ENGR 16200 Project 3:

Global Emergency Autonomous Response System (GEARS)

Team #45

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Dear Dr. Wilson,

For the last several months, Engineering Team 45 has been developing a prototype Global Emergency Autonomous Response System (GEARS) in accordance with the specifications set out by the L3Harris Disaster Response Team. This GEARS robot is able to navigate precisely, characterize and avoid hazards within its path, transmit a map, and communicate in a non-threatening way. Though the current prototype has some difficulty completing the full course without the use of checkpoints, the design team believes that with some minor technical changes, this robot is the best design that is able to achieve the goals set out by L3Harris.

The system navigates via the use of two large wheels powered by 2 EV3 motors and 2 small caster wheels. Turning was achieved via the use of differential steering, which allows for precise turns within the confines of the maze. This accurate navigation is the fundamental building block that allows the team to complete all tasks.

The custom cargo container was mounted to the rear of the GEARS via two axles attached to the chassis. When the system determined that it was out of the maze, a motor attached to a simple arm would push the container off the mounting axle. This simple, yet elegant solution was able to consistently deposit the cargo in an upright state. The GEARS is also able to use the custom decals designed by the team to communicate the contents of the cargo container in an effective, non-threatening manner.

The design of the GEARS itself is also meant to be non-threatening. It is able to effectively communicate when cargo is safe to be picked up upon exiting the maze. In addition, it is built to be as visually non-threatening as possible in both its appearance and its movement.

The proposed design performed very well during the demonstration. It was able to navigate through the maze by following the intended logic of only taking left turns, as well as successfully avoiding hazards and mapping them out. When hazards were detected, the GEARS was able to back away, record the presence of a hazard, and find a new way forward. During the demonstration, the robot was able to navigate 14 consecutive squares without contacting walls, as well as detect hazards 100% of the time. In five out of the eight trials, the system was able to pathfind past at least one checkpoint (62.5% success).

Despite the success of demonstrating the robot, it still has several small issues to be resolved. The first of these is the built-up error within the gyroscope causing the robot to contact the wall over extended straightaways within the maze. The simple answer to this issue would be to use the ultrasonic sensor to align the robot horizontally with the walls after a certain time. The other potential issue that was encountered during testing was the IR sensor's inconsistency when detecting the IR beacon when off-center. Wall alignment using the ultrasonic sensors would also resolve this issue. Frequent alignment reduces the likelihood that GEARS approaches the IR beacon at an unreliable angle.

In conclusion, Team 45 believes that the GEARS prototype proposed in the enclosed report has enough merit to be selected by L3Harris. Its excellent performance during the demonstration and its efficient design makes it stand out among other choices. Simple software-based solutions can easily fix the minor issues encountered during the demonstration.

Best Regards,

Team 45

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Executive Summary

Team 45 has successfully developed a Global Emergency Autonomous Response System (GEARS) to deliver lifesaving cargo to disaster zones. The GEARS is able to precisely navigate challenging terrain, deposit cargo, map out obstacles, and transmit hazard information. In addition, the GEARS is also able to communicate that contained cargo is non-threatening via the use of custom-designed symbols that can be widely understood across cultures.

The robot delivers cargo via the use of a custom-made, 3D-printed container. The box was made to look like a chest, as a result of the data gathered from surveys put out by the design team. The surveys also determined which images best conveyed the availability of food and water, medicine, shelter, or fuel within the cargo container. These drawings were intentionally made childlike to ensure the recipients did not feel threatened when the cargo was dropped off. As shown by surveys indicating that each label selected had an average approval rating of over four on a scale from one to five, or an average favorability rating of 80% or greater.

There are several unique features of the team's GEARS. The first is the battery compartment. The battery is placed close to the center of the mass (increasing stability) and it is easy to access the battery since it is secured with two black pins (enabling easy removal). The next unique feature is the compact sensor array. This allows the robot to sense its environment without becoming too unwieldy. The final unique feature is the system's rear navigation system. The use of custom caster wheels allows the GEARS to turn without building up error.

During the demonstration, the GEARS was able to navigate 14 consecutive squares without contacting walls, as well as detecting hazards 100% of the time. In five out of the eight trials, the system was able to pathfind through at least one checkpoint (62.5% success). However, the system was unable to complete a full run without utilizing these checkpoints. The primary reason that this occurred was the fact that the system relied on the walls being set at exactly the right distance and when this did not occur, the error from the motors built up too much and caused the robot to eventually make contact with the wall.

Design Considerations

Brainstorming

From the beginning of this project, it was understood that a comprehensive plan and framework were needed in order to ensure success. To achieve this, the team determined that certain brainstorming tools could aid the design process. To begin, a functional block diagram was laid out that presented the major hardware and software components needed to complete the mission (Figure 1.1). An engineering specification table was also created (Figure 1.2), laying out technical requirements such as percent of obstacles identified, percent of obstacles avoided, and percent of successful cargo drops. These measures of success were used to evaluate the effectiveness of the GEARS. From this very general framework, the first design decisions could be determined.

One such decision was the choice of steering strategy. Two options weighed by the team were pointed steering (similar to a car) and differential steering (similar to a zero-turn lawn mower). In order to best balance these options, a decision matrix was assembled considering the pros and cons of each choice (Figure 1.3). After weighing each factor that would be affected by the choice of steering method, the final results were calculated. From this matrix, it was determined that differential steering was the preferred option for this specific mission due to its ease of building and efficient use of motor resources. This same decision matrix process was used for other large design choices throughout the conceptual phase, including wheel type, ultrasonic sensor type, and cargo container design.

Assumptions

Throughout the development of GEARS there were two critical assumptions that were made. The first was the earth's magnetic field is small enough to not affect the reading of the magnetic field sensor. If this assumption was not true then the sensors would falsely detect the existence of a magnet and as a result, the robot would not behave as intended. The other critical assumption was that the amount of sunlight in the operating area would be negligible. This assumption was necessary, as if there was too much sunlight the IR sensor would falsely detect the presence of an IR beacon, causing unintended behavior.

Design Iterations

In mid-February, the physical design process began. Emphasis was placed on quantitative data for design decisions. One example of this was deciding the steering method (Figure 1.3), where the final decision weights were 0.67 for differential steering vs. 0.27 for pointed steering. Similar quantitative reasoning was employed throughout the iterative design process.

With the major components decided, the next step was to assemble them together in a functional way. The first prototype of the full GEARS was very bare-bones, consisting of only necessary parts assembled in the simplest way possible (Figure 1.4). The benefit of this early prototype was that it gave the team a better understanding of how the GEARS would interact with the physical environment. It became quickly apparent that sensor placement would be imperative to ensure proper navigation and hazard detection. While this initial prototype was scrapped in favor of a more developed design, it was an essential part of the design process.

By late February, a more advanced GEARS had been developed with sensor placement and coordinate navigation as a priority. With a compact, sleek design, this second prototype marked the largest physical revision of the GEARS for the rest of the project (Figure 1.5). As seen in the figure, the system now supported 3 ultrasonic sensors, with two facing leftwards and one forwards. This design also implemented an IR sensor and IMU for hazard detection, although the code to use them was not developed at that time.

In March, the GEARS was modified slightly to keep pace with the rapidly changing mission code. As mapping, maze navigation, and hazard detection algorithms were being developed, it was necessary to adapt how the robot utilized its sensor array. During this phase, the ultrasonic sensors were repositioned with one sensor facing right, another to the left, and a third forward in order to better sense the environment around GEARS. Additionally, the cargo container release mechanism was designed for this prototype, and can be seen in the image below (Figure 1.6).

In early April, a few final design revisions were made in order to polish the GEARS into the most efficient and successful configuration possible. One change was to modify the caster wheel placement to allow for dual back wheels instead of the previous sole caster wheel. This was advantageous because it reduced the weight on each wheel, cleared room for the cargo container to be deposited, and reduced the chance of the wheel getting caught during reverse motion. Additionally, the cargo release mechanism was modified to include a holding arm that secured the cargo container in place until dropped (Figure 1.7).

Final Design Description

The final GEARS is 37x26.8x16.7 LEGO® studs in volume, or 31x21x13 cm. Consisting of 220 parts, 6 sensors, and 3 motors, it is a compact and efficient machine. Three ultrasonic sensors pointed forward, rightwards, and leftwards combine with an IMU magnetometer and EV3 Gyro sensor to allow for total environmental detection. The two large 61.6mm D motorcycle wheels and two trailing custom caster wheels ensure that the GEARS can efficiently navigate to specific coordinates with high accuracy.

Additionally, there are several unique features of Team 45's GEARS that they would like to highlight. The first of these is the special battery compartment constructed for the project (Figure 1.8). This battery holder secures the heavy battery close to the center of mass where it will not affect the stability of the chassis. The battery is held in place using only two black pins, meaning it can easily be removed for recharging.

Another unique feature of the GEARS is the compact sensor array (Figure 1.9). This collection of sensors is placed optimally in the front of the robot, with each sensor in the best possible location for its respective needs. The ultrasonic sensors are located on extendable arms to either side of the array for easy adjustment.

The caster wheels that trail the drive motors are also custom. They are constructed using small "wedge belt" wheels to reduce friction, with a rotating mount to allow for 360-degree rotation in two axes. These caster wheels ensure that the GEARS can turn exact distances without building up error.

The team is also proud of their unique Raspberry Pi stack mount, which is placed in the center of mass of the chassis. The mount holds the sensor ports in the optimal location for wire access, while also securing the important "brain" of the GEARS to the rest of the system. The entire Pi case can be removed from the robot by removing four red pegs, making it extremely easy to access when necessary.

A final unique feature of Team 45's GEARS is the brightly colored headlights and taillights (visible in Figure 1.7). These non-functional additions to the robot are meant to symbolize the friendliness and safety of the robot to any victims in the disaster relief zone.

Software Design

During the build process mentioned above, the software needed to run the GEARS was being developed concurrently. In order to make programming as fast and as efficient as possible, Team 45 decided to take a unique approach to the coding of the robot. All motor and sensor control functions were abstracted away into a separate file called "gabepi.py", which was then imported as a library to the main code. Another file with more advanced detection and motion algorithms, "gears_functions.py", was abstracted and imported similarly. Combined with the main code ("main.py"), these three files were what gave GEARS the functions to detect its environment and navigate the terrain. The interaction between these libraries was planned in a flowchart constructed by the team (Figure 1.10)

This abstraction of functions to individual files had many benefits. The first and most obvious is that it reduced clutter in the main file, ensuring that it was easy to identify where issues were occurring and enabling quick fixes in the necessary areas. The abstraction also made it easy for code collaboration, because each team member could modify a separate file without the worry of overwriting others' code. Combined with GitHub, which is what the team used for code collaboration throughout the project, the software design process was efficient and effective.

Now that the building blocks were in place to design the code, the next step was to determine the algorithms needed to detect and advance through the maze. Team 45 decided upon the most simple but effective model of "left wall following" where the GEARS simply takes a left turn any time it can, and goes straight otherwise. By prioritizing the left-most wall, it is guaranteed that the robot will find the exit to the maze given enough time. To code this algorithm, the team used the ultrasonic sensors located on the GEARS' sensor array to detect nearby walls and hazards, then use the aforementioned method to determine the best course of action.

Finally, the software needed the ability to track current location and hazard locations. To accomplish this, precise distance testing was done to ensure the GEARS could move in perfect 40 cm intervals. Transferring this to a maze environment, the robot would move the desired distance between centers of maze segments, and then correct itself with the walls if necessary. At each 40 cm mark, the “main.py” class would call a mapper function, passing it the information that GEARS had moved forward one coordinate. This information was then used to track the current location and hazard locations as they appeared.

The code snippet, seen in Figure 1.11, is for the coordinate moving section of the “main.py” algorithm. The first step is to determine which direction the GEARS is moving based on its angle. Then, the system is told to turn as necessary and drive forward 40 cm while searching for hazards. This event-based programming style was found to be most effective in navigating the project, and was used similarly in other sections of the code.

Sensor Characterization

After the software was successfully implemented, the next step was to determine the correct sensor thresholds needed to detect the environment. The team needed to “teach” the GEARS what a hazard or wall looked like so that it could correctly identify them.

The first sensor that was characterized in this manner was the three ultrasonic sensors used for wall detection. As analog sensors that return a distance in centimeters, these sensors were the simplest to calibrate. Basic distance testing was done to ensure each sensor was accurate, and small coefficients were applied to the values if the readings were slightly inaccurate. This testing was completed early in the project, and did not need to be redone at any point.

The IR sensor and magnetometer, on the other hand, proved much more challenging to reliably calibrate. Since GEARS was tasked with avoiding IR and magnet hazards within a certain radius, the first test the team did was to determine IR sensor readings vs. distance from the robot (Figure 1.12). An identical test was done with the IMU magnetometer sensor (Figure 1.13). These values were a valuable base point for the team’s sensor thresholds, however in practice more tuning was required. It was noted after plotting that the ambient values of each sensor changed based on the current location of the system, which was unideal. In the end, the team tweaked the values slightly from the calibration plots in the code to ensure proper detection without any false positives.

Cargo Container Design

An independent design effort undertaken in late March was to design the GEARS cargo container. This container was to be drafted using CAD and printed in PLA on a 3D printer. Though 3D printing can be environmentally detrimental, Team 45 believes that at current scale the amount of waste is negligible. In addition, the team observed that the 3D printing process minimized waste plastic filament waste.

In order to determine the best design for such a container, the team sketched ideas on whiteboards and discussed the pros and cons of each model. Specifically, the merits of unique latching mechanisms were debated, since securing the cargo was the most important feature of this container. The next significant consideration was the structural integrity of the cargo container. Another important factor to consider was the overall physical appearance of the container, as it was intended to be a non-threatening aid resource. Significant thought was put into the best way to achieve an impartial, friendly, and useful aesthetic.

After creating a decision matrix that looked at security, ease of opening, structural integrity, ease of transport, and simplicity of design for several options (Figure 1.14), the optimal design was decided and drafted in Autodesk Fusion 360. The chosen design was based on a treasure chest, as it was determined that this model would be appealing and non-threatening to disaster zone victims (Figure 1.15). It was also very sturdy, surviving several drop tests during the prototyping phase. The final container design was just shy of 6x6x6 cm, which was the ideal size for printing on the available 3D printer hardware.

One unique feature of Team 45's cargo container design is its simple method of being retained by the GEARS. Utilizing two small holes in the rear of the container, the entire box could be slid onto LEGO® axle pieces, securing it to the chassis. With the help of a small motor arm, the container could be quickly flicked off of the GEARS in an upright position to the ground (Figure 1.16).

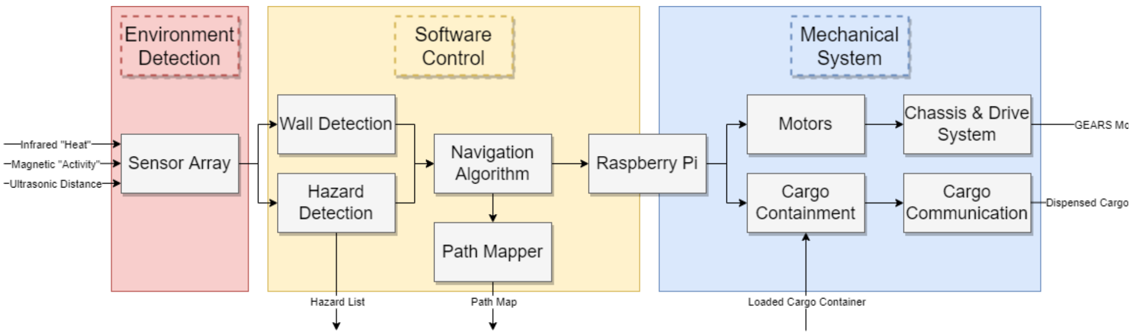
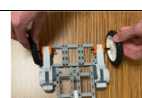
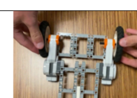


Figure 1.1: GEARS Functional Block Diagram

Customer Needs	Technical Needs	Technical Requirement	Target Value
Characterize and avoid hazardous locations	Percent of obstacles identified	>90% identified	100% identified
Precise navigation through damaged areas	Percent of obstacles avoided	>75% avoided	100% avoided
Transport cargo through unknown terrain	Percent of sucessful cargo drops	>75% successful	100% successful
Transmit a map of the path taken	Resolution of map transmitted	Accurate to <0.5 m^2	Accurate to <0.2 m^2
Indicate contents of cargo without specific language	Percent of recipients that recognized cargo	>80% recognized	100% recognized
Communicate with recipients without hostility	Percent of missions resulting in antagonistic actions	<15% antagonistic	0% antagonistic

Figure 1.2: Engineering Specification Table

Decision Criteria		**Steering Method Options**			
		Pointed Steering		Differential Steering	
					
Team Desires	**Weight**	**Value**	**Comments**	**Value**	**Comments**
Simplicity	0.3	0.5	Requires moving wheels	0.9	No moving wheels
Small turn radius	0.4	0.3	Turn radius will be large	1	Turn radius can be 0
Number of motors required	0.3	0.5	Requires one motor for steering, and 1+ for	0.6	Requires only 2 motors
Total Merit:		0.27		0.67	

Score Key	
Good	1
Ok	0.5
Poor	0.25

Figure 1.3: Steering Method Decision Matrix

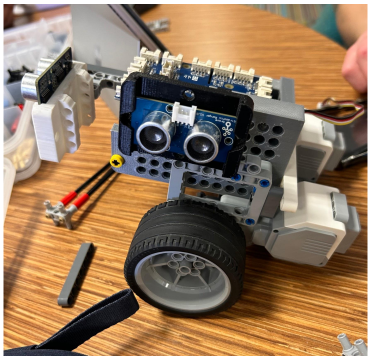


Figure 1.4: Initial Prototype

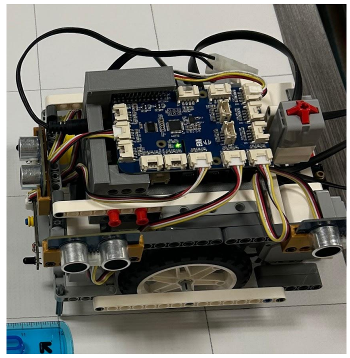


Figure 1.5: Prototype #2

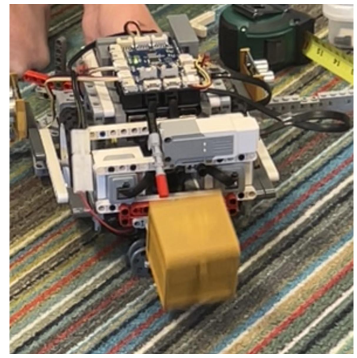


Figure 1.6: Prototype #3

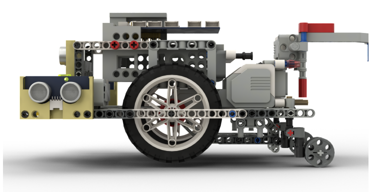


Figure 1.7: Final Design

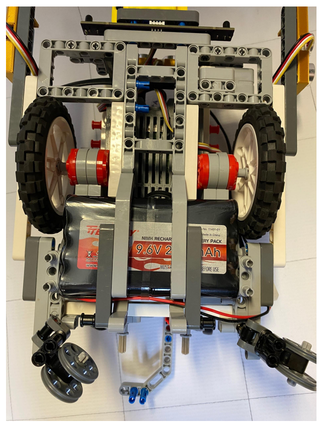


Figure 1.8: Battery Holder

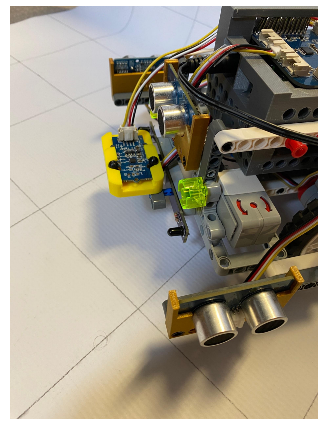


Figure 1.9: Sensor Array

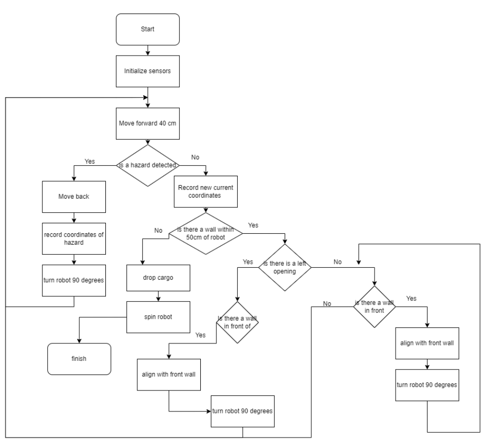


Figure 1.10: Code Flowchart

```
if (angle == 0):
        newY = currentY + 1
elif (angle == 90):
        newX = currentX + 1
elif (angle == -90):
        newX = currentX - 1
elif (angle == 180):
        newY = currentY - 1

print(f"Moving to ({newX}, {newY}) at {angle}" + chr(176))
turn_absolute(angle)
hazard = drive_distance_gyro_assist(40, initialAngle =
angle)
```

Figure 1.11: Coordinate Navigation Code

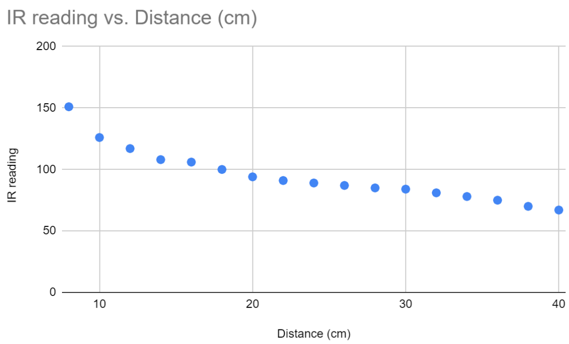


Figure 1.12: IR Sensor Calibration

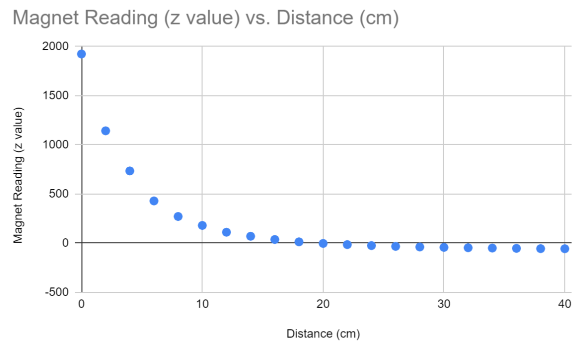


Figure 1.13: Magnetic Sensor Calibration

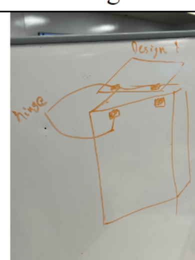
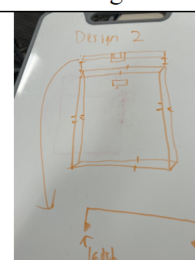
Decision Criteria		Cargo Container Options			
		Design 1		Design 2	
					
Team Desires	**Weight**	**Value**	**Comments**	**Value**	**Comments**
Secure contents	0.1625	0.5	Could open if inverted	0.9	Very secure
Ease when opening	0.1625	0.9	Hinge is easy to open	0.4	Latch is difficult to open
Ease to transport	0.1625	0.7	Simple square shape	0.7	Simple square shape
Structural Integrity	0.35	0.5	Seems fairly sound	0.7	Seems fairly sound
Simplicity of design	0.1625	0.6	Hinge hard to print	0.7	Latches have overhangs
Total Merit:		0.61375		0.68375	

Figure 1.14: Cargo Container Decision Matrix

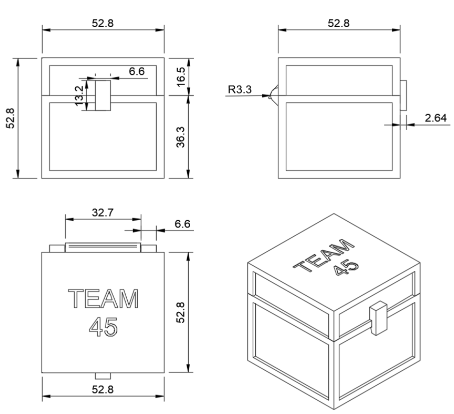


Figure 1.15: Cargo Container Design

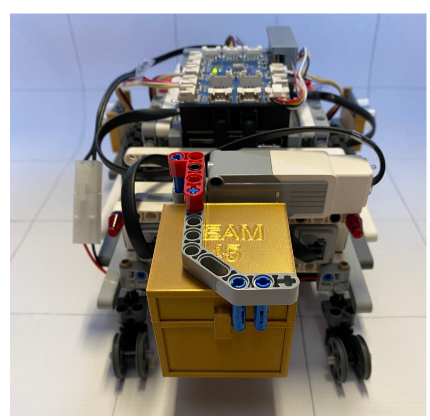


Figure 1.16: Loaded Cargo Container

Data Analysis

The proposed Global Emergency Autonomous Response System (GEARS) design implements six different sensors that need to be properly calibrated in order for the delivery system to be successful. The final design utilized three different ultrasonic sensors, on the left, right, and the front side of the GEARS, in order to detect walls or obstacles on each respective side. In addition to these, there is also an IMU sensor used for magnet sensing located at the very front of the robot, a gyro sensor located on the front left side of the robot, to be used for making accurate turns, and an IR sensor located at the front of the robot as seen in Figure 2.1. The location for all sensors was chosen so that hazards can be detected as easily. The GEARS takes input from all six of these sensors, as well as the motor encoders, after moving to the center of each square, in order to decide what course of action to take. As a result, it was necessary for each sensor to be fully calibrated and reliable.

The primary priority for the team was to first hone the motor encoders to ensure that the GEARS is traveling the exact distance of 40 cm per square. This is a crucial part of the system operation, since if there is any deviation that occurs, it not only will result in error buildup and possible collisions with obstacles and elements of the maze over time, but it may also lead to an incorrect map output. To obtain accurate measurements, the exact wheel circumference is needed in order to utilize the information from the motor encoders, which are tracked in degrees. This circumference was first estimated to be 26cm, but experimentally determined to be around 25.4 cm (Figure 2.2). This radius was then tested over a variety of distances, and the GEARS consistently and accurately traveled the desired distance. Since the wheels were never changed through iterative designs, no further testing was needed.

The first sensor calibrated were the ultrasonic sensors. Multiple tests were performed in order to determine the best cutoff values for performance. First, the ultrasonic sensors were tested for accuracy, and it was found that each sensor was fairly accurate, so no code was needed to fix inaccuracies. It was mathematically determined that the maximum distance the ultrasonic sensors should detect is 20cm because each coordinate square is 40cm by 40cm. The width of the GEARS is not factored into this measurement because the sensors should only detect a wall further than 20cm if there is an opening next to the robot. Next, the team proceeded to test the veracity of the readings of the ultrasonic sensor. This was done by varying the distance that the ultrasonic sensor was from a wall. The team then ensured that the reading of the ultrasonic sensor matched the actual distance from the wall, as seen in Figure 2.3.

The team then proceeded to calibrate the gyro sensor. The main purpose of the gyro is to make sure that the angle that the GEARS turns is as accurate as possible. During testing with a coordinate point system, it was found that the GEARS was able to create accurate 90-degree turns without any additional calibration, since it was observed that the GEARS was able to stay centered to each coordinate point after turning right or left (Figure 2.4).

Proportional control was implemented for turning using the gyro sensor's readings. Using proportional control meant that the speed of the turn was determined by how far away the sensor's reading of the angle was from the desired angle. This allowed turning to operate more smoothly, and for the actual angle turned to be as close as possible to the desired angle. The gyro sensor's accuracy was further also demonstrated when the GEARS was able to turn to any angle without any noticeable error. Following this test, the team didn't deem it necessary to perform any additional calibration for this sensor.

In addition, the team determined it was necessary to center the GEARS in both horizontal and vertical directions. Centering in the horizontal direction is handled via a custom jig that measured 40 cm, the same width as a maze square, and had markings to allow us to center the robot, which was determined using the GEARS' width of 21 cm (Figure 2.4). Centering in the vertical direction is done whenever the GEARS encounters a front wall as determined by the front ultrasonic sensor. Using the front sensor value, it will correct itself to ensure that it is 6.5 cm away from the front wall. This number was mathematically and experimentally determined by factoring in the final recorded length for the GEARS of 31 cm (Figure 2.6). Both of these calibrations ideally would ensure that the GEARS is perfectly centered each time it traverses one square, reducing and potentially eliminating error build-up.

The magnetometer and IR sensor were then calibrated in similar manners. The values read from each sensor were compared to the distance from the corresponding hazard. In the case of the IMU magnetic sensor, all dimensions of the magnet readings were analyzed, and it was experimentally determined that the z-value fluctuates most significantly in the presence of a magnetic beacon, so this dimension was chosen for magnet identification. The team was informed that the GEARS cannot enter within five inches of the magnetic hazard, and four inches of the IR hazard. This is important for determining sensor cutoff values, since a false positive detection will result in the system reversing and trying an alternate route or returning to the entrance if no other paths are possible. It is equally as bad if the system doesn't detect a hazard when there is one, since this will of course lead to the system running into the hazard, and failing to complete the delivery.

In Figures 2.6 and 2.7, each sensor reading is plotted against the distance from the hazard, and the cutoff value is visualized, after being converted to centimeters. Using these figures the cutoff values for the IR sensor and the magnetic field sensor were determined. Because of the linear relationship in the IR graph, the cutoff value was taken at face sight as 120 units.

However, with the exponential relationship of the magnetic sensor, it was determined that a higher cutoff value than what the graph predicted had to be used in order to be fully accurate in sensing magnets, and reduce false positives. Additional testing proved this to be 250 units, and that these values were sufficient given that the GEARS is perfectly centered with the hazard source, especially in the case of the IR beacon. Even after the demo performance, it is still uncertain whether or not the IR sensor can be completely reliable because of this sensitivity to angle alignment.

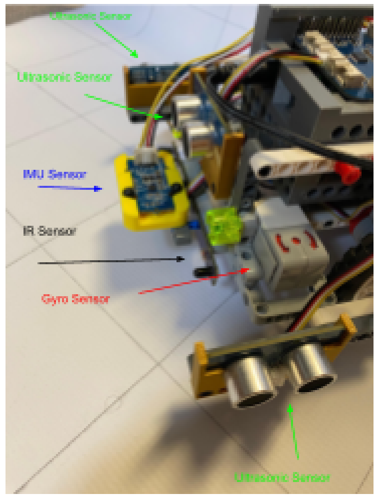


Figure 2.1 Detailed Sensor Layout

Straight line test			
Desired Distance (cm)	**Actual Distance (cm)**	**Error (cm)**	**Measured Wheel Circumference (cm)**
30	29	1	26
30	29.5	0.5	26
30	29.2	0.8	26
30	28.8	1.2	26.5
30	29.2	0.8	26.5
30	29.5	0.5	26.5
80	75.25	4.75	27
80	75	5	27
80	75.25	4.75	27
80	77.75	2.25	26
80	81.4	-1.4	25
80	80.5	-0.5	25.25
80	80.2	-0.2	25.35
80	80	0	25.35

80	80.4	-0.4	25.35
80	79.99	0.01	25.4

Figure 2.2: Circumference Testing

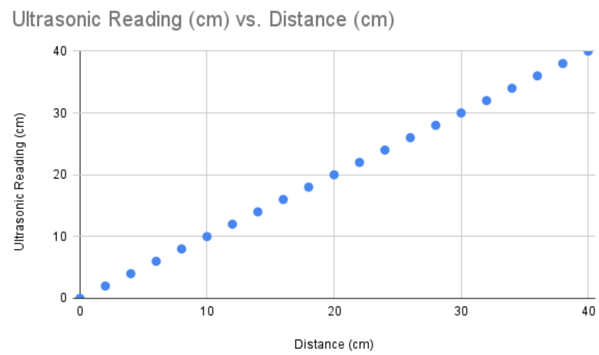


Figure 2.3: Ultrasonic Sensor vs Distance

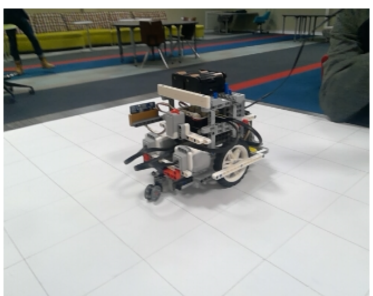


Figure 2.4: Testing proved that GEARS is always in center of desired coordinate

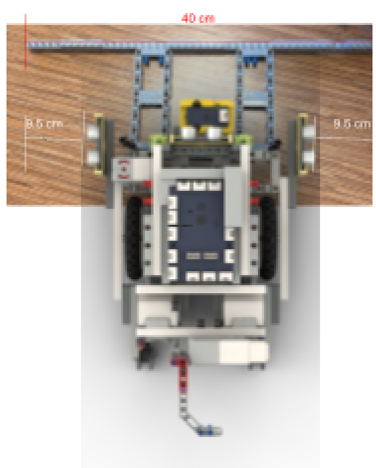


Figure 2.5: Centering jig that is 40 cm in length

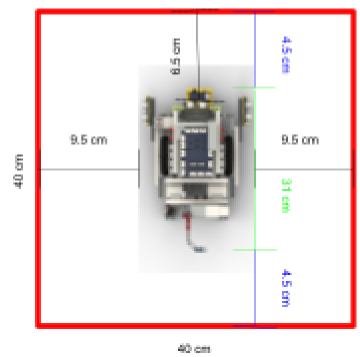
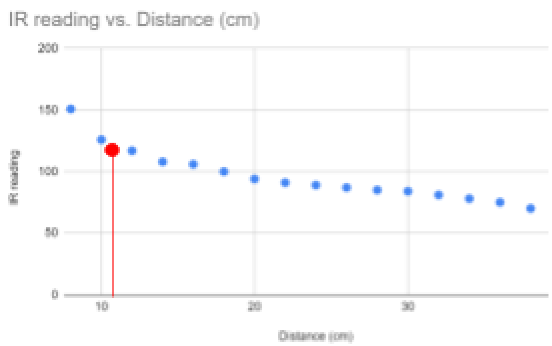
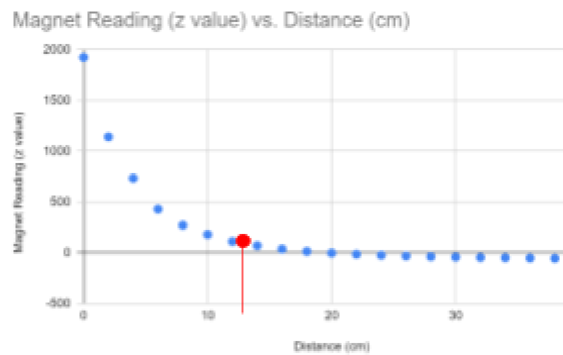


Figure 2.6: Visualization of ideal values of GEARS in a coordinate square



No entry radius: 4 in = 10.16cm
Cutoff: 120 units

Figure 2.7: IR Sensor vs Distance with cutoff



No entry radius: 5 in = 12.7cm
Cutoff: Greater than 100 units

Figure 2.8: Magnet Sensor (z-value) vs Distance with cutoff

Cultural and Ethical Considerations

The design team of the Global Emergency Autonomous Response System (GEARS) meticulously considered cultural factors and behavior in designing all components. Initially, two distinct designs with varying styles were created for each cargo container label. Subsequently, a survey was distributed among a diverse sample population to obtain impartial feedback regarding label designs, GEARS design, and cargo container design.

The survey presented only rough sketches of each cargo label design, as the focus was on the concept of what each design represented, rather than the details of the design itself. By employing rough sketches, the potential for bias in favor of a visually appealing logo, instead of one that conveys the intended message effectively, was eliminated. The team then analyzed the survey results and incorporated necessary changes, which will be discussed later. The team is of the opinion that the chosen design options are both non-threatening and easy to comprehend.

The first cargo label that was made was one for medical supplies. The final design for this consisted of a stethoscope intersecting with a perpendicular syringe (Figure 3.1). Several factors went into the decision of this design, from the green color that is universally associated with life and health, as evidenced by the greenery of plant life everywhere, to the stethoscope to nullify any negative connotations given off by the syringe.

The second cargo label made was the one for food and water. This simplistic logo depicts a tomato and a glass of water (Figure 3.2). The tomato was chosen as the symbol for food because research has shown that it is the most common fruit found worldwide (World Atlas, 2020). The water was chosen to be in a glass as opposed to a water bottle because this water might not necessarily be bottled, but rather in a jug that can be more easily used for bathing or washing.

The third cargo label, for emergency shelter, depicts a blue tent (Figure 3.3). An alternative design in the survey depicted a house, and these two designs received similar ratings, but the tent was ultimately chosen because of the more temporary implications that a tent has, as these shelters are not meant to be permanent or long-term solutions.

The final cargo label, for fuel, depicts a triangle consisting of a lightning bolt, fire, and a black blob that can be seen as either coal or oil (Figure 3.4). This triangle design was chosen in order to highlight the interchangeability of any type of fuel that is found inside. Research has shown that a lot of countries, especially in Africa, have less than 10 cars per 1000 people (Nation Master, 2014). Because of this, the team omitted depicting gas canisters, and opted for other representations of fuel and energy.

Regarding the operation of the GEARS itself, there are several ways that the team tailored the system to communicate independently and appear non-threatening. Research has shown that the more uncertain a robot's movement is, the more discomfort humans experience (Aéraïz-Bekkis et al., 2020). Because of the implementation of PID control, the system slowly accelerates and decelerates in between each movement, and moves at a reasonable speed. This gives off the impression of purposeful, deliberate movement, as opposed to jolts that make it seem like the GEARS is unprepared for when it encounters an object, which may be interpreted as the robot being dangerous.

This deliberate movement is also shown when the robot releases the cargo, and signals that it is safe to pick up by moving forward and spinning in a circle twice. Looking at the design of the GEARS, it was determined that headlights and taillights should be added in order to give it more of a car-like appearance (Figure 3.5). This design choice was chosen because even if there are countries that do not use cars extensively, there still is a sense of familiarity and recognition in seeing a vehicle that looks like a car.

In addition to this, a study conducted at Florida State University showed that many people give personalities to cars, and some cars are seen as friendly, especially when a face is perceived with the headlights as eyes and the grill as a mouth (FSU, 2009). In the case of the GEARS, the ultrasonic sensor can be viewed as eyes, ultrasonic sensor holder is viewed as a head, the headlights were added to be viewed as hands, the IMU sensor mount can be viewed as a body, and the back supports being viewed as legs, to create a happy cartoon character (Figure 3.6).

All of these final design choices were chosen in part by a survey that was sent out to the public. In this survey, participants were shown each design idea, and answered which emotions they would feel if they encountered this design on a cargo container, as well as how well (on a scale from 1 to 5) the label represents the intended cargo type.

Designs were considered good to use if the majority of responses deemed a design trustworthy and happy, and if the average rating of responses was greater than 4. The survey results for each final design are displayed below as well, with the exception of fuel. The fuel decal had to be redesigned as a result of public opinion heavily rejecting any design that included depictions of smiley faces, an example of which is shown in Figure 3.7. Both initial cargo designs for fuel depicted faces, and as a result, a more generic label was created and used as the final design. In addition to this feedback, the survey also asked about the approachability of the GEARS design itself. There was a slightly negative response, which resulted in the headlights and taillights being added in the manner that they were.

It is crucial to not only consider the interactions between the GEARS design and other cultures, but also to examine how interactions with vulnerable cultures should be conducted. When providing assistance to individuals from different cultures during disasters or conflicts, it is important to ensure that any aid and response is culturally sensitive to the victims. The type of aid that one country may require in a particular scenario may differ from what another country may require due to cultural disparities. An illustrative example of this is the foreign response to the 2004 tsunami in Indonesia, where insufficiently established guidelines for foreign aid resulted in much of the assistance provided being ineffective. This aid included “expired medicines by the truckload, culturally inappropriate food (such as pork in predominantly Muslim areas), and winter clothes” (International Federation of Red Cross And Red Crescent Societies, 2014). Inadequate knowledge of cultural norms, such as the type of food preferred or the climate experienced in Indonesia, led to unnecessary expenditure of resources. In light of this, the GEARS team considers it essential to conduct extensive research on target cultures and adjust any aspect of the design that may be deemed inappropriate or unnecessary.

Another ethical concern that needs to be addressed is the idea of truly informed consent. When giving aid to any party, it is necessary to make sure that the receiving end truly understands what is being given to them, as well as agreeing to receive it. This varies all the way from the individual level to the level of the government leader trying to gain aid from other foreign nations. For example, the earthquake in Haiti resulted in many injuries to people, some of which were severe enough to require amputation. With the influx of foreign emergency response doctors that attended to the victims, there may have been a language barrier between the patients and the doctors inhibiting the ability to gain this sort of consent, especially for a procedure like amputation. An official analysis on the response to the earthquake states that “informed consent of the patient…was standard procedure for many, but not all the medical teams in Haiti” (Grünewald et al., 2011). It is necessary for the GEARS to communicate to its targets that they are not expected to accept this aid if they do not want it. This can be communicated by dropping off the cargo in a place where people can see, yet far enough away from their temporary shelter.

Regarding human-to-human conflict most of the same ethical principles apply. However, one key difference is that by intervening in an active conflict, no matter how the third party plans to intervene, the ethical implications of involvement need to be considered. Unlike in a natural disaster, where bringing relief does no harm, the motives and perceptions of any aid sent need to be considered. One example of this is the involvement of China in Darfur, Sudan. This conflict was between rebel groups in Sudan who began to fight against the Sudanese government. China involved itself by providing humanitarian aid to the government and Sudanese civilians. However, one analysis concludes that there were “early signs that China intends to utilise its newfound power to remake international rules regarding territorial sovereignty” (Lee et al., 2011). Though it might seem that China is providing aid without any strings attached, this might not be the case, and could lead to conflict in the future. Whenever implementation of the GEARS is advocated for, it is necessary to determine whether or not the party utilizing it has the noble intentions. If not, this may lead to the GEARS being used in unintended ways or even with malicious intent.

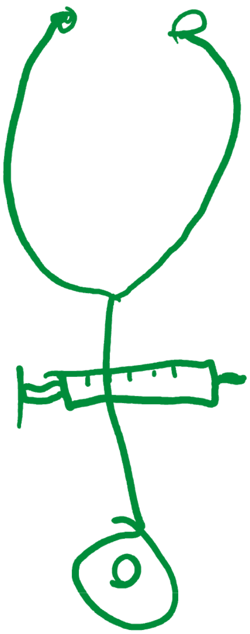
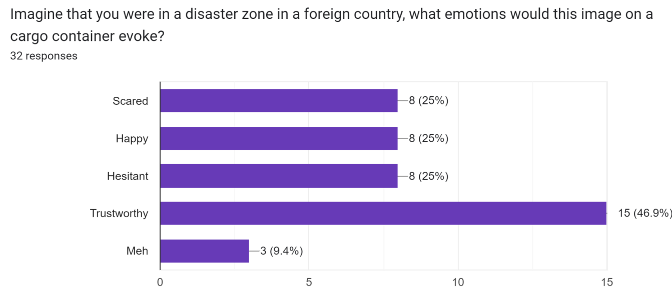
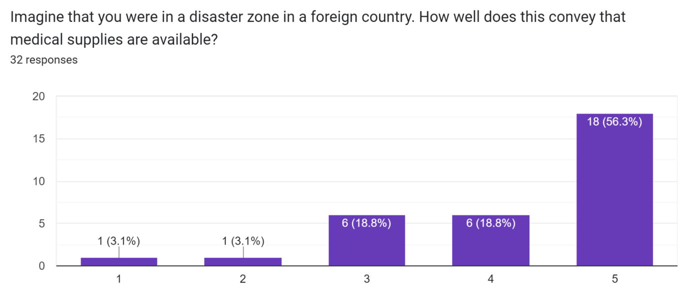


Figure 3.1: Medical Supplies Label





Figures 3.1a & 3.1b: Survey responses for Label

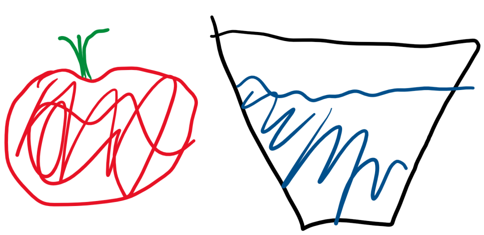
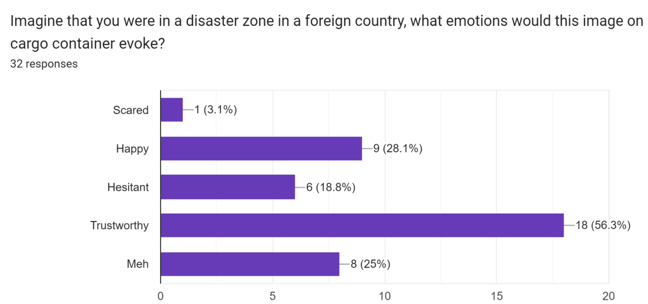
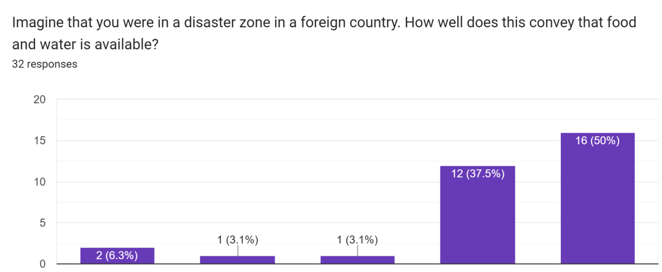


Figure 3.2: Food and Water Label





Figures 3.2a & 3.2b: Survey responses for Label

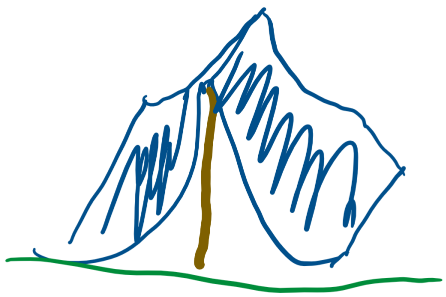
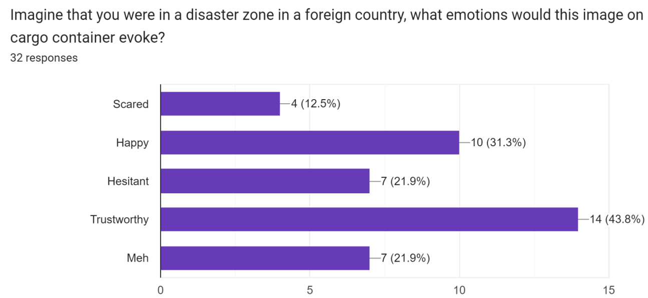
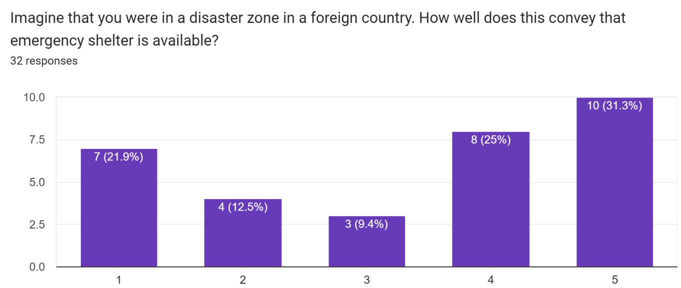


Figure 3.3: Emergency Shelter Label





Figures 3.3a & 3.3b: Survey responses for Label

Note: No survey responses applicable for previously mentioned reasons

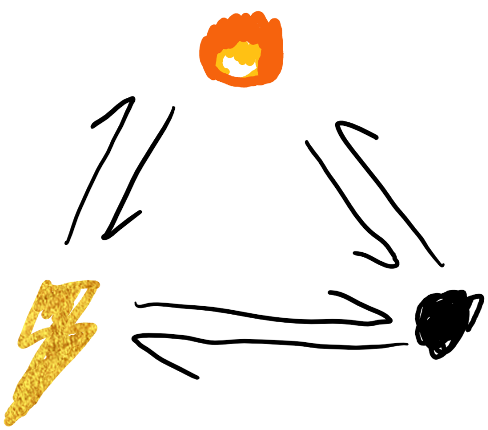


Figure 3.4: Fuel Label

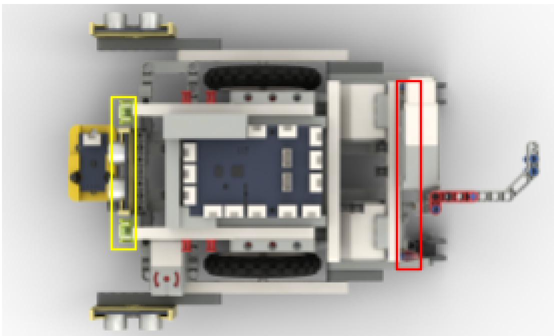


Figure 3.5: Headlights and Taillights Representation

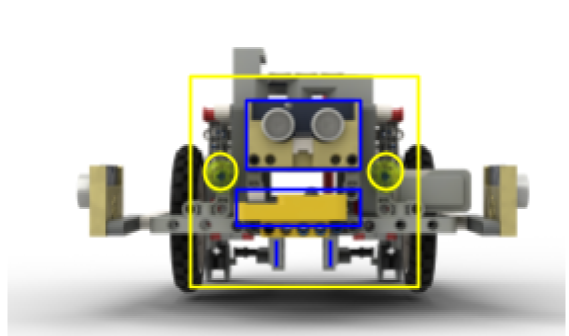
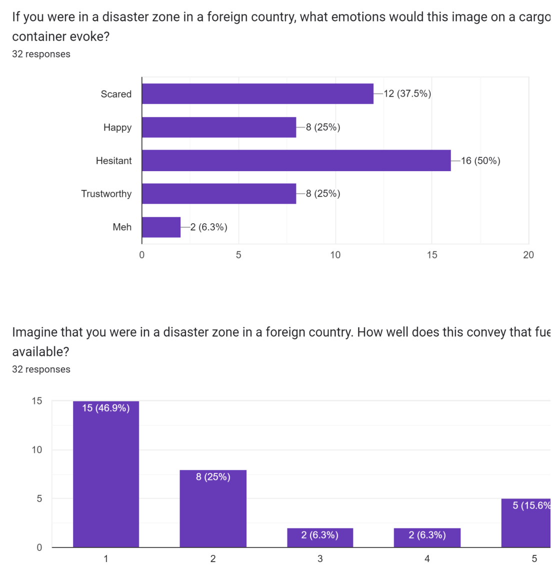


Figure 3.6: Friendliness of Front of GEARS

Figure 3.7: Rejected Fuel Label



Figures 3.7a & 3.7b: Survey responses for Label

Results and Discussion

In the final demonstration, the GEARS prototype was tasked with navigating through a maze autonomously without colliding into any walls or getting too close to any hazards that were set in the maze. Throughout this demonstration, it was revealed to the team what systems worked, what systems needed improvement, and what systems needed further testing to determine feasibility.

During the demonstration, the GEARS was able to navigate 14 consecutive squares without contacting walls, as well as detecting hazards 100% of the time. In five out of the eight trials, the system was able to pathfind through at least one checkpoint (62.5% success). The magnet detection, cargo dropoff, and map creation systems were all confirmed to be in working order. The magnet detection system was designed to turn the robot around after a magnetic field of a certain strength was detected in the z-axis of the inertial measurement unit's magnetometer. This system worked as expected, and when the robot was faced with a magnet in its path, the magnet was successfully detected and the robot backed away from the magnet.

The cargo dropoff system was designed to push off the cargo and leave the cargo upright when the robot had left the maze. This system worked as expected and successfully delivered the cargo upright once the robot left the maze. The map creation code was designed to return a CSV file that included a map of where the robot had traveled, including markers for where the robot entered and exited the maze, and markers for any hazards that were encountered in the maze. This code worked as intended and returned to the team a CSV file with the map of where the robot had traveled in the maze, with additional information for hazards that were detected inside the maze.

This demonstration also helped the team determine which systems were not operating as expected, including a flaw revealed in the overall navigation system during long straightaway stretches. During testing, the test mazes that the team set up were based on the assumption that the maze walls would be all square with uniform side lengths of 40 cm. The system performed as expected in this test maze, and stayed centered in the paths while traversing the maze. However, during the demonstration, the robot would drift off the center due to various factors including gyroscope error build-up and uneven wall placement in the demonstration maze. Correcting this error would be a top priority for future development.

While the demonstration revealed to the team what did and what did not work, there were some areas of the prototype system that were not needed during the demonstration, leaving the team unsure if the system works as intended or not. One system that was not able to be tested was the infrared light “heat” detection system. The infrared light detection system was designed to turn the robot around after infrared light of a certain strength was detected by the infrared sensor mounted on the front of the robot, which is similar to the way the magnet detection system works. However, due to the robot not encountering an infrared light tower during the demonstration, it is unknown if the infrared light detection system would have worked as intended. Further testing would be necessary to determine the feasibility of the infrared system currently in place on the prototype.

Based on the target metrics established by the team, almost all of the target values were met. The GEARS was able to identify 100% of the hazards it encountered during the demo, the labels were 100% easily identified by the oversight team. The map generated was also 100% accurate to the robot’s actual traversal. Looking at the percentage of successful cargo drops, there was one run in the demo where the GEARS falsely detected that it was outside of the maze and dropped the cargo, but this issue was easily fixed by adjusting the sensor cutoff values. In all other runs, the cargo remained on the GEARS, thus the technical requirement was met.

Finally, looking at the biggest issue of obstacle avoidance, it was evident that the GEARS did not meet the target value. While the GEARS ran into an obstacle in several trials after navigating through the maze checkpoints, it can be concluded that the percentage of squares where the GEARS successfully avoided obstacles is much higher than 75%. In all, every technical requirement was met, and the target values can be met as well with minimal modification.

Conclusions and Recommendations

Ultimately, the team has concluded that a design similar to the prototype used in the final demonstration would be the best solution for L3Harris to implement to address the challenges presented, including precise navigation, characterization and hazard avoidance,map transmittal, and non-threatening cargo content communication.

During the GEARS demonstration performance, the system was able to navigate through the maze by following the intended logic, as well as successfully avoiding hazards and mapping them out. When hazards were detected, the GEARS was able to back away, record the presence of a hazard, and find a new way forward.

Although the design did have a few minor flaws, they can be solved with minimal further testing and development. The navigation system could be improved by being able to navigate through a maze with uneven walls. This could be implemented by using constant readings from the ultrasonic sensors on both sides of the GEARS, allowing the robot to automatically keep itself centered between the pathway walls. This would then help resolve the issue that was encountered in the demonstration, where GEARS would slowly drift into the walls due to uneven wall sections.

Another improvement to the navigation system would be having a more accurate gyroscope, or having code to reduce the error buildup within the gyroscope system. This could take the form of frequently centering GEARS to ensure that the error within the gyroscope is eliminated or reduced. This combination of adding a real-time ultrasonic sensor-based alignment system and an improved gyroscope error handling would eliminate the navigational issues the prototype encountered during the demonstration.

The IR detection system will also need further testing to ensure that it works as designed, as the scenario for infrared light did not occur during the final demonstration. The magnet detection, cargo dropoff, and map detection systems all worked as intended, which will allow for those systems to be passed along for a final GEARS design.

The team recommends that the final design of the GEARS to use a magnet detection, mapping, and cargo dropoff system similar to the ones on the prototype system. The infrared system must be tested further for ensured viability. Systems involving navigation should be updated to involve more real-time detection of surroundings to stay inline with corridors.

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