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Mobile Sensing Platform: Final Project Report

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Executive Summary

The Mobile Sensing Platform Team presents their final project report for the senior design project to create a mobile sensing platform for Dr. Nickels' autonomy efforts. The sensing bed, or rover, is designed for mobility in extreme conditions in order to carry a payload of sensors and other equipment capable of collecting data into areas too dangerous for humans. The first step in achieving this goal was to create a prototype with functioning control and motor systems. As such, our design will operate using a control system that will be easily replaced for a more complicated computer.

Our team has been tasked with creating a rover (or mobile sensing platform) with the ability to navigate 30 degree inclines, a step of 25 cm, and a payload of 50 kg, similar to the weight of the sensors that a typical rover might carry. To meet these requirements, the following subsystems were designed: chassis, legs, motor assembly, power distribution, and control system. Recent changes to the composition of the group and several other external setbacks such as the winter storm and COVID-19 restrictions have hindered progress, and thus, production of this prototype has been delayed, with the remaining work to be completed by a future team.

The designed chassis and legs all withstood the required weight of the rover and payload of over 150 kg. The motor assembly was capable of supplying the necessary torque to ascend the hill, but struggled in dynamic tests under changing speeds and directions. While the power distribution system was delayed, the topology for the motor control was designed. Lastly the control system, which included the wireless controller, was manufactured and assembled, but never fully tested with the power distribution.

Overall, the mobile sensing platform team successfully identified the necessary design specifications to complete the prototype, but was unfortunately unable to finish manufacturing all of these designed subsystems. We learned so much over the course of this project, and while we wish we had been able to complete the rover as designed, we are proud of what we accomplished given the changing circumstances. The final project report to follow will detail the completed design of the rover and the design solutions engineered to meet our project requirements.

1. Introduction

Autonomous systems today are found in an ever-growing number of applications. Due to their versatility and the corresponding increase in computing power over the last several decades, artificial intelligence—more specifically machine learning—has enabled humankind to overcome obstacles previously thought insurmountable. However, while the software of machine learning is considered the greatest technological leap forward, without the hardware no such strides would have come to pass. Such hardware ranges from the silicon and copper used to manufacture and subsequently store the computer's data, to the sensors and interfaces that enable applicable inputs and outputs as a means of communicating with the external world. This is the basis of this mobile sensing platform, constructed as a means for the computer to connect to the world in order to objectively accomplish its designed purpose.

The success of the project will be determined through the following requirements, though important to note is these requirements served as targets for the design and other operational parameters. Thus, a more realizable outcome that is close to these marks will still constitute a successful project, due to the scale and budget of the project. The prototype, is only intended for use in non-extreme environments, and must be capable of: climbing a 25 cm step, ascending and descending a 30-degree slope, traversing an obstacle course made of cones, traveling at speeds of 2 mph, using an independent power supply, carrying a 50 kg payload throughout these tests, and finally utilizing a remote control system to steer. The final budget allotted to the project was increased to $2,100, and the team has spent $1,421 thus far, with additional funds allocated for the proposed next steps such as further testing equipment etc.

To achieve these project requirements, the team identified several key subsystems, subsequently focusing the majority of our efforts on their effective design and implementation, and listed as follows: the chassis, legs, motor assemblies, power distribution, and control systems. The chassis successfully demonstrated the ability to bear its own weight and the estimated 50 kg payload, as it supported over 160 kg in testing. The motor assemblies encountered reliability issues with 3D printed gearboxes, and due to the long manufacturing time was unable to complete testing for the achieved RPM. The assembly however did provide at least 18 n-m of torque, hypothetically satisfying the requirement to move the weight of the chassis up and down the 30 degree incline. Next the power distribution system used the commonly available marine battery, capable of supplying 12 V for operation at heavy load conditions for an estimated 45 minutes, however this is just an estimate and would require further testing to verify. Lastly, the remote control system was designed to navigate the rover through an obstacle course. While it does include the necessary functionality, without the completed motor assemblies, small scale tests of the functionality are all that is possible.

2. Overview of Final Design

2.1 Design

2.1.1 Chassis Design

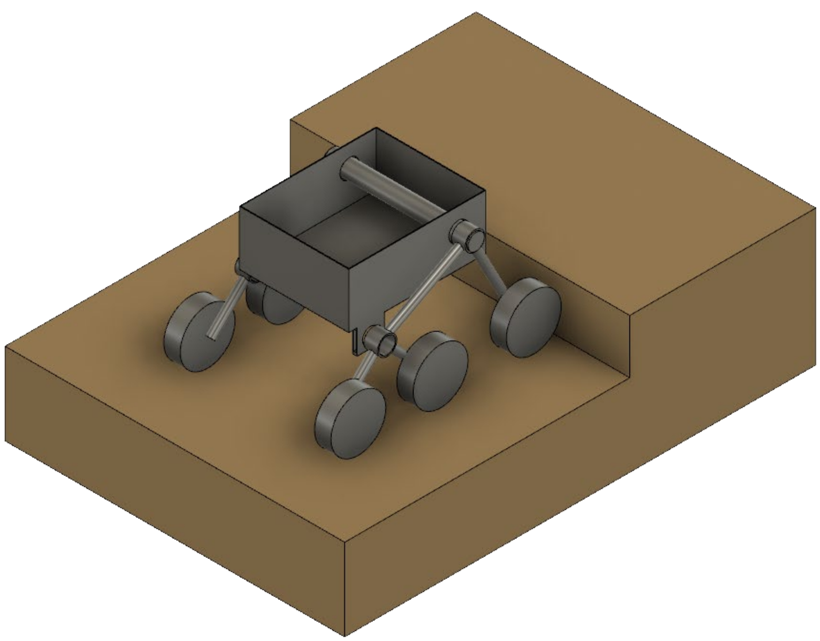


Fig 1. CAD Model of Chassis Design

Shown above in Fig 1 the most recent model of the chassis for the mobile sensing platform. The design is essentially a box with an open roof. The team constructed a frame from ¾ inch square steel piping and ⅛ inch steel plating. Each of the panels were plasma cut, and a hole cut into each of the panels for the lateral bar which attaches the legs of the rover. Lastly, two panels were welded to the lower portion of the chassis to attach the second lateral bar to fix the rear legs in place. The intent of the design is to be usable for future groups that improve on the design that we have created.

The design allows for a panel to be affixed to the bottom of the rover so that electronic components can be attached. We planned to drill holes for wiring components (the H bridges and motors, encoders, and wireless module) as necessary.

2.1.2 Leg Design

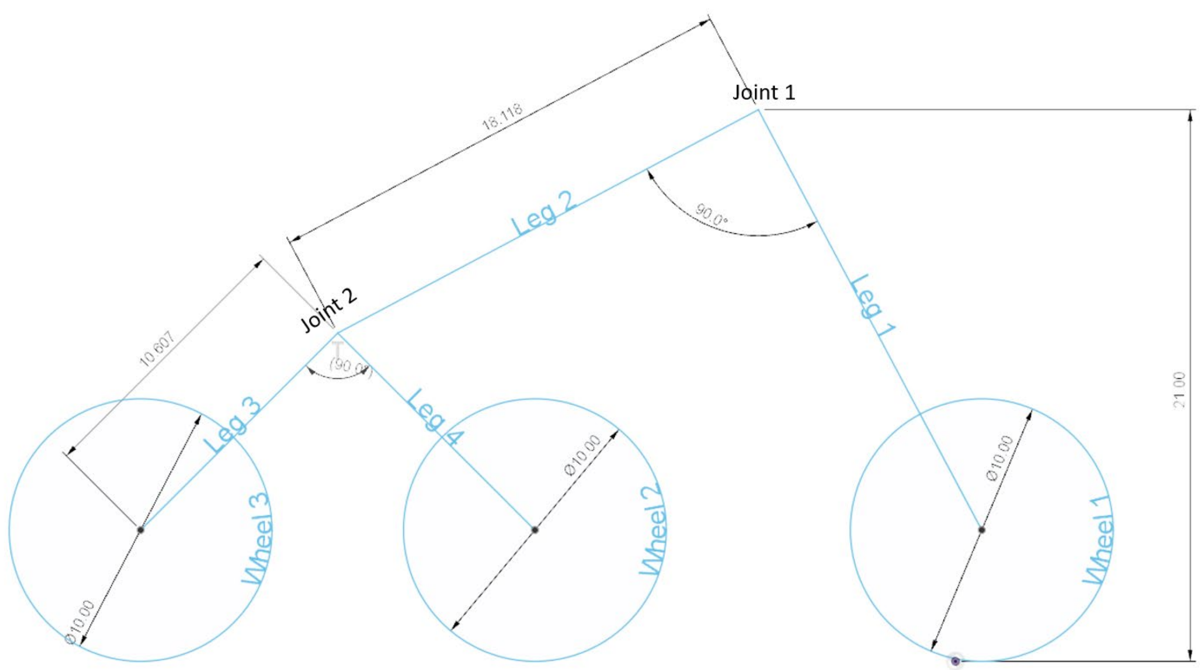


Fig 2. Leg design schematic

The legs were designed such that they could easily be modified into a rocker bogie rover by future groups. This necessitates specific angles and lengths for the legs to ensure that the rover will remain balanced and be able to climb obstacles. The first requirement is that the legs at each joint must be 90° from each other as seen in Fig 2. The second requirement is based on the height of the step: 25 cm. The wheels 2 and 3 must be far enough apart from each other such that the middle wheel can be securely on the top of the step before wheel 3 contacts the base of the step. Since the angle of the legs are locked at 90°, the only way to ensure this is to make the legs sufficiently long. Simple trigonometry yields that legs 3 and 4 must be 10.607 inches and that legs 1 and 2 must be 18.118 inches.

In a rocker bogie rover, joint 2 would be a differential joint that would allow the back wheels to rotate freely. This would result in our rover's chassis flipping since ours does not have the differential bar. To allow future groups to modify the rover, the joints were made out of steel pipe that can be ground off and replaced with the necessary differential joint. An aluminum bar runs through both joints and connects the legs to the chassis to prevent the chassis from flipping.

2.1.3 Wheel Housing Design

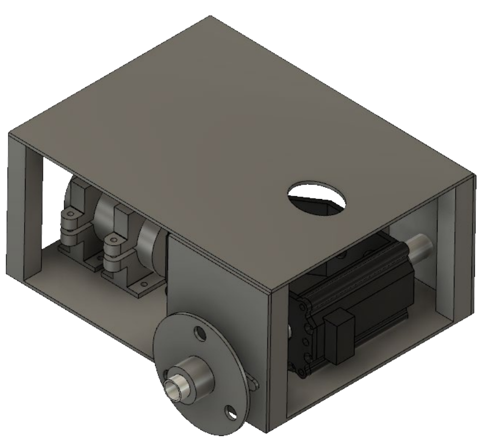


Fig 3. wheel housing with top plate

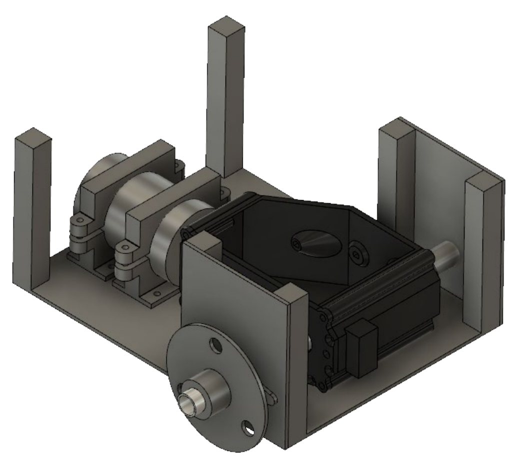


Fig 4. wheel housing without plate

The wheel housing design holds the gearbox and motor and connects their output to the wheel via an axle as seen in Figs 3 and 4. Each leg has its own independent wheel housing resulting in a total of 6 wheel housings for the entire rover. The housings are designed to be quite robust since they will be carrying the full weight of the rover and its payload.

2.1.4 3D Printed Gearbox

The 3D printed gearbox is used to change the low torque, high RPM output from the motor, to a high torque, low RPM output to the wheel. A 3D printed gearbox was chosen because low torque motors are significantly cheaper than high torque motors and because the Trinity machine shop had many of the materials for the gearboxes already which also further decreased the cost.

The base design was purchased from Brian Brocken [1], linked in the appendix, with modifications made by the team. The specs for the motor used with the gearbox are 0.2 N-m and 9500 RPM. The gearbox's gear ratio is a 162:1 which results in an ideal output of 32.4 N-m and 58 RPM. The gears were printed with Onyx Nylon from the Markforged printer in the machine shop and the box itself was printed out of PLA and ABS from the Ultimaker printer. Modifications were done to the box to fit an encoder as well as to secure the box to the wheel housing.

2.1.5 Wireless Controller

To remotely control the rover, the group designed a custom printed circuit board (PCB). The designed controller is shown in Fig 5. The main aspects of the controller are the Arduino mini pro, two voltage regulators, an nRF24L01 wireless module, and two joysticks. Data is taken as analog integer values from the joysticks (potentiometers), mapped from 1024 bits to 256 used by the Arduino, and transmitted to the main Arduino controller on the rover (an Arduino Mega) which also has a nRF24L01 module attached to receive data.

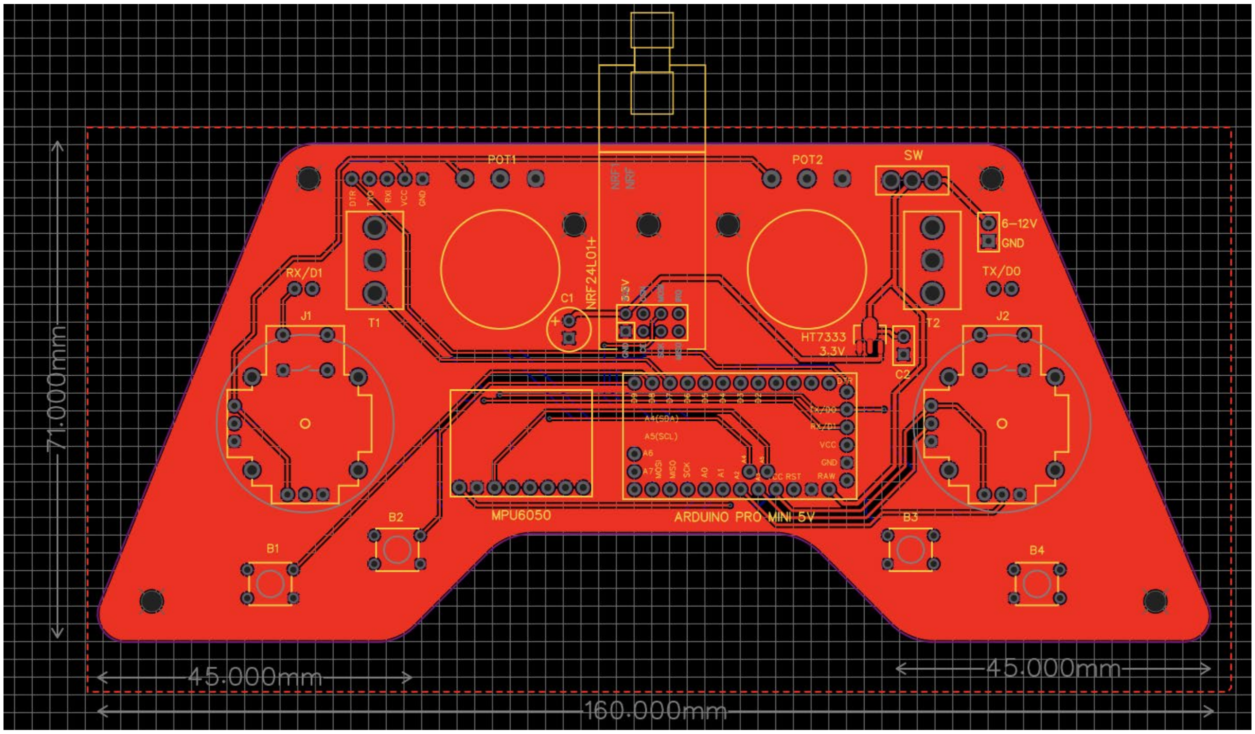


Fig 5. The PCB design for the wireless controller [2].

2.1.6 Electronic Control & Power

The team designed the power and control system with the intent to use an Arduino MEGA, 100 count encoders, H bridges, and a 12 V marine battery to control and power the rover. The control system is designed with an SPI bus from the nRF24L01 wireless module to inform the set point of the system, and the team intended to code a PID control system in order to maximize the lifespan of the 3D printed gearboxes. The PWM (pulse width modulation) pins on the Arduino Mega were designed to be used for controlling each of the H bridges, and each of the interrupt pins on the Arduino were intended to be used as inputs for each of the 6 encoders, used to control the motors. With the exception of the wireless module, each of the additional components was designed to be used with the general purpose input and output (GPIO) pins on the Arduino Mega.

Arduino code for one of the motors can be found in the appendix, Fig. A.1 [3]. This code identifies the direction of travel as a 2-bit number, and sends that desired direction to the motor. As PWM controls the percent of full rpm of the motors, taking the mapped output from the controllers joysticks allow us to speed up or slow down the rover.

2.2 Work Accomplished

Unfortunately, due to the large workload of the project, the team had a difficult time completing each of the subsystems in time for the end of the semester. We managed to get significant work done on the chassis and legs, as well as the gearbox and motor setup, though we were not able to address the majority of the controls, power, and wiring. Detailed in the following section is the work that has been accomplished on the project.

2.2.1 Construction of Chassis

Fig 6. Constructed Chassis

In Fig. 6 is the portion of the chassis that our team has been able to create this semester. Each of the steel panels were plasma cut to size, and welded onto a frame made of ¾ inch square steel tubes. The chassis panels are ⅛ inch steel hot rolled plate. Unfortunately, welding the steel plating to the bottom introduced a significant warp to the frame of the chassis. Our team elected to weld the lateral and lower panels - as they are crucial to the design - and forgo the front and back panels due to time constraints. We intended to secure individual components as needed, and include a bottom panel made with a more pleasant material to attach specific components (marine battery, Arduino MEGA, H bridges). We were significantly limited by our skill at welding and construction, as getting perfect 90° angles proved to be difficult, especially with the steel plating introducing warp into the system.

2.2.2 Leg Construction

The legs, also seen in Fig 6, were composed of steel tubes and two steel pipes for the joints. Holes were drilled into the joints to allow the tubes to slide into an easier to weld position. Unfortunately, warping from welding accentuated the imperfections in the angles of the legs and caused the legs to be slightly misaligned. The team anticipated this and will account for it in the wheel housings.

2.2.3 Gearbox Construction

The gearbox construction proved to be a much more time-consuming task than anticipated. The initial gear material, rigid resin, was very difficult to remove from the build platform of the Formlabs printer without significant cracking of the teeth. After many methods of removal were tried, the team ascertained the most effective method: a two-hour process of heating and washing the gears. This gear material proved to be too brittle to be used so a new material was chosen: onyx nylon. This was printed from the Markforged printers which had no significant hiccups.

The body of the gearbox was initially printed with PLA and later with ABS when we ran out of PLA. Both plastics were printed with the Ultimaker printer. The PLA printed nicely with no significant defects while the ABS experienced multiple setbacks. The ABS printed with cracks in the material, warped in curved sections, and adhered to the glass build plate of the Ultimaker and delaminated the glass. The cracks in the material were filled with gap filling glue to prevent short term failure but the long-term strength is in question.

With the gearbox body and gears printed, the final product was assembled. Two shafts of aluminum shafts were cut for each box and bearings were press fit into their holes. Lastly, a hole was drilled into the output axle for the output gear to be pinned through. Due to time constraints, only 2 gearboxes were fully completed.

2.2.4 Wheel housing

Fig 7. Gearbox Rear View

Fig 8. Gearbox side view 1

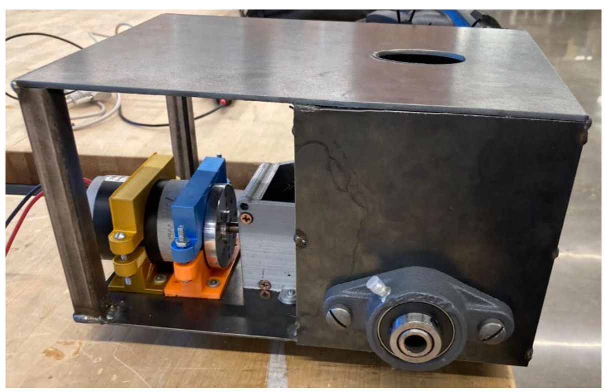


Fig 9. Gearbox side view 2

As shown in Figs 7-9, our team was able to construct and complete a single motor housing encompassing the 3D printed gearbox, motor, shaft, and wheel. The top and bottom plates were plasma cut and welded to the 6 vertical supports. Two vertical plates were also plasma cut with holes for the flange bearings and were welded to the side of the housing. Lastly, the gearbox was lined up with the axle running through the flange bearings and holes were drilled for the bolts to secure the gearbox and motor to the bottom steel plate. The wheel was attached to the shaft via a plate welded to the shaft. Holes were plasma cut into the plate in order to accommodate the bolts necessary to attach the wheel.

2.2.5 Wireless Controller

Much of the work required to assemble a functioning wireless controller has been completed. While next steps could include an nicer exterior and user interface, the functionality of the design has been demonstrated through the tests illustrated in the subsequent section. The most important aspects involved designing the PCB using the free online editor easyEDA, then contracting JLCpcb for the fabrication. Next we populated the boards with the Arduino and other components, ensuring we had access to the ports necessary to flash the device. Finally adding the joysticks prior to testing. To power the board we used a simple 4 AA battery pack, providing 6 V that is first stepped down the first 5 V with a voltage regulator for the Arduino mini pro, and then 3.3 V for the nRF24L01 wireless module. The completed PCB is shown below in Fig. 10.

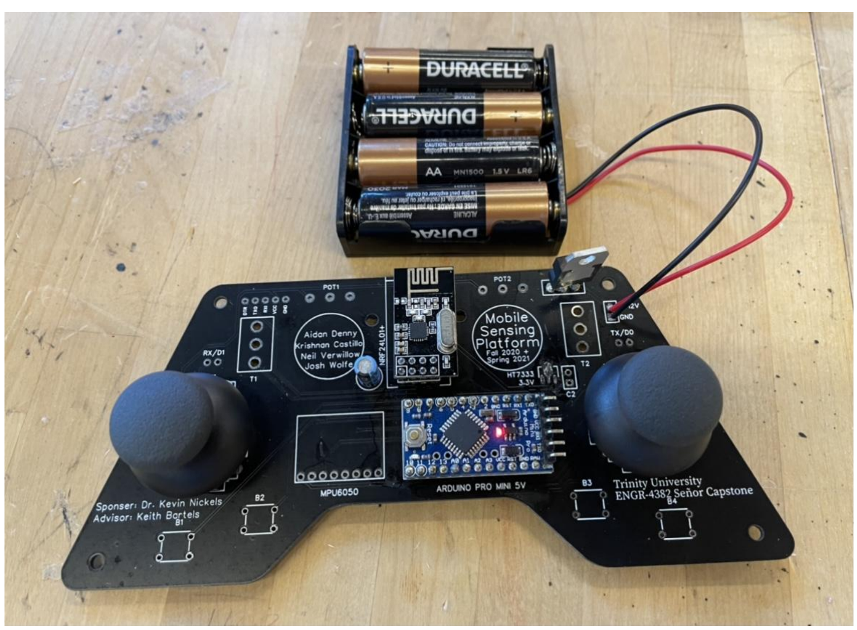


Fig 10: The completed PCB with accompanying battery pack.

This wireless controller will interface with the Arduino Mega onboard the rover, through the code listed in the appendix. Each motor will have the H-bridge assembled and connected to the Arduino in the configuration shown in Fig. 11 below.

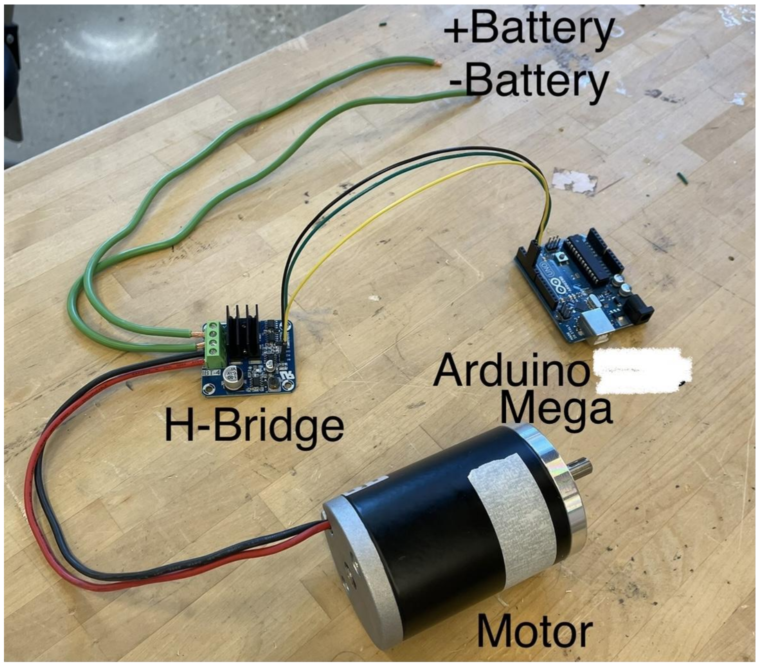


Fig 11: The motor control topology, from the Arduino to the motor.

3. Evaluation

3.1 Completed Tests

3.1.1 Motor Testing

Test Overview

This test was used to evaluate the specifications of each of our motors, including maximum rpms and stall torque and current. Stall torque and stall current were tested only on a singular motor.

Objectives

Measure the maximum rotations per minute (rpm) of each of the motors, evaluate the stall torque and stall current of the motors.

Features Evaluated

Confirmation of motor specifications for the purposes of motor evaluation and motor calibration when used in a final control system.

Test Scope

This test mostly focused on the maximum rpm ratings on each of the motors, though we did test the stall torque and current on one motor. The scope is somewhat limited, as maximum speeds are not possible under loaded conditions - such as what would occur when the motors are used on the actual rover. The scope of the stall current and stall torque tests are somewhat limited as well, as maximum stall torque may vary under dynamic loads rather than static ones (like the static load used for the purposes of our test). This test allowed us to establish effective estimates and evaluate whether or not the motors functioned as specified.

Acceptance Criteria

Results were accepted if we were able to confirm values for each of our motors that were similar to the values listed in its data sheet. Our goal was 9000 - 9500 rpm for each motor operating in unloaded conditions, and 2 amps of continuous current when operating in unloaded conditions. We additionally tested the stall torque and stall current, and wanted to confirm that the 0.2 N-m listed in the data sheet aligned with the real motor. We tested continuous and peak stall current to try to get an idea of the power necessary to run the rover up hills.

Test Results & Evaluation

Table 1. Motor RPM test results

	Test 1 (rpm)	Rpm test 2
Motor 1	8929	8930
Motor 2	9010	9027
Motor 3	8853	8847
Motor 4	9420	9415
Motor 5	8950	8944
Motor 6	8890	8902

Our team was able to confirm the 9000-9500 rpm rating for each of our motors, though some dipped slightly below the 9000 rpm rating. A strobe light tachometer was used to obtain each of the readings. These results are shown above in Table 1. Interestingly, the results hovered closer to 8900 rpm than the rated 9000 to 9500, with the one exception of motor 4, which had significantly higher values than the rest of the motors. We determined that the motors would be sufficient for the purposes of the rover. In addition, we tested the static stall torque and peak and continuous stall current of a single motor. The static stall torque tested was significantly higher than our expected value, with a rating of 0.25 Newton meters, slightly higher than the peak value listed on the data sheet. Additionally, the peak stall current achieved in our test was 36A, with a continuous current achieved of 24 A, which aligns with the data sheet values.

3.1.2 Gearbox Test

Test Overview

This test evaluates the durability of the gears, the maximum torque, and the maximum RPM of the output shaft. Additionally, the temperatures of the gears are also being evaluated.

Objectives

The goal of this test is for the gears to operate at maximum speed for 5 minutes without failure as well as reach 18.5 N-m of torque and 50 RPM.

Features Evaluated

The durability of the gears and bearings are being evaluated.

Test Scope

This is a test of just a gearbox and axle so there are some limitations to the test. We cannot test the durability of the gears if the wheel suddenly comes to a jarring stop. We can simulate this by quickly turning off the motors and allowing the gears to slow down rapidly but this is not the same as a sudden stop.

Test Plan

The gearbox was clamped to a table with the axle extending over the edge. The motor was powered with a voltage generator. For the RPM test, the speed was slow enough that a slow-motion video was sufficient to count the number of revolutions in a minute. For the torque test, a thick screw was inserted into the axle. A spring scale was attached to the end of the screw. For the temperature test, the gearbox was allowed to run for 5 minutes at maximum RPM after which a thermal imaging camera was used to measure the temperature of the gears.

Acceptance Criteria

The gears will pass the strength test if no teeth are sheared from the gear. The torque test will be acceptable if the output can supply at least 18.5 N-m of torque. Similarly, the RPM test will be acceptable if the output can supply at least 50 RPM. Lastly, the thermal test will be acceptable if all gears remain under 125° F.

Test Results & Evaluation

The initial gear suffered mild shearing after 5 minutes of operation. The team believes this to be due to a slight misalignment of the motor which interacts with that gear. To fix this, an alignment spacer was printed to ensure it is properly fitted. All other gears remained unscathed.

The torque test yielded optimistic results. We were able to measure a maximum torque of 15.5 N-m before our testing rig failed. The issue was that the screw began to bend under the high torque so the spring scale had to be moved closer to the output shaft. This resulted in the maximum torque exceeding the springs scale's measuring capacity. The team is optimistic that the gearbox can provide sufficient torque.

The RPM test was successful. The team measured a maximum RPM of 53 which exceeds the required 50 RPM.

The thermal test was also successful. The maximum temperature was 90° F after five minutes of operation which is below the maximum allowed temperature of 125°

3.1.3 Leg Strength Test

Test Overview

This test will evaluate the strength of the weld in the legs and determine if they can hold a static load of 350 lbs.

Objectives

The goal of this test is to determine if additional supports will be needed to ensure that the legs will not fail.

Features Evaluated

The strength of the pipes and the welds is being evaluated.

Test Scope

This is a static load test and is unable to determine if the legs can withstand a dynamic load. Additionally, when testing, the legs dug into the ground slightly which may have helped to prevent the legs from splitting apart but we doubt that this was a significant contribution to the legs strength.

Test Plan

The legs were supported as they will be in the finished rover with aluminum rods running between the joints as seen in Fig 4. Weights were then hung from the aluminum bars with the weight evenly distributed between both bars, and with all the weight on each bar individually.

Fig 12. Leg test rig

Acceptance Criteria

This is a pass/fail test where the legs pass if the welds do not show any signs of cracking and the pipes have no noticeable bend in them while the load is applied.

Test Results & Evaluation

The pipes and welds showed no signs of failure and the team is confident that they will hold under all testing conditions. It successfully withstood 350-pound loading. Which allowed our team to conclude that the prototype fulfilled the requirement that the rover be able to hold 50 kg. Unfortunately, our team was unable to complete all 6-wheel housings, so it is difficult to determine if a final rover would be able to withstand the same loading. We are confident, however that the distributed loading of each wheel housing would effectively withstand the weight.

3.2 Evaluation of Completed Work

Our team was not able to fulfill any of the design requirements outlined in our project proposal, with the exception of the size requirement and the ability to hold 50 kg. Due to the high volume of physical labor involved in constructing the legs, chassis, motor housings, 3D printed gearboxes, wireless controller, and potentially control system, we were unable to evaluate our prototype with respect to the tests outlined in our prototype test plan and project proposal.

3.3 Future Work

3.3.1 Chassis Completion

Our team has partially constructed the chassis for the rover, shown in Fig. 6. Due to time constraints, we elected to prioritize other parts of the design rather than fully complete the chassis. In doing so, we decided not to attach the front and back panels of the chassis. Additionally, there is no top panel for the chassis. We had not designed one, as it wasn't necessary to fulfill design requirements for this iteration of the design. Future teams working on this project should aim to design and complete the top of the chassis in order to attach a differential bar. A differential bar or gearbox will be necessary to complete our design and achieve a full rocker bogie system.

For the purposes of our design, which is intended to be deconstructed and reassembled with additional features (movement of joints for the rocker bogie), we decided to attach panels to the sides of the chassis in order to fix the rear legs of the rover. These panels are intended to be easily removed so that the chassis can still be used by future teams. We attached them with a series of tack welds, so they should be relatively easy to remove with an angle grinder

3.3.2 Control, Wiring, & Power

Owing to time constraints, our team was not able to complete the control system for the rover. Additionally, we knew we would run out of time and elected not to purchase a battery for the project as it would not have been utilized during testing. Our intent was to save money in case our project was not continued. No permanent wiring has been completed on the project, so subsequent teams will need to purchase a battery for the project, wire the motors and control scheme, and then create a control system for the rover. We have determined that the most effective battery for the project is a 12-volt marine battery. Subsequent groups should use our data (if continuing with the motors we purchased) or the data for the motors they have selected in order to inform the number of amp hours necessary to control the rover given the battery life constraint.

Our team purchased the necessary components for controlling the rover (high power H bridges and 100-count encoders). The H bridges should be effective for any group working on this project, however the 100-count encoders may have too high a resolution (and therefore generate inaccurate readings) if a group decides to choose a different motor or gearbox.

The rover our team has constructed is intended to be used to develop an Artificial Intelligence (AI) rover control system by our sponsor, Dr. Nickels. We intended to use Arduinos in order to control the rover for our design iteration. It is likely that it will be too much for a team to finish the remaining work and begin work on coding an AI control system. The Arduinos may be effective in creating a minimal control system for testing purposes, but they do not have enough power to code an AI. Subsequent groups will need to design and replace the control system with this in mind.

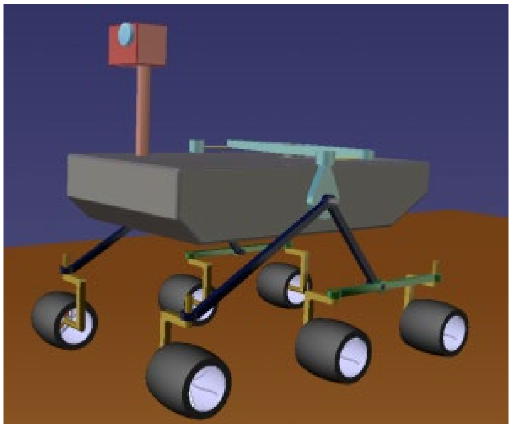
3.3.3 Leg Redesign & Creation of a Rocker Bogie

The legs designed for this iteration of the project are intended to be deconstructed and repurposed for the creation of a true rocker bogie system. In order to accomplish this, the welds would have to be grinded off of each of the legs and the sections of 3-inch steel piping that have been used as joints. A subsequent group should redesign the legs as a full rocker bogie (with two unpowered joints on each leg) and additionally create a differential bar or gearbox so that the design won't be unbalanced and the

In our design iteration, we intended to steer the rover using skid steering, as it would have been difficult to accomplish the given workload in addition to creating a more effective method of steering. The legs constructed for this iteration of the project are intended to be redesigned by future groups, a more effective steering system could be developed in a subsequent iteration of the project.

3.3.4 Differential Bar

The differential bar is a critical component of a rocker bogie rover and as such, the chassis must be designed so that it can easily accommodate it in the future. Future teams will have two options regarding this; they can either build the differential bar, which our team preferred, or they can build a differential gearbox. Both perform the same task but require different designs for the chassis. The differential bar would sit across the top of the chassis as seen in Fig 13 and would be connected to the top of the axle running through the joint. The differential gearbox would be inset into the top of the chassis as seen in Fig 14 and the gears would be built into the axle running through the joint. The team wanted to leave both options available to future groups so the axle was designed to be replaced by removing a few pins and the top of the chassis was left uncovered.



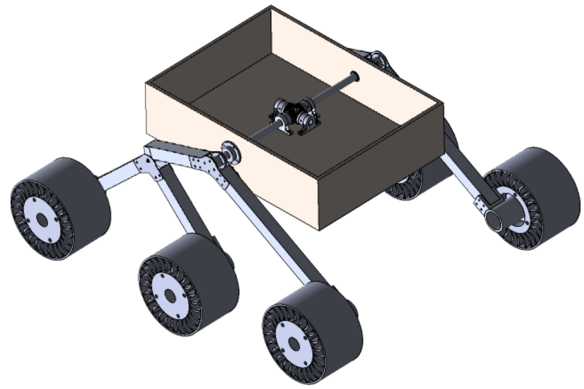


Fig 13 [4] (left) and Fig 14 [5] (right) show a differential bar and differential gearbox rocker bogie rover respectively

3.3.5 Gearbox & Motor Re-evaluation

Our team elected to 3D print gearboxes as an alternative to purchasing motors with integral gearboxes that could supply the necessary torque to drive the rover given the design requirements. These requirements being the ability to ascend a 30° incline and ascending a 25 cm step while carrying a payload of 50 kg. We determined that 3D printing the gearboxes would be the most cost-effective way for our team to achieve the necessary torque for the project. Unfortunately, 3D printed gears are not the most permanent of solutions for this project. The gearboxes constructed for this iteration of the project should be effective for a number of years if there is not sufficient funding for a better design. Purchasing different motors and gears would result in the need to redesign the motor housings (as the ones designed this year are relatively large and bulky, owing to the need to accommodate a motor and large 3D printed gearbox). Unfortunately, rocky terrain - such as what the rover is intended to move across - could break or deform gears if the vehicle moves over them too quickly. Subsequent teams should evaluate whether they should purchase motors and / or gearboxes that will become more permanent additions to the project.

Our team has looked at two ways, other than printing gearboxes, to achieve the necessary torques to satisfy the aforementioned requirements. The first was to purchase a motor with an integral gearbox that could supply the necessary output torque. The second was to separately purchase a motor and gearbox that would allow the motors output torque to be increased to a degree that it is able to supply enough torque to drive the rover. The motors purchased for this project are enough for this purpose, though the issue becomes finding a gearbox with an appropriate gear ratio and efficiency for the project. Unfortunately, both motors with integral gearboxes and metal gearboxes that would be effective for this project (as plastic ones are likely to break) are significantly outside of the budget of this project.

If a team elects to purchase different gearboxes or a different motor and gearbox combination, they may also have to redesign the motor housings designed by our team. Aspects of the design (the shaft / bearing system which connects to the wheel) may be usable, though the housing and attachment for the motor and gearbox are likely too large for most commercial gearboxes.

4. Conclusions

Our team was unable to accomplish what was outlined in the most recent version of our project proposal. We were unable to complete enough gearbox and motor housings to be able to wire and code the project. As such, we have not met any of the project requirements relating to the movement of the rover. The one project requirement that was accomplished by the group was the ability to withstand a 50 kg load, though this project requirement is partially relating to the ability to move the rover with a 50 kg load attached, which we have not accomplished. We have not been able to create a working prototype. The project requirements that we were not able to accomplish are as follows, a battery life lasting longer than 3 hours (untested), full wireless control, ability to traverse a 30° incline, ability to ascend a 25 cm step, speed of at least 2 mph, and lastly the ability to turn 90° within two body lengths. The work necessary to complete a working prototype is significant, as outlined above in the future work section. Though we were not able to satisfy the project requirements, we were able to successfully construct a chassis, set of legs for the rover, 3D printed gearbox, and motor housing. This was not enough to get the rover to move, though we have been successful in what we have been able to accomplish.

We faced significant challenges in completing work for this project throughout both semesters. Aside from the large workload of completing a project of this size, our team had difficulty getting a hold of the other sponsors who were said to be working on this project. Originally, there were intended to be two sponsors working on the project. Our second sponsor was supposed to be a professor from UTSA whose students had worked on a similar project. The plan was for this sponsor to assist our team with their experience and equipment but unfortunately that sponsor removed their support for the project. Not having this additional support significantly increased the difficulty of the project. Additionally, we discovered midway through the fall semester that the motors necessary to ascend a 30° slope, with our estimated weight and payload, would likely cause our project to go thousands of dollars over budget. Owing to this, we began working on the 3D printed gearboxes shown in this report. Early January, our team discovered that high steel costs would also cause our project to go over budget by a significant margin as well. We began working on an updated budget in order to get more money to ascertain the project's success, which took significantly longer than expected owing to one of our group members. This group member had been working on the chassis and differential bar mechanism, and we needed his input for the budget. This student stopped communicating with our group, causing significant delay in purchasing components. He was later dropped from the team and class, but the 3 week delay—exacerbated by the loss of water and electricity during the winter storm—necessitated a redesign of the body and legs, where we dropped the idea of doing a full rocker bogie, hoping to redesign in a way that would allow future groups to create a rocker bogie with our prototype. All of these setbacks took significant time away from constructing the prototype, and meant that we were unable to complete the project.

5. Appendices

```
#define enA 9

#define in1 4

#define in2 5

#define enB 10

#define in3 6

#define in4 7

int motorSpeedA = 0;

int motorSpeedB = 0;


void setup() {

  pinMode(enA, OUTPUT);

  pinMode(enB, OUTPUT);

  pinMode(in1, OUTPUT);

  pinMode(in2, OUTPUT);

  pinMode(in3, OUTPUT);

  pinMode(in4, OUTPUT);

}


void loop() {

  int xAxis = analogRead(A0); // Read Joysticks X-axis

  int yAxis = analogRead(A1); // Read Joysticks Y-axis


  // Y-axis used for forward and backward control

  if (yAxis < 470) {
```

```
    // Set Motor A backward

    digitalWrite(in1, HIGH);

    digitalWrite(in2, LOW);

    // Set Motor B backward

    digitalWrite(in3, HIGH);

    digitalWrite(in4, LOW);

    // Convert the declining Y-axis readings for going backward from 470 to 0 into 0 to 255 value for the PWM signal for increasing the motor speed

    motorSpeedA = map(yAxis, 470, 0, 0, 255);

    motorSpeedB = map(yAxis, 470, 0, 0, 255);

  }

  else if (yAxis > 550) {

    // Set Motor A forward

    digitalWrite(in1, LOW);

    digitalWrite(in2, HIGH);

    // Set Motor B forward

    digitalWrite(in3, LOW);

    digitalWrite(in4, HIGH);

    // Convert the increasing Y-axis readings for going forward from 550 to 1023 into 0 to 255 value for the PWM signal for increasing the motor speed

    motorSpeedA = map(yAxis, 550, 1023, 0, 255);

    motorSpeedB = map(yAxis, 550, 1023, 0, 255);

  }

  // If joystick stays in middle the motors are not moving

  else {

    motorSpeedA = 0;

    motorSpeedB = 0;

  }
```

```
  // X-axis used for left and right control

  if (xAxis < 470) {

    // Convert the declining X-axis readings from 470 to 0 into increasing 0 to
255 value

    int xMapped = map(xAxis, 470, 0, 0, 255);

    // Move to left - decrease left motor speed, increase right motor speed

    motorSpeedA = motorSpeedA - xMapped;

    motorSpeedB = motorSpeedB + xMapped;

    // Confine the range from 0 to 255

    if (motorSpeedA < 0) {

      motorSpeedA = 0;

    }

    if (motorSpeedB > 255) {

      motorSpeedB = 255;

    }

  }

  if (xAxis > 550) {

    // Convert the increasing X-axis readings from 550 to 1023 into 0 to 255
value

    int xMapped = map(xAxis, 550, 1023, 0, 255);

    // Move right - decrease right motor speed, increase left motor speed

    motorSpeedA = motorSpeedA + xMapped;

    motorSpeedB = motorSpeedB - xMapped;

    // Confine the range from 0 to 255

    if (motorSpeedA > 255) {

      motorSpeedA = 255;

    }

    if (motorSpeedB < 0) {

      motorSpeedB = 0;
```

```
    }

  }

  // Prevent buzzing at low speeds (Adjust according to your motors. My motors
couldn't start moving if PWM value was below value of 70)

  if (motorSpeedA < 70) {

    motorSpeedA = 0;

  }

  if (motorSpeedB < 70) {

    motorSpeedB = 0;

  }

  analogWrite(enA, motorSpeedA); // Send PWM signal to motor A

  analogWrite(enB, motorSpeedB); // Send PWM signal to motor B
}

/*  Arduino DC Motor Control - PWM | H-Bridge | L298N

    by Dejan Nedelkovski, www.HowToMechatronics.com

*/
```

Fig A.1: Sample PWM code to run one of the six motors, with mapping included [4].

6. References

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[5]“Free CAD Designs, Files & 3D Models: The GrabCAD Community Library,” *Free CAD Designs, Files & 3D Models | The GrabCAD Community Library*. [Online]. Available: https://grabcad.com/library/rocker-bogie-suspension-1. [Accessed: 07-May-2021].

Signatures		
Project Name: Mobile Sensing Platform		
The undersigned have reviewed and approved the final version of this document.		
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