Luna - The MANSEDS Lunar Rover Preliminary Design Review

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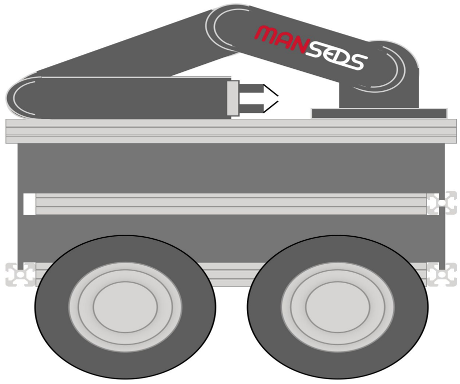

Executive Summary

This document will establish the first stages of the Manchester lunar rover and, as such, act as an important milestone in the development process. The preliminary design review aims to evaluate the current design solution. This evaluation will compare the design to the competition requirements, highlighting challenges and building on previous efforts.

Upon finalising the review, all qualities of the requirements have been met and the details of the considerations and trade-offs deciphered throughout the past few months are detailed in this review.

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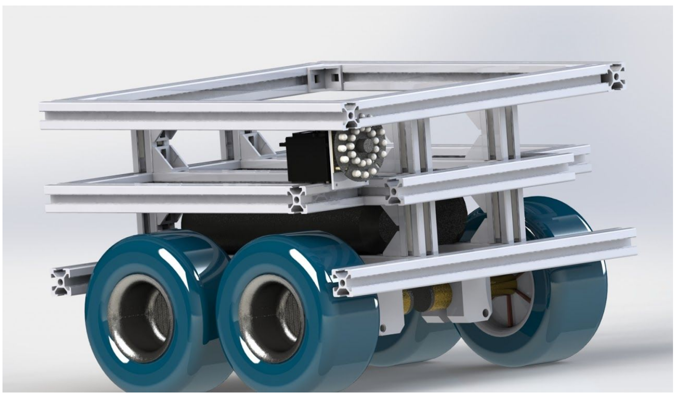


1 INTRODUCTION

1.1 Mission Statement

The mission of this team is to build a rover capable of meeting as many space requirements as possible. Throughout this process we hope to individually discover and learn more about our respective interests, as well as collectively build an ambitious yet achievable rover.

In light of this, we are designing a lunar rover capable of meeting all requirements and exceeding all expectations, while creating opportunities for ourselves to expand our knowledge in both theory and practical applications associated with complex machines. Ultimately, building a lunar rover presents us with the perfect opportunity to grasp this mission.

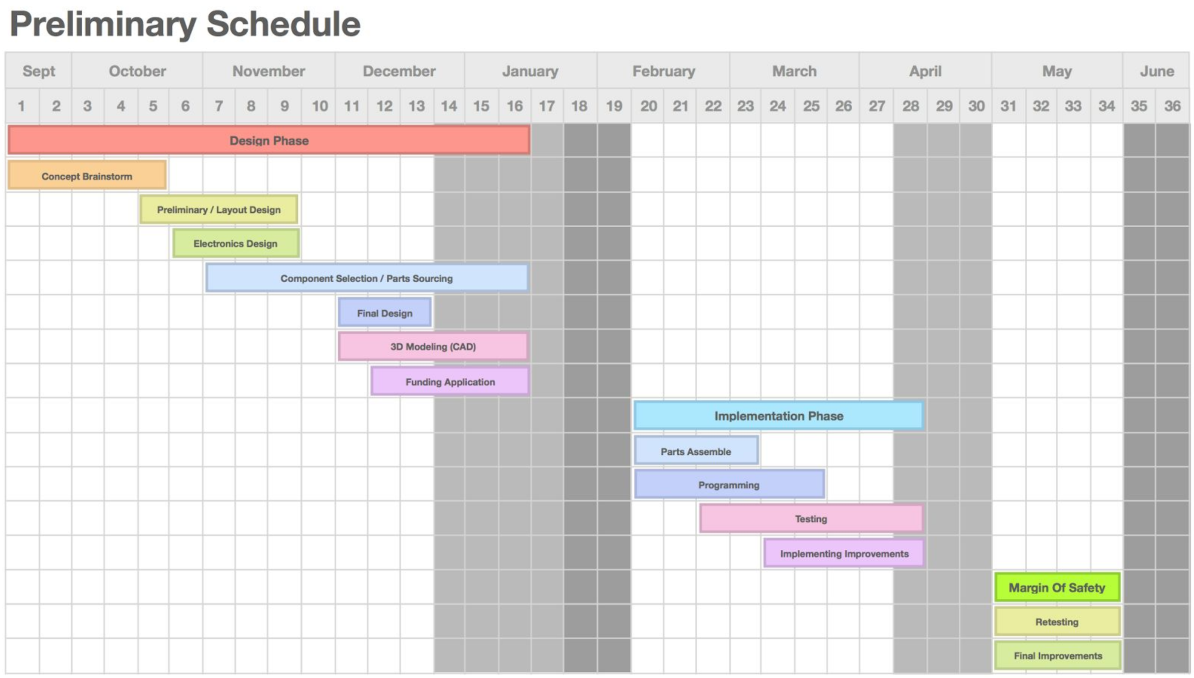
2 PROJECT MANAGEMENT

2.1 Assigned Roles & Team Roster

Name	**Role**	**Contact**	**Programme**	**Year**
Derya Kirdag	Project Leader	derya.kirdag13@gmail.com	M.Eng.(Hons) Mechanical Engineering	4
Ethan Ramsay	Lead Design Engineer / Systems Engineer	ethanlramsay@gmail.com	M.Eng.(Hons) Mechanical Engineering	4
Matthew Marshall	Co-Lead	matthew.marshall96@yahoo.com	Physics	4
Matthew Liu	Design Engineer / Code Monkey	matthewliu108@gmail.com	Physics	2
Hooi Ju Lim	Embedded Systems Engineer	limhooiju@yahoo.com	EEE	3
James Lockwood	Control Systems Engineer	james.lw129@gmail.com	Physics	1
Wilbur Chen	Structural Engineer	wilbur.wpchen@gmail.com	M.Eng.(Hons) Materials Science and Engineering	3
Rob White	Drive Systems Engineer	rsw6626@gmail.com	Physics	3
Piotr Hajduczenia	Mechanical Engineer	piotr.hajduczenia@postgrad.manchester.ac.uk	M.Sc. Mechanical Engineering Design	4

2.2 Preliminary Schedule

The diagram below indicates the estimated time required for each of the tasks we will tackle in the project, time requirements are based on past experiences in similar projects.



There are 3 main phases in this project which are the design phase, implementation phase and testing/margin of safety split into a 36 week academic year. As a team, we have agreed to have minimal workloads during the holidays indicated by areas of light gray shading and have zero workloads during exam periods indicated by areas of dark gray shading.

2.3 Preliminary Budget

Previously owned items from the MANSEDS inventory can be used with no cost. The funding for further materials is dependant on the competition funding from UKSEDS and funding received by MANSEDS as a student society.

	TASK		PRICE PER UNIT	QUANTITY	TOTAL COST (£)
Drive System	Gearmotor	link	£27.34	1	£27.34
	Motor Driver	link	£13.50	4	£54.00
	Axle and wheels		PRE OWNED	1	£0.00
Power System	Battery		£150.00	1	£150.00
	Battery Charger	link	£16.88	1	£16.88
	DC-DC converter		£7.00	1	£7.00
Structure	Framing	link	£3.75	5	£18.75

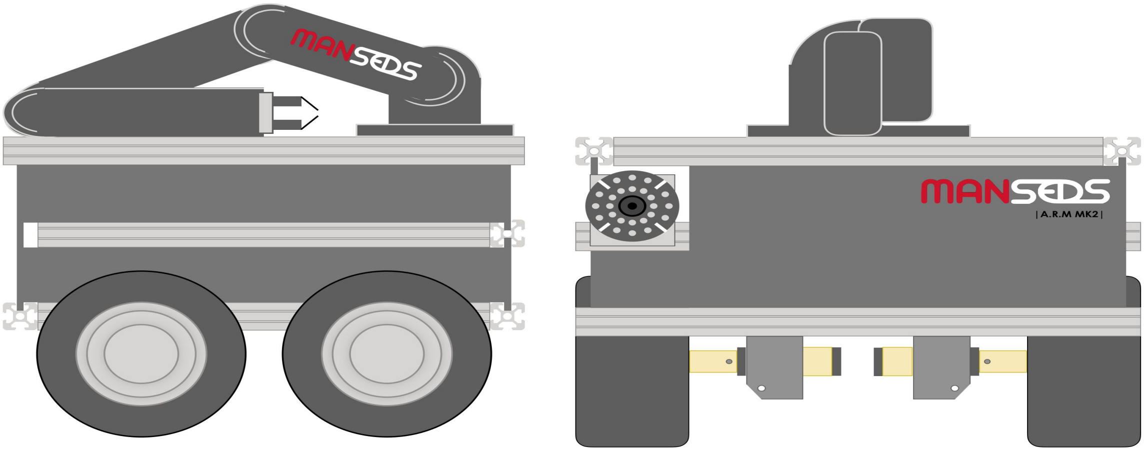
	Connections	link	£1.43	30	£42.90
	Base		**£5.00**	**1**	**£5.00**
	Proximity Sensors		**£12.00**	**3**	**£36.00**
	Proximity Sensors		PRE OWNED	8	£0.00
	Cameras	link	PRE OWNED	3	£0.00
	Thermal Sensors	link	PRE OWNED	1	£0.00
Functional Components	IMU	link	PRE OWNED	1	£0.00
Control System	Microcontroller	link	£29.99	1	£29.99
	PWM Hat	link	£16.00	1	£16.00
Arm System	Actuators		PRE OWNED	4	£0.00
	Structural Parts				£10.00
Subtotals					£413.86
Risk (Contingency)				10%	£41.39
Total (Scheduled)					£455.25

2.4 Project Risks & Management

The risk management plan consists of four steps: 1) Identification, 2) analysis, 3) response planning, and 4) monitoring, controlling and reporting; if necessary, new risks will be identified during the project duration.

Risk	**Avoid** - *Eliminate cause*	**Mitigate** - *Reduce impact/likelihood*	**Accept** - *No action*	**Transfer** - *Share risk with a third party*
Under budgeting	x	Add a markup to the budget	x	x
Failure to raise funding	Seek funds from several sources	x	x	x
Logistic delay	x	Schedule purchasing buffer and margin	x	x
Lack of expertise	x	x	x	Collaborate with experts

3 PRELIMINARY CONCEPT



The rover will be built to have 3 seperate layers joined together with struts of different lengths, the rover will also have a robotic arm mounted on the 2nd layer, with the base completely submerged below the 1st layer, providing a large range of motion for the arm.

3.1 Mechanical Design

3.1.1 Requirements

The main requirements for the rover would be to fit within a 300 x 300 x 300 mm box in its lowest effective volume configuration with a total combined weight of no higher than 5kg. The rover will also be required to withstand sinusoidal vibrations of up to 5g. It must be capable of remote controlled driving and sample collection.

3.1.2 Drive System

The rover will be driven by four individually controlled high torque 26 rpm motors in order to provide the torque required to traverse hostile conditions on the lunar surface. Each motor is electronically controlled and provides 42 kgf.cm of torque, allowing the rover to drive up the steepest slopes that its low centre of gravity and high grip wheels permit. Each motor is fixed to the structure of the rover. Steering is achieved by varying the speed of each bank of motors, which is suitable to the wheelbase / axle length ratio. Each motor is directly connected to a high grip, off-road tyre.

3.1.3 Collection System

The team came up with several options for the sample collection system, the final choice was to use a robotic arm. Consisting of three links with a double excavator bucket as the effector, this arm is powered by servos at each of the joints. The advantages of the arm are its reach, the ability to collect samples from anywhere around the rover and gathering samples from uneven planes. One of the downsides of the robotic arm is the complexity of programming the arm.

3.1.4 Structure

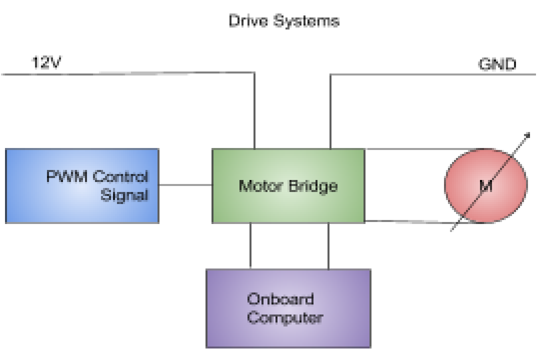
The frame for the chassis of the rover will be built from aluminium profile struts. The frame will allow the team a 3-tiered structure with spacious enough for all subsystems. This type of strut system is favourable as it provides the space required for the arm, the sensors, actuators, microcontrollers and batteries without compromising the range of motion of the arm.

3.2 Electrical Design

3.2.1 Requirements

To be able to remotely navigate through an unknown environment, electronic sensors and locomotion are required. To coordinate the sensing and actuators, a microcontroller is required. Due to the computational demands of video processing and streaming, this microcontroller would need to have a powerful processor. A system on a chip is actually the more appropriate option due to inbuilt communication, video processing and GPIO hardware.

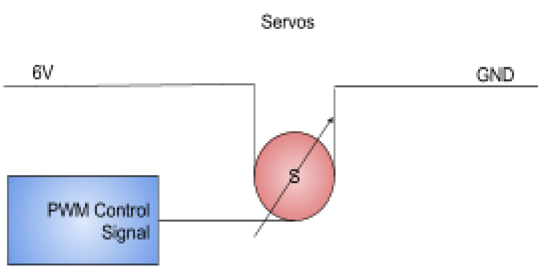
3.2.2 Drive System



The electronic motors are controlled using a PWM/Servo hat. This configuration requires motor bridges, and the PWM signal generated by the Adafruit PWM/Servo hat using code from the raspberry pi then dictates whether the motor will rotate clockwise or anticlockwise using these bridges.

The option of constructing a motor driver carrier by purchasing the individual components was considered; however, opting for a ready-built motor driver carrier (MDC) likely minimised the chance of any problems being due to faults in manufacturing it. Two dual MDCs also saves on cost as well as room taken up by circuitry on the rover, versus four single MDCs. The Pololu motor driver carrier operates at an ideal current, and did not require further circuit manufacture. Pololu is also a trusted supplier.

3.2.3 Collection System



The collection system chosen is a robotic arm connected to an excavator as the effector. This is a more precise but more complicated collection system. The precision is provided through the control of six degrees of freedom, which requires relatively complex control code to drive several electronic actuators. Each joint will have a servo controlled via pulse width modulation (PWM), which allows for positional control utilising the Adafruit PWM Servo Hat and code run on the raspberry pi. Although the higher complexity leads to a higher likelihood that a component may fail, this arm benefits from the fact that it is still operable if any one component fails.

3.2.4 Sensors

An LSM6DS33 chip has been chosen for providing a gyroscope and accelerometer. The RPi v3 board has a 3.3V pin which is the operating voltage of this chip. This chip connects via i^2c and supports i^2c's fast mode, allowing up to 400kHz polling, in addition it supports interrupt signals to allow the chip to "push" new data to the RPi immediately. The accelerometer is capable of measuring in ranges of ±2, ±4, ±8 or ±16 g, and the gyroscope can measure in ranges of ±125, ±245, ±500, ±1000 or ±2000 $°s^{-1}$ with a 2 byte resolution.

The proximity sensors will be connected over GPIO pins, and so we will use the provided GPIO module of the RPi library for Python. The data pins for the shortest range sensors (5cm) will be set up to act as interrupt signals, ensuring accidental collisions are avoided by effecting an emergency stop when triggered. All data pins will be polled to also provide data to the human controller.

A camera is required to send a live video feed of the lunar rover surroundings to the pilot in order to navigate the terrain. Although certain locations of the lunar south pole offer extremely favourable illumination conditions, illumination-darkness patterns vary significantly with the seasonal cycle and it is likely for the rover to be in less than favourable illumination conditions throughout its time on the lunar south pole. Hence, low light camera modules are considered. From last year's lunar rover competition, the team has two cameras that are able to record videos during the day, have night vision and infrared capabilities. These USB 2MP cameras have sufficient resolution for the pilot to clearly view the rover surroundings and easily interface with the RPi via USB. The team also has an additional FLIR sensor for detecting infrared light from last year's competition in order to identify ice within its field of vision. In addition to ice, this year's competition allows for the collection of soil samples as well.

3.2.5 Microcontrollers/SOCs

The Raspberry Pi 3 Model B (RPi) has been selected as the primary microcontroller to be used for managing the various sensors and motors of the rover. This selection was made due to the the fact that the RPi fits several criteria:

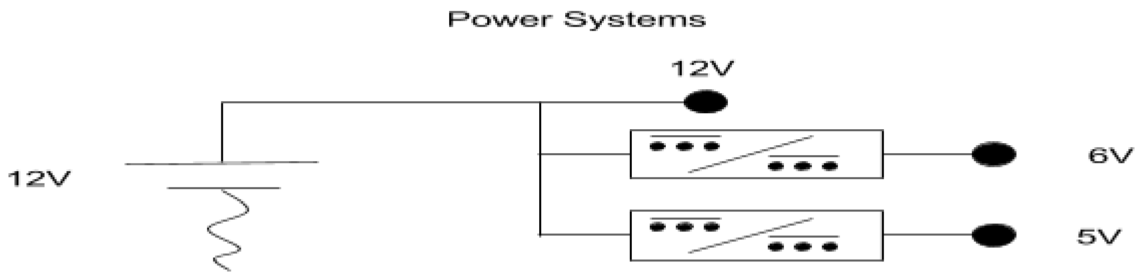
- Expandability – it features four USB connections in addition to a 40-pin GPIO strip;
- Wireless chipset – it features an 802.11n wireless chipset onboard;
- Performance – it features a quad-core 1.2GHz ARMv8 CPU;
- Power efficient – the power draw maximum is 5V/2.5A but typical draw is 5V/0.75A;
- Simple – the RPi runs Linux and easily runs C & python code;
- Cheaper – the device is already owned from the previous year.

The RPi will be used as the central brain of the rover. The first use-case is to monitor and control all of the sensors and cameras on board. In this role the RPi will assess data it receives from the sensors and, where appropriate, make decisions to best enable the rover to continue the mission. We will use the RPi's onboard WiFi chipset to provide the communications necessary to control the rover remotely. The RPi will also be used to control the motors and servos for drive as well as the arm, using information obtained as a result of decisions coming from local data analysis and a remote human controller.

3.2.6 Power Systems

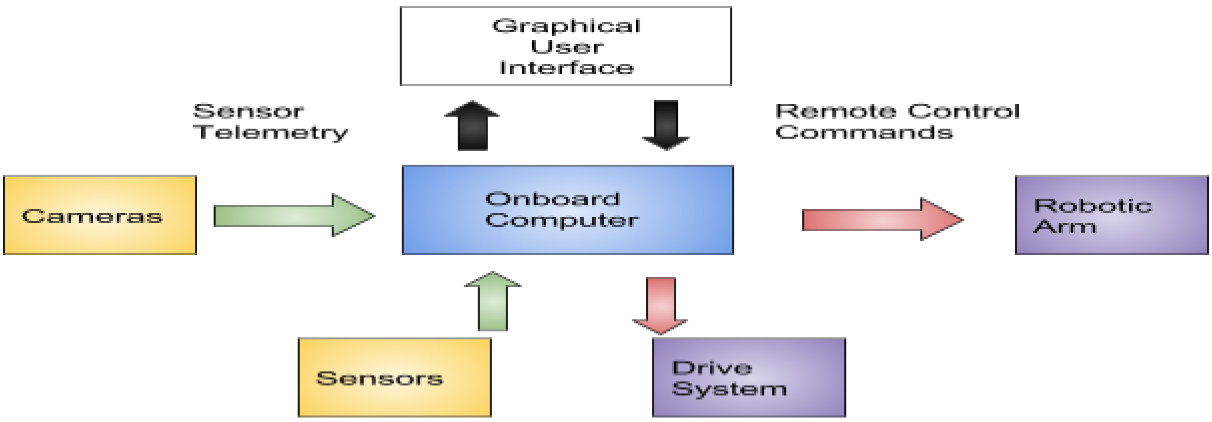
To power all of these electronic systems, an electrical power source is required. The components run on direct current, so a battery is the ideal source. A chemical battery is also favourable due to the size and weight restrictions imposed the technical specifications outlined by the competition and thus, the design solution proposed in this review. For this reason, a high energy density battery, i.e. a lithium polymer battery, is the preferred solution. The disadvantage to this selection is increased cost, however, this gives the benefit of reduced size and weight.

Further to the power requirements of the rover, the different electronic components require different voltages. There are four different voltage levels required by the range of electronic components (3.3/5/6/12V). The Raspberry Pi SoC provides 3.3V outputs but requires a 5V input. The motors require 12V while the servos require 6V. As such a single high capacity 12V battery will be used as the source. This source will be branched to three power rails (5/6/12V) using buck converters. As such, it would be valuable to note that this solution will induce efficiency losses and conduce to heat generation.



3.3 Control Design

The rover is controlled through an onboard computer, which provides a web interface for remote control.



This figure shows the route of data through the robot. The onboard computer reads sensors and cameras, generating data streams for the graphical user interface (GUI). This interface is the platform through which an operator can control the drive systems and robotic arm of the rover. Commands submitted through the GUI will be processed by the computer and sent to the actuators. Code for sensors and control has already been written. Areas for improvement of the code are: GUI UX, inverse kinematics, refactoring.

The robotic arm has five key control functions:

- Position the end effector - using inverse kinematics and cylindrical coordinates
- Open the end effector
- Close the end effector
- Move end effector above sample storage compartment (by making this the default position of the motors once sample is picked up)
- Move arm into a stowed position

The drive system has four key control functions:

- Drive forward, at a specified velocity for a specified duration
- Drive in reverse, at a specified velocity for a specified duration
- Turn, at a specified turn angle
- Brake

4 DESIGN BASELINE

The rover shown below will be capable of driving up and down steep slopes, with high torque motors driving each wheel and a low centre of gravity, therefore achieving crucial element of the competition. It is designed for stability and strength rather than speed and agility. On reaching its target location, its robotic arm will deploy. This arm provides a high level of control and a large excavator bucket as an end effector. This combination allows for precise and quick collection of a large quantity of sample material, thereby fulfilling the second condition of the competition. With the samples stored in a sample container, the rover can return to ‘the lander’ to deliver its samples, and hence, complete its ‘mission’.
To deal with the vibration test, the robotic arm will be stowable. All components will be assembled using nylock nuts. Nonessential components could potentially be affected by vibration depending on the duration of the test, however, this is not mission critical.

All this is facilitated by an onboard computer providing telemetry streams to an operator who has full control over the drive and collection systems. The telemetry streams include two visible light/IR cameras, a FLIR sensor, proximity detection and attitude data, in case it gets moody. There is the option of building autonomous control into this rover. While not entirely suitable for the competition, it is an interesting challenge for the team to look into, and has the potential to prove beneficial within the context of the competition.