Design of a Martian Mining Robot

Team # 22 Operation Manual

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Submitted: 4/7/17

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Abstract

This report details the requirements for NASA's 2017 Robotic Mining Competition (RMC). This competition entails on-site mining, a systems engineering paper, and an outreach project report. The on-site mining includes building a robot within the given size and weight limitations that will traverse simulated Martian terrain, excavate regolith and ice simulants, and return them to a collector bin. The systems engineering paper will explain in detail the methodology used during the project's inception, design, build, and testing. The outreach project report will require the team to promote STEM to the community via public outreach as well as social media. This competition is beneficial for NASA because it encourages the development of innovative robotic excavation concepts that possibly could be applied to future excavation missions.

1. Functional Analysis

The function of this project is to successfully compete in NASA's Robotic Mining Competition. The purpose of this competition is to develop an innovative robotic excavation concepts that possibly could be applied to future excavation missions. The main objective of the competition is to create an autonomous or teleoperated vehicle that can mine Martian regolith and transport the gathered material to a deposit bin in a designated space. This project will achieve these requirements by creating a two part system that separates the mining and transportation. Due to time and budget restraints, the primary focus for this project will be manufacturing and controlling the Rocker-Bogie transportation rover.

The transportation function will be handled by a six wheeled autonomous rover that incorporates a rocker bogie suspension and a tipper mechanism. The Rocker-Bogie was chosen based off background research as well as testing. The Rocker-Bogie was the optimal design because it will be able to traverse the obstacle course with ease. Also, it is a springless system that would be advantageous on Mars.

The mining function will be handled by an autonomous stationary robot that piggybacks off the transportation rover to move. It uses a rock bucket design for the collection process that allows for easy access to material beneath the surface. The mining robot will be able to collect material to a certain depth and deposit the material into the bucket attached to the transportation rover.

2. Product Specifications

The Rocker-Bogie design will incorporate six independently driven brushed Maxon DC motors. These motors are 403044 combination motor, the nominal voltage is 18 V with an unloaded speed of 3,520 rpm. The nominal torque is 427 mNm. These motors include a HEDL

5540 encoder. This encoder reads 500 counts per turn and uses a 3 channel system.

This competition requires telecommunication via wireless networking. Using an Xbox controller connected to a Laptop running Python, the team will be able to communicate wirelessly with an onboard Raspberry Pi 3. The Raspberry Pi 3 has a built in wifi chip allowing for logic communication through internet connection. The Raspberry Pi 3 contains a BCM2837 processor, 1Gbyte LPDDR2 RAM and 4 Gbytes eMMC flash memory. The Raspberry Pi then communicates with an Arduino MEGA 2560 that handles the lower level logic of the system. Due to the operating voltages of the two boards a logic level converter is required to convert data to the appropriate voltages The Arduino MEGA has 54 Input/Output pins along side 16 analog pins. The following tables show the important technical specifications for each board.

Bridging the Arduino and Maxon Motors are the Sabertooth 2x60 dual motor drivers. The Sabertooth has an operating range of 6-30 Volts and 60 Amps per channel. Channels are set to 111011 for flip switches. For wire connection make sure positive connects are connected to B+ and ground is B- as inverted connects will cause failure.

Table 1: Technical Specs of Arduino Mega

Technical specs

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37 g

Table 2: Technical Specs for Raspberry Pi 3

	Raspberry Pi 3 Model B
Introduction Date	2/29/2016
SoC	BCM2837
CPU	Quad Cortex A53 @ 1.2GHz
Instruction set	ARMv8-A
GPU	400MHz VideoCore IV
RAM	1GB SDRAM
Storage	micro-SD
Ethernet	10/100
Wireless	802.11n / Bluetooth 4.0
Video Output	HDMI / Composite
Audio Output	HDMI / Headphone
GPIO	40
Price	$35

3. Product Assembly

Seen below in Figure 1 and Figure 2 are the complete CAD model for the rover portion of the Project. The rover portion of the project includes a rocker-bogie suspensions, a bucket dumping mechanism, and six wheel powered steering.

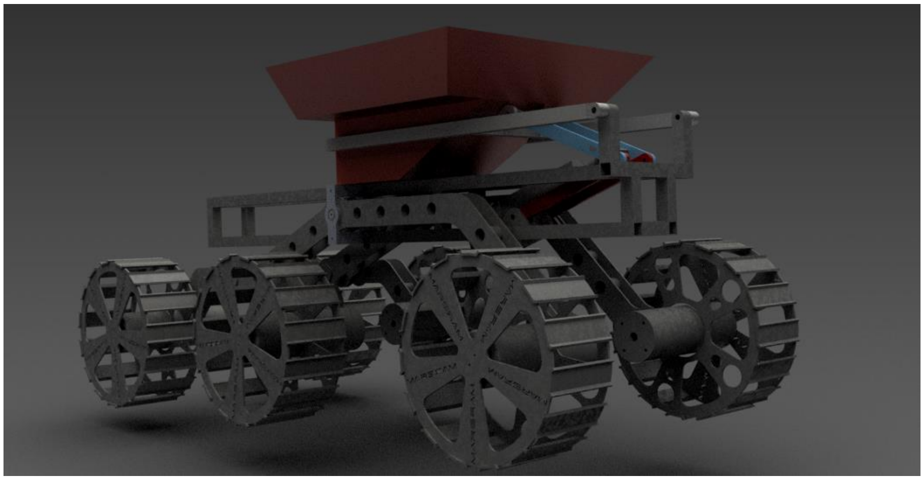

Figure 1: Isometric Front View of Rover

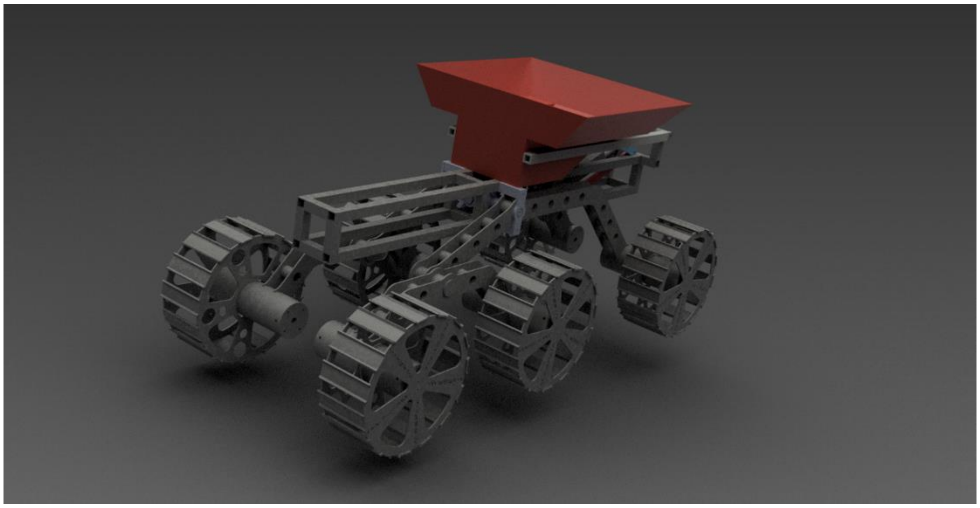

Figure 2: Isometric Back View of Rover

Seen in Figure 3 is the exploded view of the motor housing seen in the previous images. The CAD model for the motor housing includes the back cap, the shell, the bearing block, the bearing, the shaft collar, the front cap, the wheel connect and the wheel in order from left to right. Not included is the CAD model of the motor that sits inside the shell and is bolted in the front and back using M4 bolts. As with the Martian Mining Competition the protective shell is needed to protect the motor from dust and debris from a simulated Martian climate.

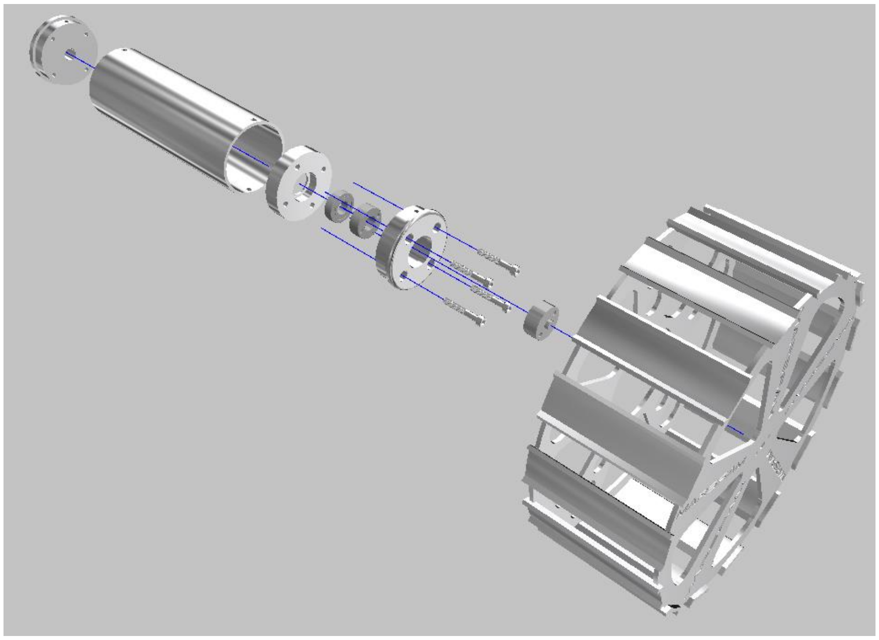

Figure 3: Exploded View of Wheel Housing

The mechanism driving the bucket arm, seen in Figure 4, can be seen below in Figure 5, which can be seen in Figure 2 with CAD models both having the highlighted blue and red linkages. The linkage design is based off the dumping mechanisms found in dump trucks.

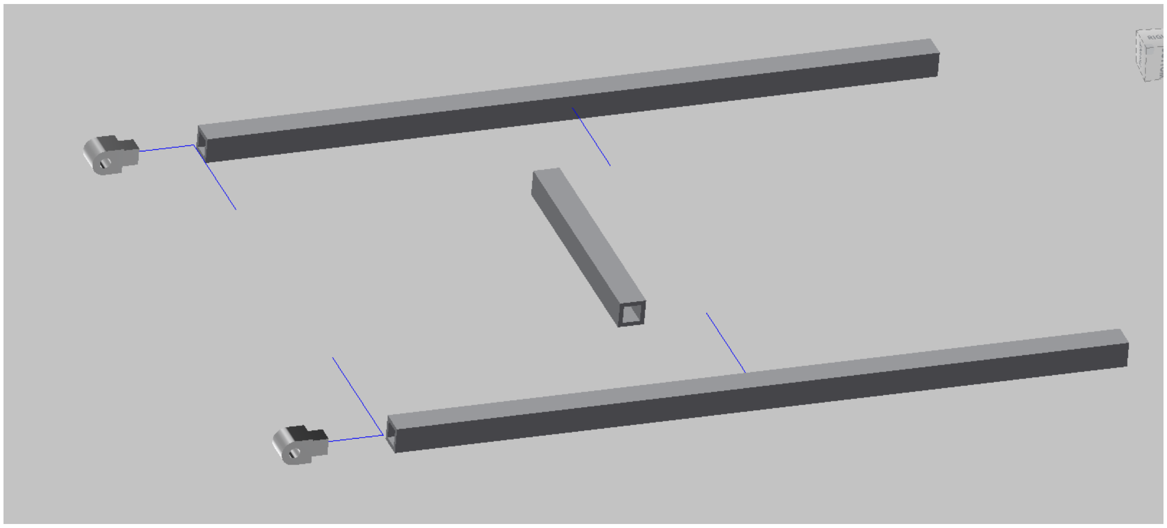

Figure 4: Exploded View of Bucket Arm

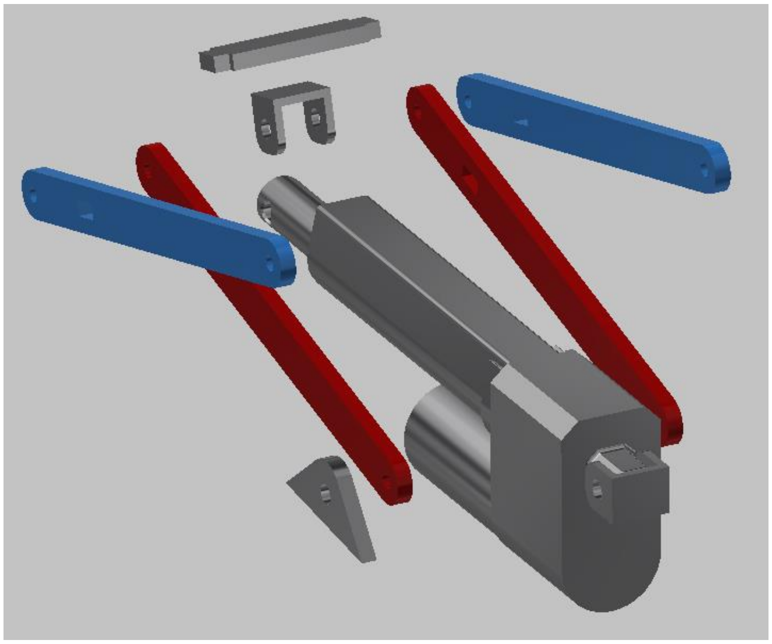

Figure 5: Exploded View of Bucket Arm Mechanism

The Rocker and Bogie were originally designed to be made of circular tubing that would be bent into shape; however, during construction this design was found to be difficult and unable to mirror itself for the opposite side of the rover. In order to increase efficiency and ease of manufacturing a simple water jetted face was constructed that was held together using the standard one inch tubing as connectors. Seen in Figure 6 and 7 are the exploded view of the rover bogie models.

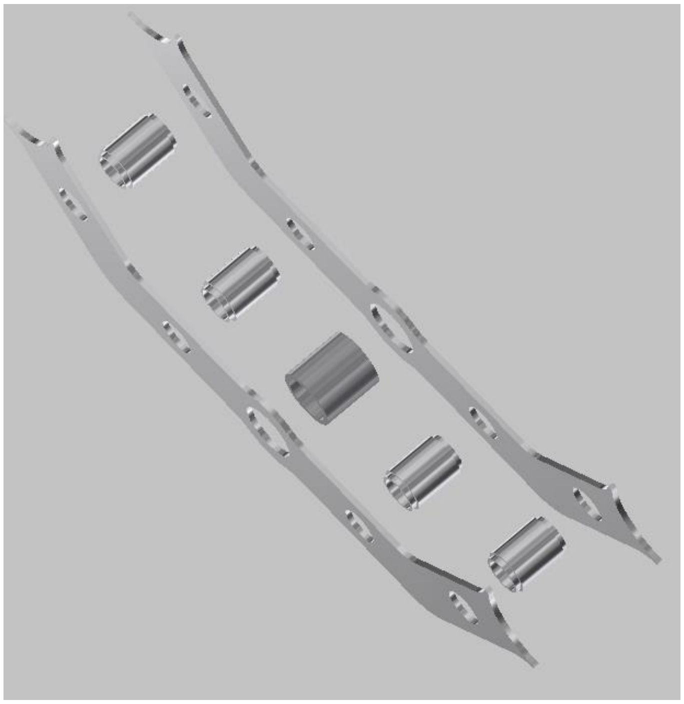

Figure 6: Exploded View of the Bogie

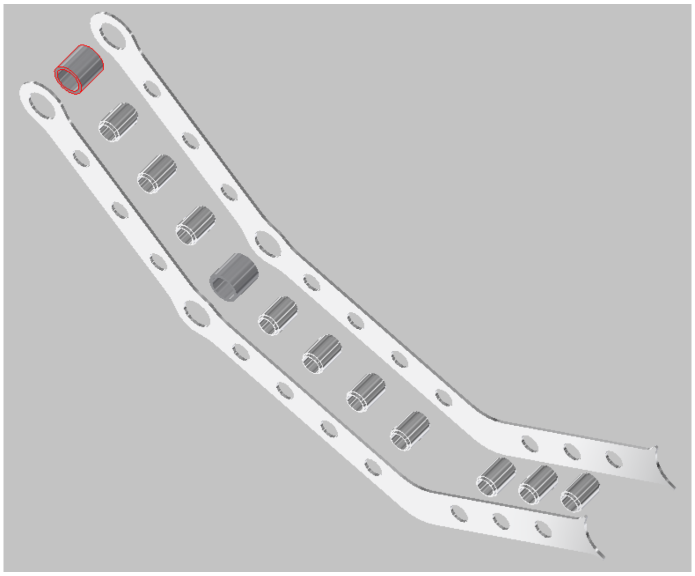

Figure 7: Exploded View of the Rocker

In Figure 8 is the exploded view of the frame for the rover. The design incorporated simple geometry that was easy to create and manufacture using square piping. The square frame design allows for an easy build and high reliability.

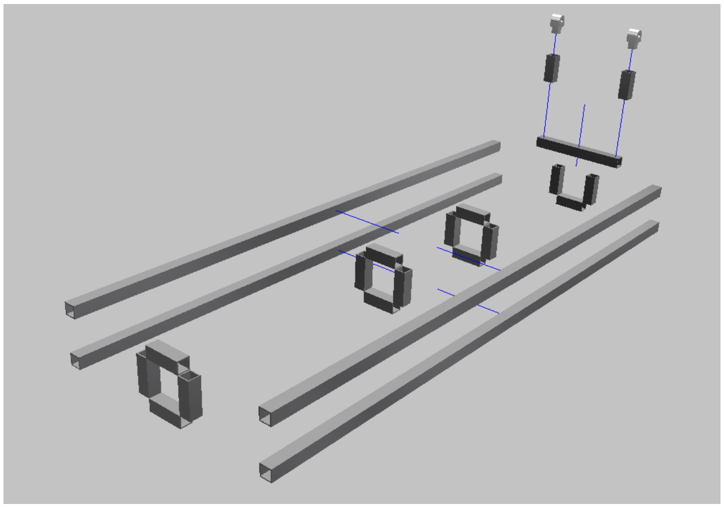

Figure 8: Exploded View of the Frame

Seen below in Figure 9 is the CAD of the mining device for the project. The mining device will be able to collect the Martian dirt simulate at a depth of 1.5 feet and collect the Martian ice simulate underneath.

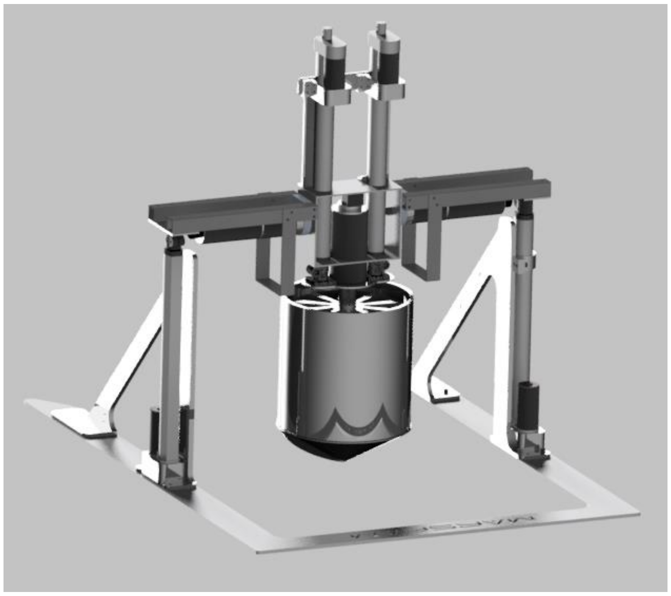

Figure 9: CAD Model for Mining Device

Holding the central mining device to the ground frame is the motor housing and the feet for the transportation of the mining device seen in Figure 10. The feet will be able to rest in the bucket of the rover and hold itself while being transported. The motor housing includes a bearing block shield for dust prevention. The center section of the Mining device can be seen in Figure 11 and contains a bucket, linear actuators with their supports and a central frame box.

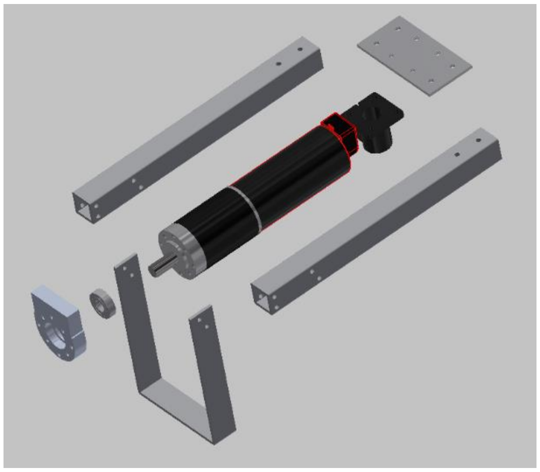

Figure 10: Exploded View of Motor Housing and Feet

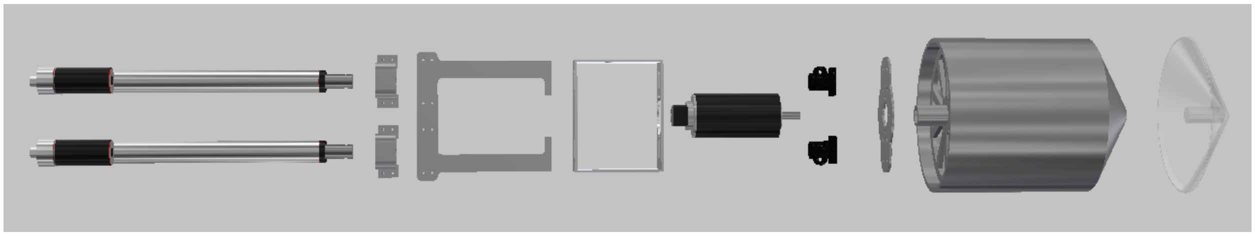

Figure 11: Exploded View of Central Mining Mechanism

4. Operation Instructions

To operate the rover, connect your laptop to the same wireless network that the Raspberry Pi is connected to. Then connect the Xbox Controller to the Laptop, the values from the controller should read into Python and wirelessly transmit to the Raspberry Pi on the rover.

i.) Inspect the rover to ensure the rover will move properly.

ii.) Ensure all wires are properly connected and complete.

iii.) Pull the Red Emergency Kill Switch to power the rover.

iv.) Check voltage regulators and ensure 5V is sent to the logic controllers and 12V is sent to the linear actuator.

v.) Maneuver the rover by using the D-Pad on the Xbox Controller.

vi.) Control the motion of the linear actuator connected to the bucket by using the Left Thumb stick on the Xbox Controller.

vii.) Push the Red Emergency Kill Switch to power off the rover.

Figure 12: D-Pad on Xbox Controller

Figure 13: Left Thumb stick on Xbox Controller

5. Troubleshooting

Compared to a typical four-wheeled fixed frame design the rocker-bogie has far more moving parts. As with all moving parts the general wear and tear of motion can have an effect on performance of the robot and can lead to adverse effects to the design. To combat these issues the design was created to have easily replaceable parts for a majority of the structure. Many of these critical pieces can be cut using a water jet and bolted back into place. Take the rockers for example; the design is created of two water jetted faces with simple one inch pipes welded into the precut holes. For the large structures that are not water jetted redundancies were implemented that in case of one structural failure the system will continue operating. For example, the base frame of the rover has several extra cross beams in the structure to reduce the effects of deflection from use.

One of the main issues that arose during the construction of the rover was the creation of the wheel housings around the motors. The original plan was to use the bolt patterns in the motor to attach a front and back cap to the motor inside an aluminum tube and tighten until friction would disallow the entire motor to spin within the shell; however, upon tightening the bolts into the back of the motor the motor shaft bound up until the bolts were loosened. To circumnavigate the issue key bolts were drilled into the side of the tubing and the front caps to remove the ability for the motor to spin freely within the frame. Tightening the back bolts will cause the butt end of the motor to actually pull out from the motor rendering it useless.

The motors used for the rover wheels can be considered crudely built. If the back screws of the motors are actually tightened too much it will cause the back end of the motor to physically pull off from the shell and break the motor. Likewise, the leads off the back end of the motors are very sensitive and cannot be replaced easily if broken or snapped off. For example, when the motors were donated one did not have leads and one only had one lead. In order to fix it a hole had to be drilled into the motor and then cleared out enough to allow some to solder a new lead. Maxon discontinued these motors for a reason so there are no spare parts.

Another issue for the rover design is the bucket dumping mechanism. While the linear actuator physically put the linkages into toggle or in a reverse motion the resting position of the bucket is not at the minimum length of the actuator. To address this a button will or will need to be placed in the linkages that deactivates the linear actuator when the bucket returns to the down position or the linear actuator will shear or bend the bolts holding it in place.

6. Regular Maintenance

Regular maintenance is required for this rover. The battery needs to be charged after every use. Also the wiring needs to be checked to make sure everything is connected properly. Since this rover will be exposed to BP1 Simulant (fine sand), the electronics will be enclosed to ensure protection of the motors, gearbox, and other electronics. Grease can be applied to the differential gear, and the shafts. Critical components of the design have been designed to be easily remanufactured using water jetted cutouts and can be easily replaced if worn down or damaged.

7. Spare Parts/ Inventory

For parts selection the materials were chosen based on their commonality and accessibility for purchase. All electronics were selected from Amazon and at this time are on Amazon Prime for quick delivery. Similarly, the bolts used within the project are standard sizes and easily found in most common hardware stores. In the tables below are the excess hardware for the team that were previously purchased and not used on the rover already designed for the project.

Table 3: Spare Parts List for Materials

Part	Critical Dimensions	Amount
Aluminum Square Piping	0.75in x 0.75in	12in Length
Aluminum Pipe	1in Diameter	20 feet
Aluminum Block	3/8x5x12in	1
M4 Bolts	65mm Length	approx 30

M5 Bolts	40mm Length	approx 30
Shaft Collars	12mm ID	4
Axial Bearings	⅜ ID	3
Axial Bearings	12mm ID	4
Aluminum Sheet	1/2in Thickness	Various
Aluminum Sheet	1/4in Thickness	Various

Table 4: Spare Parts List for Electronics

Part	**Critical Dimensions**	**Amount**
WINDYNATION 16 Inch 16" Stroke Linear Actuator	16” Stroke	4
DC Electricity Usage Monitor		1
Raspberry Pi Camera Module V2		1
Raspberry Pi Camera Case		1
CanaKit Raspberry Pi 3 Kit with Clear Case and 2.5A Power Supply		2
Electronic Component Stand Offs	Various	Various
Arduino Uno		1
Small Voltmeter		4
Logic Level Shifter		1
IR Sensors		2
Accelerometer		1
Limit Switches		1
Breadboards		1
12 Gauge Wire	12 Gauge	Approx 10 feet
Crimp Terminals		Approx 20
Motor Drivers for Linear Actuators		2

8. Conclusion

This project is to compete at NASA's Robotic Mining Competition. Due to budget and time constraints, the focus of this project is manufacturing and controlling the rocker-bogie transportation rover. This operation manual details the various product specifications used in this design. For example six independently driven Maxon DC motors will be used to drive the rover. Additionally, the specifications for the Raspberry Pi 3 and the Arduino Mega are included. The CAD product assembly drawings are displayed to detail the various manufactured parts for the rover. A concise operation instructions list is displayed to easily allow users to operate the rover. Various scenarios are addressed and resolved to troubleshoot the rover. Regular maintenance and inspections are recommended. A list of spare parts are attached if needed.

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