lay the foundation for the project so that it can be quickly iterated upon in the next semester. Namely, we wanted to verify the IMU sensor worked appropriately based on its reading of elevation and azimuth in tandem with an LCD screen, as this is the priority of the project. Currently, all individual components do work but are not integrated with one another.

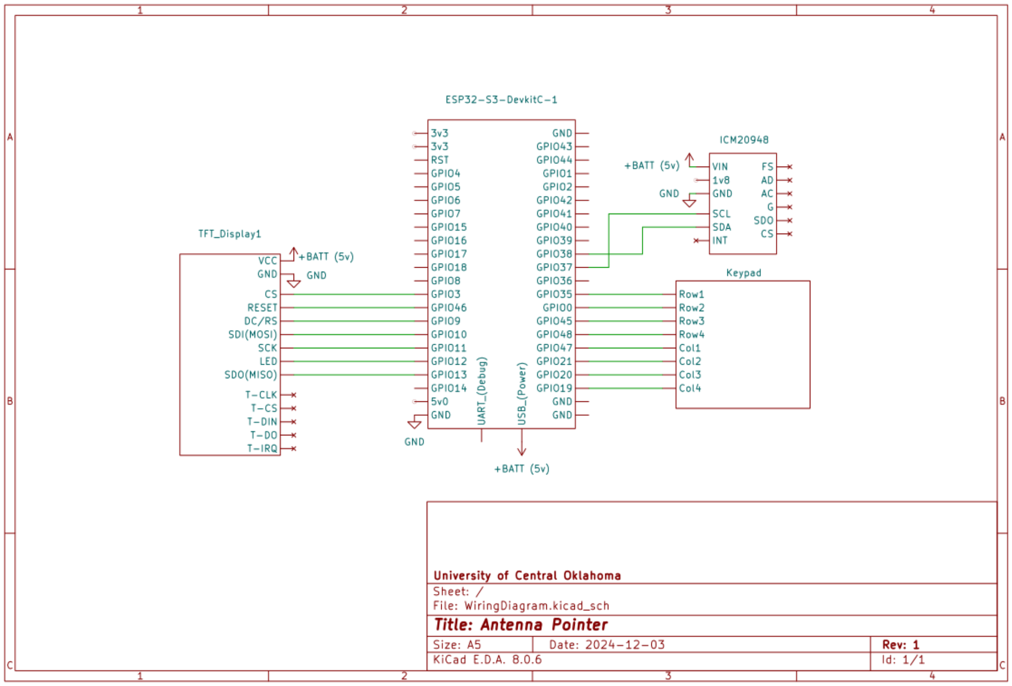

Fig 11. Wiring Diagram

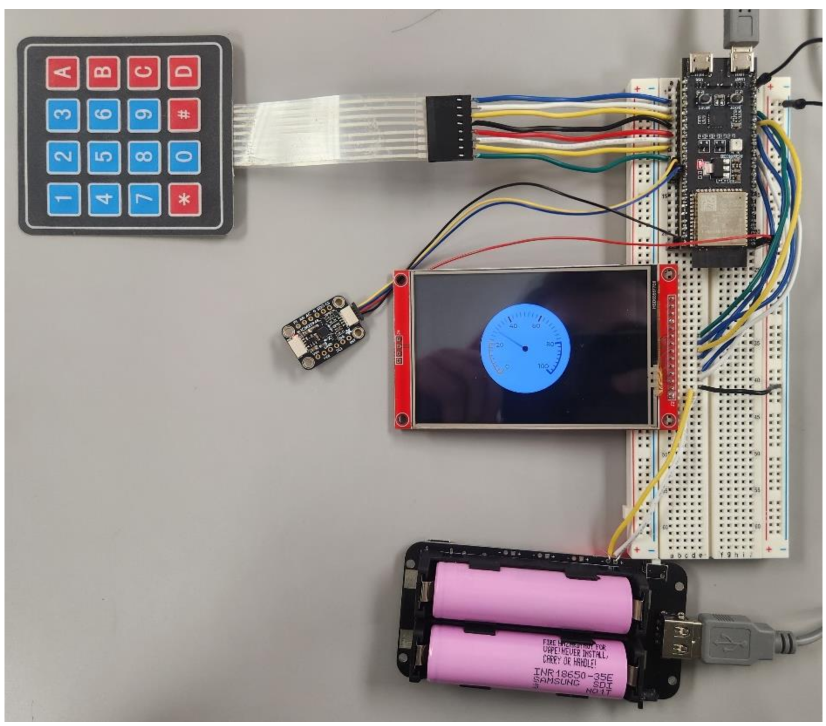

Fig. 12 Antenna Pointer Circuit

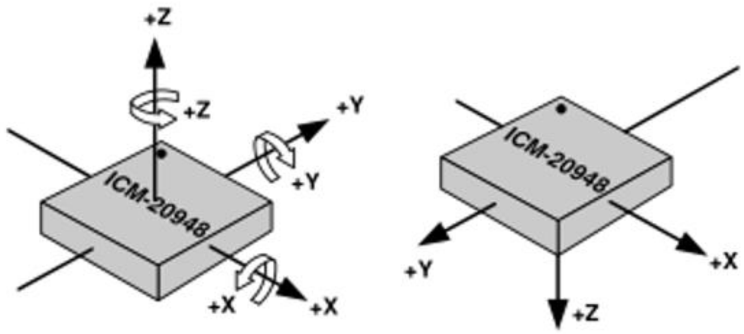

Fig. 13 IMU Axis Orientation

The first component created was the IMU. The figures above show the orientation of the IMU. The figure on the left shows the orientation for the accelerometer and gyroscope, while the figure on the right corresponds to the orientation for the magnetometer. In the software the orientation mismatch is corrected by simply making the Y and Z magnetometer axes negative. The elevation was calculated using the following equation:

$$Elevation = -tan^{-1}\left(\frac{z}{\sqrt{x^2+y^2}}\right) * \frac{180°}{\pi} + 90°$$

Azimuth has proved to be much more complicated than the elevation due to it relying on the magnetometer and needing to be adjusted for tilt. Some initial formulas were derived via vector math, however, were determined to be inaccurate as they do not account for the tilt properly. Not only this, but the raw magnetometer data needs to be calibrated for hard iron and soft iron offsets before it can be used to determine the azimuth. While the device does not currently provide accurate azimuth reading, we are outputting something that is close. Correcting this issue as well as calibrating the raw data will be a part of the main focus on the electrical side of the project in the following semester. Currently, the output is given below.

```
icm test: Azimuth: 80.749901 degrees
icm test: Elevation: 11.916349 degrees
```

Fig. 14 Output of IMU

Currently, a simple matrix keypad is being used for the inputs. The code determines which button has been pressed, and can detect things such as long presses, double presses, etc. This gives the buttons more use than just detecting which button has been pressed. Next semester we would like to create a custom PCB that can fit within the physical shell, and on the mechanical side of things, waterproof buttons to interact with the PCB will be designed as well. The outputs for the keypad are shown below.

```
BUTTON TEST: BTN0: BUTTON_PRESS_DOWN
BUTTON TEST: BTN0: BUTTON_PRESS_UP[220]
BUTTON TEST: BTN0: BUTTON_SINGLE_CLICK
BUTTON TEST: BTN0: BUTTON_PRESS_REPEAT_DONE[1]
BUTTON TEST: BTND: BUTTON_PRESS_DOWN
BUTTON TEST: BTND: BUTTON_PRESS_UP[105]
BUTTON TEST: BTND: BUTTON_SINGLE_CLICK
BUTTON TEST: BTND: BUTTON_PRESS_REPEAT_DONE[1]
BUTTON TEST: BTNC: BUTTON_PRESS_DOWN
BUTTON TEST: BTNC: BUTTON_PRESS_UP[175]
BUTTON TEST: BTNC: BUTTON_SINGLE_CLICK
BUTTON TEST: BTNC: BUTTON_PRESS_REPEAT_DONE[1]
BUTTON TEST: BTNB: BUTTON_PRESS_DOWN
BUTTON TEST: BTNB: BUTTON_PRESS_UP[190]
BUTTON TEST: BTNB: BUTTON_SINGLE_CLICK
BUTTON TEST: BTNB: BUTTON_PRESS_REPEAT_DONE[1]
```

Fig. 15 Keypad Output

The screen was created via a pre-existing library driver for the ILI9488 and the LVGL GUI. Currently, a simple meter that does not relate to the project is being shown. Once again, this was to get the screen working, and the GUI will be developed next semester. Throughout this project, we have extensively run trial and error experiments based on the completion of each component to ensure that the device works as desired.

Fig. 16

Mechanical:

The device was designed to fit the electrical components as well as fit comfortably in the hands of the user. Since the size was mainly driven by needing to be held and operated while wearing gloves, we went with a "larger" device than most would find comfortable. Variations could be designed to be more comfortable in different scenarios, however, the scope of this project dictates a larger scale. Additionally, certain materials were researched based on their respective properties to determine where the best place to begin modeling and testing them would be. This also includes the thermal properties and sealing capabilities of the selected materials once we begin prototyping without the use of 3D printed plastic. This semester, as previously stated, was more focused on the electrical aspects of this project in order to obtain necessary dimensions of the device before we begin calculations and testing as to not waste time or resources if the dimensions needed to be changed to house the electrical.

The device constructed this semester functions such that it houses the electrical components, fits comfortably in the hands of a user with gloves, screws onto a tripod or stand to allow for gyroscopic orientation, allows access to the electrical components (charging the batteries), and has space for when the appropriate material is selected for the seals. The completion of the device is well within grasp as the focus on the mechanical side will be to perform heat transfer calculations and ensure the device is not accessible to liquids.

The remaining mechanical aspects of this project are primarily rooted in the fields of Heat Transfer and Material Science. Both of these disciplines were studied extensively, involving a combination of detailed experimentation and comprehensive calculations. This approach ensured not only a strong theoretical grasp of the material but also practical knowledge of how to apply these principles effectively. Through this process, a deep understanding was developed to address and solve the mechanical challenges associated with this project, ensuring a well-rounded and methodical approach to its completion.

Design Challenges and Improvements:

Many aspects were altered throughout the process as they provided unnecessary complication, better solutions were thought of after the fact, or challenges presented themselves which needed to be overcome. One of the first challenges was deciding the “brain” of the device. As previously mentioned, we went through a few alterations of what would be used and why. Additionally, the microcontroller we selected, the ESP32 and ESP-IDF, were completely new and we worked with it extensively to see how it worked and how to appropriately incorporate it into the device. The keypad for the device has also proved a challenge as it needs to be incorporated into the device also, as well as it needs to be properly insulated to prevent moisture contamination. As of now, the sensor still provides slightly inaccurate data to the device and will be fixed in the following semester. The shell of the device has been altered a few times based on component space and more research needs to be completed such as inspecting the properties of something like silicone gaskets.

Cost Analysis:

UCO has given our team a budget of $750 to work with. The current components that have been used up to this point cost $139.62, leaving us with $610.38. Most of the cost is backup components in the event a component does not work. This is a relatively inexpensive device and could be easily replicated as everything was chosen to be off-the-shelf and compatible with one another. The breakdown of the costs thus far can be found in *Figure 17* below:

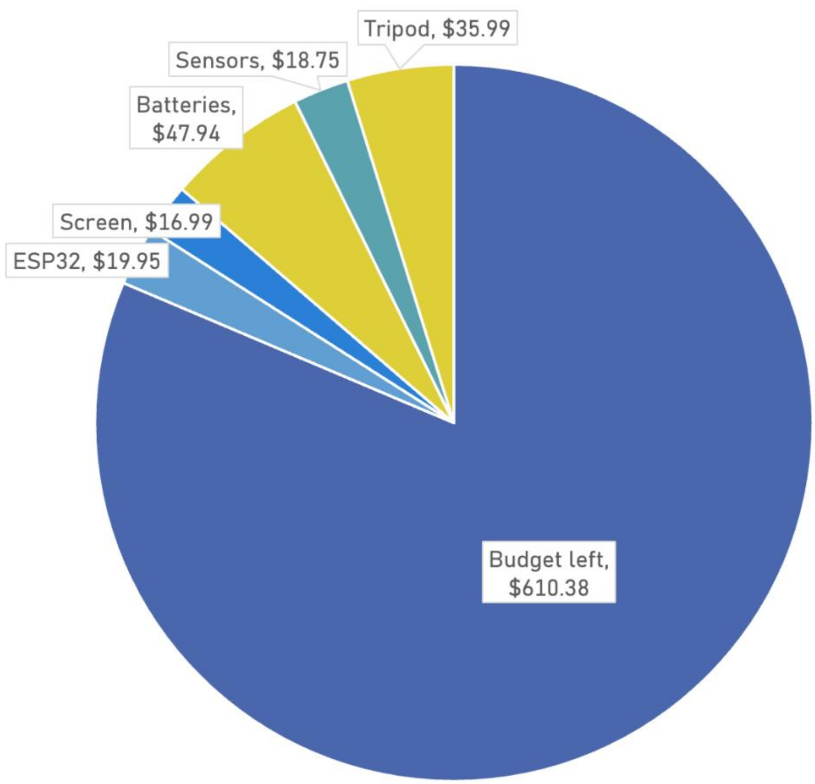

Fig. 17. Budget Pie Chart

Under the assumption that the members of this group made an average salary based on $80,000 a year with the assumption of working 40 hours a week, we can break down the hourly wage to be $38.46 per hour. With that, our team agreed that we worked roughly 7 hours each over the course of 16 weeks, amounting to a salary payout of $4,307.69 per team member, or $12,923.08 in total. The supplies did not incorporate the cost of the materials provided by UCO, such as the PLA used to print the prototype, however, once the materials are selected for the shell, they will be incorporated. Equipment which was used such as computers, software, 3D printer, and others were also not incorporated specifically for a few reasons. The equipment can be deemed as “expensive one-time buy”, and though they occasionally need replacement or renewal, other projects can be completed within their lifespan. Potential equipment costs for next semester may include something in which to cast our selected material, however.

As of now, the team has stayed well under budget for the device, as well as much of the budget included excess equipment which is not particularly part of the project, such as the tripod. The investment in the device will not only indicate it could be replicated in a relatively cheap fashion, but marketing and selling the devices over cost would provide a profit for the manufacturer. For the user, the device will also provide an investment in saving the cost associated with the time required to set up antennas using current methods.

Project Timing:

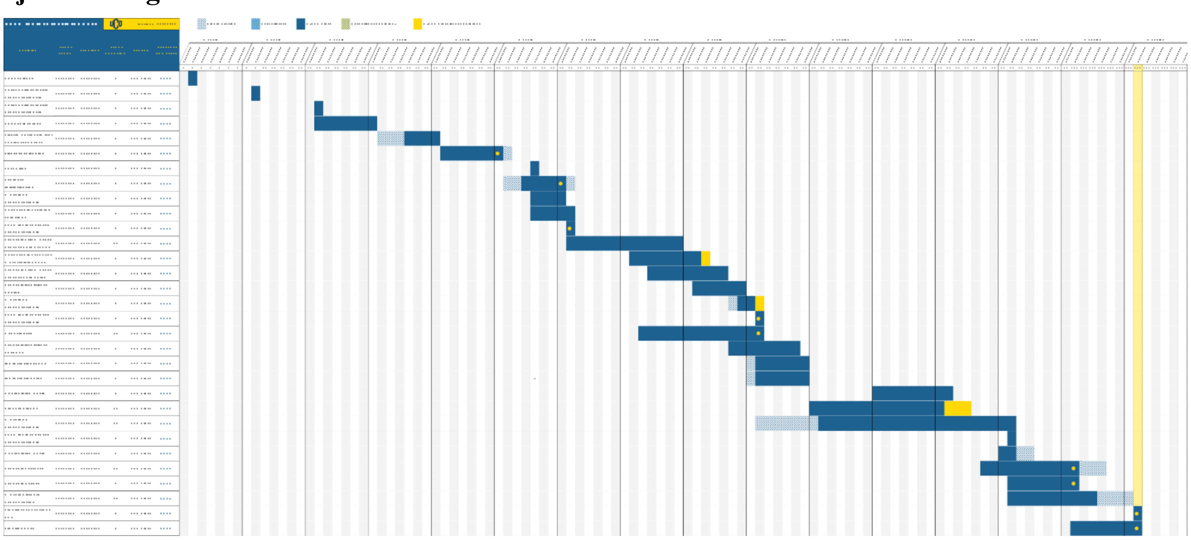

Fig. 18 Full Gantt Chat

The main deviations which occurred throughout the semester were related to roadblocks set up by a task which we did not know needed to be completed first. For example, we initially worked with a raspberry pi, only to find out it drained the battery, resulting in us eventually using an ESP32, which was new to all of us, and we needed to learn how to use it. To avoid these roadblocks in the future, we intend on doing more extensive research into each task before assigning deadlines to them or working on tasks which require completion of another task first.

Design Considerations & Engineering Standards:

Criteria & Impacts:

Our device had criteria set by the FAA to ensure safety, functionality, and raise no ethical concerns. One of these criteria was that for the device to operate as needed, it needed to be accurate within 1 degree. If not, the device would not serve better than the compass and plumb bob they currently use. The device also had to withstand temperatures which we were unfamiliar with. This criterion was specifically placed, because if not, the device would have been designed simply to house the electrical with minimal thought to insulation.

Regarding safety of the device, it is necessary for it to function properly as, in the scenario of which it fails, sensitive information can be leaked or not sent, or the ATC who needs it set up properly may not be able to convey information to aircraft. While the device itself does not convey the information and has no way of recording said information, if the device fails and setting the antenna becomes a time sensitive issue, then it can cause plenty of irreparable damage.

Engineering Standards:

Communication is a critical infrastructure, and one that is taken advantage of all the time. Adhering to ASME and IEEE standards below:

- ASME Y14.5

- IEEE 315
- IEEE P145

We were able to acquire information regarding material tolerances and dimensions, designing proper circuit diagrams, and the draft standards for antennas.

Summary and Future Work:

Thus far, we have created a device which will provide sensor data based on its azimuth and elevation, while also outlying the dimensions necessary for the device to be comfortable and house the necessary components. We have learned of new electrical components such as the ESP32 and IMU sensor, as well as investigated the use of the World Magnetic Model and how it can affect calculations based on geographical data. Next semester, we have planned to do the following:

- Integrating all the electrical components to work together
- Ensure the sensor data is accurate
- Create custom keypad to be waterproof
- Design device clamp for ease of use
- Experiment with extending IMU (remove the use of the clamp)
- Test device accuracy
- Test material selection for device shell
- Potentially redesigning user interface

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