University of New South Wales

# ENGG1000 Team Ten
# Mars Regolith Collection
# Engineering Design Report

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# Contents

# 1. Summary

*Future Martian explorers will require protection from radiation. One potential solution is to mine Mars regolith and 3d print radiation shelters from it. This project explores the design and fabrication of a prototype regolith collection rover. A primary design principle of simplicity was adopted. Design features were analysed and a prototype designed in CAD. The prototype was constructed and evaluated as a solution*

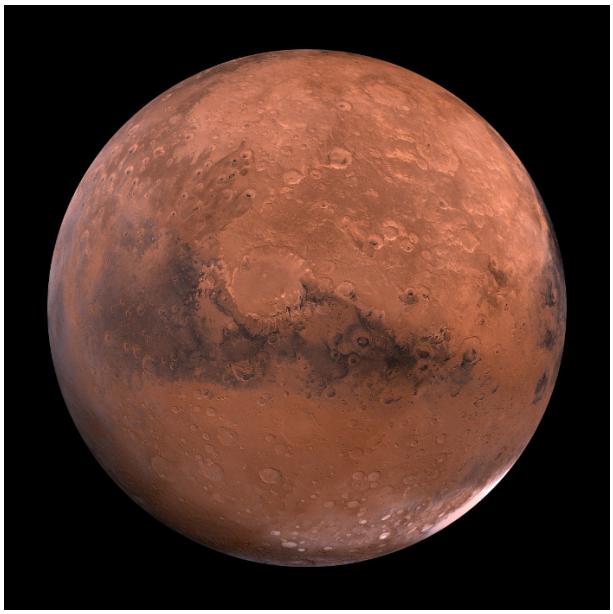

Figure 1.1: Mars.

# Acknowledgements

*We would like to acknowledge the support of Mitchell Torok our team mentor. We are also grateful to Binghao Li and the School of Minerals and Energy Resources staff for guidance and advice over the course of this project.*

# 2. Problem Definition and Background

## 2.1 Background

### 2.1.1 Setting the scene

The exploration of Mars has taken place over hundreds of years. Numerous probes, satellites and several rovers were sent to the Red Planet for geological investigations, habitability potential,surface exploration,life existence and natural resources research.The latest success is the landing of InSight probe on Mars on Nov. 26, 2018.

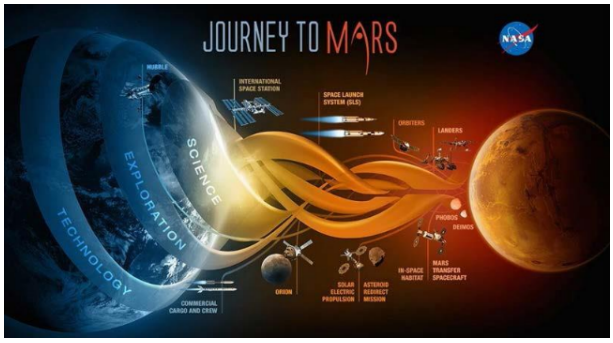


Figure 2.1: NASA's Mars Exploration Road Map

Many people have long advocated a manned mission to Mars as the next logical step for a manned space program after lunar exploration. Fifteen years ago, this idea was hardly taken seriously. Today however, there are real projects the leading space companies are working on. For example, The European Space Agency, ESA[5] has plans to land humans on Mars between 2030 and 2035. Manned exploration by the United States was identified as a long-term goal in the Vision for Space Exploration announced in 2004. The Orion spacecraft, successfully launched in 2014, is planned to be used to send a human expedition to our Earth's moon by 2020 as a stepping stone to a Mars expedition as NASA aims to put a person on Mars by 2037

There are numerous problems an initial habitant will face once they have landed on Mars. One of these difficulties is the high radiation exposure. New spacesuits and spacecraft are to be designed and built before a Mars walk will be safe for a human being. This project examines a later stage – the building of a radiation protection shelter for a Mars colony or resource storage. As it is expensive to deliver building construction materials from Earth, it seems more efficient to use materials sourced locally. As a terrestrial planet, Mars consists of minerals containing silicon and oxygen, metals and other elements that typically makeup rock. This project requires the design, construction and testing of a machine that can drive on a "Mars-like surface", collect/mine resource and bring it to the container for resource shelter building for radiation protection.[7]

### 2.1.2 Project Design Objective

The project objective as given to us states:

" This project requires the design, construction and testing of an item of equipment that can drive on a "Mars-like surface", collect resource and transport it to the feeder of a 3D printer on "Mars". Mined resources will be used to print a shelter/radiation protection infrastructure for Mars colonisation. We will provide you with a map of the Martian surface your rover is to traverse, so you can plan your resource collection strategy. How you are going to collect the resource and deliver it to the feeder is up to you.You may need to do some filtering out of larger items if crushing may be a challenge? However shelter building needs a lot of resource - the more – the better...The objective of this project is for your team to design and build a prototype rover that is able to transit on a "Mars-like surface" and collect samples of the resource. As are representative test bed we will use a beach terrain with small rocks, sand hills and recesses(see Figure 2). The test area measures $9m^2$,equipped with a container for collected resource (Dimensions:0.5x0.5x0.3m (WxLxH)).[7]"

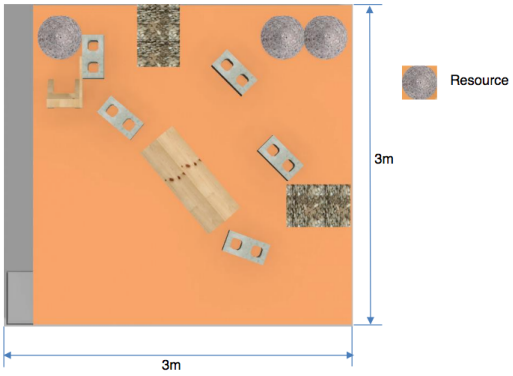


Figure 2.2: Test Area

Figure 2.3: Regolith Advanced Surface Systems Operations Robot (RASSOR) Excavator.

## 2.2 Research

The first step in designing our solution for the project was to do as much research as possible. We started by researching general Mars exploration and mining on earth. As we gained better understanding of the project constraints and objectives we focused our reading on small scale robot design and then on specific robot construction and programming techniques. Research was not a phase that took place once at the beginning of the project. As the design evolved and especially as we had to adapt the design during the build phase we returned to the research phase many times.

As a primer we read two general Mar engineering books. 'The Right Kind of Crazy'[14] and Mars Rover Curiosity: An Inside Account from Curiosity's Chief Engineer[8]. Both are about the successful design and deployment of the Curiosity rover. These gave the team an idea of the unique challenges faced by Martian engineers.

We used YouTube to research NASA's Lunar Mining competition for ideas and features. We also watched videos of open pit mining machines on earth to see what designs are actually used in earth mining.

- NASA's off-world mining solution: RASSOR.[3]
- Lunarbotics competitions[9]
- Bucket wheel open pit mining)[4]
- Excavator mining.[1].

Our mentor whose team won the previous years MERE project was our best source of information and was able to give extremely focused advice throughout the project. He advised us to start the build early and keep the design simple as the project is not easy and most teams fail to produce a working design.

We were also shown video and pictures of previous designs. We analysed these for common features and why they may been chosen.

Figure 2.4: A previous years MERE project.

Figure 2.5: Another previous years MERE project.

As the project progressed we needed specific information on building small scale radio controlled robots to implement the features we selected. An advantage of using the Arduino microprocessor is that thousands of projects are documented on Github and various websites. In particular we relied on mobilerobotsand rcarduino for ideas and inspiration. For the practical technical information we needed to build and program our rover we used two main references. 'Practical Electronics for Inventors'[12] and 'Arduino Robotics'[6]. Both of these books are excellent and having access to them was a major factor in the success of the project. In a research meeting we polled our team members for resources and skills they already had access to that we could utilize.

From the initial research phase we concluded that the major constraint on the project was the ten week time limit. A simple design would be the easiest to construct and facilitate completion and testing within the time-frame.

We decide to adopt some of the design features we saw successfully used in previous years designs to reduce development time. We also saw that the most successful previous design were larger with enough power and capacity to carry a large amount of regolith and the Arduino and electronics. The weaker designs were small and barely powerful enough to carry more than a few pieces of regolith. We resolved to avoid this mistake. From our team poll we concluded we had access to a radio control transmitter and 24V Lipo batteries we could use to control and power our design and reduce our costs.

# 3. Problem Statement Generation

## 3.1 Considerations

To generate our problem statement we considered the following elements.

- **Who** A group of first year engineering students. The client is 'NASA' but in relation to the actual problem the client is the course assessor and our team as we will be the ones operating it.
- **What** Design and build a prototype rover that is able to transport on a Mars-like surface and collect resources.
- **Constraints**
    1. Limited skills - it must be built by undergraduate students with little or no experience in building robots.
    2. Limited time: - a working prototype must be produced in ten weeks.
    3. Limited operating area - It must also operate in a $3 * 3m$ environment so must be small enough to manoeuvre in this space but also large enough to carry approx. 1 kg to 5kg of regolith. More is better.
    4. Limited operating time - the rover has four minutes to collect the regolith.

## 3.2 Problem Statement

After considering the above we generated the following problem statement;

"As part of their assessment for a first-year engineering program students are required to produce a working prototype of a rover within approximately 10 weeks.

The rover needs to be able to transit through a Mars-like surface, simulated by the use of small rocks, sand hills and recesses and collect resources, which are simulated by small pebbles. It must operate continuously for 4 minutes and traverse an area approximately $9m^2$.

The assessment will take into account whether a prototype is produced and the rate of regolith collection. Marks will also be given for energy efficiency and innovation."

## 3.3 Design Principles

From the problem statement we identified that our **key issues** were limited time and limited skills.
The **actions** we took to mitigate these issues were to formulate two design principles.
These were;

1. **Simple: easy to design, build and operate.**
    - made from readily available materials that don't require special tools.
    - The simplest design possible with the least number of parts.
    - Use as much 'off the shelf' electronics and parts as possible to minimize development time.
    - Make use of resources we have already to minimize expense and complexity.
2. **Powerful and large enough to move between 1 - 5kg of regolith in four minutes.**
    - Use high voltage (12 or 24 volts) instead of 9 or 5 volts.
    - Be large enough to carry between one and five kilograms of regolith at one time to minimize trips.

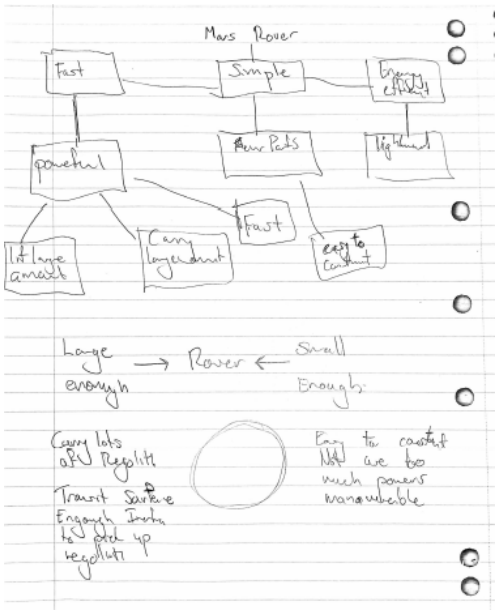


Figure 3.1: Drafting design principles.

# 4. Design Concept Generation

## 4.1 Concept Sketches and Inspiration

Our team generated many design concepts incorporating ideas and features from the research phase. The main features mooted were the regolith collecting system, method of movement and steering and method of storing and dispatching the regolith. We also considered different power sources. These concepts were sketched up and their merits analysed against our design principles.

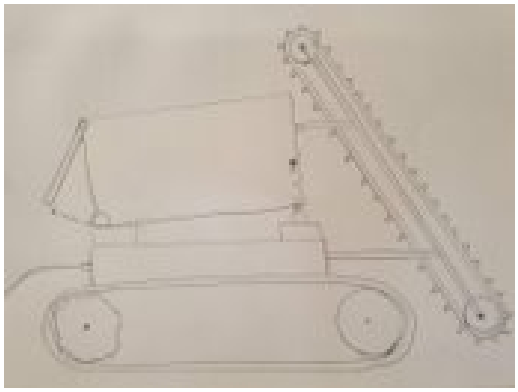

Figure 4.1: Tracked with small buckets on conveyor belt concept sketch.

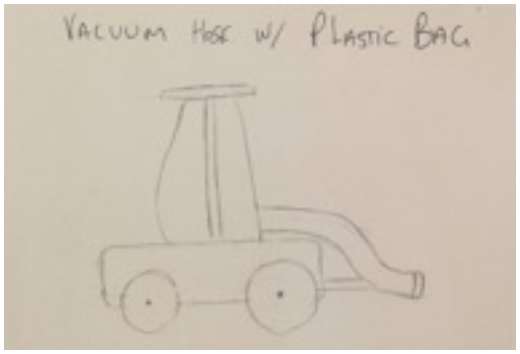


Figure 4.2: Vacuum mounted on wheel concept sketch.

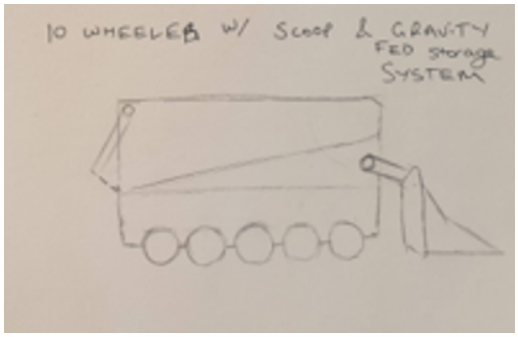


Figure 4.3: Multiple wheeled with scoop concept sketch.

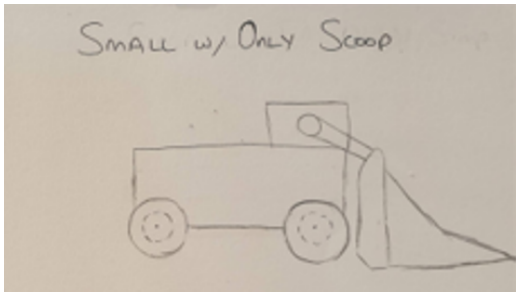


Figure 4.4: Small with regolith transported in scoop concept sketch.

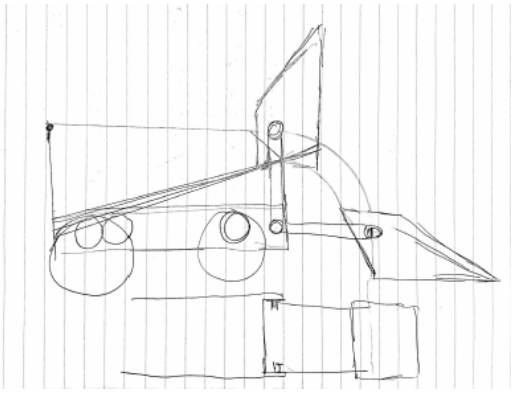

Figure 4.5: Scoop with gravity fed regolith container.

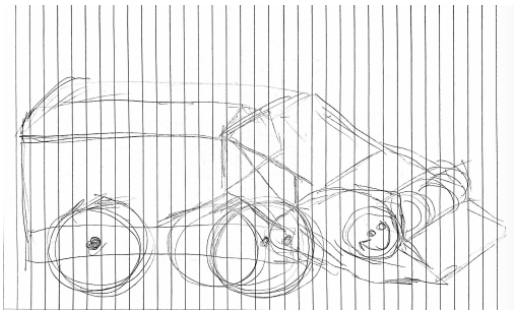

Figure 4.6: Horizontal sweeping roller concept sketch.

### 4.1.1 Analysis of Potential Features

**Dimensions and Regolith Capacity** We analysed the map of the test area in figure 2.2. Some regolith is located closer to to the dispatch area but is located in a 'cave'. We decided to ignore the cave regolith and dimension the rover to carry and collect as much as possible from the more accessible piles whilst still be small enough to manoeuvre around obstacles. We decided on a length of between 30 and 50 cm and a width of not more than 30cm. To be able to contest the competition record we aimed for design load of between 1 and 5kg.

**Movement** Initially we were in favour of using tracks over wheels. We though tracks would provide better traction on sand and be easier to implement as only one motor would be need for each side of the rover. However, after researching track mechanisms and current mars rover designs we decided in favour of a wheeled design. Track systems are very expensive to buy and complex to build. We also briefly considered using a drone with a claw system attached, but quickly rejected this idea as drones are very complex to build and control. RC truck wheels of various sizes are readily available and relatively inexpensive.

**Regolith collection** The method of collecting the regolith provoked the most debate. The analysis was complicated by a sample not being available. Therefore we had to consider the ability of each method to handle regolith of many different scales. This was the main factor in favouring a scoop design. A vacuumn cleaner' approach was considered. This is a great idea in theory but on closer examination falls apart. The main reason for rejecting this idea is that it would not work on Mars due the density of the Martian atmosphere being approximately 1 percent of Earths.
A rotating bucket collection device was considered, but rejected because of the complexity. The two designs considered viable were a scoop or bucket as seen in previous MERE projects or a horizontal sweeping roller. had we seen the regolith sample before deciding on the features we would probably have chosen the sweeping roller as it would have suited the actual regolith well.

**Regolith storage and dispatch** Two concepts were considered. A triangular box with a sloping floor to dispatch the regolith by gravity or not having a container at all and carrying regolith in the collection device. Although not having a separate storage container is the simplest option it would not allow a high rate of collection so was rejected.

## 4.2 Morph Chart and Design Feature Selection

### 4.2.1 Morph Chart Generation

To create our solution to the design problem we used our research findings and the viable solution from the feature analysis above to generate a number of potential solutions. These were drafted into the Morph Chart matrix below.

In a group meeting each feature was analyzed for its compatibility with our design principles. A discussion of the morph chart features and the reasons for selection follow:

### 4.2.2 Morph Chart

| Function / Feature | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Body Material** | Plywood | Aluminum Sheet | Fiberglass | Carbon Fiber |
| Fabrication Method (subsystem of material) | Nuts & Bolts | Glue (Titebond or JB Weld) | Screws | |
| **Power Source** | Batteries | Fuel Cell | Solar Panels | Internal combustion |
| Battery Type (Power source subsystem) | Li-po | Lead-Acid | Ni-Cad | |
| Voltage (Battery subsystem) | 24v | 12v | 9v | 5v |
| Propulsion (power source subsystem) | DC Electric Motors (Direct Drive) | DC Electric Motors (Indirect Drive) | | |
| **Movement** | Wheels (Four-Wheel Drive) | Wheels (Two-Wheel Drive) | Tracks | |
| **Steering** | Differential steering | Two moveable wheels | Four moveable wheels | |
| **Control Method (Microprocessor)** | Arduino | Raspberry Pi | STMicroelectronics NUCLEO-F401RE | |
| **Control Method (Communication)** | Radio Control 2.4 GH RC transmitter and receiver | Bluetooth | Wi-Fi | Autonomous |
| **Regolith Collection** | Scoop | Horizontal sweeping roller | Vacuum System | Rotating Drum with scoops |
| Scoop Actuator (Regolith Collection sub-system) | Linear actuator | Servo | Pneumatic/Hydraulic | |
| **Regolith Dispatching System** | Gravity fed with gravity opened gate. | "Dump-Truck" – tipping tray. | | |
| Gate Actuator (Regolith Dispatching sub-system) | Solenoid | Linear actuator | Servo | |

Figure 4.7: Morph Chart: green indicates selected features

### 4.2.3 Body Material

Plywood is really the only serious contender. It is light, strong, cheap and easy to work. We will use 7mm ply for the main body and 3mm ply for the scoop and rear gate.

In the age of composites, ply-wood seems like a backwards choice. However, plywood has many of the advantages of composites and almost none of the disadvantages. See A brief history of Plywood for details.[13]

### 4.2.4 Fabrication Method

We will use machine nuts and bolts in combination with angle brackets to construct the mechanical components. This allows us the flexibility to modify and rebuild the prototype throughout the build and test process. This is one of the most importance aspects of our design. The ability to develop the prototype during the build and test phases as inevitable issues and technical problems arise and solutions need to be developed. Some of these issues can be avoided by the use of CAD and simulation but built in flexibility is crucial to success. It also greatly improves the ease of maintenance once the prototype is operational.

### 4.2.5 Power Source

Batteries are the obvious choice. We have available 6x 22.2 nominal voltage 1450 mAh Li-Po batteries. We will use these because Li-Po's are energy dense, light weight and expensive. Not having to buy batteries is a huge cost advantage. We also have the charger and they are pre-wired with Anderson Power-poles. See Li-Po Batteries[11] for more information.

### 4.2.6 Battery type and voltage

Battery type and voltage are dictated by our choice of Li-Po's. The advantage of using 24v is that the currents draw is lower. This means lighter gauge wires can be used and losses from heating are reduced. It also means that digital systems running from the main battery can maintain a steady 5V supply even under significant voltage drop from start-up/ stall loads etc.

### 4.2.7 Propulsion

Propulsion system is obviously electric, and DC as dictated by our choice of battery. We have chosen direct drive from geared down 24V motors with a no-load RPM of 120. Direct drive saves space and reduces the complexity of the design as there are no external gearboxes or axles.

### 4.2.8 Movement

Here we have chosen to accept a slight increase in complexity. Four-wheel drive needs the addition of two motors and draws twice as much current, but gives a large increase in the ability of the rover to deal with sand and carry more regolith with less risk of getting stuck on Mars. Our system is based on the robot detailed here.[10]

### 4.2.9 Steering

Differential steering was the obvious choice here, no complex steering mechanisms (particularly as we have selected 4-wheel drive) and as the solution is software based it is infinitely adjustable to suit driver and robot operating conditions.

### 4.2.10 Microprocessor

Arduino is the obvious choice. There are dev boards with much higher specs (e.g Pi and the Nucleo) but the amount of documentation, support, libraries and open source code solutions already available on Github etc made this choice for us. We used the Arduino Mega to maximise the number of inputs and outputs.

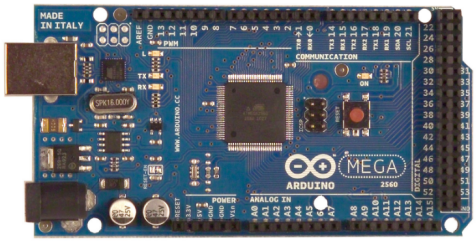


Figure 4.8: Arduino Mega 2560

Figure 4.9: The drive train of our rover is based on this design by mobilerobots.pl.

### 4.2.11 Control method

We have a 7 Channel 2.4 GH Radio Control transmitter and receiver already available. Again, this choice means a slight increase in complexity because we need to code the Arduino to process the PWM signals from the receiver this is acceptable because the rover will be much easier to control as the transmitter is designed to control models. There is also a large amount of information available about this application and signal processing. See RC Arduino[2]

### 4.2.12 Regolith Collection

Initially we were in favour of a horizontal sweeping roller to collect the regolith as we felt it would offer a faster rate of collection. However, after the problem statement generation exercise and discussions with the team we decided to go with a scoop. The reasons for this were;

1. In all the previous rovers that we saw, no solution included a roller even though we know a lot of teams considered it. This made us think it was harder to implement than it seems.
2. We haven't seen a sample of the Regolith yet. It may or may not be suitable for a sweeping roller system. A scoop can deal with many different types of Regolith, but a roller would be more likely to need customisation to operate with a particular 'spec'.
3. A sweeping roller would need a system to raise and lower the roller arm and a system to spin the roller adding complexity. We are aiming for the simplest solution possible.
4. Scoop are a 'tried and true' system. We know they work from the many examples in earth moving and mining machines and the almost exclusive use of them by previous teams.

### 4.2.13 Scoop Actuator

We have chosen a linear actuator over servos for three reasons.

1. Using a Linear actuator lets us apply force to the scoop arm at a distance from the hinge reducing the load on the system.
2. Most readily available servos run on 5 – 7.5 Volts. We want to use a standard voltage for the whole system to reduce complexity.
3. 24V linear actuators are relatively cheap (60 dollars) compared to 24V servos 200 dollars).

### 4.2.14 Regolith Dispatching System

Here we have made a compromise towards simplicity at a reduction in load capacity. A gravity fed system needs no moving parts but requires a triangular profile that cuts the useful volume of the rover in half. We have designed a gate that closes under gravity and opens under the weight of the Regolith. Therefore, the only electro-mechanical system need is a device to keep the gate closed whilst the regolith is loaded and transported and allow it to open at the dispatching area. The 'area under the triangle' is utilised for the battery and electronics so it is not 'wasted space'.

### 4.2.15 Gate Actuator

To allow the gate to open and close we will use a 24 Volt solenoid that when activated allows the gate to open and keeps it closed when shut.

## 4.3 CAD Design

We designed the rover in Fusion 360 following the design principles and features outlined above. To save time only the basic structure and dimensions were designed in CAD. The fabrication brackets and smaller components were not modelled.

The design is a box shape with an angled 'floor' running most of the length to form the regolith container and provide structural support. There are two cross braces at the top of the rear and bottom of the front to make a triangular support structure that is strong and light.

The motors are bolted directly to the side panels. The linear actuator is supported by 6mm stainless steel threaded rod and located in the centre. The rear gate hinge is offset so it closes under its own weight. The solenoid is located on the top brace and prevents the gate from opening.

If we had been more familiar with Fusion 360 we could have used some of the more advanced features such as movable joints and simulation. The use of CAD was a great help in analysing the geometry of the scoop and positioning the motors.

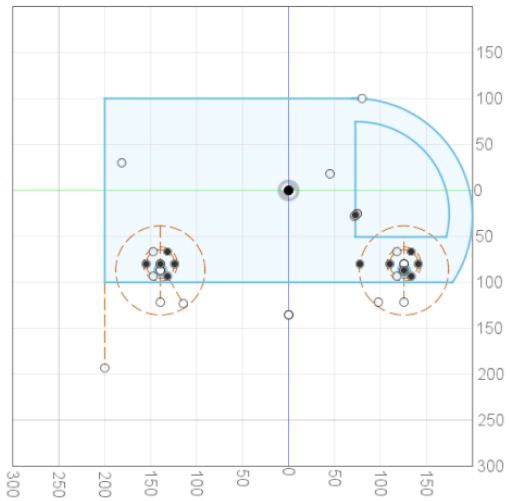


Figure 4.10: Main body profile sketch.

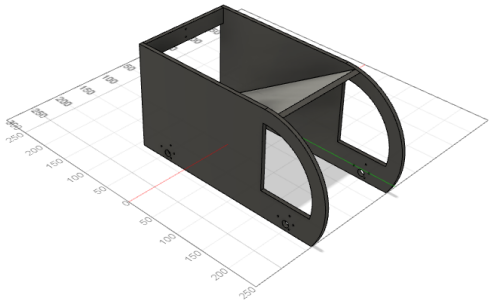

Figure 4.11: Main body in Fusion 360.

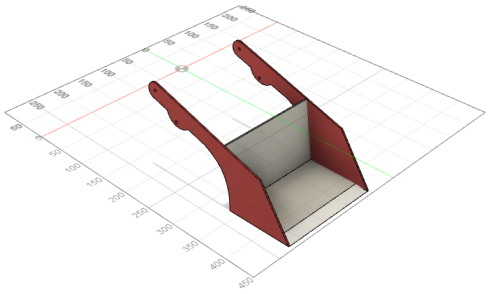

Figure 4.12: Scoop in Fusion 360.

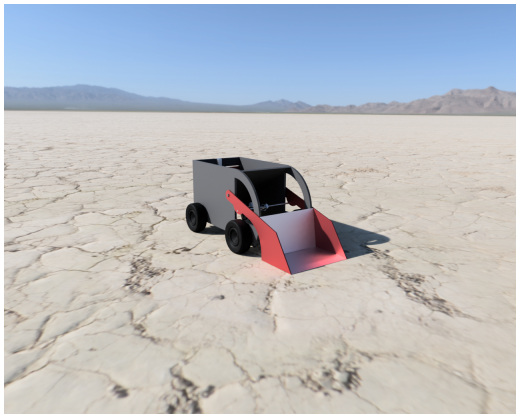

Figure 4.13: Fusion 360 render of rover on mars.

# 5. Rover Build Process

## 5.1 Mechanical Assembly

### 5.1.1 Sourcing Components

As per our design principles our rover was constructed of readily available materials. All components were purchased from ebay, Facebook Marketplace, Bunnings and Jaycar Electronics. A complete purchasing list is included in Appendix A.

### 5.1.2 Laser Cutting

One of the key reasons we used CAD was that the design sketches can easily be used to laser cut the profiles. A video of laser cutting the scoop arms is here.

### 5.1.3 Materials and Method of Construction

The main body was constructed of 7mm interior ply. The scoop was constructed from 3mm ply. We used galvanised right-angle brackets and M3 countersunk bolts and nuts with flat washers. The use of nuts and bolts was important as it gave our rover the ability to be dismantled and reassembled easily. The linear actuator pivots, rear gate pivots were constructed from 6mm diameter stainless steel threaded rod.


Figure 5.1: Secondhand $\frac{1}{10}$ Scale RC Off-Road Truck Wheels.

Figure 5.2: Main body and scoop assembled.

Video of body and scoop assembled.

## 5.2 Electro-Mechanical Assembly

### 5.2.1 Scoop Redesign

In contrast to the construction of the rover main body, the integration of the electro-mechanical systems had many issues and required a major redesign of the scoop mechanism, rear gate operation and general rover layout.

### 5.2.2 Linear Actuator Issues

These issues stemmed from trying to save on costs by purchasing a non-branded cheap linear actuator. The actuator sourced from (pictured below) is approximately five times cheaper than a brand name item. The main Issue is that it had no data sheet and the vendor could not obtain one. This meant when the CAD model was designed, we underestimated the actuator dimensions and weight by a factor of two. The geometry of the scoop operation had to be redesigned with the actual actuator size.

To fit the large actuator, we moved the attachment of the scoop pivot from a metal rod between the scoop arms, to attached directly to the scoop. We also re fabricated the floor and back of the scoop in sheet metal because it was flexing by 20mm under the load from the actuator. We also changed the diameter of the actuator pivot from 6mm diameter stainless steel rod to 8mm to eliminate some bending that was occurring during testing.

We also needed to remove the front brace and move the intended location of the Arduino because both were in the way of the actuator.

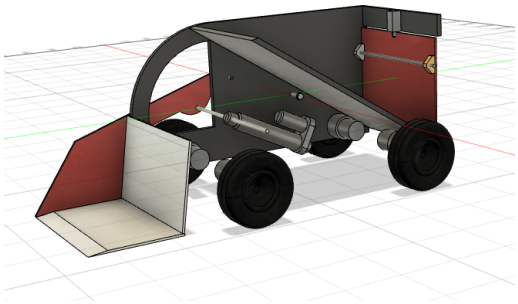

Figure 5.3: Actuator and scoop as designed in CAD.

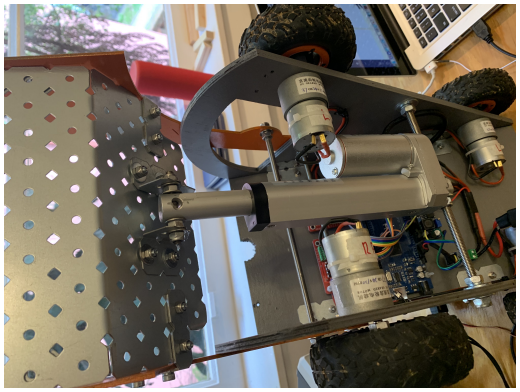

Figure 5.4: Actuator and scoop after redesign

### 5.2.3 Rear Gate Control Issues

The original design controlled the rear gate with a 24V solenoid (see fig 5.7). Unfortunately very late in the build period the eBay vendor that we purchased the solenoid from canceled the order. With the COVID-19 quarantine in full effect we did not have time to purchase another solenoid. The design was adapted to use two Gaui GS-311 metal gear servos to actively hold the gate closed. This also required adjusting the Arduino power from 12 V to 6V as the servos are powered directly from the battery. This design worked well, but because it was implemented at a very late stage, looks out of place. We may replace these with the original design in a second iteration of the pototype.

A video of a rear gate servo operation test is here.

### 5.2.4 Regolith Sample and Testing

We were provided with a regolith sample in week four. It would have been advantageous to have this sample before the design was completed but we could not afford to delay construction due to time constraints.

The 'regolith' is angular and has a lot of flat surfaces. It has a high angle of repose (approximately 40 degrees) and does not slide easily. This is difficult for gravity fed systems to handle and we had to adjust the angle of the scoop back to allow it to slide. To lower the friction co-efficient we constructed a corflute inner on the scoop and regolith container to allow it to slide more easily. This worked reasonably well and has the added advantage of being easily replaceable when damaged.

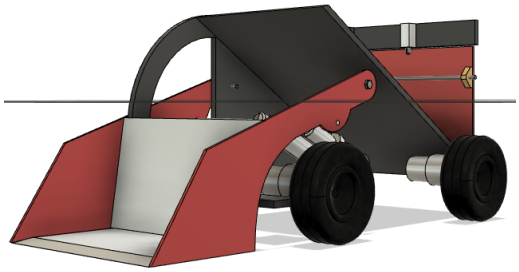

Figure 5.5: Rear gate and solenoid as designed in CAD.

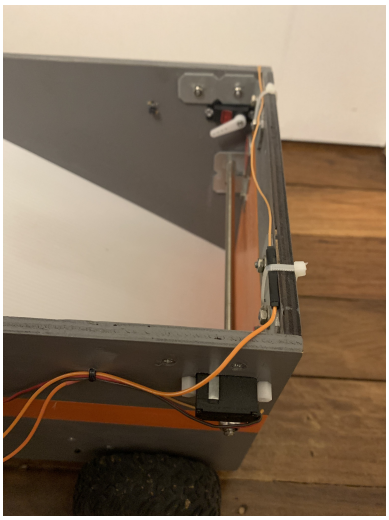

Figure 5.6: Rear gate control servos after redesign

Figure 5.7: A 'Regolith' Sample

## 5.3 Electronics and Control System

### 5.3.1 Components

We had a few options when decided how to implement the electronic control system. As per our design principle of simplicity we had chosen an Arduino controlling four 24 volt motors and a linear actuator via three motor controllers. A 24 V solenoid was initially specified to secure and release the rear gate. Unfortunately, the eBay vendor cancelled the order so we replaced it with two servo's we had available.

### 5.3.2 Implementation

To implement the electronic system we considered two options:

1. Pre-constructed Arduino compatible modules wired together
    - Pros – simplest option, quick to implement, easy to test and very likely to work first time.
    - Cons – takes up lots of space and requires more wiring, parts of some modules are not used. If something goes wrong, it may take more time to figure out the issue.
2. Design a separate PCB with Arduino, DC power stepdown, motor controllers on one board.
    - Pros – compact and uses less power, no redundant components, the team knows exactly how it works.
    - Cons – takes much more time to implement

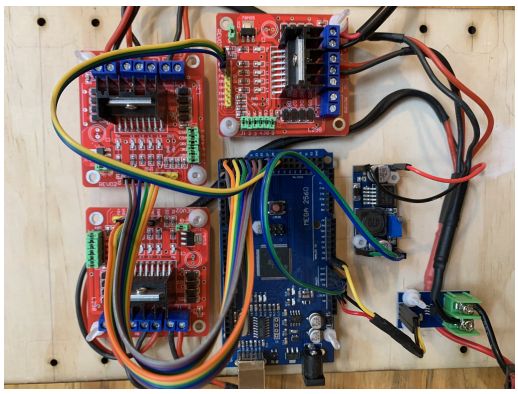

Figure 5.8: Electronics Layout.

Figure 5.9: Complete electronics and mechatronic system removed from the rover for testing.

We chose option one due to project time constraints and lack of access to PCB manufacturing facilities. If we continue to develop the design in the future, we would like to design a custom PCB to make more space available for other sensors.

The system has seven components:

- A receiver to receive signals from the transmitter.
- Arduino Mega microprocessor to process the receiver inputs and send signals to the motor controllers.
- Three L298N Dual Motor Drivers – Left and right motors have one each and one to drive the linear actuator. The actuator driver has one redundant input/output.
- A DC – DC converter to provide power to the Arduino and rear gate servos from the battery.
- An ACS712 Hall-Effect Current Sensor to measure the system current draw.

Data sheets for the electronics and mechatronic components can be found in Appendix B.

Most of the work on the electronic system involved constructing the wiring loom. A lot of time was spent making sure the loom would be reliable and not compromised by vibration or allow shorts to occur. This was done by heat shrink insulation around vulnerable areas and using nylon fastenings to secure the PCBs to the board.

The operation of Arduino, DC MOSFET motor controllers and PWM signals is well documented in many resources so we will not re-explain it here. A detailed explanation can be found in Monk et al. (2016) in chapters 13 and 15.[12]

One feature we should have included but did not is a fuse. During testing we shorted out the battery wires resulting in a small but spectacular fire as the current sensor acted as an involuntary and expensive one way circuit breaker. This incident could have resulted in a serious battery fire and a fuse will definitely be included in the next iteration of the rover.

## 5.4 Final Assembly

### 5.4.1 Colour Scheme

Figure 5.10: Inspired by Riddley Scott's 'The Martian'.

Figure 5.11: Painting the components.

When we were satisfied that the systems were working we disassembled and painted the rover main body components. This was done to increase the aesthetic appeal of the rover. Vision is one of the most dominant senses in humans. A design that 'looks cool' is more likely to be selected. We chose an orange and grey colour scheme as a reference to everyone's favourite Mars movie 'The Martian'.

Final assembly was carried out using Loctite on all nuts and bolts to reduce the chance of vibration induced failures.

The linear actuator and rear gate pivots were lubricated with a lithium based dry lube.

The battery was attached to the rover with zip ties. These add no weight and hold the battery securely.

# 6. Arduino Code Development

## 6.1 Code Development and Testing

### 6.1.1 Test Environment

The rover has an USB port to enable the Arduino IDE to be plugged into the Arduino and tested immediately. This was a great help in developing the code quickly. We were also able to monitor the current draw and RC inputs to the Arduino with the serial plotter in real time.


Figure 6.1: Serial monitor plot of throttle and steering channel inputs.

### 6.1.2 Resources

The code for this project is based on and developed from the ExplorerBot code in Arduino Robotics[6].
The complete test and operating programs are included in Appendix B.

### 6.1.3 Motor Controller Issues

The motor controllers were tested with a simple motor demo code that did not have any real time input. This allowed us to test the controller and Arduino were working correctly and become familiar with the outputs required.

One issue with the linear actuator motor controller was identified. The controller had power and the Arduino was switching the inputs correctly, however the controller was not supplying power to the motor output. After a few hours of testing everything independently we discovered the cable to the enable input of the controller had an intermittent fault that tested fine, but when put back in the system was not sending the PWM signal to the controller. This did not show up on the controller as the switching LED's do not required the enable signal to illuminate. We should have used the scope to test this signal instead of relying on the LED's.

A video of the motor demo test code running.

## 6.2 Operating Code

### 6.2.1 General Principles

The idea behind radio control of the rover is simple. The RC transmitter sends PWM signals to the receiver. These inputs are processed by the Arduino and output as signals to the motor controllers to steer the rover and operate the scoop.


Figure 6.2: The transmitter. The right stick y-axis controls forward and reverse. The x-axis controls left and right. The left stick y-axis controls the scoop.

We analyzed the output from the receivers to determine the centre and minimum and maximum value of each channel.

A video of this process is here.

The PWM frequency of the Arduino outputs was changed to $32kHz$. This raises the frequency of the PWM signal above the threshold of human hearing so the motor controllers operate silently.

The main part of code is a series of 'nested if' loops. This loop constantly checks the position of the control sticks and changes the output signal to the motor controllers in response.

The skid steering is implemented by slowing the 'inside' wheels proportionally to the input from the steering channel. If there is no input from the forward/reverse channel the 'inside' wheels will reverse to spin the rover on the spot.

The scoop control is a simple on/off code. If the channel value is negative the scoop will be raised. It is it positive the scoop is lowered. There is a 'deadband' when the stick is centred to stop the scoop at a given position.

The complete code which is well commented in included in appendix B.

The servo's that keep the rear gate shut are controlled directly from the receiver because the PWM signal does not need to be processed.

# 7. Testing

## 7.1 Testing Principles

During the build and development process we tested each separate system as soon it was operating. The idea was to eliminate as many issues as possible at an early stage. This was very successful as the rover only required one small alteration once completed.

## 7.2 Scoop and Linear Actuator

The linear actuator and scoop system required the most testing. As mentioned above, the scoop was redesigned in metal after the original wooden design was flexing too much. A lot of testing and retesting was required to balance the range of motion of the actuator with the angle of the scoop. Because the geometry of the design had been changed, we were not able to raise the scoop to the degree that was originally planned. This meant the regolith would not slide off into the storage container and was a serious problem. As mentioned above this was solved by use of a Corflute inner to adjust the angle of the rear face of the scoop.

## 7.3 Integrated Testing

The separate system tests meant an extensive integrated testing phase was unnecessary. One small modification was needed after integrated testing. We added rubber pads to the rear gate to eliminate a small gap that was allowing regolith to become stuck and prevent it closing properly.

Figure 7.1: Completed rover ready for testing.

Figure 7.2: Rubber pads added to rear gate assembly.

Because of the COVID-19 quarantine conditions we were unable to test our design against other teams. We designed three tests for our rover. Test A was a recreation of the team competition where we tried to gather as much regolith as possible in two four minute periods. Test B was a test to determine the maximum speed of the rover. Test C tested the maxiumum load the rover could carry whilst remaining controllable. For tests A and b we measured the energy use of the rover.

To measure the energy use we used a programmable battery charger that records the mAh required. By recharging immediately after the test we hoped to measure energy use accurately.

### 7.3.1 Test A

**Aim:** To determine the regolith collection rate and energy efficiency of the rover. We also evaluated the driving experience and general effectiveness of the design.

**Method:** A sand and gravel driveway with a gentle slope was used to simulate a 'Mars-like surface". Two 4kg piles of gravel chip similar to the regolith sample provided was setup 4.25 metres from a regolith collection box. To simulate an obstacle indicated in the map of the usual test environment the collection box was reached via a ramp. See figures 7.3 and 7.4 below:

Starting from the collection area the rover collected as much regolith as possible from the piles and deposited it in the collection area. The collected regolith was weighed and the batteries recharged.

The average collection rate was determined by dividing the total a mount of regolith collected in both four minute tests by the total time in seconds. This was converted to kilograms per hour.

We took care to only use each battery for the duration of the test. Each battery was recharged immediately after the test and mAh put back into the pack recorded.

The energy used was calculated by the multiplying the average mAh recorded by the battery voltage. This product was multiplied by .015 to get the energy use per hour in Watt hours.

A time-lapse of the first run in this test is here.

**Results and Calculations:**

Table 7.1: Test A. Regolith collection results.

| **Run One** | | | |
|---|---|---|---|
| Date: 20/4/20 | **Time [s]** | **Regolith Collected [g]** | **Energy Use [mAh]** |
| **Battery One** | 240 | 2155.7 | 113.00 |
| | | | |
| **Run Two** | | | |
| Date: 20/4/20 | **Time [s]** | **Regolith Collected [g]** | **Energy Use [mAh]** |
| **Battery Two** | 240 | 2177 | 109.00 |

$$\frac{2155.7[g]+2177[g]}{240[s]+240[s]} = \frac{4332.7[g]}{480[s]} = 9.03[g/s] = \frac{(4332.7[g]/1000)}{(480[s]/3600)} \approx 32.5[kg/h] \tag{7.1}$$

$$24[V](\frac{113[mAh]+119[mAh]}{2}) * 0.015 = 41.76[Wh] \tag{7.2}$$

**Discussion and Conclusions:** The results in this test can only give an indication of the rovers regolith collecting ability. A large factor in the collection rate is the ability of the driver. Intuitive controls and ease of operation play a large part in the success of the design. We do not have our peers designs to compare against but the results are in the mid-range of our design goal which was to achieve a collection rate between 15 and 75 kg per hour. We feel that the results in test A could be improved by up to a factor of two given sufficient practise by the operator.

The energy usage test can also only give an indication of the energy efficiency of the design. As with the collection rate, a lot is dependant on the skill of the operator. The batteries used in the two tests have different internal resistance. If we ran the test again we would practise more beforehand, use the same battery for each test and and run the tests over a longer time period.

### 7.3.2 Test B

**Aim:** To determine the maximum speed.

**Method:** A sand and gravel driveway with a gentle slope was used to simulate a 'Mars-like surface". A five metre course was measured out and the rover timed of 10 runs up and down for a total distance of 100 metres. For each run the rover was driven as fast as possible. For the first five of these runs the rover was unloaded. For the second five it carried 1kg of regolith. The runs were timed visually with an iphone stopwatch. This means the times are only accurate to 5 tenths of a second. The rovers speed was calculated by dividing the total distance driven by the total time taken. This figure was then converted to kilometres per hour. We thought that there might be a measurable difference in speed between the loaded and unloaded runs. The loaded run was slightly faster but this could have been due to timing errors or the operator being better at negotiating the course.

**Results and Calculations:**

Figure 7.3: The 'regolith'

Figure 7.4: Regolith collection box.

Table 7.2: Test B. Maximum speed test results

| **Test One (Empty)** | | | | | |
|---|---|---|---|---|---|
| **Date:25/4/20** | **run 1** | **run 2** | **run 3** | **run 4** | **run 5** |
| **Time 1(s):** | 9.48 | 9.63 | 9.88 | 9.44 | 9.76 |
| **Time 2(s):** | 9.01 | 8.74 | 8.53 | 8.39 | 8.86 |
| **Run Distance (m)** | 5 | 5 | 5 | 5 | 5 |
| **Total distance (m)** | 10 | 10 | 10 | 10 | 10 |
| **Test Two (1 kg load)** | | | | | |
| **Date:25/4/20** | **run 1** | **run 2** | **run 3** | **run 4** | **run 5** |
| **Time 1(s):** | 9.71 | 9.66 | 10.16 | 10.06 | 9.80 |
| **Time 2(s):** | 8.55 | 8.72 | 8.75 | 8.63 | 8.75 |
| **Run Distance (m)** | 5 | 5 | 5 | 5 | 5 |
| **Total distance (m)** | 10 | 10 | 10 | 10 | 10 |

Figure 7.5: The 5 metre run for test B.

Figure 7.6: The rover loaded with 1kg of regolith.

Table 7.3: Result calculations

| | **run 1** | **run 2** | **run 3** | **run 4** | **run 5** | **Total** |
|---|---|---|---|---|---|---|
| **Time 1[s]** | 9.48 | 9.63 | 9.88 | 9.44 | 9.76 | |
| **Time 2[s]** | 9.01 | 8.74 | 8.53 | 8.39 | 8.86 | |
| **Total [s]** | 18.49 | 18.37 | 18.41 | 17.83 | 18.62 | *91.72* |
| **Distance [m]** | 10 | 10 | 10 | 10 | 10 | *50* |
| | **run 6** | **run 7** | **run 8** | **run 9** | **run 10** | **Total** |
| **Time 1[s]** | 9.71 | 9.66 | 10.16 | 10.06 | 9.80 | |
| **Time 2[s]** | 8.55 | 8.72 | 8.75 | 8.63 | 8.75 | |
| **Total [s]** | 18.26 | 18.38 | 18.91 | 18.69 | 18.55 | *92.79* |
| **Distance [m]** | 10 | 10 | 10 | 10 | 10 | *50* |

$$\frac{(10[m] * 10)}{(18.26 + 18.38 + 18.91 + 18.69 + 18.55 + 18.49 + 18.37 + 18.41 + 17.83 + 18.62)[s]} = 0.54[m/s] \tag{7.3}$$

$$0.54[m/s] * (\frac{3600}{1000}) = 1.94[km/h] \tag{7.4}$$

**Discussion and Conclusions:**

The results in this test give good indication of the rovers speed. The test was carried out on a mars like surface with sandy areas and small rocks. Some operator input was needed over to maintain a straight course due the the sand. Due to the low gear ratio and four wheel drive it has very good acceleration and torque. We had thought there might be a difference in speed with the 1kg load but no difference outside the expected error in the results was observed.

### 7.3.3 Test C

**Aim:** To determine the maximum operating load.

**Method:** A sand and gravel driveway with a gentle slope was used to simulate a 'Mars-like surface". The rover was loaded with an increasing amount of regolith and the effects observed. The load was increased until normal operation was difficult. The load was weighed and this weight recorded as the maximum operating load.

Figure 7.7: The rover during maximum load testing.

A video of the rover with maximum load is here.

**Results and Conclusions:** The rover was able to operate with a load of $5.8kg$ of regolith. The rear gate and all controls were still operable. The tyres which are 1/10 scale RC truck tyres were compressed by the weight so the rover was unable to turn. At the maximum design load of 5 kg operation was normal, however the maximum speed by attenuated by a factor of two.

**Note:** The regolith for this test was not loaded via the scoop. It was poured into the container by hand. It may or may not be possible to load this amount via the scoop. The largest amount loaded via scoop was $2.5kg$.

# 8. Conclusion

## 8.1 Design Effectiveness Analysis

### 8.1.1 Specifications

Table 8.1: Rover Specifications

| **Dimensions** | ***Length [cm]*** | ***Width [cm]*** | ***Height[cm]*** |
|---|---|---|---|
| Scoop Lowered | 55 | 27.5 | 23 |
| Scoop Raised | 47 | 27.5 | 40 |
| **Weight [kg]** | 4.3 | | |
| **Maximum Load [kg]** | 5.8 | | |
| **Maximum Speed [km/h]** | 1.94 | | |
| **Collection Rate [kg/h]** | 32.5 | | |
| **Energy Use [Wh]** | 41.8 | | |

### 8.1.2 Revisiting the problem statement

A successful design is a valid solution to the problem statement. Our rover is a successful design because it was completed and tested in the ten week time constraint. It is able to transit on a mars like surface and collect resources. It has a high rate of resource collection. Each of these metrics was tested and quantified.

The design principles we formulated and adhered to throughout the design and build process are a major factor in the success of this project. Our principal of simplicity allowed us to keep the project within the specified timeline. It meant we were able to start the build early and complete the rover with time for an extensive test program. Our design was also able to be built with limited tools and commonly available materials. This enabled us to be flexible in the design when COVID-19 denied us access to UNSW facilities and overseas components.

Some of the non quantifiable aspects of the design are evaluated below.

### 8.1.3 Driving Experience

The rover was very easy to drive and operate. This is due to the use of a RC transmitter as the control interface. The control sticks are intuitive to use. with directional control on the right and scoop operation on the left. The transmitter is programmable so many controls can be customised to suit different drivers. For example the rear gate control switch can be programmed to any of the switches on the transmitter. During testing many operators (including children) were able to accurately control the rover within 1 or 2 minutes.

### 8.1.4 Would it work on Mars?

Our rovers suitability for Martian operation requires expert assessment that we did not have access to due to COVID-19. We consider that in most areas the rover would operate successfully on the Red Planet. It can easily transit on sand and negotiate obstacles and small rocks. It has a small lightweight power supply and does not require an oxygen atmosphere.

Some form of radiation shielding would need to be provided for the electronics. Some radiation protection is provided by most of vulnerable components being mounted under the regolith container. Assessment of radiation shielding is beyond the scope of this report.

## 8.2 Recommendations for future improvement.

The prototype design performed very well. All design objectives were met. The rover required very little modification when completed. This is due to our use of CAD and testing each system extensively during the build process.

It is extremely robust and is easy to manoeuvre on surfaces of sand and small rocks. It is able to collect and operate with a load more than 130 percent of its weight. During the testing phase of approximately 4 hours of continuous operation no components failed. The only maintenance required was lubrication of the actuator pivots and motor gearboxes.

**Features that could be improved in the future are:**

Use a better quality linear servo that is lighter and better suited to the design geometry. As mentioned above the use of a much larger linear actuator required a redesign of the scoop geometry and a large increase in the operating weight of the rover. The linear actuator pivots should also be replaced with bearings to increase the lifespan of the joints and reduce strain on the actuator.

The scoop could be redesigned to optimize regolith capacity and increase collection rate.

Use larger diameter wheels to give more ground clearance and improve the maximum speed.

The rear gate closure system could be reconfigured to the original solenoid design mentioned above. The servo implementation works well. However, at high loads the servo's are under constant load.

A fuse should be included in the power supply system as mentioned above.

The electronics could be condensed onto a single PCB to use less space and reduce the amount of wiring. Real time telemetry could be added. Real time information on current draw while operating would be useful. The current iteration only allows current measurement when physically plugged into the Arduino IDE. Some semi-autonomous features could be added such as obstacle avoidance.

## 8.3 Notes on the effect of COVID-19

### 8.3.1 Design Complexity

Due to delivery of the rotary encoder being delayed proportional scoop control was not able to be implemented. The design was simplified slightly to a binary on/off operation. We found this had little effect on the final operation.

### 8.3.2 Cost

Due to the COVID-19 related problems shipping electronics from china we had to source many of the electronic components from within Australia leading to budget overruns. The motor controllers, DC-DC voltage converter, Solenoid, and axles were ordered from China in February, but have still not arrived. These parts were re-brought from Australian vendors at a premium. We were able to buy the Arduino from Germany and the motors made it from China before the shutdown.

### 8.3.3 Build Quality

We had planned on using the laser cutters in the for all the plywood machining. We were only able to cut the main profiles, all other machining was completed in a home environment with a Dremel and cordless drill. Therefore the build quality is not as high as could have been achieved.

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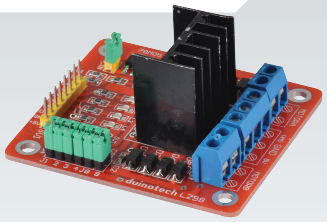
# Appendix A: Datasheets

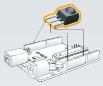

Figure 8.1: Arduino Mega

duinotech

XC4492

# Dual/Stepper Motor Controller Module



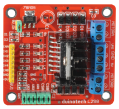


- Type: Module
- Application: Add On Module
- Control the speed of two DC motors or one stepper motor
- Dimensions: 69(L) x 56(W) x 36(H)mm

| Specifications | |
|---|---|
| | Dual/Stepper Motor Controller Module |
| Maximum Current | 4A |
| Logic Voltage | 5VDC |
| Operating Voltage | 3VDC - 30VDC |
| Chipset | L29BN |
| Dimensions | 69(L) x 56(W) x 36(H)mm |
| Additional Features | Status LEDs |

| Pinout | | |
|---|---|---|
| Module | Duinotech | Function |
| ENA | D6 | Enable Motor A |
| IN1 | D4 | Motor A Forward |
| IN2 | D7 | Motor A Reverse |
| IN3 | D3 | Motor B Forward |
| IN4 | D2 | Motor B Reverse |
| ENB | D5 | Enable A |
| GND | GND | Ground Connection |
| +5V | 5V | 5V |
| VMS | - | Power for Module (up to 30V) |
| GND | - | Negative Return for VMS |

Dual/Stepper Motor Controller Module Sample Projects:



Dual/Stepper Motor Controller Module Overview:

Using the powerful L298N Dual Motor Driver, this module allows full control of two DC Motors or one stepper-motor. Features back-EMF and over-temperature protection, it is ideally suited to drive two-motor robot kits such as our KR3130 & KR3132. An on-board 5V regulator can also be used to power your project.

What is included: 1 x Dual Motor Controller Module

Essential Accessories: Robot Chassis (a or KR3132)

Optional Accessories: Battery Pack to provide power for motors

Did you know: There is a 5V regulator on the module which you can use to power your Duinotech mainboard, just make sure the 5V_EN jumper is in place

| Jumper | Function |
|---|---|
| J9/CSB | Place a current sense resistor between these pins to measure current on channel B, or short with jumper if not using a current sense resistor. |
| J8/CSA | Place a current sense resistor between these pins to measure current on channel A, or short with jumper if not using a current sense resistor. |
| J4/UR1 | Jumper on to activate 1KOhm pullup resistor on IN4 (usually not necessary if connected to Arduino). |
| J3/UR2 | Jumper on to activate 1KOhm pullup resistor on IN3 (usually not necessary if connected to Arduino). |
| J2/UR3 | Jumper on to activate 1KOhm pullup resistor on IN2 (usually not necessary if connected to Arduino). |
| J1/UR4 | Jumper on to activate 1KOhm pullup resistor on IN1 (usually not necessary if connected to Arduino). |
| 5V_EN | Jumper on to provide +5V power to the board from 5V regulator from VMS supply |

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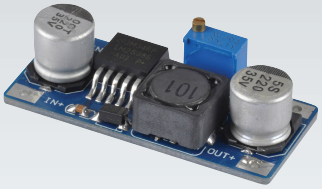
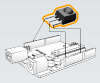
Figure 8.2: L298N Motor Controller

duinotech

XC-4514

# DC- DC Stepdown Module





- Type: Module
- Application: Add On Module
  Step Down DC voltages.
- Dimensions: 49(L) x 26(W) x 12(H)mm

DC - DC Stepdown Module Overview:

This module accepts any voltage from 4.5 - 35VDC, and outputs any lower voltage from 3-34V. Output is adjusted via a multi-turn potentiometer. Use it to run your 5V Duinotech projects from a 6v, 9v or even 12v Supply

Note: With new modules, the pot might be at its highest setting. You will have to turn the potentiometer around 10 times counter clockwise before you see the voltage change.

| Specifications | |
|---|---|
| | DC - DC Stepdown Module |
| Input Voltage | 4.5V - 35V |
| Output Voltage | 3V - 34V |
| Maximum Current | 2.5A |
| Dimensions | 49(L) x 26(W) x 12(H) |

What is included: 1 x DC - DC Stepdown Module

Essential Accessories: 8xAAA Holder (PH9209)

Optional Accessories:

DC - DC Stepdown Module Sample Projects:

Did you know:
The dropout voltage can be as low as 0.8V when the unit is supplying 1A, and it more efficient than the voltage regulator built into the Duinotech UNO Board

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Figure 8.3: DC DC Converter

# Appendix B: Arduino Code

## Test Code

```
// connect motor controller pins to Arduino digital pins
// Linear Actuator - A

int LIN_enB = 46;
int LIN_in3 = 50;
int LIN_in4 = 48;

// Left front - Motor - A
int LF_enA = 2;
int LF_in1 = 3;
int LF_in2 = 4;

// Left Back- Motor B
int LB_in3 = 5;
int LB_in4 = 6;
int LB_enB = 7;

// Right Front- Motor B
int RF_enB = 8;
int RF_in4 = 9;
int RF_in3 = 10;

// Right Back - Motor A
int RB_in2 = 11;
int RB_in1 = 12;
int RB_enA = 13;

void setup()
{
  // set all the motor control pins to outputs
  pinMode(LIN_enB, OUTPUT);
  pinMode(LIN_in3, OUTPUT);
  pinMode(LIN_in4, OUTPUT);

  pinMode(RB_enA, OUTPUT);
  pinMode(RB_in1, OUTPUT);
  pinMode(RB_in2, OUTPUT);

  pinMode(RF_in3, OUTPUT);
  pinMode(RF_in4, OUTPUT);
  pinMode(RF_enB, OUTPUT);

  pinMode(LF_enA, OUTPUT);
  pinMode(LF_in1, OUTPUT);
  pinMode(LF_in2, OUTPUT);

  pinMode(LB_in3, OUTPUT);
```

```
  pinMode(LB_in4, OUTPUT);
  pinMode(LB_enB, OUTPUT);
}

void demoOne()
{
  // this function will run the motors in both directions at a fixed speed
  // turn on Linear Actuator for 6 seconds
  digitalWrite(LIN_in3, LOW);
  digitalWrite(LIN_in4, HIGH);
  // set speed to 200 out of possible range 0~255
  analogWrite(LIN_enB, 255);

  delay(6000);
// Reverse linear actuator for 6 seconds
  digitalWrite(LIN_in3, HIGH);
  digitalWrite(LIN_in4, LOW);
  // set speed to 200 out of possible range 0~255
  analogWrite(LIN_enB, 255);

  delay(6000);


// Set Motors to forward for 6 seconds
//Right Back
  digitalWrite(RB_in1, LOW);
  digitalWrite(RB_in2, HIGH);
  // set speed to 200 out of possible range 0~255
  analogWrite(RB_enA, 255);

//Right Front
  digitalWrite(RF_in3, HIGH);
  digitalWrite(RF_in4, LOW);
  // set speed to 200 out of possible range 0~255
  analogWrite(RF_enB, 255);

//Left Front
  digitalWrite(LF_in1, LOW);
  digitalWrite(LF_in2, HIGH);
  // set speed to 200 out of possible range 0~255
  analogWrite(LF_enA, 255);

//Left Back
  digitalWrite(LB_in3, HIGH);
  digitalWrite(LB_in4, LOW);
  // set speed to 200 out of possible range 0~255
  analogWrite(LB_enB, 255);

  delay(6000);

 // Set Motors backwards for 6 seconds
//Right Back
  digitalWrite(RB_in1, HIGH);
  digitalWrite(RB_in2, LOW);
  // set speed to 200 out of possible range 0~255
  analogWrite(RB_enA, 255);

//Right Front
  digitalWrite(RF_in3, LOW);
  digitalWrite(RF_in4, HIGH);
  // set speed to 200 out of possible range 0~255
  analogWrite(RF_enB, 255);
```

```
110
111 //Left Front
112   digitalWrite(LF_in1, HIGH);
113   digitalWrite(LF_in2, LOW);
114   // set speed to 200 out of possible range 0~255
115   analogWrite(LF_enA, 255);
116
117 //Left Back
118   digitalWrite(LB_in3, LOW);
119   digitalWrite(LB_in4, HIGH);
120   // set speed to 200 out of possible range 0~255
121   analogWrite(LB_enB, 255);
122
123   delay(6000);
124
125 }
126
127 void loop()
128 {
129   demoOne();
130   delay(1000);
131 }
```

# Operating Code

```
/**
*This RC rover operating code is based on the ExplorerBot source code in Chapter 8
*of Arduino Robotics by Warren, JD et al.
*Used with permsision.
*
*****************************************************************************
*Title: ExplorerBot_mixedSteer
*Author: Warren, JD
*Date: 1-8-2010
*Code version: 1.0
*Availability: https://sites.google.com/site/arduinorobotics/home/chapter8
*****************************************************************************
*
*Controls 3x L298N motor controllers connected to 5x 24 Volt motors for RC operation of
*a Mars Regolith Collector prototype.
*The 4 drive motor channels have full 0-100% high-resolution pwm speed control
*The Scoop channel is bi-directional ON/OFF.

*****************************************************************************
*Title: Rover_mixedSteer_v3
*Author: Sharp, D
*Date: 15-4-2020
*Code version: 3.0
*Availability: https://sites.google.com/site/arduinorobotics/home/chapter8
*****************************************************************************
*
*/

// Inputs from RC receiver
int ppm1 = 47;
int ppm2 = 49;
int ppm3 = 51;

// connect motor controller pins to Arduino digital pins
// Linear Actuator - Motor B

int LIN_enB = 46;
int LIN_in3 = 50;
int LIN_in4 = 48;

// LEFT
// Left Front - Motor A
int LF_enA = 3; // PWM
int LF_in1 = 2;
int LF_in2 = 4;

// Left Back - Motor B
int LB_in3 = 5;
int LB_in4 = 6;
int LB_enB = 9; // PWM

// RIGHT
// Right Front - Motor B
int RB_enB = 10; //PWM
int RB_in4 = 7;
int RB_in3 = 8;

// Right Back - Motor A
int RF_in2 = 12;
```

```
int RF_in1 = 13;
int RF_enA = 11; //PWM

unsigned int servo1_val; // unsigned integer simply means that it cannot be negative.
int adj_val1;
int servo1_Ready;

unsigned int servo2_val;
int adj_val2;
int servo2_Ready;

unsigned int servo3_val;
int adj_val3;
int servo3_Ready;

unsigned int servo4_val;
int adj_val4;
int servo4_Ready;

////////////////////////////////

int deadband = 100; // sets the total deadband - this number is divided by 2 to get the deadband for each direction. Higher value will yield larger neutral band.
int deadband_high = deadband / 2; // sets deadband_high to be half of deadband (ie. 10/2 = 5)
int deadband_low = deadband_high * -1; // sets deadband_low to be negative half of deadband (ie. 5 * -1 = -5)

// You can adjust these values to calibrate the code to your specific radio - check the Serial Monitor to see your values.
int low1 = 900;
int high1 = 2000;
int low2 = 900;
int high2 = 2000;

int x; // this will represent the x coordinate
int y; // this will represent the y coordinate

int left; // X and y will be converted into left and right values
int right; // X and y will be converted into left and right values

int speed_low;
int speed_high;

int speed_limit = 255;

int speed_max = 255;
int speed_min = 0;


void setup() {

  TCCR1B = TCCR1B & 0b11111000 | 0x01; // change PWM frequency on pins 9 and 10 to 32kHz
  TCCR2B = TCCR2B & 0b11111000 | 0x01; // change PWM frequency on pins 3 and 11 to 32kHz

  Serial.begin(9600);

  // set all the motor control pins to outputs
  pinMode(LIN_enB, OUTPUT);
  pinMode(LIN_in3, OUTPUT);
  pinMode(LIN_in4, OUTPUT);

  pinMode(RF_enA, OUTPUT);
```

```
  pinMode(RF_in1, OUTPUT);
  pinMode(RF_in2, OUTPUT);

  pinMode(RB_in3, OUTPUT);
  pinMode(RB_in4, OUTPUT);
  pinMode(RB_enB, OUTPUT);

  pinMode(LF_enA, OUTPUT);
  pinMode(LF_in1, OUTPUT);
  pinMode(LF_in2, OUTPUT);

  pinMode(LB_in3, OUTPUT);
  pinMode(LB_in4, OUTPUT);
  pinMode(LB_enB, OUTPUT);

  //PPM inputs from RC receiver
  pinMode(ppm1, INPUT);
  pinMode(ppm2, INPUT);
  pinMode(ppm3, INPUT);

  delay(1000);

}


void pulse(){

  servo1_val = pulseIn(ppm1, HIGH, 20000); // read pulse from channel 1
  // make sure servo 1 value is within range (between 800 and 2200 microseconds)
  if (servo1_val > 800 && servo1_val < 2200){
    servo1_Ready = true;
  }
  else {
    servo1_Ready = false;
    servo1_val = 1500;
  }

  servo2_val = pulseIn(ppm2, HIGH, 20000); // read pulse from channel 2
  if (servo2_val > 800 && servo2_val < 2200){
    servo2_Ready = true;
  }
  else {
    servo2_Ready = false;
    servo2_val = 1500;
  }

    servo3_val = pulseIn(ppm3, HIGH, 20000); // read pulse from channel 3
  if (servo3_val > 1800){
    raise_scoop();
  }

  else if (servo3_val < 1200){
    lower_scoop();
  }
  else{
    stop_scoop();
  }
}



void loop() {
```

```
181
182   pulse(); // read pulses
183
184   ////////////////////////////////
185
186   if (servo1_Ready) {
187
188     servo1_Ready = false;
189     // map servo value from 1500 microseconds (neutral) to a value of 0.
190     //If pulse is above neutral (forward) value will be 0 to 255, otherwise it will be 0 to
      -255 for reverse
191     adj_val1 = map(servo1_val, low1, high1, -speed_limit, speed_limit);
192     adj_val1 = constrain(adj_val1, -speed_limit, speed_limit);
193
194     x = adj_val1;
195
196   }
197   if (servo2_Ready) {
198
199     servo2_Ready = false;
200
201     adj_val2 = map(servo2_val ,low2, high2, -speed_limit, speed_limit);
202     adj_val2 = constrain(adj_val2, -speed_limit, speed_limit);
203
204     y = adj_val2;
205
206   }
207
208
209
210   if (x > deadband_high) {  // if the Up/Down R/C input is above the upper threshold, go
      FORWARD
211
212     // now check to see if left/right input from R/C is to the left, to the right, or centered
      .
213
214     if (y > deadband_high) { // go forward while turning right proportional to the R/C left/
      right input
215       left = x;
216       right = x - y;
217       test(); // make sure signal stays within range of the Arduino capable values
218       left_forward(left);
219       right_forward(right);
220       // quadrant 1
221     }
222
223     else if (y < deadband_low) {   // go forward while turning left proportional to the R/C
      left/right input
224       left = x - (y * -1);  // remember that in this case, y will be a negative number
225       right = x;
226       test();
227       left_forward(left);
228       right_forward(right);
229       // quadrant 2
230     }
231
232     else {   // left/right stick is centered, go straight forward
233       left = x;
234       right = x;
235       test();
236       left_forward(left);
237       right_forward(right);
```

```
238     }
239   }
240
241   else if (x < deadband_low) {    // otherwise, if the Up/Down R/C input is below lower
        threshold, go BACKWARD
242
243     // remember that x is below deadband_low, it will always be a negative number, we need to
        multiply it by -1 to make it positive.
244     // now check to see if left/right input from R/C is to the left, to the right, or centered
        .
245
246     if (y > deadband_high) { // // go backward while turning right proportional to the R/C
        left/right input
247       left = (x * -1);
248       right = (x * -1) - y;
249       test();
250       left_reverse(left);
251       right_reverse(right);
252       // quadrant 4
253     }
254
255     else if (y < deadband_low) {   // go backward while turning left proportional to the R/C
        left/right input
256       left = (x * -1) - (y * -1);
257       right = x * -1;
258       test();
259       left_reverse(left);
260       right_reverse(right);
261       // quadrant 3
262     }
263
264     else {   // left/right stick is centered, go straight backwards
265       left = x * -1;
266       right = x * -1;
267       test();
268       left_reverse(left);
269       right_reverse(right);
270     }
271
272   }
273
274   else {     // if neither of the above 2 conditions is met, the Up/Down R/C input is centered
       (neutral)
275
276     if (y > deadband_high) { //spin right
277
278       left = y;
279       right = y;
280       test();
281       left_forward(left);
282       right_reverse(right);
283
284     }
285
286     else if (y < deadband_low) { //spin left
287
288       left = (y * -1);
289       right = (y * -1);
290       test();
291       left_reverse(left);
292       right_forward(right);
293
```

```
    }

    else {

      left = 0;
      right = 0;
      left_stop();
      right_stop();
    }

  }

  Serial.print(left);
  Serial.print("   ");
  Serial.print(right);
  Serial.print("    ");

  Serial.print(servo1_val);
  Serial.print("   ");
  Serial.print(servo2_val);
  Serial.print("    ");
  Serial.print(servo3_val);
  Serial.println("   ");
}


int test() {

  // make sure we don't try to write any invalid PWM values to the h-bridge, ie. above 255 or
    below 0.

  if (left > 254) {
    left = 255;
  }
  if (left < 1) {
    left = 0;
  }
  if (right > 254) {
    right = 255;
  }
  if (right < 1) {
    right = 0;
  }

}


// Create single instances for each motor direction, so we don't accidentally write a shoot-
    through condition to the H-bridge.

void right_forward(int m2_speed){
  analogWrite(RF_enA, m2_speed);
  digitalWrite(RF_in1, LOW);
  digitalWrite(RF_in2, HIGH);
  digitalWrite(RB_in3, HIGH);
  digitalWrite(RB_in4, LOW);
  analogWrite(RB_enB, m2_speed);
}

void right_reverse(int m2_speed){
  analogWrite(RF_enA, m2_speed);
  digitalWrite(RF_in1, HIGH);
```

```
  digitalWrite(RF_in2, LOW);
  digitalWrite(RB_in3, LOW);
  digitalWrite(RB_in4, HIGH);
  analogWrite(RB_enB, m2_speed);
}

void left_forward(int m1_speed){
  analogWrite(LF_enA, m1_speed);
  digitalWrite(LF_in1, LOW);
  digitalWrite(LF_in2, HIGH);
  digitalWrite(LB_in3, HIGH);
  digitalWrite(LB_in4, LOW);
  analogWrite(LB_enB, m1_speed);

}

void left_reverse(int m1_speed){
  analogWrite(LF_enA, m1_speed);
  digitalWrite(LF_in1, HIGH);
  digitalWrite(LF_in2, LOW);
  digitalWrite(LB_in3, LOW);
  digitalWrite(LB_in4, HIGH);
  analogWrite(LB_enB, m1_speed);
}

void right_stop(){
  digitalWrite(RF_in1, LOW);
  digitalWrite(RF_in2, LOW);
  digitalWrite(RB_in3, LOW);
  digitalWrite(RB_in4, LOW);
}

void left_stop(){
  digitalWrite(LF_in1, LOW);
  digitalWrite(LF_in2, LOW);
  digitalWrite(LB_in3, LOW);
  digitalWrite(LB_in4, LOW);
}

void raise_scoop(){
  digitalWrite(LIN_in3, HIGH);
  digitalWrite(LIN_in4, LOW);
  analogWrite(LIN_enB, 255);
}

void lower_scoop(){
  digitalWrite(LIN_in3, LOW);
  digitalWrite(LIN_in4, HIGH);
  analogWrite(LIN_enB, 255);
}

void stop_scoop(){
  digitalWrite(LIN_in3, LOW);
  digitalWrite(LIN_in4, LOW);
  analogWrite(LIN_enB,0);
}
```

# Appendix C: Purchasing List

| **Component List** | | | |
|---|---|---|---|
| **No** | **Description** | **Quantity** | **Vendor** |
| **Main Components** | | | |
| 1 | Interior Plywood Sheet 897mm*600mm*7mm | 1 | Bunnings |
| 2 | Interior Plywood Sheet 1200mm*810mm*3mm | 1 | Bunnings |
| 3 | Threaded Stainless Steel Rod 1200mm*6mm | 1 | Bunnings |
| 4 | Angle Bracket 25mm*25mm*40mm | 3 | Bunnings |
| 5 | M5*35mm Machine Bolt | 3 | Bunnings |
| 6 | M5 Flat Washer 35Pk | 1 | Bunnings |
| 7 | M5 Hexagon Nut 20Pk | 1 | Bunnings |
| 8 | M6 Nylon Lock Nut 6pk | 2 | Bunnings |
| 9 | M6 Nylon Stainless Steel Nut 6pk | 2 | Bunnings |
| 10 | M3*15 mm Machine Bolt | 3 | Bunnings |
| 11 | M3 Flat Washer 35Pk | 1 | Bunnings |
| 12 | M3 Hexagon Nut 200Pk | 1 | Jaycar |
| 13 | Threaded Stainless Steel Rod 1200mm*8mm | 1 | Bunnings |
| 14 | Corflute | 1 | Bunnings |
| 15 | Rustoleum Spray Paint (Orange & Gray) | 2 | Bunnings |
| 16 | MEGA 2560 R3 Arduino ATmega2560 | 1 | eBay |
| 17 | 37mm 24V DC High Torque Gear Box Motor | 4 | eBay |
| 18 | Module DC-DC Volt Regulator Arduino Comp | 1 | Jaycar |
| 19 | DC24V 100mm Multi-function Linear Actuator | 1 | eBay |
| 20 | Spektrum AR6210 2.4G 6CH Receiver | 1 | Secondhand |
| 21 | Arduino Compatible Stepper Motor Controller Module | 3 | Jaycar |
| 22 | Arduino Compatible 5A Current Sensor Module | 1 | Jaycar |
| 23 | 15 Gauge Hookup wire (Red & Black) | 2 | Jaycar |
| 24 | Mini Brass Spade Connector 100Pk | 1 | Jaycar |

# Appendix D: YouTube Playlist

A YouTube playlist of the build and testing videos is here.