AUTONOMOUS LAWNMOWER

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VALIDATION PLAN

REVISION – 3
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1 Validation Plan Introduction

This report will include an explanation as to how we achieved the conditions we outline in the validation plan on the previous page. The requirements in the validation plan are directly taken from the FSR report which can be found in this from the table of contents on page 2 of this report. Our validation consists of the requirement number and description from the FSR, the method by which we would validate the given requirement, the status of the validation of the given requirement, the team member responsible for validating the given requirement, the team member who validated the given requirement, as well as any additional comments necessary. In the status column you can see a multitude of different colors that represent different statuses. Green indicates that the requirement has been completely satisfied. Pink indicates that the requirement was conditionally satisfied or the requirement was changed in the process to more accurately reflect the autonomous lawnmower. Red indicates that the requirement was not satisfied by the autonomous lawnmower.

2 Validation Proof for Various Requirements

This section will include any figures or tables as well as other data that was recorded to validate the various requirements on the validation plan.

2.1 Validation for FSR Section 3.2.1

2.1.1 Validation for FSR section 3.2.1.1

This requirement states that the autonomous lawnmower shall be able to operate continuously for at least 1 hour continuously on flat, obstacle free terrain

This requirement was met by first recording the current used while the autonomous lawnmower was operating. It was found that the autonomous lawnmower operated at 8A while driving straight, and would spike to up to 10.6A while turning, depending upon the force with which the motors had to overcome. Based upon these values, and approximating that the autonomous lawnmower turns approximately 40% of the time. We can find the total current consumption of the autonomous lawnmower for a one hour period.

(10.6A * 0.4) + (8A * 0.6) = 9.04A

While saying we turn 40% of the time is an overestimate of how much time is spent turning, it proves we can indeed meet this requirement. With a battery capacity of 13Ah the 9.04Ah consumed by the mower clearly allows it to operate continuously for one hour without issue.

2.1.2 Validation for FSR section 3.2.1.2

This requirement states that the autonomous lawnmower shall perform operations at least every 7 days.

This requirement was met by validating the charging rate in conjunction with requirement 3.2.1.1 as specified above. Due to the late changing of the batteries, our new batteries could each be charged in about 30 minutes to full power, meaning that the total charge time would be only 1 hour. This means that the autonomous lawnmower system would be able operate much more often than once every 7 days.

2.1.3 Validation for FSR section 3.2.1.3

This requirement states that the system shall avoid all obstacles that are harmful to the overall system, running over small obstacles that only impact blade sharpness or appearance is acceptable.

This requirement was met by validating our navigation and obstacle detection code. A video showing our obstacle detection and avoidance system within our navigation path was shown during demo time. In that video you can clearly see the autonomous lawnmower going about its navigational path, when it is interrupted by an obstacle, then the blade shuts off and the autonomous lawnmower avoids the obstacle, before resuming the navigational path.

2.1.4 Validation for FSR section 3.2.1.4

This requirement states that the system shall use internal sensors to follow a spiral pattern within the boundaries outlined by the user.

This requirement was met by validating the full run of the navigation code in the completion of a shrinking rectangular pattern that would represent the typical action taken when mowing a lawn. This requirement included the need to implement a turning function, which we implemented using shaft encoder readings to measure distances. We attempted to use GPS for turning, however the GPS only would refresh once per second and only could adjust while the system was in motion, meaning it would take far too long in terms of both time and distance to implement. We also tried to use a gyroscope in order to determine how many degrees the system had turned and correct to 90 when necessary, however the yaw function on the gyroscope was not functioning as intended.

2.1.5 Validation for FSR section 3.2.1.5

This requirement states that the autonomous lawnmower shall be able to be aware of any obstacle in the hypothetical box extending forward from the front of the mower as far as 2W and as wide as the widest point of the mower.

This requirement was conditionally validated by utilizing a plastic shelf that was approximately the same width as the body of the mower and placing it on the ground in front of the mower in order to read the distances that the sensors would output. Below in figures 1 and 2 you can see that the obstacle is placed 60cm in front of the sensors and their corresponding output. In figures 3 and 4you can see that the obstacle is placed 90cm in front of the sensors and their corresponding output. You can see that the sensors worked correctly up to 90cm in front of the autonomous lawnmower. When the sensor array was validated on a testbench, the sensors could read up to 3M in front of them for an object as wide as the autonomous lawnmower. It is our belief that the heavy vibration generated by the motors as well as the process of moving the sensors may have been damaged.

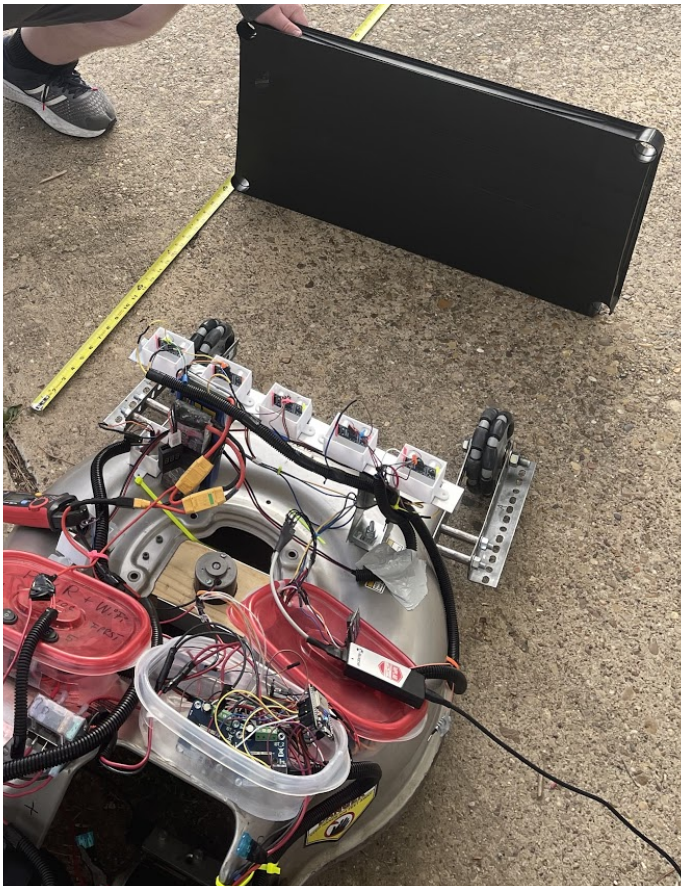

Figure 1: Obstacle Placed 2ft (~60cm) in Front of the Autonomous Lawnmower

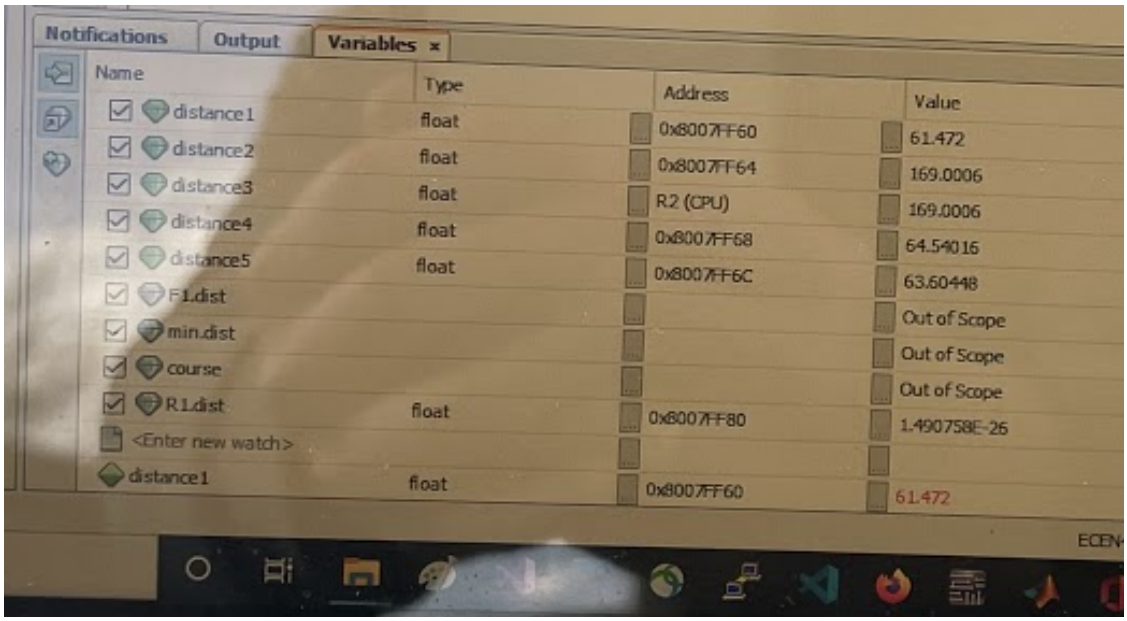

Figure 2: Sensor Readings for an Obstacle Placed 2ft (~60cm) in Front of the Autonomous Lawnmower

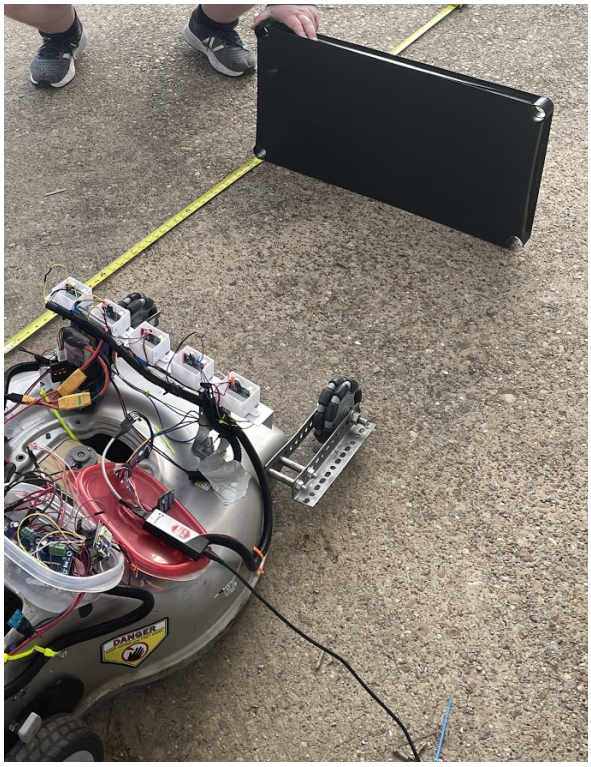

Figure 3: Obstacle Placed 3ft (~90cm) in Front of the Autonomous Lawnmower

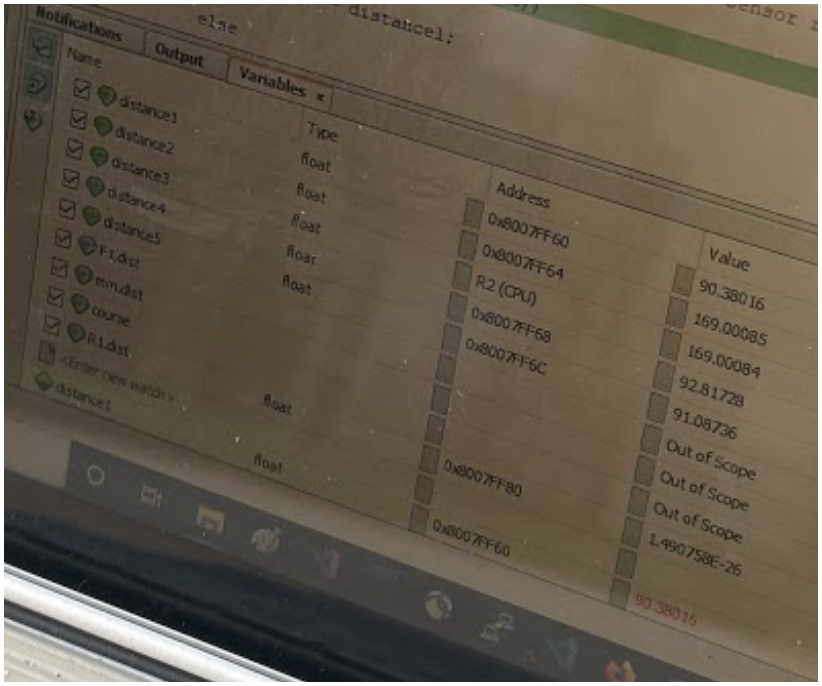

Figure 4: Sensor Readings for an Obstacle Placed 3ft (~90cm) in Front of the Autonomous Lawnmower

2.2 Validation for FSR Section 3.2.2

2.2.1 Validation for FSR Section 3.2.2.1

This requirement states that the autonomous lawnmower shall not exceed a maximum weight of 70lbs.

This requirement was validated by having one of our team members (Josh Samaniego) stand on a scale while holding the autonomous lawnmower unit in order to determine its weight. When measured the weight of the team member and the autonomous lawnmower was 225lbs, with some subtraction we get the following result:

Figure 5: Total Weight of Team Member and Autonomous Lawnmower

Total Measured Weight - Team Member Weight = Autonomous Lawnmower Weight
225lbs - 190lbs = **35lbs**.

Based on this measurement we concluded that the autonomous lawnmower weighed 35lbs, well below the 70lb maximum.

2.2.2 Validation for FSR section 3.2.2.2

This requirement states that the autonomous lawnmower shall be no larger that 30 inches in height, 25 inches in weight, and 40 inches in length

This requirement was validated by measuring the assembled autonomous lawnmower with a tape measure. The measured distances were **15 inches in height, 23 inches in width, and 40 inches in length (15h x 23w x 40l)**.

2.2.3 Validation for FSR section 3.2.2.3

This requirement states that the autonomous lawnmower's components shall be mounted in a fashion to resist vibration that is incidental to lawnmowing, with service once every 6 months when used weekly (one weekly use for one hour for 26 weeks).

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.3 Validation for FSR Section 3.2.3

2.3.1 Validation for FSR Section 3.2.3.1

This requirement states that the autonomous lawnmower system shall not be damaged by any possible inputs or signals produced by the system. No user input should result in the autonomous lawnmower system engaging in unsafe or damaging operations. The validation of this requirement is dependent upon the validation of requirements 3.2.3.1.1, 3.2.3.1.2, and 3.2.3.1.3.

2.3.1.1 Validation for FSR Section 3.2.3.1.1

This requirement states that the power consumption of the autonomous lawnmower system shall not exceed 200W.

This requirement was modified, and thus conditionally validated, upon the ordering of new motors and new motor driver boards to be a 250W maximum power consumption. We increased this specification due to the drastic increase in the size of the motors we purchased. The initial motor specifications were for three 30W motors, and at the end we ended up using a 30W motor for the blade and two 230W drive motors. Calculations were performed based upon the component current and voltage while the system was running. As shown below in table 1, the total power consumption was just under the allotted 250W maximum at 243.749W.

<table>
<tr><th>Component</th><th>Voltage</th><th>Current</th><th>Power Consumed</th></tr>
<tr><td>PIC32 MCU</td><td>3.3V</td><td>0.13A</td><td>0.429W</td></tr>
<tr><td>ESP32 MCU</td><td rowspan="3">5V</td><td>0.1A</td><td>0.5W</td></tr>
<tr><td>Ultrasonic Sensors (7)</td><td rowspan="2">0.06A</td><td rowspan="2">0.3W</td></tr>
<tr><td>Shaft Encoders (2)</td></tr>
<tr><td>Blade Motor Relay</td><td rowspan="2">12V</td><td rowspan="2">0.41A</td><td rowspan="2">4.92W</td></tr>
<tr><td>Blade Motor</td></tr>
<tr><td>Motor Driver Boards (2)</td><td rowspan="2">24V</td><td rowspan="2">9.9A</td><td rowspan="2">237.6W</td></tr>
<tr><td>Drive Motors (2)</td></tr>
<tr><td colspan="3">Total Power Consumed</td><td>243.749W</td></tr>
</table>

Table 1: Autonomous Lawnmower Power Specifications

2.3.1.2 Validation for FSR Section 3.2.3.1.2

This requirement states that the input voltage level for the autonomous lawnmower system would be less than 14.4 VDC.

This requirement was validated by measuring the voltage in the two Lithium Polymer batteries on the lawnmower. The battery output voltages are shown below in figures 6 and 7.

Figure 6: Voltage Output of the 5Ah LiPo Battery

Figure 7: Voltage Output of the 8Ah LiPo Battery

2.3.1.3 Validation for FSR Section 3.2.3.1.3

This requirement states that the autonomous lawnmower system shall receive external commands from the user interface via a WiFi connection.

This requirement was validated by testing the start and stop buttons on the android application. The start and stop buttons are mutually exclusive meaning you cannot start the mower while it is already moving, or stop the mower while it is already stopped. Figure 8 below shows the view of the buttons on an android emulator. We had also attempted to implement a go home function, in which the lawnmower would return to its starting position, however due to limited time late in the semester we were unable to implement it in the navigation code.

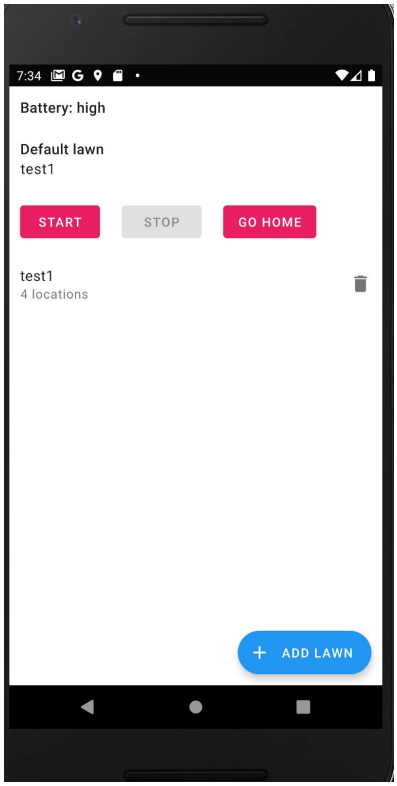

Figure 8: Android application screen showing start and stop buttons

2.3.2 Validation for FSR Section 3.2.3.2

This requirement states that the autonomous lawnmower system shall have two forms of output, data outputs and diagnostic outputs. This requirement was validated based upon the validation of requirements 3.2.3.2.1 and 3.2.3.2.2.

2.3.2.1 Validation for FSR Section 3.2.3.2.1

This requirement states that the autonomous lawnmower shall inform the user of problems and fault conditions through the user interface app via WiFi.

This requirement was not validated as we were unable to connect a circuit that would read the battery level to report to the user. The android application does contain code that would have displayed the battery level if it were to be given a voltage reading from the mower, which can be seen above in figure 8.

2.3.2.2 Validation for FSR Section 3.2.3.2.2

This requirement states that the microcontroller shall include a hardware debugging port that may be interfaced to a computer for diagnostic purposes.

This requirement was validated in the fact that both our microcontroller's contained built in hardware debugging ports. In figure 9 below you can see the hardware debugging port on the PIC32 microcontroller and in figure 10 you can see the hardware debugging port on the ESP32.

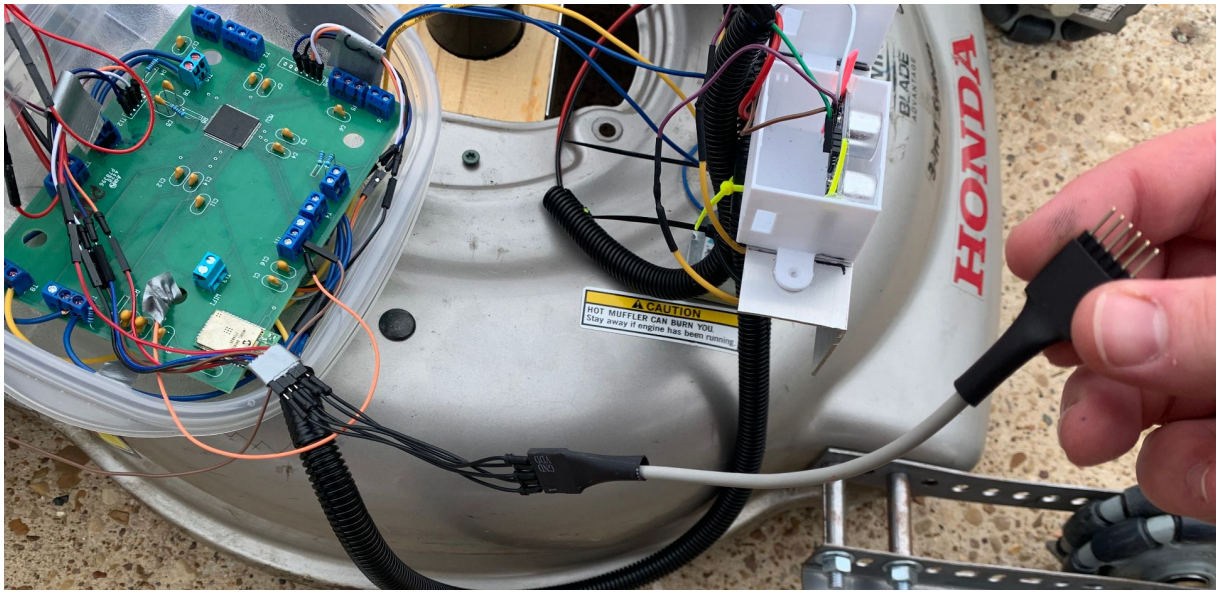

Figure 9: Hardware debugging port on the PIC32 microcontroller

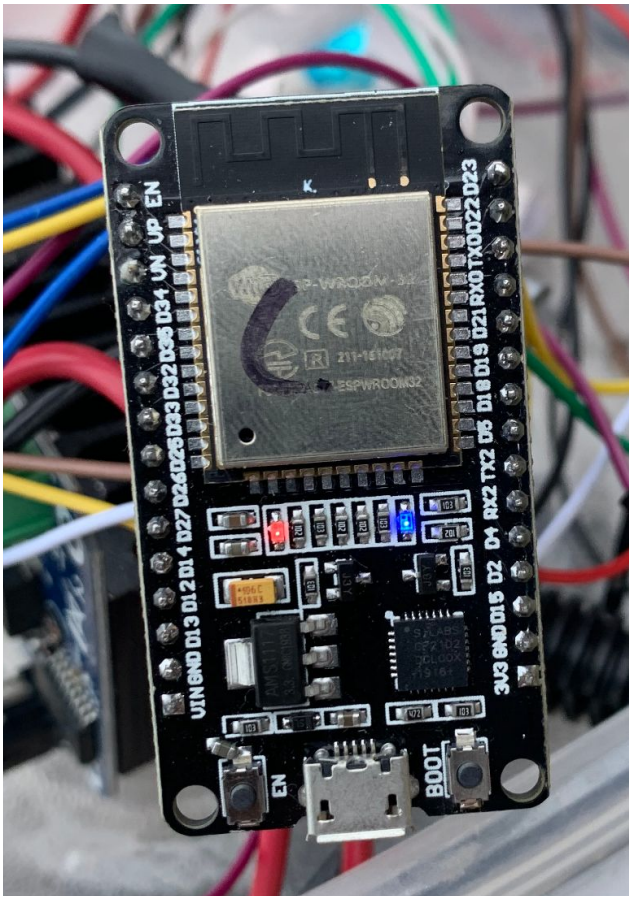

Figure 10: Hardware debugging port on the ESP32 microcontroller (on the bottom)

2.3.3 Validation for FSR Section 3.2.3.3

This requirement states that connectors (electrical or other) shall be resistant to vibration incidental to lawnmowing, with service no more than once per 6 months when used weely.

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.3.4 Validation for FSR Section 3.2.3.4

This requirement states that the wiring for signal and power interfaces shall be routed clear of any moving internal parts, clear of all possible outside interference, and protected as appropriate.

This requirement was validated via a visual inspection of the system. The top view and rear view of the system can be seen below in figures 11 and 12 respectively. These images show that the wires are all inside of protective casing, except for where they connect to their respective signal pins or component power supplies.

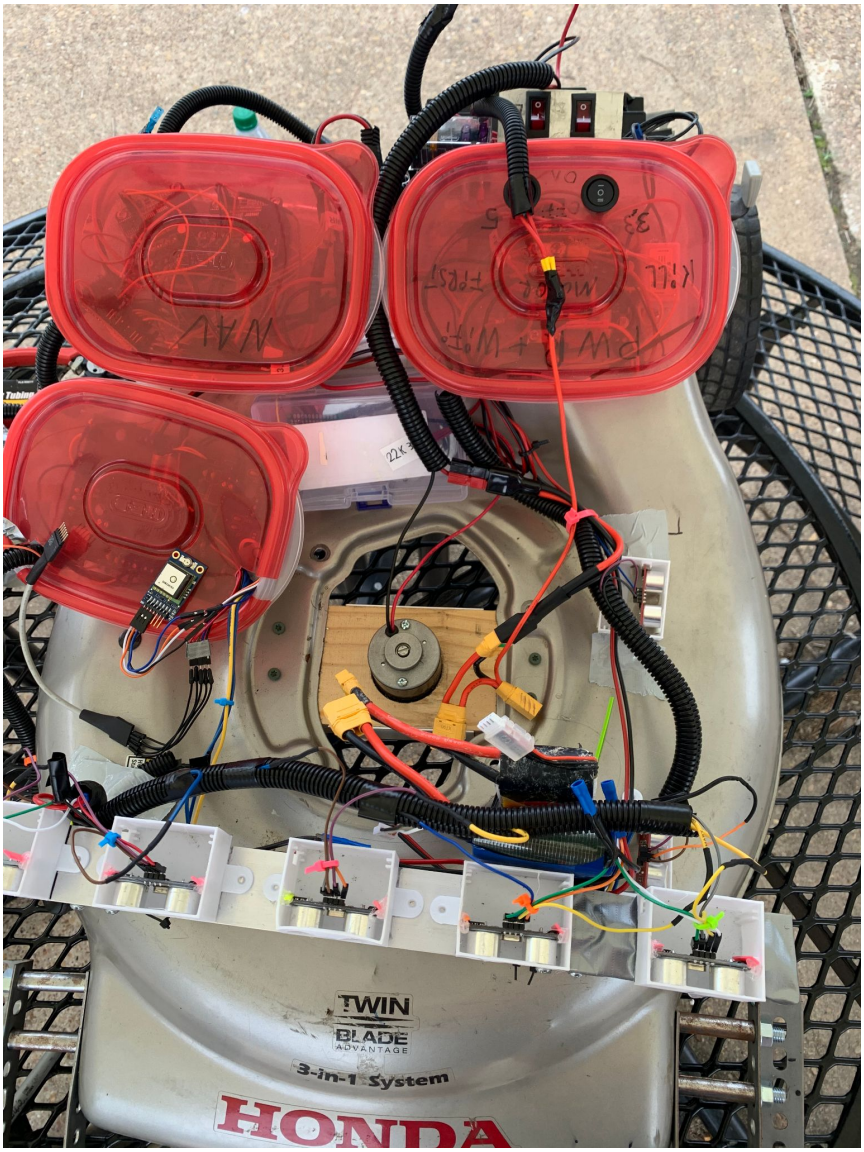

Figure 11: Top View of Assembled Autonomous Lawnmower

Figure 12: Rear View of Assembled Autonomous Lawnmower

2.4 Validation for FSR Section 3.2.4

2.3.1 Validation for FSR Section 3.2.4.1

This requirement states that the autonomous lawnmower system shall operate in temperature ranging from 40°F to 120°F.

This requirement was conditionally validated based upon the temperature data we were able to test at, as it did not reach as high as 120°F or as low as 40°F in march or april in southeast central Texas. We were able to record temperatures varying from 54°F to 66°F and from 72°F to 82°F Our system had no issues with any temperature within the ranges tested.

2.3.2 Validation for FSR Section 3.2.4.2

This requirement states that the autonomous lawnmower system shall be immune to dust and debris. The lawnmower systems shall either be protected from, or insensitive to debris 1mm or larger, as well as dust.

This requirement was conditionally validated based upon the sealed containers the components were placed in to protect them accordingly. Debris under 1mm has no effect on the motors or sensors as both are used to being outdoors in environments similar to the ones we tested in. The components inside of the red tubs as show in figures 11 and 12 on pages 16 and 17 are as follows: in the top right container there is the power bus bar, 12V to 3.3V convertor, and 12V to 5V convertor; in the top left container there is the two motor driver boards and the ESP32 microcontroller; and in the bottom left container is the obstacle detection PCB which includes the PIC32 microcontroller as well as the GPS unit. Through our testing we had no issues with dust or debris.

2.3.3 Validation for FSR Section 3.2.4.3

This requirement states that the autonomous lawnmower system shall not operate in the rain.

This requirement was validated upon the fact that the system was not assembled with waterproof components or wiring, and the components were not placed in water tight containers. The autonomous lawnmower is neither waterproof nor water resistant.

2.3.4 Validation for FSR Section 3.2.4.4

This requirement states that the autonomous lawnmower system shall be able to operate temporarily in conditions up to 100% humidity, but shall operate at lower humidity or will require higher maintenance for long term storage and performance.

This requirement was conditionally validated based upon the humidity data we were able to test at, as it did not vary all the way from 0% to 100% on the days at times that we tested the system. We were able to test at humidities ranging from 41% to 44% and from 56% to 71%. Our system had no issues for the humidity ranges it was tested in.

2.3.5 Validation for FSR Section 3.2.4.5

This requirement states that the autonomous lawnmower system shall be able to operate on moist, but not wet solid, level terrain.

This requirement was not validated, since we were unable to run the autonomous lawnmower system on grass due to an uneven weight distribution. The autonomous lawnmower's rear wheels would slip when trying to turn on grass as they would lift in the air. As a result we cannot say that the autonomous lawnmower can operate on any type of soil.

2.3.6 Validation for FSR Section 3.2.4.6

This requirement states that the autonomous lawnmower system shall be able to communicate with the network at the operating site from at least 100ft away and through at least 1 wall of wood and drywall construction.

This requirement was validated by testing the start and stop functionalities of the android application from within the apartment of one of our team members (Max Lesser) apartments, which was approximately 100ft from the autonomous lawnmower system. The start and stop functionalities both functioned with no issue

2.3.7 Validation for FSR Section 3.2.4.7

This requirement states that the autonomous lawnmower system shall be able to operate with light to medium foliage overhead.

This requirement was made in order to test that the GPS would still be able to maintain readings while operating under cover, however our system operates without the use of a GPS, so it does not matter what amount of cover is overhead, thus this requirement is validated

2.3.8 Validation for FSR Section 3.2.4.8

This requirement states that the autonomous lawnmower system shall operate without failure, under vibration incidental to lawn mowing for at least 6 months, when operated weekly for 1 hours

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.5 Validation for FSR Section 3.2.5

2.5.1 Validation for FSR Section 3.2.5.1

This requirement states that the autonomous lawnmower's user interface system shall notify the user if the blade is stuck on an obstacle and at the same time shut the blade down.

This requirement was not validated as the autonomous lawnmower system does not send information to the user via a WiFi connection and the android application. The blade does stop when the mower enters its obstacle detection protocol, but it has no such feature for actually striking an obstacle.

2.5.1 Validation for FSR Section 3.2.5.2

This requirement states that the autonomous lawnmower system shall power down, disabling the blade and alerting the user, if the system becomes stuck.

This requirement was not validated as the autonomous lawnmower system does not send information to the user via a WiFi connection and the android application. In cases where the autonomous lawnmower system becomes stuck, it simply continues to try to move upon its programmed navigational path.

2.5.1 Validation for FSR Section 3.2.5.3

This requirement states that in cases where the autonomous lawnmower system loses a WiFi connection the system shall continue on its programmed path and return to its rest position.

This requirement was validated by turning off the mobile hotspot on one of our team members phones (Jonathon Poulose) in order to monitor the systems response to the loss of WiFi connectivity. The system simply continued on its navigational path upon losing its WiFi connection.

2.5.1 Validation for FSR Section 3.2.5.4

This requirement states that in cases where the autonomous lawnmower system loses a GPS connection it shall attempt to follow the planned navigational route to the best of its ability.

This requirement was validated based upon the fact that we do not use the GPS for navigation, meaning that turning off the GPS has no effect on the navigational path. We tested this by disconnecting the power to the GPS during a test run.

2.5.1 Validation for FSR Section 3.2.5.5

This requirement states that in cases of system failure, the autonomous lawnmower shall alert the user through the user interface, disable the blade and return to the start position if possible

This requirement was validated by disconnecting the sensor array and seeing how the system would respond. When the sensor array was disconnected, the system stopped moving and turned off the blade as a safety precaution.

2.5.1 Validation for FSR Section 3.2.5.6

This requirement states that in cases of critical system failure, or in cases when the microcontrollers lose all ability to control the mower or its subsystems, the autonomous lawnmower system shall power off its blade.

This requirement was validated by turning off the microcontrollers mid test run and monitoring the response. Upon losing power in the microcontrollers the blade motors immediately power off as it no longer is receiving a high signal from the ESP32 microcontroller.

3 Validation Plan Conclusion

In the end, we were able to validate all but four requirements in either a complete or conditional manner. While we would have liked to be able to look at our validation plan at the end and seen nothing but completely validated requirements, we are proud of what we have accomplished. It is apparent now that we were a bit ambitious in the creation of our requirements in our functional systems requirement document back in October. I believe had we had a greater understanding of our project then, we would have been able to generate more accurate requirements for our project description.