Field Testing Marsobot, A Mars Society Australia Robotics Project.

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Summary: This paper introduces Mars Society Australia's Marsobot project, and describes the performance of robots during engineering testing at Arkaroola, South Australia. Two teleoperated rovers, one four-wheeled (Little Blue) and a larger eight wheeled machine (Miner), have been built using off the shelf components as part of the project in order to characterise strengths and limitations of different size machines. Both rovers underwent standardised DHS-NIST-ASTM tests over the period 5 – 12 July, 2014. The tests were conducted in controlled conditions and were designed to provide useful engineering data on the rovers' range and mobility, as well as highlight potential flaws and limitations in design. Both Little Blue and the Miner performed well in the tests, though specific limitations in design robustness and endurance were observed. Lessons learned from these tests will be incorporated into future improvements of the rovers, and refining of the Marsobot project overall.

Keywords: Mars, analogue, rover, research

Introduction

No manned mission has ever been to Mars and the only methods currently available for exploration are remote sensing and the use of robotic lander missions. To date eight successful landing mission have visited Mars, including static stations and rover missions [1]. Although the static landers provided a wealth of data regarding their immediate environment, the use of mobile robotic platforms vastly extended the amount of terrain that could be explored [2]. Thus the use of mobile platforms continues to be a preferred method of Martian exploration.

Earth based concept and trainer hardware has been and remains an integral component for developing space missions. Examples of this include the Rocky series of rover trainers that were use as concept testers for the Sojourner mission [3], as well as the FIDO precursor to the Mars Exploration Rovers (MER) Spirit and Opportunity [4]. In addition, Earth hardware is ideal for training students in the applications of remote exploration [5]. Similarly, a range of trainers have been used to access the role of human-centred robotics in exploration [6, 7]

We have developed Marsobots, wheeled training platforms based on commercial off the shelf hardware and open source software within a limited budget. In this contribution we describe the testing of two Marsobot rovers against engineering criteria developed by the US National Institute of Standards and Technology (DHS-NIST-ASTM for response robots) during MSA's Arkaroola Robot Challenge over the period 5-12 July 2014 [8]. We will provide an outline of the rovers, their performance in the tests as well as lessons that were learned from the experience.

2.0 Marsobot Platform Description

The Martian environment has proven extremely harsh for machines, with over half of all mission sent to the Red Planet failing [1]. Successful surface based operations have been hampered by the large temperature differential between day and night, the abrasive dust and the overall harshness of the Martian terrain. Although the development of a space qualified rover is far beyond the budget of the Marsobot project, engineering and mission testing of earth based vehicles in analogous environments has proven invaluable for preparing for actual Martian operations [4].

Arkaroola is located in the Northern Flinders Ranges, South Australia, and was chosen as the Mars Society Australia's (MSA) primary Mars Analogue research site [9, 10]. The diverse geology, semi-arid conditions and temperature extremes have made it an ideal site for testing various aspects of Mars research [11]. The Marsobot machines were tested between 5-12 July 2014.

The Marsobot project fielded two rovers of different scales. The engineering and mission constraints and chosen hardware we used for both rovers are summarised in Table 1 and will be described in greater detail below. Little Blue (Fig. 1) was built to correspond with the size of Sojourner, a microrover deployed to Mars in 1997 [12]. The Little Blue chassis is based on a heavily modified Toyabi Monster truck, though the original motors have been replaced with four Dagu 1:131 12 volt motors coupled to the hub of each wheel and driven by a Sabretooth 2 X 24 amp motor controller to provide four wheel drive.

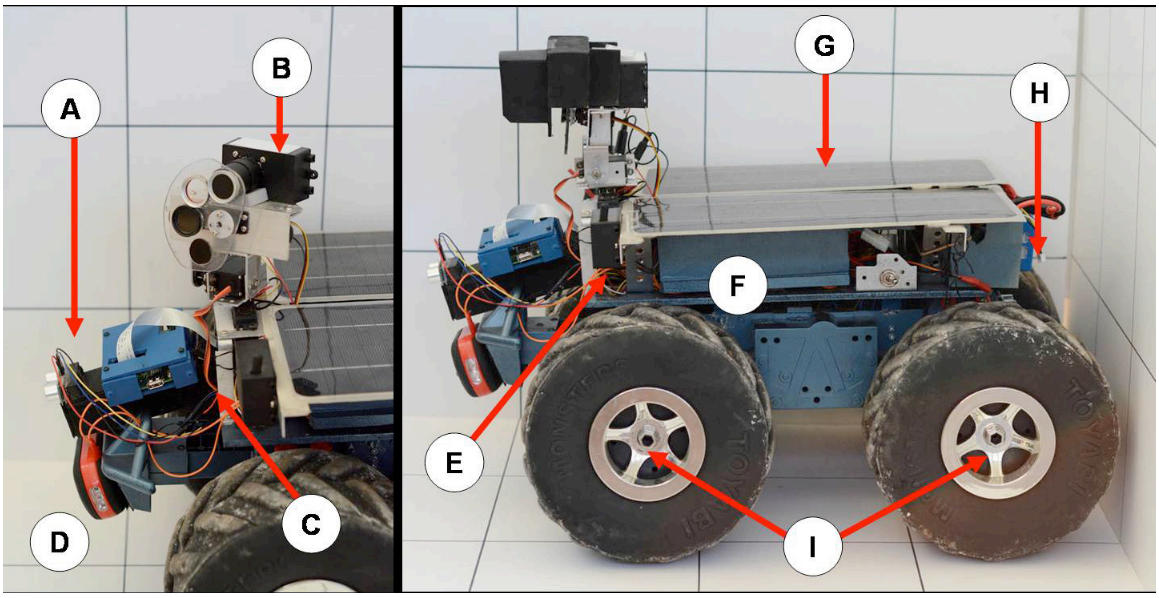

Fig 1. Overview of Little Blue rover with key components marked. (A) Forward distance sensor. (B) Multispectral imaging system. (C) Reflectance spectrometer. (E) Weather sensors. (F) Electronics box. (G) Solar panels. (H) Rear distance sensor. (I) Four wheel drive skid steer mobility.

Little Blue is equipped with range finding ultrasonic sensors (Fig. 1A, [13]) and a first person video (FPV) camera fitted with a filter wheel (Fig. 1B). The camera set up allows for the capture of multispectral images by sequentially photographing through a visible and three near infrared (NIR) filters. These separate images are transmitted to a ground station where they are exploited further. This type of camera was also used on the Mars Pathfinder mission [12]. Little Blue also carries a visible light reflectance spectrometer, controlled by a Raspberry Pi Model A on a WiFi link (Fig. 1C). This instrument collects spectra from materials of interest in order to identify mineralogical composition [14]. A BMP085 temperature and pressure sensor [15] and a DHT 11 temperature and humidity sensor [16] provide Little Blue with the ability to sense weather information (Fig. 1E).

Fig. 1F shows the location of the power and controller systems for Little Blue. We have based control of the sensor and science suite of both rovers on the Arduino 8-bit microcontroller. This microcontroller is well supported and has been used in many robotics applications [17, 18]. The Arduino Uno is programmed using the open source Arduino environment and possesses 14 digital input/output pins and six analog input pins. We use these pins on Little Blue to operate a relay to power the camera, interface with the forward and rear ultrasonic sensor, control the camera filter wheel servo and read data from the two weather sensors.

The rover employs independent power systems for the operation of the mobility system and the science system. This was conducted in order to provide redundancy in case one or the other system failed, allowing for useful science to be conducted in case of mobility failure, and vice versa. The Little blue Rover mobility system is powered with a 14.6V 5Ah Lithium Polymer (LiPo) battery, while a 11.2V 2.4Ah LiPo battery powers the wireless camera and Arduino. Power generation for Little Blue is supplied through two solar panels to provide a maximum power generation of 16 W (Fig. 1G). The solar panels are connected via a LiPo charger wired into the 11.2V battery. Aft of the solar panels is a rear facing ultrasonic sensor (Fig. 1H), providing some degree of hazard detection while reversing the rover.

Mobility of Little Blue (Fig. 1A, B) is achieved using skid steering in a similar manner to the Soviet Lunokhod rover [19]. Skid steering, or tank steering as it is sometimes called, operates by varying the speed of motors on either side of the vehicle. The skid steer system is commonly used in robotics applications owing to the ease at which it can be employed, as well as the minimum number of motors required for its operation [20].

Design and overall layout for the Miner rover (Fig. 2) is similar to that of Little Blue, though the Miner has twice as many wheels and is much larger. The Miner is fitted with a visible light FPV camera and a two-band multispectral camera atop its imaging mast (Fig. 2A). This instrument uses an NIR sensitive camera filtered with a #25 red filter, and controlled by a Raspberry Pi. This camera system allows for the capture of red/NIR ratios and has been used for vegetation analysis [21]. The charge of the 12V 12Ah battery of the Miner is supplemented by a 10W solar panel (Fig. 2B), and the rover possesses an additional 11.1V battery for its camera system to provide redundancy.

The Miner has sufficient torque to carry additional payloads (estimated up to 10 kg), such as an environmental logger that operates independently and passively records UV light intensity, temperature and humidity onto an SD card for post mission download and analysis (Fig. 2C). Additional instruments could include a BMP085 temperature and pressure sensor identical to Little Blue and a Ublox GPS module (Fig. 2D). Suspension is designed around an eight wheeled rocker bogie system (Fig. 2E) with each wheel driven by a 6 V electric motor. The Miner rover also possesses a similar Arduino Uno architecture (Fig. 2F), and is used to interface with GPS, sensors and camera relay. Communication between the Arduino of both rovers is accomplished by using AP220 2.4 Ghz serial wireless modems communicating at 9600 baud.

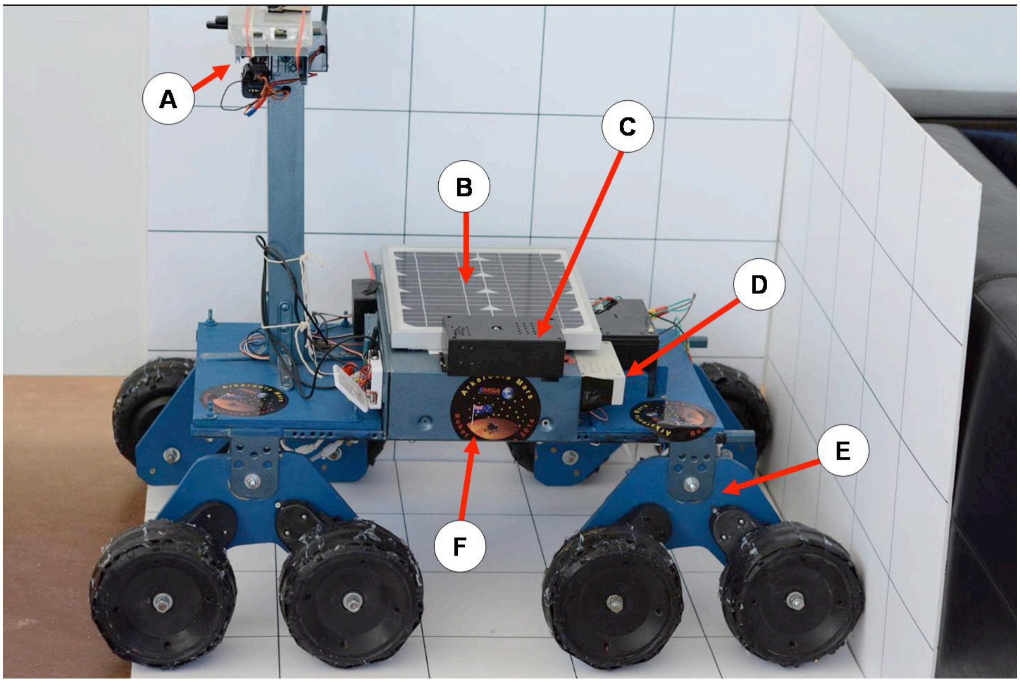

Fig 2. Overview of the Miner rover with key components marked. (A) Forward distance sensor. (B) Multispectral imaging system. (C) Reflectance spectrometer. (E) Weather sensors. (F) Electronics box. (G) Solar panels. (H) Rear distance sensor. (I) Four wheel drive skid steer mobility.

Chassis and mobility

Control and Programming

All of the rovers so far sent to Mars have possessed a degree of autonomous operation (high-level commanding) necessitated by the 8 - 48 minute time delay for communication signals to make the round trip between Earth and Mars [1]. In order to simplify the overall design and remain within budget we opted for a teleoperated mode of rover control. This mode has been used in previous space missions, such as the Lunokhod rovers sent to the Moon (Greeley 2013), or development of vehicles that would assist astronauts in operational tasks [22]. Teleoperation represents the operation of the rover in conditions where real-time or near real-time communication is feasible, such as at a manned Mars base. It is likely to be one mode of operation of real robots deployed at such bases. Mobility control of both Little Blue and the Miner rovers was achieved by a combination of a 2.4 Mhz four channel R/C system This was chosen for its simplicity, reliability and range, sufficient to control the rover within the specified operational radius of approximately 200m. Two channels of the R/C system controls the forward/reverse motion of the rover, as well as steering.

DHS-NIST-ASTM Testing

Details of the NIST methodology and test design are beyond the scope of this paper. For details, see [8]. Six engineering tests in standard, reproducible test apparatuses and two operational tests i.e. tests more closely approximating a real operational scenario for the machine as in [23] we conducted on the Marsobot rovers. The tests require the target machine to be teleoperated in real time by an operator who is out of direct visual and audible contact. The tests are designed to characterise the strengths and limitations competing designs. Tests performed by Little Blue and the Miner rovers included the following:

- Logistics: Robot Test Config and Cache Packing. The process required the completion of forms for every participating machine to capture details of the physical properties, equipment specifications, configurations, toolkit, packing and transport logistics.

- Energy/Power: Endurance : Terrains: Pitch/Roll Ramps. A test rig consisting of 15° wooden ramps measuring 1200 x 600mm was laid out in a specified alternating sawtooth pattern to repeatably measure the robots' performance on discontinuous terrain. Operators guided the robots around a 15m figure-eight path on the ramps around two vertical pylons. Distance and time from full battery charge to inoperability are measured.

- Mobility: Terrains: Flat/Paved Surfaces (100m). Two pylons were placed 50m apart on a flat surface. The ground around each was marked with a circle 2m in diameter. The robots were to make 10 timed figure-of-eight laps around this course, without deviating from the circumscribed path. Thus both speed and control are important.

- Mobility: Towing: Grasped Sleds (100m). The robots dragged an aluminum sled, carrying an operator-designated payload, around 10 figure-of-eight laps on the 100m course specified in the third test.

- Radio Comms:Line-Of-Sight Environments. The robots were tested for navigation control and video feed on a straight course at 50m, then stations every 100 m thereafter. The last station at which both navigation control and video of 100 x 100 m hazardous targets were perfectly reliable (complete circle and all four visual tests correct) was reported.

- Sensors:Video:Acuity Charts and Field of View Measures. The robots were placed on a 15° ramp 6 m and then 40 cm from a far-field Landolt-C vision chart. The operator viewed the chart at their control station via the robot's camera and read down the chart to the smallest line at which the orientations of the C shapes were discernible. No more than two errors were permitted on a line. This is reported as a percentage of the 6-6 (20:20) vision standard.

The operational tests were conducted in an old road base quarry at Wooltana station. The quarry site was chosen as it presented a Mars-like variety of smooth, rocky, eroded and rough terrain within a localised environment. Specifics of the operational tests included:

- Irregular Terrain Traversal. A 106m course consisting of four gates (1.2m pylons spaced 2m apart) was arranged over rough, natural, Mars-like terrain. It included slopes of between approximately 20° - 40°, loose sand, and large irregular stones.

- Context Imaging. A small, brightly painted 100g target object was 43 to 76m from the starting point. The operator was to locate the object as quickly as possible, then photograph it in context. Time to locate the target and distance to target were recorded. Each of four best images were examined by three expert field geologists who scored each. The mean rating over all images and criteria was then calculated. The Miner was unable to participate in this test due to time constraints.

An additional, qualitative field testing that was not part of the NIST suite was conducted on Little Blue’s imaging system. Arkaroola contains an abundance of fossil stromatalites – some of the oldest forms of life on Earth [24]. As discovery of similar evidence of fossil life on Mars would be of great interest to exobiologists, a robotic method of identification of these fossils would be of great interest to the planetary science community [25]. Our trial consisted of Little Blue photographing stromatolite bearing rocks with non-stromatolitic control rocks at set distances of 1m, 50cm and 25cm respectively. The photographs were then sequentially presented to an experienced palaeontologist who was then asked to positively identify the stromatolite bearing rocks from the control group.

Results and Lessons Learned

Fig. 3A-C shows the series of true-colour images returned from the Little Blue vision system of the stromatolite identification test site. The maximum resolution of the images was 640 X 480 pixels and progressively show greater detail as the rover was driven closer to the target. Textures became visible in the target rocks as Little Blue reached 50 cm (Fig. 3B), with striations and banding discernable at 25 cm, the closest Little Blue was able to approach the target (Fig. 3C). We note that although these details were observed in Little Blue imagery, as well as the overall colours of the rocks, the paleontologist was unable to positively distinguish between stromatolites and naturally occurring features. The results of Little Blue’s qualitative image acuity test has implications on the type and resolution of sensors required for positively identifying potential fossil life using a remote sensing platform. Possible methods for improving the capability of Little Blue in discerning between biological and natural processes would be an upgrade to a higher resolution camera, or the addition of a microscopic imager or spectrometer similar to those carried aboard MER [26]. The inclusion of such instruments would come at the expense of greater power and bandwidth requirements, and higher cost. These would equate to a larger vehicle size in order to accommodate the increased weight from larger solar panels and batteries, as well as larger, more powerful drive system. We also note the historical difficulty in obtaining consensus for interpretations of previous search for life experiments carried aboard previous missions [27].

Positive imaging results from a future Mars missions may not be sufficient to resolve the question of extraterrestrial life on Mars – many independent observations may be needed. Nevertheless, Little Blue’s qualitative test has highlighted the importance of some of the factors, such as image resolution that are required to make meaningful assessments on the identification of extraterrestrial fossils.

Fig. 4A-D shows an overview of testing of the Marsobot rovers. The mobility and endurance testing of the Miner rover and Little Blue is shown in Fig. 4A-B, and the preliminary results of context imaging tests from Little Blue are shown in Fig. 4C-D. Table 2 lists the NIST test performance of both of the Marsobot rovers in more detail. As shown in Table 2 Little Blue’s overall performance was quite high. Little Blue’s small dimensions and large wheels with respect to the rover size assisted the rover’s maneuverability. The high power torque of the motors assisted its negotiation of the 15^{o} maneuvering ramps (Fig. 4B), as well as the off-road test (Table 3). Little Blue’s dual power supply allowed for the continuation of science or rover recovery in case one of the systems failed and the solar panels delivered enough energy to the science systems to keep them operating for an extended period.

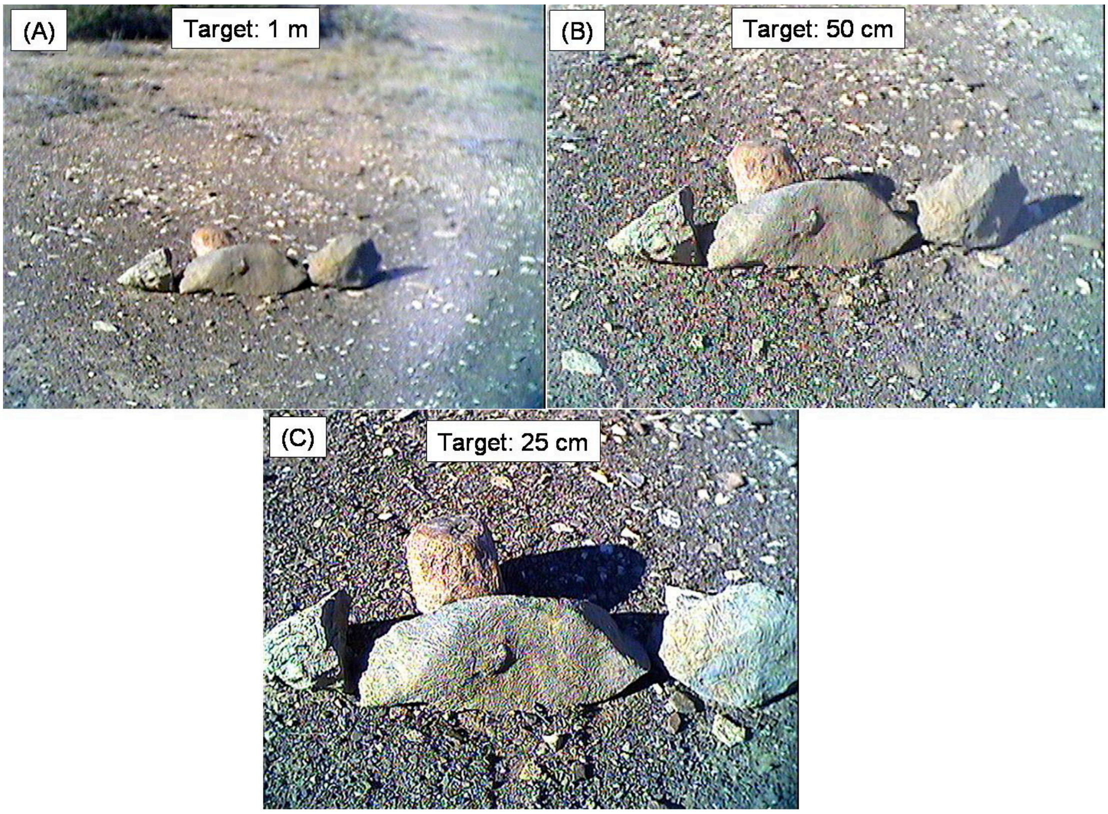

Fig 3.Results from Little Blue qualitative fossil identification trial. Target consists of a mixture of stromatolite and non stromatolite bearing rocks. (A) Image from 1 m distance. (B) Image from 50 cm distance. (C) Image from 25 cm distance.

Little Blue was able to complete 10 laps of the sustained speed test, as well as seven complete laps of the energy/endurance test (Table 2). In addition the R/C controller, FPV camera and wireless modem ranges (~200 m, Table 3) exceeded the initial engineering design for Little Blue (Table 1).

Visual acuity of Little Blue's camera system was 15-20%, reflecting the limited resolution allowable for live video transmission. The visual acuity of the system was sufficient to allow for finding of an imaging target in the search and find field test in under seven minutes (Fig 3C, Table 2). In addition a false colour NIR image was able to be obtained (Fig. 3D), from which the absorbance characteristics of the target were illustrated.

Despite the overall performance of Little Blue, problems highlighted by the testing were observed. Little Blue shed its front left wheel during the ramp test. Although field repairs were quickly made, this catastrophic failure highlighted the criticality of a robust coupling of wheels to motor. Further modifications for future designs may include additional batteries in order to provide greater endurance, though this would be at the cost of increased weight and greater strain on the motors.

The Miner Rover also performed well on the DHS-NIST-ASTM tests [8] (Table2). The Miner was able to negotiate the outdoor irregular terrain traversal test (0.11m/s), despite suffering a failure of a microprocessor power regulator in one irregular terrain traversal. Visual acuity was lower than for Little Blue, (15-20% cf 15-25%, Table 2), probably due to the wider field of view of the imaging system. In addition, the Miner was able to pull 6 kg over flat ground during the sled dragging attempt.

As with Little Blue the testing revealed some design flaws and limitations of the Miner rover.

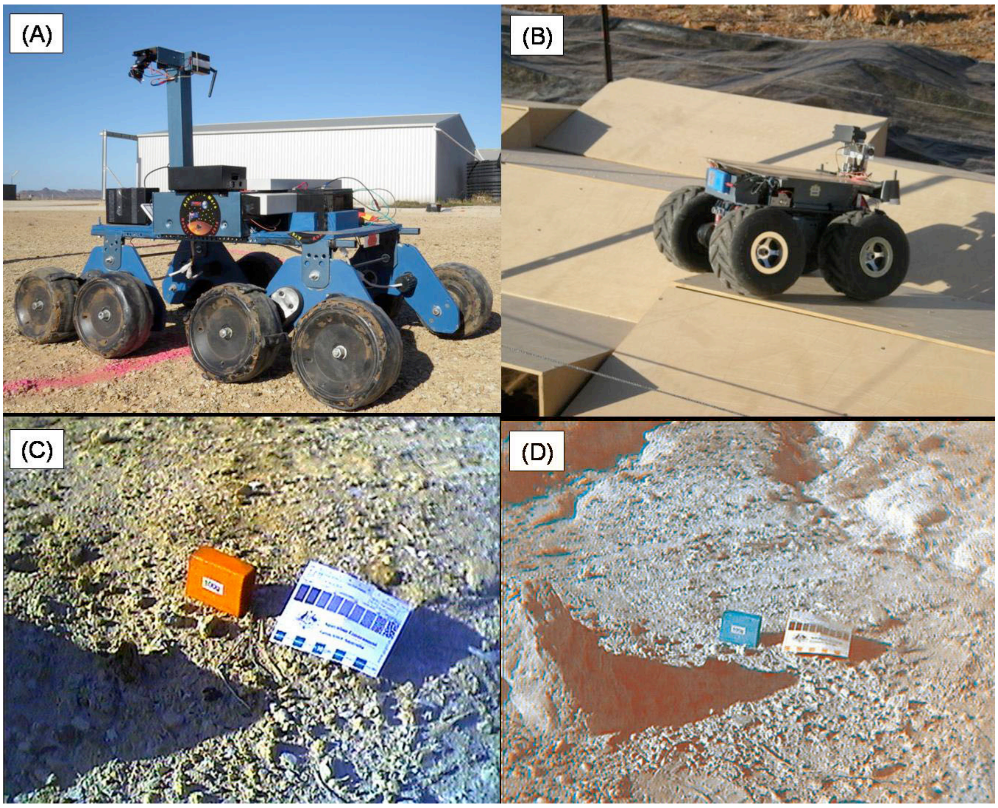

Fig 4. Overview of NIST tests for Marsobot rovers. (A) The Miner undertaking the endurance tests. (B) Little Blue rover on mobility ramps. (C) Context image of target imaged by Little Blue rover. (D) False colour image of context target using NIR. Blue tone of target denotes NIR absorbance of target.

It was found that the power supply for the Miner was inadequate, with the rover unable to complete 10 laps of the sustained speed test (eight laps completed, Table 2). This was due to complete discharge of the 12V battery supply, for which the solar array was unable to compensate. The Miner has capacity for a heavier duty power supply which will be included in future upgrades.

The plastic wheels of the Miner provided insufficient grip on the surface to climb steep slopes. This issue was partially mitigated on site by addition of rubber strip treads across the wheel width of four wheels to increase traction. Further traction losses arose from rocker bogie pivots being too stiff and suspension lift off occurring during high energy turns [28], caused by the wheel base being too narrow. Extending the width of the Miner rover, and providing better freedom of movement for the bogies would provide for better all-wheel ground contact over irregular terrain and thus greater mobility. Integration of the ground station controls would also be of benefit the operation of both rovers. The current system requires the rover operator to switch attention between three independent systems (R/C control, sending and receiving commands, capturing imagery). Combining these interfaces would be likely to significantly reduce the workload of the rover operator, reducing the need to coordinate between systems for mobility control, image acquisition and receiving telemetry data.

Part of the study involved evaluation of the robots in the astronaut support role. Both robots accompanied pairs of people wearing simulated space suits and provided support such as video coverage of their activities, imagery of rocks and, in the case of Little Blue, spectral data (Fig 5).

Table 2: Test results of Little Blue and Miner rovers.

Rover	**Little Blue**	
NIST Test Method (metrics)	**Result**	**Comments**
Energy/Power:Endurance:Terrains:Pitch/Role Ramps (distance, time - full charge to inoperability)	105 m 2363s	Completed 7 repetitions (mean speed 0.04m/sec)
Mobility:Maneuvering Tasks:Sustained Speed 100m (mean time per repetition)	214.8 s/rep.	Completed 10 repetitions (mean speed 0.47m/sec)
Radio Comms: Line-of-Sight Environments (Max distance for functioning control and vision)	200m	Note: range measured at 100m stations
Visual Acuity (Far Field lowest line Landolt C chart, Near Field lowest line)	15% 25%,	
Operational Test Method (metrics)	**Result**	**Comments**
Operational Task: Irregular Terrain Traversal (time to complete, average speed)	531s 0.2m/s	Performed well despite hard wheels
Operational Task: Context Imaging (time to locate target, % mean rated quality of 4 context images)	417 s 65%	Distance to target 43.12m Quick to locate target object!
Rover	**The Miner**	
NIST Test Method (metrics)	**Result**	**Comments**
Energy/Power:Endurance:Terrains:Pitch/Role Ramps (distance, time - full charge to inoperability)	Abstained	Vehicle dimensions do not agree with ramp dimensions
Mobility:Maneuvering Tasks:Sustained Speed 100m (mean time per repetition)	297.75s/rep.	Completed 8 repetitions (mean speed 0.34m/sec)
Mobility:Maneuvering Tasks:Grasped/ Hitched Sleds 100m (weight, mean time per repetition)	6.47kg 299s/rep	One repetition only – test aborted due to battery failure
Visual Acuity (Far Field lowest line Landolt C chart, Near Field lowest line)	15% 20%,	
Operational Test Method (metrics)	**Result**	**Comments**
Operational Task: Irregular Terrain Traversal (time to complete, average speed)	941s 0.11m/s	Lost some time on slopes

While both robots were able to perform these tasks, they found it difficult to keep up with the simulated EVA team over smooth ground and were not able to deal at all with rougher terrain. While further analysis is needed, these preliminary observations suggest that small rovers are better suited to deploy-and-leave operations, where they are carried to a site and then left to carry out further studies independently or to explore area unsuited to astronaut teams, such as soft ground. The EVA support role might be better carried out by suitably equipped unpressurised support vehicles. This is exemplified in the R-Gator tested by the United States Military, which is able to act as a light transport for personnel, autonomously follow them while they are on foot, or operate under remote control in a support role [29].

Fig 5. Marsobot rovers in EVA support role. (A) Little Blue. (B) Miner.

Conclusion

The Marsobot project represents the Mars Society's work in developing analogue robotic vehicles that are capable of trialling future experiments for actual planetary missions. Readily available, off the shelf components were used, and an open source development system employed to allow for ease of development and collaboration. The Arkaroola NIST tests provided an opportunity to quantify the capabilities and limitations of both rover vehicles in an outdoor environment. Both the Little Blue and Miner rovers performed well in most of the tests, proving the ability of low cost systems to operate in a Mars analog environment. Lessons learned from the results of these tests will be incorporated into future improvements of the rovers, and refining of the Marsobot project.

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