Mobile Robotic Platform Deployment as Part of a Martian Mission Simulation

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Abstract

In January of 2014 a seven-person crew of analogue astronauts (Crew134) conducted a two week, high-fidelity Mars mission simulation at the Mars Society's Mars Desert Research Station (MDRS) in the high altitude Utah desert. Part of the mission simulation included testing of a mobile robotic platform and a stereo camera system (SCS). This paper summarizes the results of this testing and provides lessons learned and recommendations for future analogue deployments and flight systems design.

1 Introduction

The first objective of this testing was to examine the benefits and feasibility of using the MDRS terrain as a location for a future prototype rover deployment. While the CSA and other organizations continue to conduct analogue rover field trials, the increased fidelity of a deployment at a high fidelity analogue location could provide benefits which outweigh the associated incremental costs compared to deployment at a local site.

The second area of specific focus was the process of preliminary terrain mapping using the SCS mounted to the mobile platform. The purpose of preliminary terrain mapping is to generate a set of usable 3D data (point cloud and intensity) via post-processing of stereo images that can be used to conduct the detailed mission planning for a future rover deployment. Secondary objectives of this activity are to validate the SCS hardware (HW) and control software (SW) and generate a set of data collected in an appropriate analogue environment to validate algorithms used for terrain mapping, obstacle detection, and localization.

In addition to the hardware testing that was conducted, the third portion of this paper studies the logistics of a rover field deployment at MDRS.

2 Hardware Description

The two major elements of the HW that were used during this testing are the SCS and the robotic mobile platform – the Kuon – that the SCS and other sensors were mounted to. This section describes the HW and setup.

2.1 Mobile Robotic Platform

The Kuon rover is a rugged off-road capable robotic platform developed by Colorado based RoadNarrows Robotics LLC and provided on loan to MDRS Crew134. The 122.5 kg, four wheel, skid-steered vehicle is 133 cm long, 109 cm wide and 59 cm in height. Each of the four brushed DC hub motors is rated at 92 Nm of torque at stall. The Kuon is shown Figure 1.

Figure 1 Kuon at MDRS

The Kuon can accommodate payloads up to 227 kg using a customizable and modular interface plate and provide power at 5, 12 and 24 VDC.

Control of the rover is accomplished via wired or wireless Ethernet connection to a laptop running the Kuon control SW. More details of the control are provided below.

2.2 Stereo Camera System

The SCS used during the mission simulation is a breadboard model (early prototype) developed by NDG in support of an upcoming Mars flight mission.

Due to the expected mission scenario, the SCS has been designed as a small, lightweight and low-power device capable of displaying, capturing, and correcting (where necessary) stereo imagery. The SCS is comprised primarily of two commercial off the shelf (COTS) cameras, each of which includes a Complementary Metal Oxide Semiconductor (CMOS) Image Sensor, mounted on a lightweight stereo bench. The SCS records images with a resolution of 1024 x 1024 using commercial lenses which have a variable aperture between approximately f/4 and f/16; an f-number of 11 was used for the Martian Mission Simulation.

The SCS interfaces to an external laptop via USB, for all command and control. A custom application, developed by NDG, is then responsible for capturing pictures, synchronizing the cameras, removing distortion and calibrating the images.

Figure 2 illustrates the SCS installed on the rover platform, and the support laptop in the background. (This figure also shows the Inertial Measurement Unit, which is mounted to the SCS bench, although not directly related to the SCS itself.)

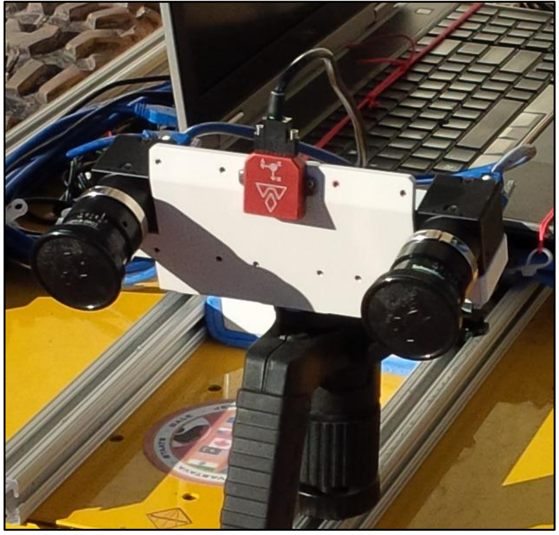

Figure 2: SCS Installed on Rover Platform

2.3 Peripheral Sensors

In order match images captured with the SCS with rover pose data the Kuon was equipped with a GPS receiver unit and an Inertial Measurement Unit (IMU).

The IMU was a VectorNav VN-100 which combines 3-axis accelerometers, 3-axis gyros, 3-axis magnetic sensors, a barometric pressure sensor, as well as a 32-bit processor into a miniature surface mount module. This unit was set to log rover yaw, pitch and roll during operation.

The GPS receiver was also set to log position during operation and the resulting .gpx files can be loaded into Google Earth to provide an exact map of the Kuon’s traverse route.

In addition to these sensors a support laptop required to control the SCS and IMU was mounted to the Kuon along with a USB hub for additional interfacing.

2.4 System Setup

The SCS was mounted on the forward extent of the Kuon’s payload interface, slightly to the port side of center. A manual hand clamp was used to mount the SCS. This provided a versatile means to set up the SCS parallel to the Kuon’s front face. The SCS was set up with a downward facing angle of 17.6 degrees from horizontal, closely matching the intended end-use application of the flight model SCS.

2.5 SW and Communications Debugging

While designed to perform as a semi-autonomous robot or remotely controlled payload transport, the Kuon was loaned to Crew134 configured for close-proximity remote control via the commercial Sony PS3 game controller (PS3-GT).

The PS3-GT provides a large quantity of controller switches available to the human user however the wireless range was quite limited and the unit provided no built-in feedback on connectivity status.

The control flow was as follows:

USER → PS3-GT → WIFI DONGLE → LAPTOP → WIFI → KUON

The system workflow as follows:

Power-ON Kuon → ACTIVATE Kuon → Power-ON LAPTOP → launch shell SCRIPT → ACTIVATE PS3-GT → drive Kuon

Initial integration and testing identified that the Kuon had a very limited maximum range of approximately 8 to

10 meters. If this range was exceeded, the user would lose control of the Kuon. Re-approaching the Kuon to within the allowable distance did not result in an automatic re-connection. The entire power cycle process was required to regain control.

Various attempts were made to cycle only segments of the system. For instance, resetting the PS3-GT, cycling power on the Kuon or restarting the shell script on the laptop.

Using a Linux command line on the laptop the following iterative tests were executed:

```
ping [kuon-ip]
ps aux | grep [kuon-control]
top
[kuon-control-feedback]   (a self-reflective
                          function in the Kuon app)
```

By monitoring each of these as the system workflow was executed, when the Kuon reached its wifi range limit, and when any one of the unique workflow segments was power cycled, it became clear that the shell script ([kuon-control]) did not execute a clean exit function such that when the script was re-launched, it spawned a second, third, nth copy. As such, any attempt to control the Kuon rover was prevented by the communication between the PS3-GT and the laptop due to more than one active copy of the script attempting to receive the signals, which usually resulted in null.

A full power-cycle of the total system would restore all parameters to initial conditions by which the total workflow functioned.

3 MDRS Deployment Site

"In order to help develop key knowledge needed to prepare for human Mars exploration, and to inspire the public by making sensuous the vision of human exploration of Mars, the Mars Society has initiated the Mars Analog Research Station (MARS) project" (Mars Society, 2014). This MARS project primary site is the Mars Desert Research Station located in the high altitude Utah desert near the town of Hanksville. The MDRS site includes the main habitat, a green-habitat for growing vegetables, an observatory and an engineering support building. The habitat provides the analogue astronauts with living quarters including a bathroom, lab space, and Extra-Vehicular Activity (EVA) room and airlocks.

Power to the facility is provided by a pair of redundant diesel generators. Rovers and peripheral HW are reliant on this infrastructure for battery charging.

Water is delivered to the site via trailer and transferred to holding tanks onsite by means of electric pumps.

3.1 Rover Terrain

The diverse terrain surrounding the MDRS site includes numerous possible locations for prototype rover deployments. A preliminary investigation into the surrounding terrain revealed several appropriate locations at which a rover deployment could be focused. One specific area was identified as being appropriate for consideration as a Martian analogue – described in section 3.2 – as well as being advantageous from a rover mobility perspective. This area was well bounded by ridges providing natural boundaries for an almost self-contained testing area. It also contained an appropriate distribution of rocks; enough to provide a challenge to rover operators or navigation algorithms, but not so many as to make navigation impossible. In addition, this location featured a variety of soil types and a range of different slopes. There was little vegetation and virtually no standing water. The site was located approximately 1.5 km to the southeast of the MDRS habitat.

3.2 Terrain Geology

A geological and geomorphological survey was conducted for the prototype rover deployment site. Field observations of geological units were matched with a published USGS geologic map of south central Utah (Williams & Hackman, 1971). The site, near MDRS, is located entirely within the late Jurassic Morrison Formation. It is a heavily eroded, semi-arid badland, devoid of vegetation. Environmental conditions at MDRS are typical of a cold desert: low moisture, fluctuating extreme temperatures and soils with a high salinity. Sedimentary deposits here are composed primarily of red clay and mudstone, interbedded with white sandstone rich beds. Occasional conglomeratic sandstone lenses, sandstone boulders, gravel sheets and other alluvial deposits are present in the area.

The geomorphological, physical and sedimentary processes that shape the badlands are analogous to those occurring on Mars today, and in the past (Stoker et al., 2011). These include the aqueous alteration of sedimentary deposits by ground water, mass wasting events, thermal cycles, and both fluvial and aeolian erosion (Stoker et al., 2011). Geological analogies between Mars and the Morrison Formation include: the formation of small, round concretions in sandy lenses (Clarke and Stoker, 2011); layered sedimentary deposits that represent ancient fluvial processes (Malin & Edgett, 2000b; Battler et al., 2006; and Stoker et al., 2011); dry channel features, serving as proxies for Martian rivers and gullies (Malin & Edgett, 2000a; Clarke & Pain, 2003); and stream channel conglomerate deposits (Pain et al., 2007; Stoker et al., 2011; and Clarke and Stoker, 2011).

In terms of mineralogy, the MDRS region is composed primarily of terrestrial and marine siliciclastic sediments (Stoker et al., 2011), while Martian crust and regolith is mostly basaltic (Murchie et al., 2009). Despite the differences in geology, the soils in the prototype rover deployment site offer numerous geochemical similarities to Mars. Stoker et al. (2011) and Kotler et al. (2011) used a Terra X-ray diffractometer for mineralogical analysis. It was a field version of the CheMin instrument, part of the NASA Mars Science Laboratory mission, currently on Mars. They found the soils in the Morrison Formation to be rich in phyllosilicates comparable to those observed on Mars from orbital measurements: clay minerals such as montmorillonite and nontronite (Murchie et al., 2009). Future missions to Mars will be targeting predominantly phyllosilicates when searching for organic matter (Zegers et al., 2011). Ca, Na, Mg and Fe rich sulphate species (for example gypsum and thenardite) are also present both at this site and on Mars (Murchie et al., 2009; Stoker et al., 2011; Borst et al., 2010; Kotler et al., 2011; Clark et al., 2005). Furthermore, iron oxides (e.g. haematite) are responsible for the red colouration of the soils in the Morrison Formation (Murchie et al., 2009; Chan et al., 2004; Ormo et al., 2004). These highly oxidising conditions are another common geochemical feature between MDRS area and Martian geology (Stoker et al., 2011).

As such, the study site is an excellent Martian analogue location, with respect to its geology, geomorphology and geochemistry. Therefore, it is an ideal setting for the field testing of instruments and rovers planned for future missions to Mars.

3.3 Deployment Conditions

The deployment was conducted in the latter half of January, 2014. Daytime temperatures were typically between 5 and 10 °C. Humidity was very low. Lighting conditions varied on a daily basis although most days were sunny without clouds.

4 Deployment Summary

Only a portion of the two week mission simulation could be dedicated to the testing described in this paper. Each activity conducted outside of the habitat required the analogue astronauts to conduct a formal EVA. The process for obtaining approval from mission control included the submission of an EVA plan one day in advance of the EVA. Following each EVA an EVA report had to be submitted. For each EVA the analogue astronauts had to be suited in simulation EVA suits and follow protocols surrounding ingress and egress. Analogue astronauts had to work in tandem while on EVA. Given these constraints along with other testing activities competing for resources only six days could be allocated fully to this testing.

Approximately one day was required for scouting and site selection. Approximately two days were required for system setup and debugging described in section 2.5. Therefore only three days were available for formal operation. These days were focused on terrain mapping of the selected deployment area. Each day’s work is described below.

4.1 Day 1

The first day of formal testing was January 26, 2014. The EVA was conducted in the early evening. The SCS system was initialized and set to capture images immediately upon departure from the habitat. Images were thus captured during the ~1.5 km traverse to the selected deployment area as well as in the area itself. Due to time constraints only partial coverage of the deployment area was possible. In addition to the SCS images a GoPro consumer video camera was mounted to the rear of the rover and set to capture video during the entire traverse.

This day provided several lessons learned to be incorporated in the following testing. For this day the SCS and IMU control laptop was left open, with the display fully active. This caused the laptop battery to deplete more quickly and it eventually died prior to completing a complete contour of the deployment area. This was subsequently avoided by setting the laptop not to sleep when it was closed. Additionally, when the laptop died, the IMU data log file was lost. For subsequent tests the IMU process was frequently paused and the log file saved to ensure that any unplanned shutdown of the laptop or SW wouldn’t mean the loss of the entire dataset.

4.2 Day 2

The second day of formal testing was January 28, 2014. The EVA was conducted at midday. The SCS was only initialized and set to capture images after arrival at the deployment area. A full traverse of the deployment area contour was completed and a full set of IMU data and SCS images were captured. The GoPro camera was not available for testing on this day.

The SCS images captured were over-exposed. Unfortunately this was not discovered until after the EVA as there was little real-time review of the images during the EVA. The gain and exposure time were set to maximize the image quality but the dynamic range of the camera was not exploited.

4.3 Day 3

The third and final day of formal testing was January 30, 2014. The EVA was conducted before, during and just after sunrise. The timing of this EVA was selected to maximize the variety of lighting conditions present during testing. A full traverse of the deployment area contour was completed and a full set of IMU data and SCS images were captured. In addition to the SCS images a GoPro was mounted to the rear of the rover and set to capture video during the entire traverse.

Taking advantage of lessons learned on previous days the quality of the images was continually monitored and the gain and exposure time was adjusted and recorded frequently. This proved to be the best day of testing despite an unexpected laptop shutdown at the end of the deployment area contour which caused the loss of the last IMU file.

An image of the GPS log file (.gpx) from Day 3 as displayed in Google Earth is shown in Figure 3 below.

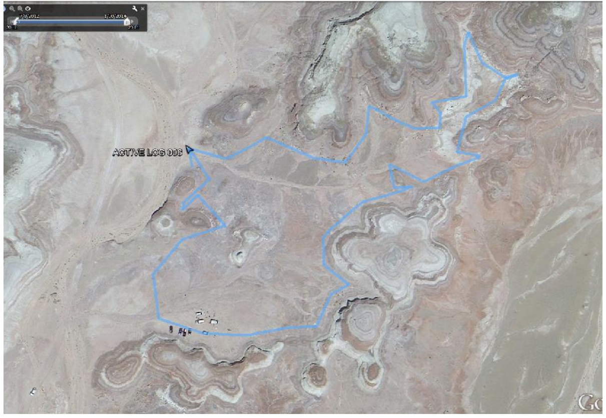

Figure 3 Day 3 Google Earth view of Route

5 Terrain Mapping

As part of this deployment, multiple objectives were achieved involving terrain mapping. First, 2D and 3D data of the scene, along with pose information was collected with the intention to aid future deployments to this area. Second, the performance of the Stereo Camera System was evaluated in this mission-like environment. These objectives are further detailed in this section.

5.1 Algorithm Development and Testing

To continue the development of vision and navigation algorithms at Neptec the testing of the SCS at MDRS included several pre-defined steps and approaches.

In order to generate a 3D terrain map of the deployment area which could be used for future deployments, the SCS images were captured, time-tagged, and coupled with GPS and IMU data. This entire data set can be processed to generate a complete terrain map of the deployment area. The raw 2D imagery can also be coupled to the 3D data to provide additional context to this dataset.

The imagery collected by the SCS is also useful as a standalone dataset to test visual odometry techniques. Of particular interest in this dataset are significant shadows and contrast due to a low sun angle, which is useful to study the effectiveness of visual odometry in challenging lighting environments as would be found in a Martian or lunar polar mission.

5.2 Camera Performance

The performance of the SCS during the Martian Mission Simulation was considered successful in that stereo images were recorded throughout the traverse of the Mobile Robotic Platform.

No faults or failures were observed during the operation of the SCS and multiple image pairs were successfully captured and corrected for use in subsequent processing. Figure 4 shows one such image pair, captured on day 3, illustrating the detail that the SCS was able to capture during the simulations.

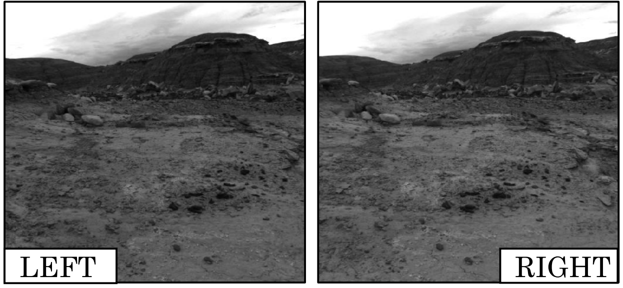

Figure 4: Left and Right Images Captured Day 3

All primary SCS objectives for Martian Mission Simulation (listed below) were achieved:

1. The SCS was successfully able to capture stereo images from both cameras
2. The SCS was successfully able to capture and store images throughout the mission duration, without interruption

3. The SCS was able to successfully capture images, from both cameras, in multiple lighting conditions
4. The SCS was able to successfully capture images using various camera settings, such as gain and exposure time.
5. The SCS successfully survived the mechanical and thermal loads of the Martian Mission Simulation, without performance degradation.

Despite the overall success of the SCS, some areas require further improvement. In particular, since no attempts were made to adjust the dynamic range of the cameras, some images appear washed-out. Figure 5 below shows an example of images captured on day 2 (high light intensity) without accommodating for the cameras' dynamic range.

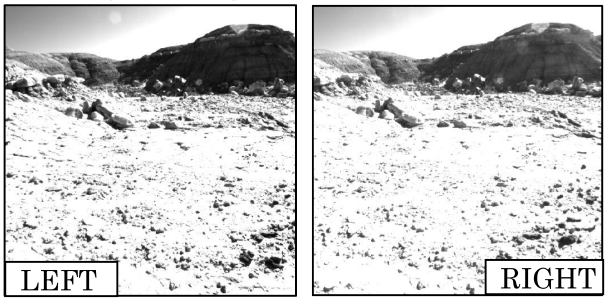

Figure 5: Left and Right Images Captured Day 2

Furthermore, investigation (post-test) revealed that one of the two stereo cameras showed an increased level of noise. The increased noise level was attributed to a fault in the COTS camera, and has since been repaired by the manufacturer. This increased noise was more evident at higher light intensities (or longer exposure times) and can be illustrated by a close examination of the same feature imaged by both left and right cameras, as shown in Figure 6.

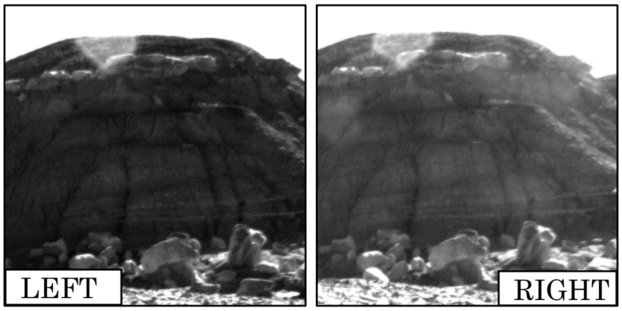

Figure 6: Clean Image (left) vs. Noisy Image (right)

Future work with the SCS will focus primarily on advancing the TRL in preparation for a flight mission. In particular, COTS parts will be replaced with custom, flight-quality components and the overall assembly will be ruggedized to survive the typical Martian environment. The SCS software will be enhanced to offer more control to the image acquisition parameters, to compliment the dynamic range of the image sensor and ensure quality imagery is provided. Furthermore, all components used on subsequent hardware builds will be subjected to a more thorough screening process to ensure sufficient quality, prior to test.

6 Prototype Rover Deployment Logistics

In order to continue to conduct analogue field testing of rover prototypes and other prototype HW the logistics of deployments should be studied and analyzed. The resources required to accomplish a successful field trial on schedule and on budget can be difficult to estimate making it difficult to obtain approval. Difficulties encountered during field trials are often challenging to overcome and can compromise the efficacy of the testing or the results. This section describes the deployment of the Kuon at MDRS and provides insight and recommendations into potential future rover prototype deployments at MDRS. This knowledge could also be applied to field deployments in other locations.

6.1 Kuon Deployment at MDRS

Overall the deployment of the Kuon robotic platform at MDRS was a success. The Kuon provided a straightforward interface to mount the SCS and other sensors. During operation it was relatively easy to control and provided more than enough torque, speed, and payload power. In addition it provided useful field testing of the platform which will help RoadNarrows as they continue their development.

Despite this success several aspects of the deployment proved challenging and are useful lessons learned for future deployments.

1. Storage: there was no appropriate indoor storage area available in which to house the Kuon while not in use. This did not create any problems as the nighttime temperatures did not dip below approximately -10 °C and there was very little precipitation. Two nights at the end of the mission saw some snowfall and for these the Kuon was protected by a large sheet of plastic.
2. Support equipment: as this was the first time that the Kuon was operated by the crew at MDRS little foreknowledge was possible in terms of the support equipment and tools required. The support tools which are available at MDRS were not chosen to support robotic testing and in many cases were

insufficient.

3. Cleaning: the nature of the soil at the MDRS location was such that it was very hard to remove from the Kuon's tires and body. No appropriate cleaning equipment (pressure washer, etc.) was available. Cleaning was not completed following testing and the Kuon was returned to Colorado mush dirtier than it departed.

6.2 Future Deployments at MDRS

The terrain surrounding the MDRS location is an excellent analogue for Martian terrain. The Mars Society is founded upon the premise of promoting Mars Exploration. MDRS is crewed by scientists and engineers dedicated to advancing the state of planetary exploration science. For these reasons a future prototype rover deployment at MDRS could prove an excellent choice for advancing the technology readiness level of a rover, rover subsystems or associated algorithms.

In planning a future deployment at MDRS the following recommendations are offered:

1. Mars Society Approval: Each testing activity conducted at MDRS must be pre-approved by the Mars Society. The approval process is not onerous but the criteria for approval can be ambiguous. The Kuon testing was temporarily dis-approved and only latterly approved as a result of perceived limitations of the generator system to charge the Kuon batteries. If approaching the Mars Society with a test plan the parties involved should be sure to account for delays in acquiring Mars Society approval. In addition, if possible it would be beneficial to rely on outside resources to alleviate the strain on the limited and closely monitored MDRS resources. For instance a portable generator and fuel supply could be used to charge a rover without use of the MDRS infrastructure.
2. Mission Control Support: As each EVA requires pre-approval from mission control it would be useful to clarify EVA requirements to mission control in advance. Ideally some form of pre-approval could be obtained. Several times during this mission the mission control team did not allow an EVA to be conducted which impacted the testing timeline. If testing priorities were delivered to mission control early with a detailed EVA plan to cover the entire mission duration in advance, there is a reduced likelihood that last minute disapproval could impact testing.
3. Bandwidth and Rover Remote Tele-Operation: the testing described in this paper did not include any element of tele-operation. The Kuon was controlled with line-of-sight at all times. In order to advance rover systems, vision systems, and navigation sensors an element of remote tele-operation would be a useful addition to a future MDRS prototype rover deployment. For this to be feasible several things would be required. Firstly, it would be necessary to secure pre-approval for robotic tele-operations from the Mars Society. Secondly, if the remote tele-operation were to occur at a site outside the habitat, an examination of the communications link and bandwidth requirements would be essential. Currently bandwidth is strictly limited at MDRS both to keep the simulation as high fidelity as possible and also due to limitations in the local network. Thirdly, detailed scheduling would be required to coordinate tele-operation from a remote site.

7 Conclusions

The testing summarized in this paper achieved its objectives. The MDRS site was found to include an area of Martian analogue terrain that is appropriate to support a future rover prototype deployment. The SCS was deployed and operated successfully and captured a dataset sufficient to generate a 3D terrain map of the selected deployment area. The logistics of rover field deployment at MDRS were examined and provided useful information for future deployment planning.

The benefits of the MDRS location for a future rover prototype deployment are the level of fidelity of the analogue site from a geological perspective, the applicability of the selected deployment terrain for rover mobility testing and the presence of a team of scientists and engineers available for collaboration.

While achieving all primary objectives, the testing of the SCS also provided useful lessons learned pertaining to noise and dynamic range. The results of this testing will be used to advance the technology readiness level of the SCS.

Planning for a future field deployment at MDRS should include consideration for bandwidth and other infrastructure limitations including power supply and storage. In addition, Mars Society and Mission Control approval processes should be considered a top priority in the deployment planning process.

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