Project 3 Report: Mars Rover Mobility System

Team 78

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Dear Dr. Ortega,

We are team 78, and we are writing to you to propose to you our design for a Mars Cargo Mobility System, or MACRO, that fulfils the given requirements of being able to autonomously navigate Mars' surface and deliver cargo to the correct drop off location. Since the increased development of space exploration in recent years and NASA's work with Curiosity, designing a Mars rover that can autonomously deliver cargo has been increasingly important in the coming years. Therefore, with much research, planning, and design, we have designed a prototype that fulfills all the necessary requirements of a rover delivery system on Mars so that your company can continue to work on improving our understanding of other planets and pave the way for a better future in space.

Our design has three main mechanical components: the chassis, the dropping mechanism, and the sensors. After many design iterations, the chassis is comprised of five wheels: two center ones connected to motors, and three support wheels. The design of our rover is similar to that of a pickup truck in which the front half has the motorized wheels which pull the second half, the bed of the truck, which holds the cargo. In the bed of the truck, there is a medium sized motor which triggers a trap door in the bottom of the cargo bed. When the trap door mechanism is moved, it drops the cargo upright into the appropriate drop zone. The final system that controls and connects all the entire robot together is the sensors. We have a number of various sensors located around our robot which control everything from where the robot goes to where the dropping mechanism is triggered. Our sensor system is comprised of an ultrasonic sensor which detects any obstacles, line finders which help the robot traverse the route, and a hall sensor which tells the robot where to drop the cargo.

In terms of software, the main goal of our program is to connect the outputs of the various sensors to the actual mechanical system it is related to. In the end, we have a robot that will turn when faced with an obstacle 15cm away, will dispatch cargo in the proper drop zone, based on the magnetic field, and will follow a given line to successfully traverse the rough terrain of Mars.

Overall, we were faced with some issues and there are still many aspects that can be improved upon in our prototype. We plan to improve the line finding capabilities so that the rover moves more smoothly, fix up the dropping mechanism to enhance the efficiency of the cargo system, and make the chassis a bit more robust to accommodate the treacherous terrain better. However, our design is unique, utilizing a trap door mechanism which can prove as a big positive especially since it uses fewer moving parts, making it more reliable and efficient than other more conventional ideas. With some extra time and resources, we are confident that we can design a more efficient and reliable MACRO in a timely manner, that will enhance your capabilities on other planets and ensure your place in the future of space exploration.

Executive Summary

The designed MACRO system is required to carry payloads, navigate the Martian terrain, and deliver the cargo to designated locations within the facility safely and efficiently. The key customer needs include precise navigation, hazard recognition and avoidance, secure transport of the payload without dropping, and timely delivery of cargo.

The precise navigation requirement was met through dual line sensors in parallel orientation where the robot would naturally drive straight and if the left line sensor detected the guideline, the robot would then slightly turn left. The hazard recognition and avoidance need were met using an ultrasonic sensor. Whenever the ultrasonic sensor detected an obstacle within 15 cm, the robot would come to a stop until the obstacle is removed. The cargo was able to be securely taken to the drop-off location and released in the proper orientation through a trailer-like mechanism. The dropping/trailer mechanism was a trapdoor that would activate upon the magnetic detection of a hall sensor. Timely delivery and the controlled macro speed requirement were completed through the IMU sensor. Within the software, user input speed values determined the MACRO's speed as it navigated the course providing an accurate speed estimate and time management.

Throughout the demonstration, the line following navigation system was faulty resulting in the MACRO struggling to navigate the course. The cargo dropping mechanism also had issues detecting the magnet resulting in no cargo being delivered. However, the trailer successfully carried the cargo throughout, and the speed was exceptionally accurate as the MACRO had a time of 9.96 seconds when traversing a 200cm distance at a target speed of 20m/s.

Overall, the MACRO had an unsuccessful demo. However, with further testing, the systems and mechanics of the MACRO can be optimized to better navigate the mars terrain and transport the payload in a timely manner. Therefore, Team 78 highly recommends the systems and mechanics used in the MACRO.

Design Considerations

The first step in the design process was the development of the MACRO's chassis. The chassis is a very logical starting point, but beginning with this was also extremely important for project management and for the layout of the subsequent design process. Starting with a simple, reliable chassis that was separate from the other mechanisms of the robot allowed for the freedom to build off the chassis without having to waste time making huge changes to the chassis or driving code. While brainstorming and developing rough prototypes for the chassis, our team quickly realized that there was a limit on the amount of people who could work at once. To maximize time and efficiency, the team decided to compartmentalize the robot into three sections: the chassis, the sensors, and the dropping mechanism. This way, the sensors and dropping mechanism could easily be taken off the chassis, allowing for up to three people to build at once. This would also help with testing, as not all three components needed to be finalized or connected to each other to test coding.

For the chassis, there were multiple different designs that were considered. The main focus of the chassis was the driving wheels and how the robot would turn itself. The two main options considered were a zero-turn system comprised of two separately driven wheels, or a driven axel with front wheels for turning, similar to a car. The goal for the chassis was to maximize the mobility and power of the robot while keeping it compact and simple. It was clear that the latter option was more complicated yet would have less mobility than a zero-turn system, so the team started by developing the first option. With simplicity in mind, the chassis was built straight off of the raspberry pi holder. Two large motors were used on either side of the pi for maximum power for the hill and speed tests. In the first two iterations (see figures 1 and 2), the raspberry pi was raised higher off the ground. This was later changed (see figure 3) so that the chassis was lower to the ground, as it had better results when going up the hill and allowed the sensors to be positioned closer to the ground. These wheels worked well, had enough power to get up the hill, and were easy to incorporate into the turning code. The downside to using separately driven wheels was some inconsistency in turning, which could have been improved with more testing and changes to the MACRO's center of mass.

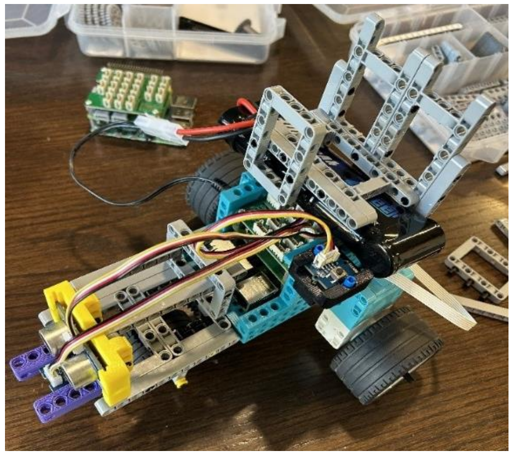

Figure 1: First chassis and sensor integrated design

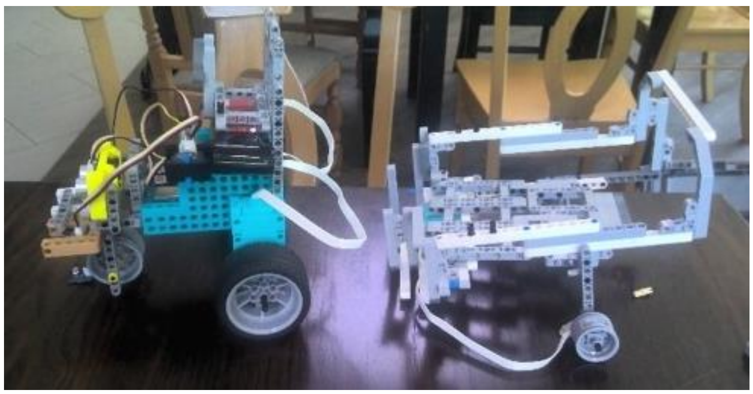

Figure 2: Second chassis and sensor design with disconnected dropper

Figure 3: Final chassis and Sensor Design

To keep the robot balanced, one front wheel was used with the rubber taken off to provide less friction and make turning side to side easier. This front wheel was initially on a swivel (see figure 1) which was later removed after the realization that the robot turned just as well without it. The last part of the chassis was the battery placement. The battery is very useful for changing the robot's center of mass, and the battery was initially placed directly over the two wheels to provide the most traction. This placement was helpful during testing and proved itself during the first POC, where the robot successfully made it up the hill and obstacle. The battery holder was later changed to be on the front of the robot (see figure 3) to keep it out of the way of the sensor ports, lower the center of gravity, and balance out the weight that was on the back of the robot due to the cargo and dropper. This was equally effective at giving the wheels enough traction for the hill. The holder was also designed so that the battery could be moved from side to side in an attempt to straighten out the robot since the two wheels often had slightly different speeds. This worked, but it was inconsistent and too easy to move the battery. This could have been improved by testing different battery positions and choosing a more permanent place for it on the chassis.

For the sensor section of our robot, the team wanted quick response time with the sensors in the front of our robot, so they were built off the front of the pi holder. Initially, a platform held the ultrasonic sensor, one line sensor, and the aforementioned swiveling support wheel. The first prototype was very experimental, and it was found that the robot would need more line followers and that the platform would need to be shortened so that the cords could reach from the sensors to the pi. While developing the line following code, we went through multiple designs regarding the line sensors, which will be covered later. Throughout these iterations, the ultrasonic sensor went through very few changes as it worked very well during our testing early on. Other sensors such as a button and an IMU sensor were also included on the pi for testing and data collection.

As for the line following, the team spent a lot of time trying to figure out the best way to implement the line sensors to create the most optimized and efficient turning. First, three line sensors were used, two straddling the line and one always on the line. The MACRO had a hard time getting readings on the lines, so the team tried switching over to a color sensor, but still had many issues determining the best thresholds. Therefore, we reverted back to the original use of the line followers but this time with only two line followers. This worked well after the sensors were calibrated. Once the sensors started providing accurate numbers, the team began coding the final line sensor code. The final code was a very simple program that took data from the line sensors: if the robot was on the line they would both read 0, but if one of the line sensors read one, meaning it was seeing the line, the robot would do a zero point turn in that direction to get it back on the line. This code was tested in the second presentation of competency, and it worked. The team continued testing and making minor changes to make it more reliable. However, in later testing, there were inconsistencies with the line sensor reading the line, which the team tried to troubleshoot but were unable to solve before the final demonstration.

After some development of the dropping mechanism and code, the hall sensor was added underneath the robot. After testing with the hall sensor, the team determined that it worked best if it was close to the ground, which is why it was placed so far down. This sensor was coded to count the number of times the robot passed over a magnet, which corresponds to which drop zone was input at the beginning of the demonstration. This code was then combined with the dropping code so that when it encounters the correct magnet the robot will stop and drop the cargo. This code had some issues due to inconsistencies in the hall sensor as well as problems with other parts of the code. Because the line following code was spotty, the hall sensor would not read the magnet when the robot was slightly off track.

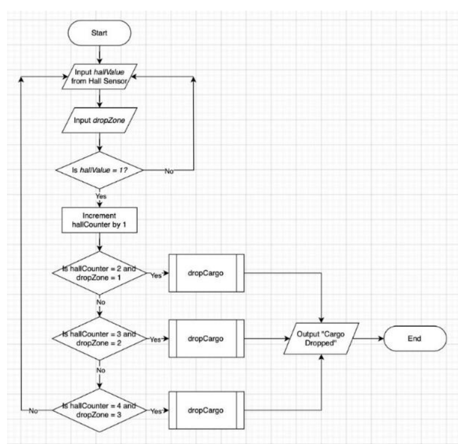

Figure 4: Flowchart of hall sensor code

For the dropping mechanism, there were multiple design goals to be achieved. First was the speed of the drop off, which influenced the type of mechanism chosen and made having the dropper on the back of the robot a necessity. It is important to be able to drop the cargo behind the robot so that it would not be in the way while navigating away from the drop zone. The size of the dropper is also very important, as the team wanted the option to carry any of the 3 cargos. This meant that it would have to be big enough for the largest one but also be able to work with any of the other shapes. The dropper also needed to carry and drop the cargo off in the correct position. The last goal was that it would be easy to develop, meaning it wasn't overly complex, it could be detached from the chassis for work and testing, and it would be stable without using too many supplies.

During brainstorming, the team came up with three main ideas for a solution. First was a claw that would pinch the cargo from either side, releasing it using a motor. In theory, this design would be very accurate, as the cargo could be positioned directly on top of the zone upon release. However, this seemed slightly more complicated than other ideas since the claw would have to account for the different sizes of the cargos, and it may struggle to support the weight of the cargo while driving. The second idea was a trap door mechanism which would slide out from underneath the cargo. A trap door seemed sturdier as it would support the cargo from the bottom and allow for some support underneath the apparatus. A conveyor belt could also be used to roll the cargo off a platform or a ramp. There were concerns about the accuracy of this design, since the cargo could easily tip over after sliding down, and it would also take longer to drop since it had to be moved horizontally. After comparing these designs with a decision matrix (see figure 5), the team decided to build and test the trap door design.

	Weight	Trap Door	Conveyor Belt	Claw
Speed Rating	10	9	7	7
Accuracy Rating	15	8	7	9
Complexity	10	8	6	7

Score		29	23.5	27.5

Figure 5: Dropping mechanism decision matrix

The first iteration of this design utilized a rack and pinion to move the platform from underneath the cargo (see figure 6). When tested, this mechanism could hardly even hold the cargo, much less function while under weight. Instead, a platform was used that could be rotated 90 degrees, which was supported by a frame to keep the cargo secure. The initial design used a large motor to power this platform, which didn't have enough power to move while under the stress of the cargo (see figures 7 and 8). Two gears were added to this design, but we later realized that we needed to use a medium motor due to the design specifications. The final design used a series of 5 gears connected to the medium motor in order to provide enough torque to drop the cargo (see figures 9 and 10). The additional gearing worked much better during testing and could drop any of the cargo very consistently.

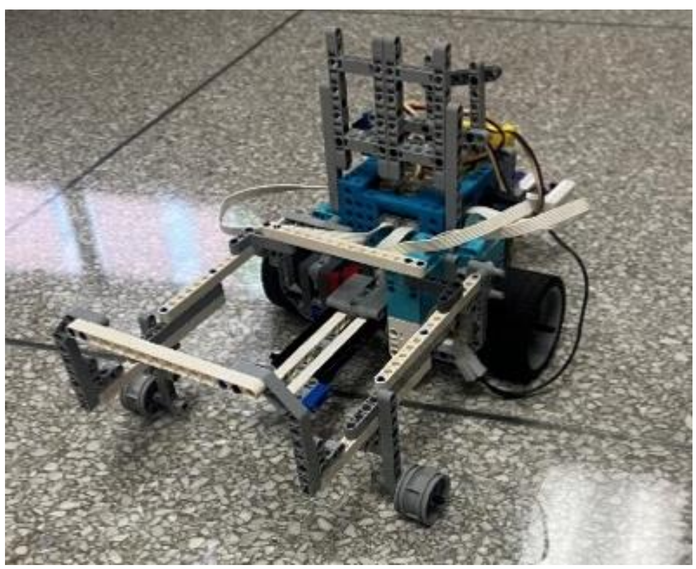

Figure 6: Dropper design 1 using a rack and pinion

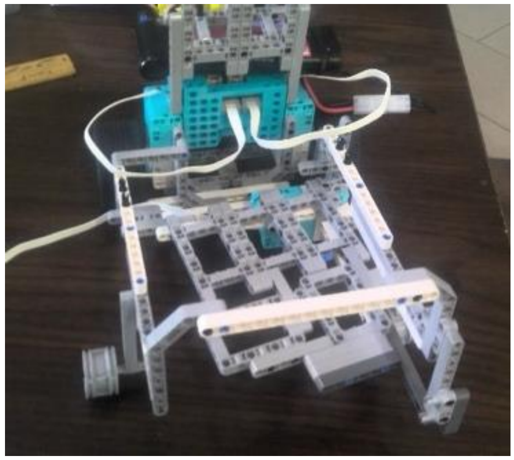

Figure 7: Dropper design 2 using a large motor and rotating platform

Cargo Type	# of times dropped out of 3 tests
power	2
water	0
habitat	0

Figure 8: Cargo testing 1

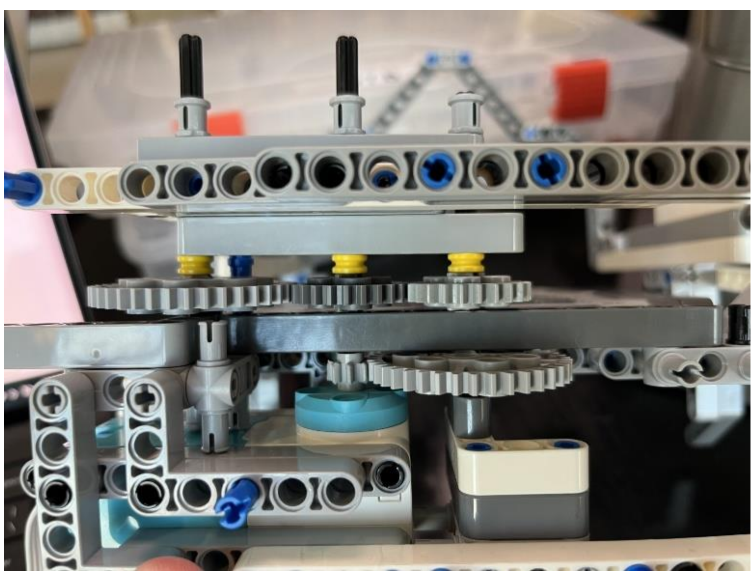

Figure 9: Dropper design 3 using medium motor and gear box

Cargo Type	# of times dropped out of 3 tests
power	2
water	3
habitat	3

Figure 10: Cargo testing 2

To support the weight of the cargo, the dropper used wheel rims that could slide on the track while turning. These wheels needed to be strengthened, as they often bowed outwards under the weight. After multiple changes to the wheels, a set of sleds were used instead, as they still had little friction but provided sturdier support (see figure 11). During the POCs and testing, the support sleds sometimes restricted the robot from using the ramp because they lifted the drive wheels off the ground at the start of the ramp. Because of this the dropper connection to the chassis had to be changed. The final design used a trailer-like connection: an axel that had freedom to rotate up and down and some freedom side to side while still holding some of the weight of the cargo. This integration helped the robot traverse the hill and also improved the robot's turning as it gave the dropper more freedom.

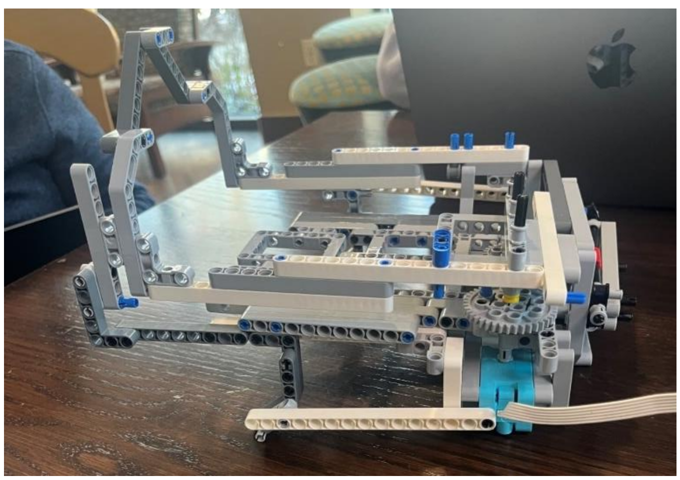

Figure 11: Final dropper design using sleds for support

The initial dropping code used the turn to position function for the motor, but this did not work well against resistance. Instead, telemetry was used to run the motor until it reached the desired 90 degree angle. The actual position of the motor was different due to the gears, so gear ratio calculations along with experimentation was used to find the correct motor position in the code. This dropping code was then integrated so that if the correct magnets were detected, it would stop, drop the cargo, and move forward to get out of the way of the cargo. This code worked in testing, but as mentioned earlier it did not work during the demonstration due to issues with sensing the magnets.

Our robot ended up with a very unique, modular design. The chassis focused on simplicity and functionality, which allowed the use of few resources while being able to turn and get over obstacles easily. The dropping mechanism was robust and was able to hold and drop any type of cargo very consistently. The integration between each part also allowed the team to work efficiently while providing maximum functionality to our robot.

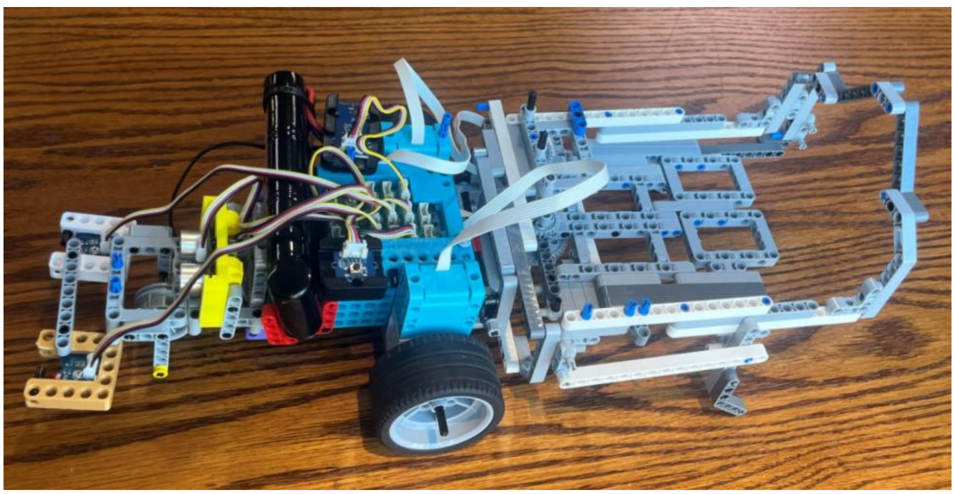

Figure 12: Final robot design, fully integrated

MACRO Physical Analysis

Five different requirements were given by L3Harris to measure the MACRO's success. These requirements were defined in a needsfinding chart (Figure 13) as: maximizing carrying capacity of cargo mass and trapdoor operations, maximized speed, hazard and obstacle avoidance and recognition, precise navigation, and reliable cargo transportation. Through physical analysis and testing of our robot, we have determined that our prototype successfully met each of these requirements.

Customer Need	Technical Need	Technical Requirement	Target Value
Precise Navigation	The proportion of the course length it can follow the guideline	Stays on guideline at least 75% of the course	Stays on guideline the 100% of the course
Recognition of Hazards	Number of hazards hit during transportation	Less than 2 hazards hit in 12 minutes	0 hazards hit
Reliable Transportation	Number of pieces of cargo to that fall off during transportation	Less than 2 pieces of cargo fall off in 12 minutes	0 pieces of cargo fall off
Speed	Max speed in cm/s	Max speed between 15 to 30 cm/s	Max speed between 15 to 30 cm/s
Maximize Carrying Capacity	Number of pieces of cargo	At least 2 habitat cargo containers carried	1 habitat, 2 water, and 1 power containers carried

	that can be carried		

Figure 13: MACRO requirements needsfinding chart

One of the strongest aspects of the MACRO's design was the trailer's carrying capacity of cargo mass. In L3Harris' project breakdown, they provided the minimum mass the trailer must support to be successful. Before any design was considered, the minimum of 0.475kg must be supported by the trailer. This meant that the final design of the trailer, it was necessary to meet a value significantly higher than .475kg, as the exact mass of the cargo would only be effective in ideal conditions. Understanding the harsh atmosphere and unpredictability of the mars surface, it is necessary to assume the maximum mass supported must be considerably larger to offset any obstacles or challenges encountered during the delivery runtime. Through weight testing, the trailer finally had issues supporting cargo mass around 2.3kg, and the trapdoor had issues functioning with cargo mass of 0.3kg. Considering the dropping mechanism was having issues, a gearbox was created to strengthen the motor allowing it to support up to 0.8kg of cargo mass. This proved that the trailer and dropping mechanism design were sufficient to handle the maximum cargo weight despite any obstacles or debris encountered during the demo run. In terms of the surface of mars and the optimal course to the MITEER facility, it can be expected that scaling the trailer to a rover scale will have a positive relationship with the amount of mass able to be supported. Therefore, the MACRO should have no issues with supporting and properly dropping the cargo at the MITEER facility.

Speed is one of the most important factors behind efficiency of cargo delivery. In L3Harris' project breakdown, the provided threshold of successful MACRO speed was between 15 cm/s and 30c m/s. As the chassis design was being developed, the motor strength was a key concern when meeting this requirement. However, by setting the motors to the highest possible speed, it was determined that no additional strength through a gearbox was necessary to meet the threshold. Due to the compact, lightweight chassis, there was an opportunity to exceed L3Harris' required speed allowing for more efficient delivery allowing for more leniency in less effective systems. Through speed testing (setting the motors to the highest possible speed), it was determined that the max speed of the MACRO was 36cm/s. In terms of the mars surface and scaling the macro, it is expected that the macro speed will fall within a proportional comparison of L3Harris' initial requirement. Even though the MACRO currently exceeds this requirement, once the parts are scaled with heavier materials, it is likely the motors will not be nearly as efficient even at an upscale. However, there is still plenty of success behind the speed of the MACRO, and it is an efficient design to meet project needs.

To prevent damage to the MACRO from debris and various obstacles, L3Harris requires a hazard and obstacle avoidance and recognition system. L3Harris defines success as sustaining no damage from obstacles due to an effective detection method. To meet this requirement, the MACRO utilizes an ultrasonic sensor that is programmed to detect obstacles within 15 cm. This distance was determined through testing of several different distances to determine the most effective value for the ultrasonic sensor (Figure 14). As the distance increased, there were larger inconsistencies on whether the robot detected the obstacle within that range. Where when the distance was closer, it was more consistent, but whenever the sensor did not detect, the robot would have already sustained damage. Therefore, finding the necessary distance was crucial to meeting this requirement to prevent either inconsistent performance or sustained damage. The MACRO's ultrasonic sensor set to 15cm both consistently detects obstacles and stops in time to prevent potential damage. Therefore, the MACRO successfully meets L3Harris' requirement as the MACRO is entirely optimized in this respective need. When the macro is scaled, an upgraded ultrasonic sensor will need to be recalibrated to determine the new optimized distance for the rover. Depending on the terrain, this distance may need to be decreased or increased due to potential obstacles being common causing interference within the software. The MACRO's hazard detection is very easy to change and reoptimize, making it an effective asset during mars navigation.

Distance (cm)	Out of 10 trials, how many did not read near the input distance
10 cm	1/10 or 10%
12 cm	2/10 or 20%
15 cm	2/10 or 20%
18 cm	4/10 or 40%

20 cm	5/10 or 50%
25 cm	6/10 or 60%

Figure 14: Ultrasonic Sensor Data

The most important requirement given by L3Harris was the need for precise navigation. Though this requirement was given with general criteria, the target goal was broken down into percentage of the guideline followed during the cargo run. The target value pursued was 100% of the guideline followed. This was accomplished by two parallel line following sensors at the front of the MACRO that would straddle the guideline. Whenever the left line sensor would detect, the MACRO would turn left, and the reverse is true for when the right detects. To test the performance of the line following system, the MACRO was placed in a 0.5m radius circle with the minimum guideline width (0.875 in, provided by L3Harris). For every 8^{th} of the circle the MACRO was able to successfully navigate, 12.5% of the guidelines followed was added to the successfully navigated percentage. The MACRO ran in both the clockwise and counterclockwise directions to ensure equal calibration of line following sensors. On average, the MACRO's guideline efficiency can be generalized to 75% precise. Although this does not meet the target value broken down from the L3Harris requirement, the MACRO was still within the technical requirement range. With a few future programming adjustments, this precision percentage could be increased to 87.5% or even 100%. In a mars surface context, this is the hardest feature to scale, but our MACRO proves that it is very likely to successfully navigate to the MITEER facility, providing efficient cargo delivery.

L3Harris specified three separate types of cargo that would need to be transported: habitat cargo, water harvesters, and power generation units. Each of these different cargos had separate dimensions and weights, and it is critical that the MACRO has the ability to carry them all. The cargo must also be carried in the correct orientation (not more than 30 degrees off) and land in the correct orientation. To keep the cargo stable while driving, the team aimed to keep the carrying area below 15cm by 15cm, since the largest cargo was a sphere with diameter of 12.7 cm. This goal was successfully met with a cargo area just over 12.7 cm by 14 cm. This accommodated for the largest cargo, while still preventing the smaller cargos from tipping during all testing.

Scaling to Official Mars Project

Given the fact that Mars has many qualities and conditions that are entirely different from the surface of the earth, where the team tested the MACRO prototype, many adjustments will have to be made to the final MACRO design so it can operate optimally on the planet. For example, one such difficulty the MACRO will have to navigate will be the vastly fluctuating temperatures. According to the NASA website page on Mars, the temperature can fluctuate between 70°F (20°C) and -225°F (-153°C) (NASA, 2024b). Furthermore, any heat from the sun easily escapes Mars' thin atmosphere. With this wide range of temperatures and the fleeting heat from the sun, it is necessary to include insulation in the design as well as a temperature regulator/thermometer within the MACRO to account for any change in temperature, so that the MACRO's electrical components don't overheat or freeze up.

Additionally, the MACRO will have to navigate intense wind and dust storm conditions, as the NASA website states, which are known to cause damage to sensors/solar panels or cause them to have difficulty reading data due to dust settling (NASA, 2024b). As such, the MACRO should include some kind of dust-removing mechanism for the sensors, a robust frame and covering that can withstand high wind speeds, and a wind monitoring system that can allow the robot to temporarily reduce power and stop during a wind or dust storm to reduce possible damages.

Mars also has a low gravitational acceleration, which, according to NASA's website, is about 38% of the gravitational acceleration on the earth's surface (NASA, 2024b). This can cause, as a 2020 research paper on the effects of low gravity on rover mobility explains, the soil to have a greater displacement from the surface, possibly causing a MACRO to sink or slip while moving (Niksirat & Skonieczny, 2020). It can also cause the MACRO to behave differently on rough terrain or any hills that it may encounter due to the way gravity would affect it. Team 78 recommends addressing this issue by adding special wheels that provide more traction in the soil and more torque to the wheels, so the MACRO moves better through these surface conditions. The weight of the MACRO should also be increased to account for the 38% weight difference between the earth and Mars.

To understand how much the team's MACRO prototype should increase in size, its size can be compared to that of real mars rovers. For example, the specifications of the Curiosity mars rover are around 10ft (3m) by 9ft (2.7m) by 7ft (2.13m), which is about the size that the front portion of the MACRO's chassis should be (NASA, 2024a). Using these specifications as a marker, the prototype MACRO's specifications should be multiplied by a magnitude of 15 in order to maximize the amount of cargo carried. The MACRO-to-prototype size ratio would then be 15 to 1.

The entire main chassis of the prototype (including all the following pieces: the raspberry pi base, the wheels, and the sensor section) had a measurement of about 23cm in length by about 20.5cm in width at its widest point, and an overall height of around 10cm. By scaling up this model according to the chosen ratio, the final MACRO's main chassis would be around 3.5m by 3.1m by 1.5m, with an overall final volume of 162.75m^3. The sensor portion of the chassis (not including the line-followers at the very front) had specifications of 11cm by 6.5cm by 10cm (including the ultrasonic sensor in its height) and was in the front of the MACRO. After scaling this section of the chassis, it comes around to about 1.65m by 1m by 1.5m. The line sensor portion on the prototype was about 11.5cm wide and 4cm long, with a void of 5cm between the two sensors, which is scaled up to 1.7m by 0.6m with a void of 0.75m between the two sensors. The line sensors were also 2.5cm off the ground, which should be around 0.375m off the ground in the final MACRO.

As for the trailer section of the MACRO prototype, it measured about 24cm lengthwise by 20.5cm width by 18cm of height, which translates to about 36.m by 3.1m by 2.7m overall. The trapdoor itself measured 15cm lengthwise and 13cm widthwise, so in the final, full-size MACRO, it would have sides of 2.25cm by 1.95cm. The trapdoor was 5cm off the ground, which means that, in order for cargo to be dropped about the same proportionally to the prototype, the trapdoor on the final MACRO should be 0.75m off the ground. A stability arch across the back of the trailer, which was meant to prevent cargo from sliding off the trapdoor and out of the vehicle, was 11.5cm in height on the prototype, so in the final model it should have a height of around 2m.

The MACRO prototype should also be scaled in factors other than just size. The navigation features of the code and design should be updated to account for a larger guideline as well as updated accuracy (between 87%-100%) in turning and detecting where it is supposed to go via magnets and/or other forms of indication that the MITEER facility uses. Furthermore, the obstacle detecting distance should be increased from 15cm on the prototype to around 2.25 meters (or more) in front of the robot (scaled up using the same multiplication as the upscaling of the physical mode), to account for all of the possible obstacles that the MACRO will come across over the surface of Mars.

The MACRO's specifications should remain relatively the same between the testing facility on Earth and the facility on Mars, with a handful of exceptions. As discussed previously, the gravity on Mars is around 38% of what the gravity is on Earth, so the Mars MACRO will be able to carry significantly more cargo than the one on earth. One main difference between the final MACRO that will be tested at Devon Island and the final MACRO that will be sent to Mars is their mass capacities. Since the mass capacity of the prototype ended up being around 0.800kg, the team used calculations based on the gravity of the planets to derive that the Earth-tested model should be able to support 117.5 kg and the Mars model should support 162.28 kg.

Team 78 also recommends that the speed of the MACRO remains similar to that of the prototype, if only a little bit slower to account for the dangerous hazards in the environment and in the terrain. Since the final MACROs will be much larger than the original prototype, it will weigh more overall, especially since it will be carrying more mass. The prototype was easily able to travel at speeds between the range of 15m/s to 30m/s, though it will be more difficult for the larger MACRO to go the same speeds. This will require more energy to be put into the vehicle through a larger battery or other charging means, as more work will need to be done on the MACRO in order for it to move at the same speed with larger mass.

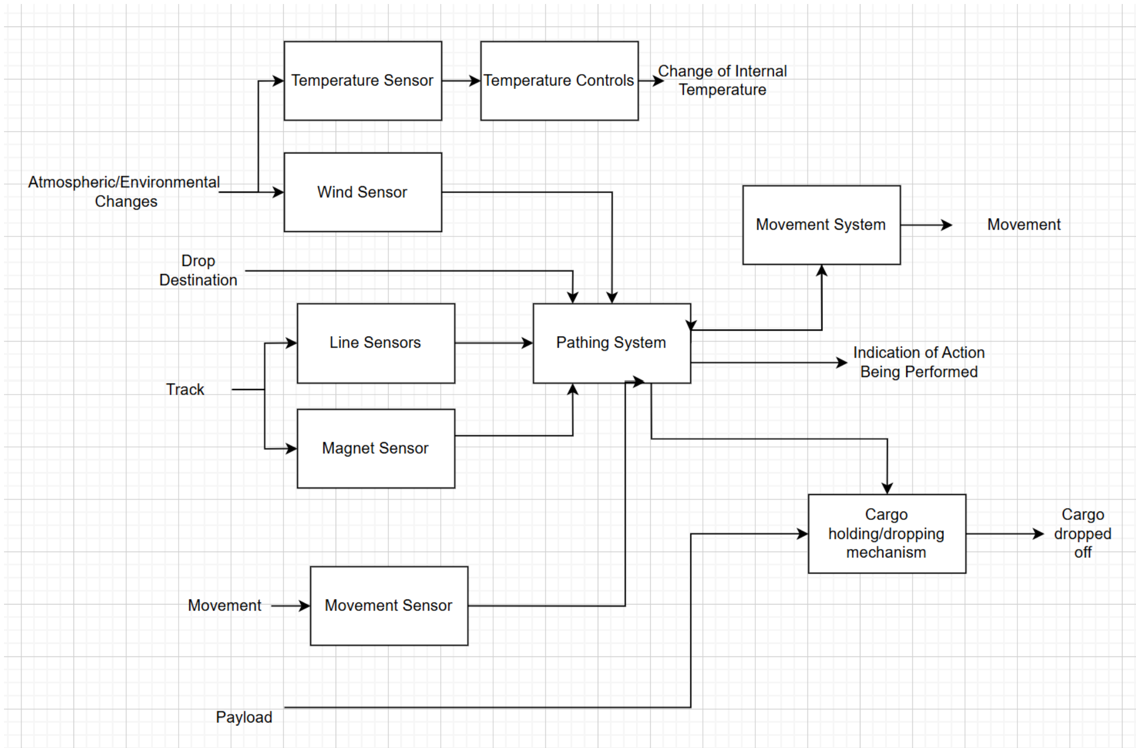

Figure 15 - Functional Body Diagram of Entire Final MACRO System

Rover Specifications	Small-Scale Prototype	Final MACRO – Testing on Earth	Final MACRO – Working on Mars
Volume of Chassis	4715cm^3	162.75m^3	162.75m^3
Size of Chassis	L: 23cm W: 20.5cm H: 10cm	L: 3.5m W: 3.1m H:1.5m	L: 3.5m W: 3.1m H:1.5m
Weight Carried	0.800kg	117.5kg	162.28kg
Volume of Trailer	4715cm^3	162.75m^3	162.75m^3
Size of Trailer	L: 23cm W: 20.5cm H: 10cm	L: 3.5m W: 3.1m H:1.5m	L: 3.5m W: 3.1m H:1.5m
Size of Trapdoor	L: 23cm W: 20.5cm	L: 3.5m W: 3.1m	L: 3.5m W: 3.1m
Max Rover Speed	20m/s	Between 15 to 30 m/s	Between 15 to 30 m/s

Figure 16 – Specifications for all models, including the prototype and both testing MACROs.

Regarding the feasibility of one of the three major subsystems shown in Figure 15, the movement system is closely mirrored by NASA's Perseverance Mars rover's chassis, which uses materials such as aluminum and titanium (NASA, 2020). This would translate well over from the prototype, considering aluminum is a very lightweight and more pliable than other metals, making it a good substitute for the Lego parts used in the prototype. As for the titanium, it would reinforce weaker areas of the chassis, providing both structural support and elasticity to endure Mars' harsh conditions. Lastly, for the wheels' motors, NASA uses Maxon DC brushless motors equipped with a gearhead that increases torque and decreases speed (Maxon, 2024). These motors would be a good replacement for the current Lego motors on the prototype, considering the specified speed in Figure 16. In addition, the gearhead is helpful, especially since the rover needs to have more torque to have the capability to go over steep terrain. Therefore, considering a large enough budget, the prototype chassis would be feasibly scaled up.

Next, the second major subsystem is the pathing system, which can be scaled up from the prototype using technology similar to that of Perseverance. The Hazard Avoidance Cams (or HazCams) can replace the Raspberry Pi's ultrasonic sensor in detecting hazards (NASA, 2020). As for the prototype's line finding, Perserverance uses Navigation Cams (or NavCams), which helps the robot drive autonomously and give the NASA scientists eyes on Mars (NASA, 2020). The NavCams would be an upgrade from our current navigation system, the Raspberry Pi line finders, demonstrating that our sensors could be feasibly adapted to a final design and improved with sufficient funding.

The final major subsystem is the dropping mechanism, which may be harder to scale up, considering it has never been implemented on Mars. However, considering the simple design just consisting of a motor with a gearbox, a platform, and a truck bed, scaling it up should not prove too difficult. Using motors and gearboxes similar to those of the wheels would suffice for the dropping mechanism. With a little less torque, the motor will be able to activate the trap door. As for the platform and the truck bed, the titanium and aluminum used for the chassis would be perfect substitutes for the Lego pieces. Therefore, with these parts, the dropping mechanism, although never done before in space, would be feasible, with some testing.

Results and Discussion

The robot did not perform compared to how the team thought. In the presentation of competency events, the robot was able to successfully complete all four individual tasks and one of the integrated tasks. However, when it came down to the demonstration, the robot was only able to complete the first section of the course with the dowel rod. The robot was unable to correctly follow the lines to make it to its destination. One issue it was having when testing beforehand was the sensor not picking up the line. Since the sensors straddle the line, sometimes if the robot was moving too fast, it would not sense the line and therefore not know to turn. In addition, in some cases the robot's line sensors did not even pick up the line even when it spent time on the line. This was a big issue that caused the bulk of the robot's failures in the demonstration. The team figured out that we should have spent more time working with the line sensors to figure out the optimal way to place and code the line sensors to eliminate this problem.

Another big issue the robot had was that with the cargo in the trailer, the robot was a bit off balanced causing the robot to sometimes veer off to the right. This was due to the placement of the medium motor that controlled the trap door mechanism. Since it was on the right, it was heavier on that side, causing it to put more pressure on that side and therefore, make the robot inadvertently turn. During the demonstration, we tried to overcome this issue by increasing the speed of the right motor to account for the extra weight, but it still proved difficult to fix. A better solution would have been to better the weight distribution beforehand by either adding the motor to the middle of the robot or by adding a counterweight to the left side to make it more balanced.

The last thing that caused the robot problems during the demonstration was our drop off program. Since we spent a lot more time on the line finding code, there was a late start on the drop off code, which caused a not as developed or robust code. We did not have enough time beforehand to do through tests with the drop code causing issues with the hall sensor during the demonstration. This caused the robot to not be able to find where to drop the cargo since it could not sense the magnets in the course. To improve this, we should have split up the work better instead of all of us working on the line finding, some of us should have worked on testing the hall sensor and the drop code.

One aspect of our demonstration that went well was the speed test. The robot was able to traverse the two-hundred-centimeter course in 9.96 seconds, successfully running at twenty centimeters per second. Because of the extra weight of the robot and friction the robot's motors were set to thirty-four centimeters per second, so that the actual speed of the robot would be twenty centimeters per second. In addition, individually the parts of our system worked very well together as seen in the presentation of competencies throughout the timeline of the project. Through those events, it can clearly be seen that the robot’s line finding does work and that our dropping mechanism can be executed quite efficiently. This is a huge plus that should be acknowledged when considering our prototype since we believe our demonstration itself was not an all-encompassing depiction of the design.

Conclusions & Recommendations

In conclusion, we recommend using our design for the most efficient delivery method and ease of improvement. The trap door dropping mechanism is the most efficient design and very accurate in delivering cargo upright. It is also a simplistic design that will prove beneficial with problem solving. Our chassis is very compact and well-built with two sleds like slates in the back to support the cargo and three wheels in the front to complete zero point turns which make line following easier. It carries all of our needed sensors from the ultrasonic to the hall to the line followers to the IMU. In addition, the robot has a battery holder in the front which helps with equal weight distribution from the front to the back. Overall, our robot's biggest strength is the structure of each system to allow it to be easily removable and improved. This proved incredibly useful during the individual tasks of the presentations of competency, where our robot was able to complete each task.

Despite our individual components working well together, our robot faced many issues when tasked with integrated challenges. Our major drawback in our design process was time management throughout the project. We didn't start early enough with the integration of sensors, which proved difficult down the line when we needed more time to test each sensor and calibrate them. The sensor that caused the biggest issues was the line sensor which limited the tasks we could do considering it was the only way to traverse the course. Given more time, we would have addressed the issues with the line sensors by adding a color sensor to help better detect the line and ensure a more accurate reading. In addition, with our chassis we would have distributed our weight better so that there was less veering and also, so it was easier to get over the hill.

Despite these flaws, we believe that our prototype should be considered due to its strengths and ease of improvement. Therefore, we recommend choosing our prototype, which, with a little fixing up, could prove to be a very competitive design in this market, leading the way to a future closer to Mars.

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