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The Mobility System of the Multi-Tasking Rover (MTR)

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Abstract—**Current and planned robotic rovers for space exploration are focused on science and correspondingly carry a science payload. Future missions will need robotic rovers that can demonstrate a wider range of functionality. This paper proposes an approach to offering this greater functionality by employing science and/or tool packs aboard a highly mobile robotic chassis. The packs are interchangeable and each contains different instruments or tools. The appropriate selection of science and/or tool packs enables the robot to perform a great variety of tasks either alone or in cooperation with other robots. The multi-tasking rover (MTR), thus conceived, provides a novel method for high return on investment. This paper describes the mobility system of the MTR and reports on initial experimental evaluation of the robotic chassis.**

I. Introduction

On November 17, 1970 the Soviet spacecraft Luna 17 landed on the moon. It carried Lunokhod 1, the first exploration rover to be deployed on the surface of a celestial body of our Solar System. The remotely operated eight-wheeled vehicle weighted just under 900kg and was designed to operate for 90 days while operated by a 5-person team. It explored the Mare Imbrium for 11 months and traveled more than 11km [1].

As time progressed, exploration advanced and so did mankind's expectations from its wheeled robotic explorers. Lunokhod's successors evolved in order to satisfy increasing requirements imposed by the exploration of hostile environments of our Solar system. Rover systems have been equipped with enhanced mobility systems since they need to traverse over natural rough terrain. In addition they have been equipped with a number of scientific instruments and cameras in order to allow scientists to explore the new worlds. The Sojourner rover [2] not only carried scientific instruments, but also a scoop mechanism to facilitate the collection and closer examination of samples, whereas the MER rovers [3], operational since January 2004, are each equipped with a robotic arm and a number of science instruments, in order to provide better remote geology. The European Space Agency's ExoMars mission (planned for 2009) will deliver on the surface of the Red Planet the Pasteur rover whose equipment includes an on-board Drill System [4].

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Current scenarios for Mars and Moon habitation assume the use of robotic semi-autonomous rovers for the construction of habitats prior to crew arrival [5]-[7]. In order to prepare the infrastructure rovers will have to work cooperatively [8-9] and in some cases they will be used to deploy other systems [7]. Special tools and gripping mechanisms [8] will be required for manipulation, assembly and transportation of large structures and raw materials.

All rover designs presented to date or planned for the near future focus on specific aspects of space exploration. In this paper we present a new design for a rover. The Multi-Tasking Rover (MTR) is a novel approach that aims to integrate advanced mobility and varying functionality under one system. The main idea behind the MTR is that instead of using multiple robotic systems, each dedicated to a specific task, a reconfigurable system can be employed which can offer varying functionality according to the exploration needs. The design of the system focuses on modularity, re-configurability and upgradeability.

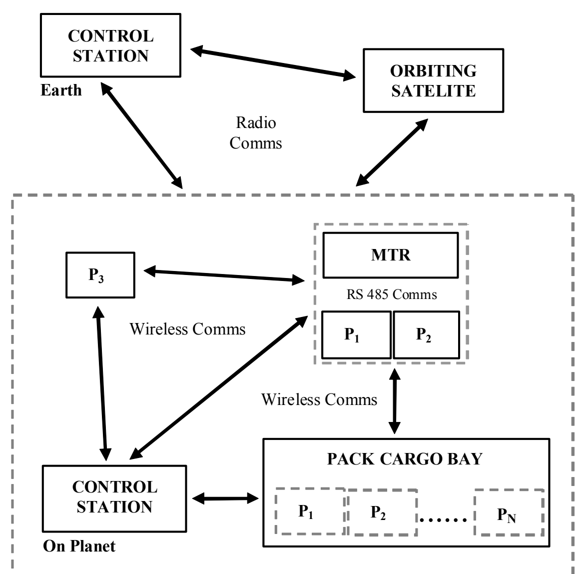

Fig. 1.The operational context for the MTR

The MTR does not carry any scientific instruments or tools. It works in conjunction with Science Packs (SP) and/or Tool Packs (TP), which encapsulate science instruments or tools. It can acquire the Packs by means of mechanically coupling with them. When the task is completed the packs can be returned to a storage location. The Packs can also be other robotic mechanisms i.e. a robotic mole, that once deployed, operate independently of the rover. In the latter scenario the rover would be used to offer mobility to those smaller systems. The MTR can carry

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a maximum of two Packs. Future needs could be accommodated by sending new Packs rather than complete rover systems. Figure 1 depicts the complete MTR system scenario.

This paper describes the implementation and preliminary testing of the MTR mobility system. The remainder of the paper is organized as follows. The following section provides a detailed description of the mobility system of the MTR. Section III describes the way in which the MTR operates with Packs. Section IV presents preliminary results of testing the mobility system of the MTR. Finally, section V provides a summary, conclusions, and future work.

II. The Mobility System

The four-legged rover system employs 3 degrees of freedom per leg and two more for the operation of its active differential system. The overall system can be divided in the following subsystems: the Steering/Drive System, the Shoulder Articulation System (SAS) and the Active Compliant Differential Suspension (ACDS). Fourteen motorized actuators are required for the operation of the subsystems described in detail below.

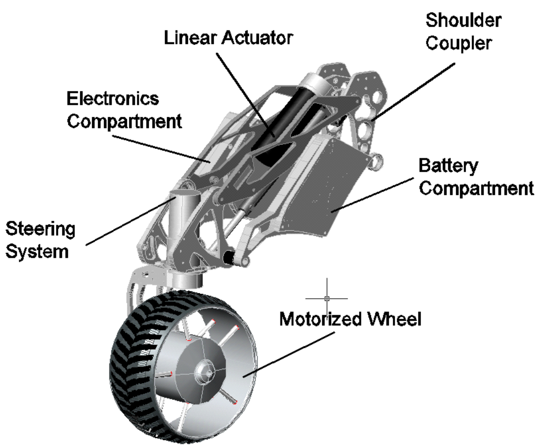

Fig. 2. Elements of a leg.

A. Steering/Drive System

The MTR is a four-wheeled rover able to achieve a maximum speed of 7cm/sec, which is delivered through a motor/gearbox combination incorporated within each wheel hub. Ten stainless steel spokes are arranged in five pairs between the rim and the hub of the wheel. The aluminum wheels measure 175mm in diameter. Each of the wheels can be steered independently, giving the rover the highest mobility possible. The MTR can traverse forward/backward, turn on the spot, take hard/soft turns and crab to any direction maintaining the orientation of the body. The rotation of each of the wheels is restricted to ±185 degrees by limit switches. Each of the steering motors is also equipped with a custom made potentiometer in order to obtain information on the absolute position of the wheels.

B. Shoulder Articulation System (SAS)

The SAS is used to control the angle between two legs of a shoulder. As mentioned, each wheel, situated at the end of each leg, is steerable and independently driven. The two steering axis of a shoulder are always kept in parallel. This functional characteristic is a result of the geometry of the design of each leg as well as the way two legs are linked to form a shoulder. Each leg assembly comprises of the six main elements shown in Figure 2. The steering system section, which is linked to the shoulder coupler via four parallel links and a custom made linear actuator. The shoulder coupler is mutually shared between, and effectively links the two legs. It also connects the shoulder to the main body. The two bottom links include compartments for batteries and electronics respectively.

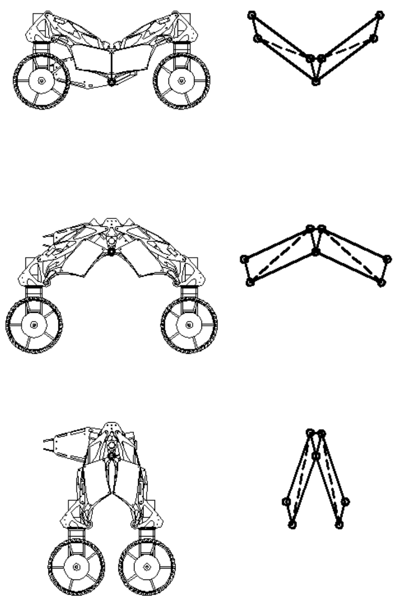

Fig. 3. The MTR lift/lower the main body section using the SAS system.

The powerful custom made linear actuator controls the geometry of each leg. It acts much like an adjustable diagonal in a parallelogram. By adjusting the length of the diagonal the tilt angle of the parallelogram, which is determined by the four links of the parallelogram, the steering section and the shoulder coupler, changes. By combining all four legs the MTR can attain some very interesting geometrical configurations. This is illustrated in figures 3 and 4. In both of these figures the left column shows the actual configuration of the robot system while the right column shows the configuration of the parallelogram; the linear actuator in the parallelogram is depicted by a dashed line.

The SAS can be used in many different ways. When used on flat terrain it can move the body section up/down, by lifting/lowering all legs, by more than ±150mm. It can shift the body forwards/backwards by ±60mm, by lifting the front and lowering the rear legs and vice versa. It can be used to alter the vehicle's roll angle by more than ±35 degrees, by lifting one shoulder whilst lowering the other and finally, by giving equal and opposite deflections to certain leg pairs it can rotate the rover about its yaw axis by about ±10 degrees. That amount of re-configurability could prove very advantageous for the pick-up, deployment and in some cases operation of SP/TPs.

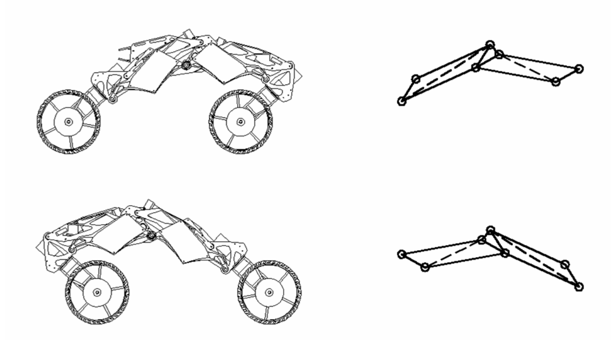

Fig. 4. Shifting the centre of gravity backwards and forwards using the SAS.

On rough terrain, the SAS acts like a centre of mass re-allocation system. It can shift the vehicle's centre of mass forwards/backwards, left/right and/or up/down. This allows the rover to traverse slopes more than ±35 degrees in inclination and maintain its four axis of steering parallel to the vector of gravity. Furthermore the MTR can lift one of its legs to overcome obstacles more than 2½ times the wheel diameter. By employing center of mass re-allocation through the ACDS (described below), the rover can be statically stable whilst doing so. The adaptability of the vehicle to local terrain irregularities can be increased further by linking the two shoulders with a differential mechanism.

C. Active Compliant Differential System (ACDS)

During traversal the shoulders of the vehicle are to be at different inclinations with respect to each other; for example, when one of the four wheels is in a higher position than the rest. To account for this, current rover systems [10], [11] employ a passive differential mechanism. This allows all wheels to stay in contact with the ground, with the weight evenly distributed between them. It also halves and reduces the deflection of the body's pitch and roll angles, respectively. The amount of reduction in the roll angle depends on the width of the vehicle. The mechanism's driving force is the vehicle's own weight. The SAS alone can cope to a fair degree with altitude differences between the wheels but the addition of a differential further increases the re-configurability of the suspension system. Having both systems present effectively allows the flexibility of accounting for differing terrain using the differential mechanism, and further adjusting stability by shifting the rover's centre of mass through the SAS. Furthermore the SAS allows elimination of the roll angle deflection by opening/closing the opposing shoulders.

The MTR employs a hybrid differential mechanism. The ACDS (Fig. 5) effectively controls the angle between each shoulder and the body. Two shafts one on each side of the body, come out so that the shoulders can be mounted. Each shaft rests on bearings located inside the body. It is linked to a DC motor-gearbox combination via a pulley drive such that its rotation is controlled. Each pulley drive is allowed a ±5 degree spring-loaded backlash, so that effectively this is translated between each of the shoulders and the body. This gives passive compliance to the active differential system.

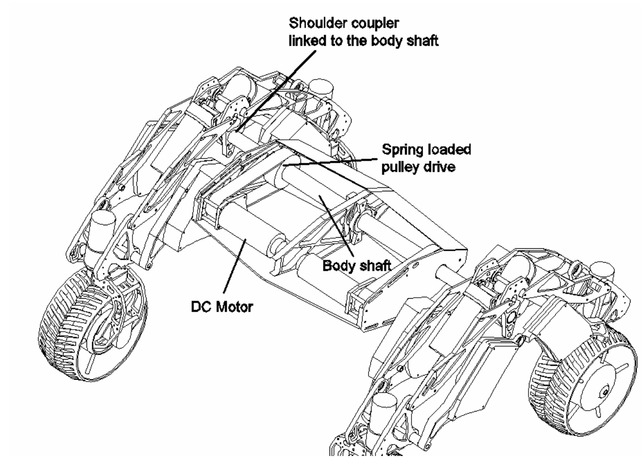

Fig. 5. Description of the ACDS

There is a certain amount of deflection that the suspension can cope with passively, before active compensation mode is engaged. The threshold value will be software selected and limited by design to a maximum of 10 degrees difference in rotation between the two shoulders about their pivot points to the body. Inside the spring mechanism, pressure sensors are located and the amount of deflection of each spring is recorded. This offers the possibility, if so desired, of reducing the pressure but not losing contact between the two diagonal pairs of wheels and the ground.

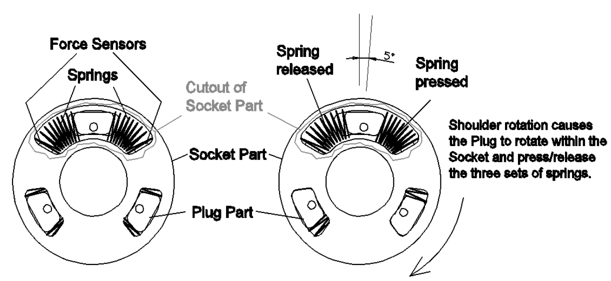

Fig. 6. The ACDS force Sensor

This mechanism is primarily designed in order to sense whether all wheels are in contact with the ground during traversal in rough terrain. This is necessary for the operation of the suspension system since the MTR employs active control of the differential drive between the two shoulders and the body. The pulley drive design has been modified recently to accommodate the merits of passive suspension control. Effectively the two spring-loaded pulley drives provide both active and passive re-configurability to account for the anomalies in the terrain.

Another feature of the ACDS is that it allows the main body to rotate around its pivot point to the shoulders. The amount of rotation is not limited to any angle or number of revolutions. This aspect of the suspension is used for vehicle centre of mass re-allocation, but more importantly, it allows flipping the main body by 180 degrees so as to pick-up and hold a second Pack. Four custom-made electrical rotary unions are used to link the two shoulders to the main body. These allow electrical connections between the two shoulders and the body, while there is rotation between them. All the attributes of the hybrid suspension system, when combined, give unique capabilities to the rover system.

The SAS and ACDS systems are used not solely for centre of mass re-allocation but also for the operation of any Packs. For example, a Drill Pack might have to operate vertically or at an angle. Finally, the SAS and ACDS together give the ability to the rover to adjust the main frame accordingly in order to pick-up a Pack no matter what its orientation, (the roll angle and the clearance of the body with respect to the ground can be controlled via the SAS, the body pitch by ACDS and the yaw angle can be determined through the steering/drive system). Effectively the body has six degrees of freedom of motion which can be actively controlled.

III. Science Packs, Tool Packs And Possible Configurations

The costs associated with launching a robotic mission into space are extremely high. Engineers and scientists work closely together so that the desired functionality is obtained within allowable limits. The overall MTR system design approach has been focusing in increasing the functionality that a rover system can offer, whilst bringing down the payload specification and therefore the related costs.

For example the Cliff-bot system [12] comprises three rover systems: two Anchor-bots and the SRR2K. The latter is allowed to descend steep slopes with the aid of ropes whose tension is controlled by the two Anchor-bots. The drawback of this approach is that the two robots are engaged to a very limited role. If the MTR system was employed for the same task, it would again require three rovers to obtain the desirable results, but the difference would be that after the completion of the task, the rovers would be able to re-configure by placing the 'Anchor-Packs' to a storage location and by picking a new set of Pack. For example a Manipulator Pack and a Spectrometer Pack [13] could be engaged to complete a remote field geology task.

Scenarios have been presented where rover systems have been employed for the transportation of extended payloads [5], [7], [9]. It has been demonstrated in [8] that dedicated manipulators are required for such cooperative working. Again, the manipulator systems could be encapsulated within Tool Packs so that a set of cooperating MTRs could each acquire such a Pack and use it when necessary to perform the task.

As mentioned above the MTR rover system presents enhanced re-configurability that assists rough terrain stability/mobility and so. Hence, it could allow scientists to reach places of interest involving less risk for the mission. Centre of mass re-allocation could also be enhanced with the aid of specialized Packs comprising a movable mass or even an extra leg.

As mentioned earlier, the MTR has the capability of deploying two Packs. These can be Science Packs, Tool Packs or a combination of the two. The robotic mechanisms or science instruments that can be incorporated within a Pack can be limited by the maximum allowable size of the Pack and the lifting/transportation capability of the MTR. Given the weight of the rover upon completion to be around 16kgs, the maximum volume for a Pack is limited to 5litres and its weight should not exceed 4kgs. Nonetheless this configuration offers great external re-configurability since a great variety of devices can be deployed.

Both SAS and ACDS have an important role in the pick-up, deployment, operation and storage of the Packs. The SAS is responsible for lowering and lifting the body during pick-up and put-down operations, whilst the ACDS allows the flipping of the body so that a second Pack can be accommodated. Additionally, both systems enable the rover to acquire a specific stance and assist the operation of a Pack.

The generic principles of operation of the MTR in conjunction with a Pack i.e. pick-up, integration with the rover and put-down, will be demonstrated using a simple Battery Pack, depicted in Figure 7.

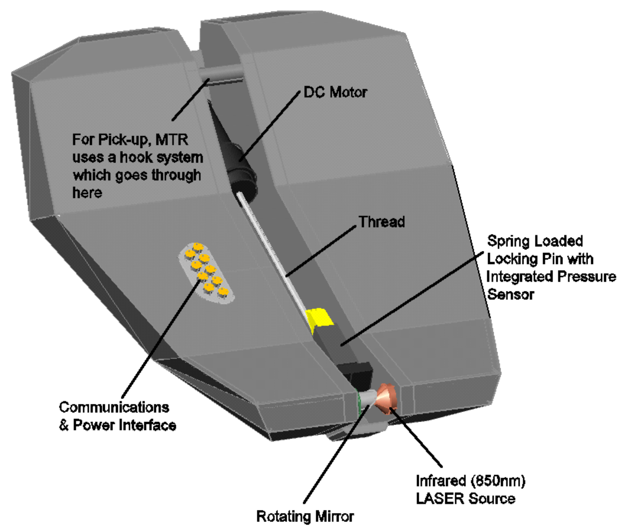

Fig. 7. The Battery Pack contains the necessary parts required to demonstrate the concept.

The body of the rover will offer a set of mounting points on which a spring loaded locking pin on the Pack will be attached via a lead screw drive encapsulated within the Pack. The locking mechanism is situated inside the Pack rather than the rover so that the scenario of having multiple Packs stacked together can be exploited in the future. A rotating mirror working in combination with an infrared LASER source will be used for alignment of the MTR with a Pack during a pick-up operation. The communications and power interface allow the rover, in that instance, to draw power from and obtain information about the status of the Battery Pack. The mechanisms incorporated in this design are the standard elements required to acquire and use any Pack and should be included in all future Pack designs. Figure 8 illustrates a CAD model of the MTR having acquired the Battery Pack. The Pack pickup operation will be the subject of future papers.

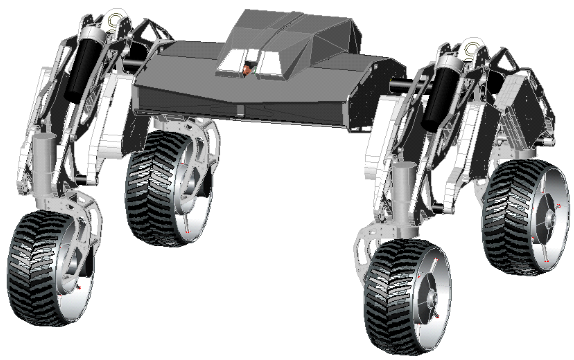

Fig. 8. The Battery Pack on the MTR.

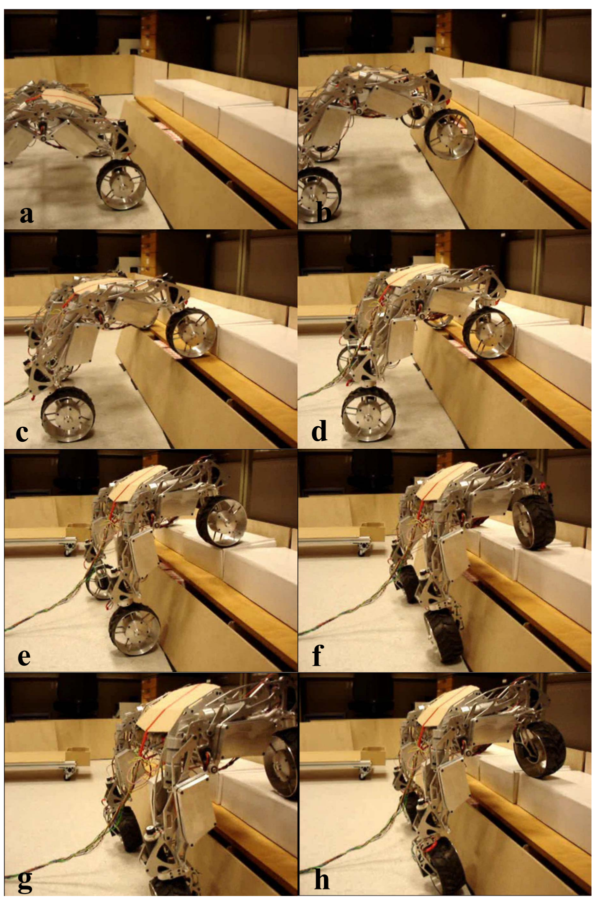

Fig. 9. Demonstrating centre of mass reallocation to enhance stability.

IV. Preliminary Testing

Most of the electromechanical systems of the rover are now in place. A custom made joystick has been constructed so that groups of motors i.e. all the steering motors or wheel motors or SAS motors, could be controlled together. The MTR has been tested indoors in various different setups in order to evaluate its performance.

The setup shown in Figure 9 comprises two vertical steps constructed to demonstrate centre of mass reallocation using the SAS. The first step measures approximately 320mm in height whilst the second 110mm. The MTR climbs the first step without reconfiguring (a-c). In order to climb the second one the SAS is engaged and the centre of mass of the vehicle is shifted forwards (d). Following that, the rover climbs the second step (e) and then traverses laterally (f-h).

The next setup, shown in Figure 10 (a-c), illustrates the operation of both the ACDS and the SAS. The rover traverses over a ramp with one of the shoulders still on flat terrain. The ACDS allows contact of all four wheels and the ground and the SAS maintains the body leveled. A point to note here is the maximum values the suspension can deliver have not been attained since without sensory feedback and microcontroller control this could prove dangerous for the system.

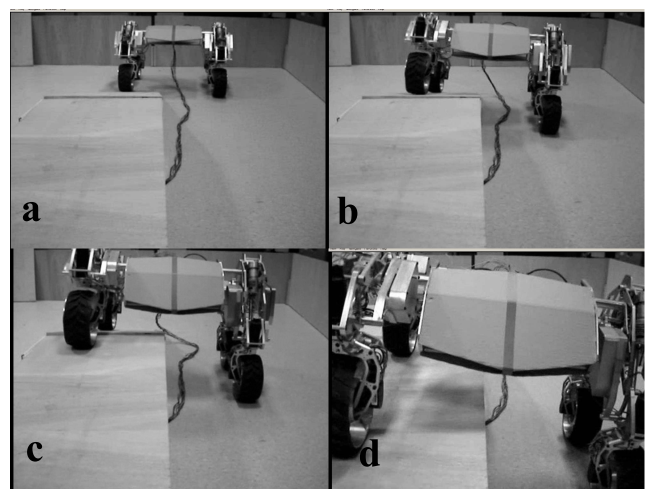

Fig. 10. SAS and ACDS working together

V. Conclusion

In this paper we have presented an approach to the design of space robot systems that combines a highly mobile robotic platform with a set of packs that can incorporates science or tool functionality. Equipping the rover with the functionality required to complete a task either alone or in cooperation with other robots means the selection, retrieval, and deployment of the appropriate combination of packs from a pack container unit. The approach offers an efficient strategy for space exploration based on sending a small number of rovers and a set of swappable packs that together offer the range of functionality required to complete the mission; rather than sending a separate rover for each mission task. We have implemented and carried out preliminary testing of the robotic platform, the multi-tasking rover (MTR). Work will now focus on development and demonstration of pack pickup and deployment.

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