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FIELD TESTING A ROBOTIC ASSISTANT FOR USE IN EXTRA-VEHICULAR ACTIVITIES

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ABSTRACT

For an astronaut conducting field research, the dangers and constraints imposed by the environment limit what can be accomplished in the time available. To improve the speed and efficiency of field work, the aid of a robotic assistant would be immensely useful. Such an assistant, under development by the Pennsylvania State University Mars Society (PSUMS), was tested at the Mars Desert Research Station (MDRS) during the rotation of Crew 25 (February 29 - March 13, 2004). Field testing in Mars-like conditions revealed where and how a robotic assistant would be useful in the field. Future testing will include a comparison of identical Extra-Vehicular Activities (EVAs) conducted with and without robotic assistance. Factors such as safety, speed, and ease of EVA completion will be assessed in both situations. Through periodic testing and design revision, the team will be able to determine and implement the most desirable qualities in a robotic assistant.

INTRODUCTION

With the renewed desire of many countries to be leaders in space exploration, increased budgets are making manned missions to Mars within two decades a realistic goal. Given the imminence of such missions, the goals of these missions and methods of reaching these goals need to be identified. The extent of the mission objectives will be limited by time constraints and budgetary restrictions. Operating efficiently within these constraints is crucial to ensure that field research produces useful results. With this idea in mind, the use of robotic assistance is vital for efficient operation.

A robotic assistant should have the ability to aid in Extra-Vehicular Activities (EVAs) by performing autonomous tasks as directed by the astronaut. To create a capable assistant, the necessary tasks need to be determined through extensive research. An effective mode of communication between the astronaut and the assistant must also be developed.

The Pennsylvania State University Mars Society (PSUMS) has been developing such a robotic assistant to help an astronaut carry out a large number of tasks quickly and efficiently in the field. The PSUMS rover is a robotic assistant controlled by virtual reality gloves. It features the ability to hold one of several modular toolkits, which can be interchanged to prepare the rover for any particular EVA. The development and features of the PSUMS rover are explained in detail in “A Modular Multi-Function Rover and Control System for EVA,” which can be found in the proceedings from the 2002 International Mars Society Conference¹.

Field testing a robotic assistant such as the PSUMS rover in a Mars-like environment will identify the most beneficial functions the robotic assistant can perform. To determine these functions, a variety of testing methods must be employed under simulated Martian conditions. EVA simulations without robotic assistance reveal which tasks require improved efficiency. Operation of the assistant in the simulated environment further specifies design requirements. Once these requirements are incorporated into an updated design and implemented, the same simulations will be performed with the assistant. To assess the PSUMS rover’s ability to aid an astronaut, many factors such as its effect on EVA efficiency, the simplicity of human-rover interaction, and astronaut safety will be investigated at this stage. To further evaluate the rover design, various sensors incorporated into the rover design will determine how it is affected by typical operating conditions in the testing environment. The data and observations from the field testing will then be incorporated into another stage of design revisions.

FIELD TESTING OF THE PSUMS ROVER

The first two of the aforementioned testing methods have been put into practice in field testing the PSUMS rover during a two-week Mars exploration simulation at the Mars Desert Research Station (MDRS) by Crew 25 (February 29 - March 13, 2004). The crew logs and reports are available from the International Mars Society website, under the 2003 field season at MDRS². There in the deserts of southern Utah, the rover had its first exposure to a realistic Mars-like environment. As such, the field testing revealed many unforeseen issues, which must be taken into account as development progresses.

Rover Testing

At the time of the field testing, the rover consisted of a motorized base that held one module—a soil sampling device. The first difficulty was noted upon assembly of the rover in the habitat. In the extremely space-efficient habitat, finding space to assemble and store the rover was very difficult. Furthermore, simply getting the rover into the airlock and outside the habitat proved to be a major challenge. Thus, the first lesson learned was to make the rover smaller and more portable to deal with the cramped conditions likely to be encountered in a manned Mars mission.

Once outside, the crew had plenty of space to test the rover. However, when traveling a long distance, the rover's slow speed makes carrying it preferable to driving it. Though carrying the rover is normally a simple task, when one is wearing a spacesuit and a heavy pack, it becomes unwieldy and almost not worth the effort of carrying it along. This observation leads to the idea that a robotic assistant should move quickly enough to keep up with an astronaut, and it should be able to strap onto someone's back in cases where climbing is necessary to reach an EVA site. This in turn requires that the rover also be light enough to make backpacking feasible.

Lastly, the environment itself created some issues. The rough terrain requires a more robust rover design than was anticipated. The frame, steering, and suspension were not strong enough to survive repeated impacts and prolonged operation on extremely rough ground, and would have to be strengthened. Furthermore, the sampling device design (shown in Figure 1) in use at the time required flat or nearly flat ground to extract a sample. However, in the Mars-like desert in Utah, flat ground is scarce. Though it was anticipated that the crew might have to specifically seek flat ground for sampling sites, the true difficulty of finding such sites was not clear until the field testing. Keeping the terrain in mind, a new system for collecting soil samples would need to be devised.

Intended Uses of a Robotic Assistant

While information about the rover's performance in a realistic environment is crucial, the activities of the crew should also be studied to determine how a rover could best assist astronauts in the field. Though the rover was deemed unprepared to assist in EVAs at this point in its development, the crew was still able to carry out typical EVAs without robotic assistance for the first stage of the field testing. The EVAs conducted by Crew 25 fell into three main categories: biological EVAs, which focused on taking soil samples to check for microbial life; geological EVAs to collect representative rock samples from an area; and general exploration to explore the terrain and identify possible sites for future scientific EVAs. In each of these areas, certain difficulties were clearly identified, indicating areas in which a robotic assistant could be invaluable.

Biological Field Work

In collecting soil samples during biological EVAs, numerous tasks must be performed, and many of the more complicated ones could be completed by a robotic assistant. The PSUMS rover, equipped with an effective soil sampling module, would be able to extract and store soil samples onboard. Having the rover complete the extraction bypasses the difficulties of transferring soil from a corer to a sample container and sealing that container by hand in a motion-restricting spacesuit. Storing the samples onboard is also easier for the crew than carrying them.

In addition to performing these complex tasks, the rover could also perform simple tasks that are merely very time-consuming. For example, taking a temperature reading from the soil required waiting for the reading to stabilize, sometimes for several minutes. In this case, the rover's ability to multitask would be particularly beneficial, since it could take the temperature reading and extract the soil sample concurrently.

With the robotic assistant available to perform these tasks, the EVA could be conducted with only two crew members instead of the three required otherwise. In addition to putting fewer people at risk and increasing EVA efficiency, this would allow an extra person to remain at the habitat to perform laboratory work or routine maintenance.

Geological Field Work

For sampling rocks during a geological EVA, a robotic assistant would probably not be used to collect the actual sample, but it would be invaluable in recording data about the sampling site. For creating panoramic photographs of an area, a camera onboard the rover would provide an excellent alternative to taking a set of photographs by hand. Unlike a camera set up on a tripod, which requires flat ground, the rover's camera could be made self-leveling. In addition, the whole sequence of repeatedly taking a picture and rotating the camera could be automated. A crew member could give a single command to the rover to take a panoramic photograph, and then continue with other tasks while the rover completes the procedure. Again, the increased efficiency frees crew members for other tasks, making the robotic assistant a valuable addition to the team.

General Exploration

For the purpose of general exploration, the role of a robotic assistant will vary depending on the goal of the exploration. For terrain mapping, a GPS module on the rover could keep track of the path taken and note locations at which the crew stops. Photographing capabilities would also be helpful in such situations, in case the crew plans to return to a particular site.

If the crew stops to explore an area at length, a rover could have other purposes. If an interesting site is not easily accessible, further exploration of the area may prove hazardous, or simply troublesome. However, a module for the rover could include a smaller version of itself, either tethered to the main rover or in wireless communication with it. This would simply contain a camera and a light source to give a good view of the area in question. With a viewscreen incorporated into the onboard part of the module, the astronaut could maneuver the mini-rover into an area as far as the tether or wireless network could reach. This is a much safer and often simpler alternative to sending an astronaut into unknown territory.

IMPROVEMENTS FOR THE SECOND GENERATION ROVER

Over the next two years, PSUMS will design a new rover to improve and expand upon the current design, based on the lessons learned from the experience of Crew 25. First, the structural issues will be addressed and incorporated into the new rover base. Later, improved modules will be developed to prepare the rover for use in EVA simulations. The goals for this project are to develop a rover with improved performance, human interface, and testability, and to conduct more extensive field tests. With a more capable rover, it is hoped that these field tests will help demonstrate the viability of virtual reality glove control, tool modularity, and the robotic assistant concept in general. In addition, they will provide insight into how to further refine and enhance this and future designs.

Performance

The first rover design showed room for improvement in several areas. The first was the frame, which was constructed of aluminum c-channel. With the addition of a battery that was much heavier than anticipated, the frame was no longer able to adequately support the weight of the onboard systems, so steel bars were fit into the c-channel for reinforcement. The reinforced frame is shown in Figure 2. This change allowed the rover to support all its onboard systems, but increased the weight considerably. Steel was also used for various mountings and ad hoc additions, adding still more weight.

The frame for the new rover will be designed to be both stronger and lighter than the current frame, so the rover is easier to transport and more structurally sound. The most important change will be the use of aluminum tube instead of c-channel. Unlike the old c-channel section, tube is very strong against bending. The increased strength of the new section will eliminate the need for steel reinforcements, thereby reducing the weight. Likewise, the use of aluminum will be favored over steel in all other components of the rover. Where additional strength is needed, titanium will be used. Like the current frame, the new frame will be assembled by TIG welding, which provides very high quality aluminum welds.

The other major issue of the current rover was the design of its steering and suspension. Originally, it was designed to steer using split front and rear axles. Figures 3 and 4 show drawings of this steering system in its conceptual phase. Once constructed and tested, it proved to be overly complicated and unable to support the heavy frame. In particular, the two pivots where the split axles connected to the frame were overloaded due to bending and provided a lot of resistance to steering. Eventually, a single front axle design was used. This worked much better because the single central pivot did not undergo any bending. Aside from inflatable tires, the current rover has no suspension, which is unacceptable for use in rough terrain, even at low speeds.

There are many steering options for the new rover including tank style steering, pivoting axles, and pivoting wheels, among others. There are also several suspensions that could be useful including passive, active, and rocker-bogie. In order to allow for different steering and suspension schemes to be field tested for suitability, the new rover frame will be designed to accept any steering/suspension assembly provided it attaches to the frame in the same way. The first system to be designed will be a simple four-wheel tank style steering assembly. It will feature a passive spring-damper suspension. Additional steering/suspension systems will then be designed to fit the same attachment points as the tank style system. This concept of modular suspension will be utilized during field testing to determine which systems perform the best and if different systems are more suited to some mission profiles than others.

There are several other performance improvements planned for the new rover. Dust proofing enclosures will be used to keep particles out of moving parts and bearings. Power and computing wires will be distributed inside the frame to two module loading bays. This unobtrusive wiring system will reduce the possibility of damaging connections. Finally, lightweight electronics and tool module enclosures will be constructed out of polycarbonate, foamed PVC, or some other rigid, lightweight material.

Human Interface

The primary aspect of the human interface to be improved is the virtual reality glove control system. The current rover can be driven using simple gestures to move forward and backward and steer. The next step is to develop a more comprehensive command set and control structure. The increased set of gestures will allow both manual and automatic control of the rover's motion and the operation of any onboard tool modules. It will also let the user navigate and use an interactive menu, specify the rover's operational state or active feature, and request feedback. Considerable research will need to be done to determine how to structure the gesture set to maximize ease of use and accuracy.

Another improvement will be in the way tool modules are loaded onto the rover. Loading a module onto the current rover involves securing the tool with nuts and bolts and then connecting several wires to the rover's electronics. This process requires a wrench and is not consistent from one module to the next. The new rover will use a standardized module bay. Tools will be locked down using latches in a tool-less process. Also, all power and input/output lines will be run to each module port and consolidated into a single plug. This should make loading and unloading modules much faster and easier.

Testability

In contrast to the current rover design, which provides very limited feedback, the new rover will be designed to provide significant data about the performance of its mechanical, electrical, and software systems. In order to provide information about the mechanical performance, various sensors will be embedded in the design. These will include strain gages, vibration sensors, attitude sensors, and optical encoders on the wheels, in addition to others. Data from these sensors will be time-stamped and logged during periods of testing. Voltage and current will be measured across the battery and motors to indicate the draw on the battery and the power used by each motor. Finally, software logs will be kept of the commands sent and the interaction between various programs and the microcontroller to help diagnose problems and improve efficiency.

Damage Prevention

In some cases, the rover may need to operate outside the astronaut's field of vision. For this situation, a camera or cameras onboard the rover would provide the astronaut with enough information about the rover's surroundings to reach a destination and avoid obstacles. However, without a view of the rover's position and orientation accidental damage becomes a concern. The same is true of situations in which the rover is acting semi-autonomously and the astronaut's attention is on another task. For such situations, various sensors would report data necessary to evaluate the safety of the rover.

On slanted ground, attitude sensors would report the angle at which the rover rests. The onboard computer would interpret the data to determine whether the rover is likely to tip if it proceeds. Similarly, strain gages and vibration sensors placed on the body of the rover indicate the

possibility of structural damage. Together, these sensors would provide the information necessary to determine if a situation is potentially hazardous for the rover. The computer would make decisions on whether to allow a command or not based on this information.

Speed and Position Calculation

Optical encoders or mechanical switches adjacent to the wheels are feasible sensors for determining speed. Incoming data can be interpreted by the rover's onboard computer and reported back to the astronaut to relay the speed of the rover. The readings will not be exact since the computer can only transmit a digital signal in discrete time segments, but they will be enough to determine approximately how fast the rover is moving. From the rover's speed and the time spent at that speed, the distance traveled can be approximated. These data are critical for semi-autonomous functions and remote control using the onboard cameras.

Power Monitoring

Over time, the power a battery can supply decreases due to the nature of a practical battery. By monitoring the voltage of the battery under a small load, the computer can obtain general information about how much power is available for use. With this information, it can shut itself down safely or bring itself and the rover systems safely into a low-power mode when necessary. This prevents problems storing data in the computer's memory due to a power-off when writing. Since the computer will initiate a shutdown sequence before the battery voltage becomes insufficient to power all the onboard systems, the risk of damaging hardware and losing data due to power loss is nearly eliminated.

Software Debugging

Since most software errors are encountered during use rather than by reading through the program, it will be highly beneficial to detect and even correct errors while the rover is in operation. For these purposes, a small LCD screen will be attached to the rover to provide information about the commands received and the status of the modules in use. A keypad will be added to allow interaction with the rover during the diagnostic and debugging processes. This debugging hardware will help reveal unexpected faults and pinpoint the location of these faults within the complex system. In the case that an error cannot be corrected in run time, the module in question can be deactivated to allow the rest of rover to function properly.

FIELD TESTING THE SECOND GENERATION ROVER

When the second rover is ready for field testing, simulated EVAs will be performed to test the overall effectiveness of the robotic assistant concept, the suspension and steering systems, and the glove command concepts. The testing will also reveal new design flaws and additional avenues of development.

Field Testing Methodology

As mentioned earlier, the next stage of field testing will rely on comparative runs. The general concept of a glove controlled robotic assistant will be evaluated by running identical EVAs with and without the rover. In both cases a time-stamped log of mission events will be recorded. The completion times for different mission objectives such as reaching the target location, completing specified tasks at the target location, and returning to the habitat will be the primary metric of efficiency. Other notable events, such as unforeseen delays or dangerous situations will be recorded and considered as well. In testing this version of the rover, most of the focus will be on the effectiveness of the EVA team at the target location, since the rover's primary function is to cut the workload onsite.

Testing of specific systems will also be performed. In order to determine which suspension and steering systems are most suitable for the rover's mission profile, similar EVAs will be performed with different systems attached to the frame. As in previous testing, a mission log will be kept to gauge performance and note difficulties encountered. Additionally, sensor data will be logged to indicate performance in terms of power usage, vehicle speed, and vibration.

The glove command system will be tested similarly. Several command structures will be developed, each representing the same commands with different sets of gestures. Investigating different command sets is important because there are many distinct, logical ways to specify tasks like steering, throttling, and system control. By performing field tests with many command sets, the most accurate and intuitive concepts can be selected and developed.

Design and Testing Iterations

As the design for the new rover matures, additional systems will likely benefit from similar testing. However, optimizing each system while also evaluating the need for a robotic assistant may become extremely complicated. To avoid testing every permutation of suspensions, modules, steering systems, and other add-ons, a number of preliminary experiments can be designed to select the optimal systems of each type. Only permutations of the chosen systems need to be tested further. Beyond investigating various components of the rover, repeated field testing will bring to light shortcomings in the rover's overall design and point to improvements which could not be predicted with other tests. Continued iterations of the design revision and field testing processes will further improve the rover, eventually creating a robotic assistant ideally suited for field research on Mars.

CONCLUSION

Simulations of field research on Mars clearly show that robotic assistance would be of immense value in many situations. An assistant such as the PSUMS rover could increase the safety and efficiency of a variety of Extra-Vehicular Activities by performing repetitive, tedious, or dangerous tasks in lieu of an astronaut. The capabilities required of such an assistant are already well defined from the experience of completing simulated EVAs without robotic assistance. Performing the same EVA simulations using a robotic assistant with these capabilities will show the degree to which robotic assistance can be useful. From repeated testing in a Mars-like environment and improvements based on the test results, an effective design can be developed. The ideal rover design is achieved when a human-rover pair acts more efficiently than a pair of

humans. As the development of the PSUMS rover progresses, subsequent iterations of field testing and design improvements will bring the rover ever closer to being an ideal robotic assistant.

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[2] The Mars Society. "Messages and Reports from the MDRS: 2003-2004 Field Season – Daily Reports and Photos." <http://www.marsociety.org/MDRS/fs03/>

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FIGURES

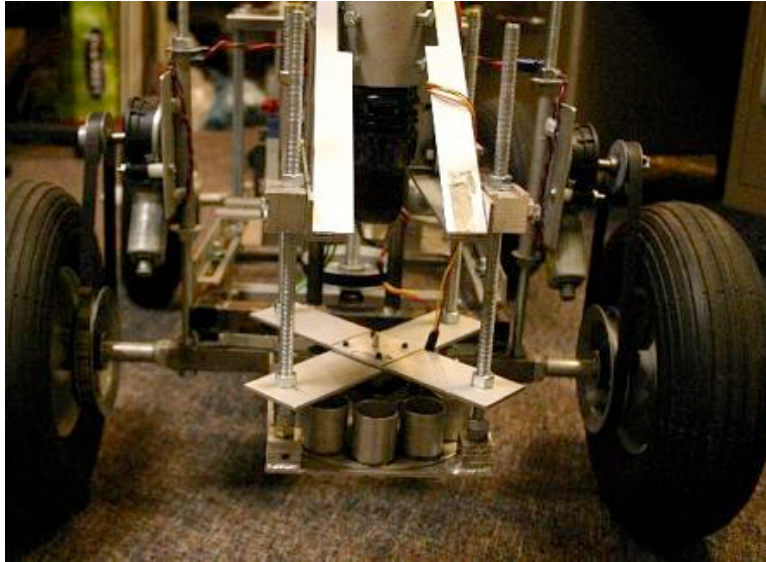


Figure 1: Sampling Device Module

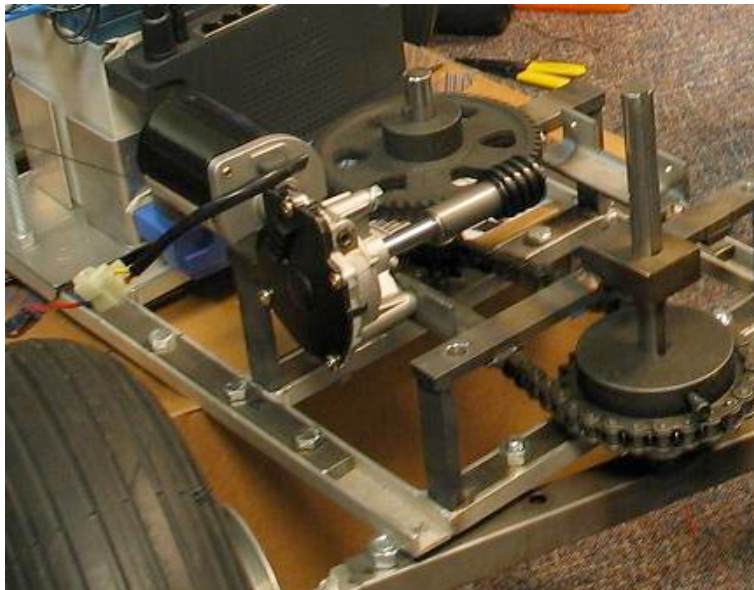


Figure 2: Steel-Reinforced Frame

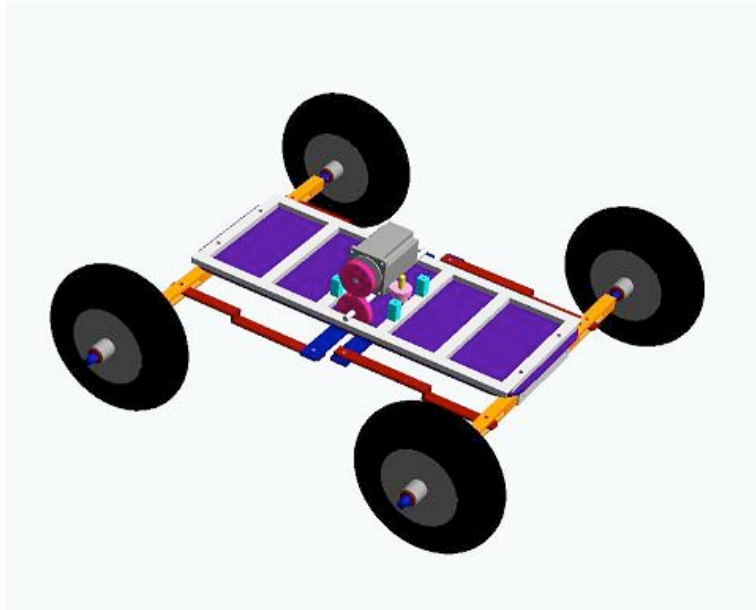


Figure 3: Old Steering System, Top View

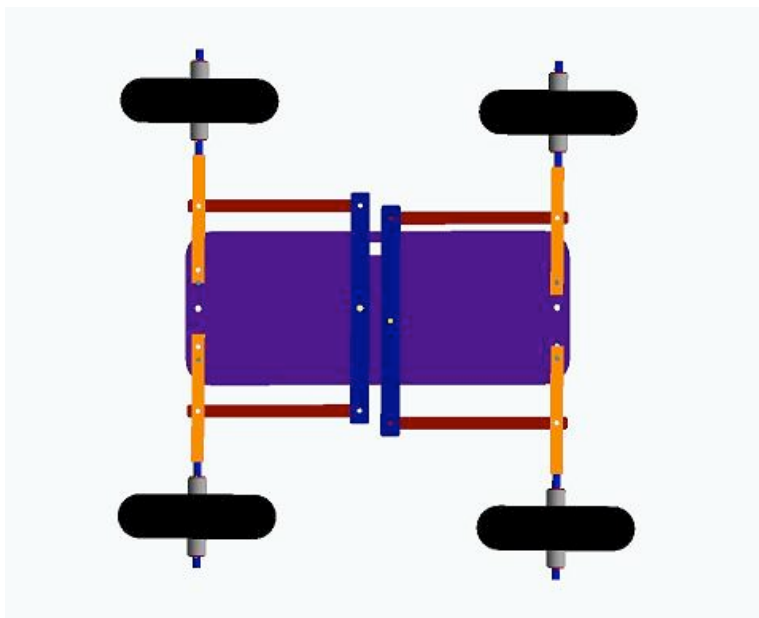


Figure 4: Old Steering System, Bottom View