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A Multitasking Surface Exploration Rover System

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1. Introduction

Exploration of the unknown and survival have always been generic instincts of the human nature. According to our knowledge about the universe and the available technology, exploration progressed from a quest for land across the horizon, to a search for planetary bodies in our galaxial neighbourhood, which given the appropriate infrastructure, could sustain artificial ecosystems.

The best candidates for exploration within our Solar System are the Moon and Mars. The Earth's moon is the nearest celestial body and therefore most easily accessible. It has been excessively studied throughout the centuries but it wasn't before the 70's that the Luna [Harvey, 2005] and Apollo programs successfully delivered both tele-operated, semi-autonomous and remotely-operated [Muirhead, 2004] [Young, 2006] rover vehicles onto its surface. Many scenarios for lunar stations have been and continue to be considered [Smith, 2005]. These involve the deployment of similar in nature, but more advanced surface mobility systems for infrastructure development.

Mars has also been visited using wheeled robotic explorers. The Sojourner deployed in 1997 [Matijevic, 1997] and more recently the two Mars Exploration Rovers (MER) [Erickson, 2006], all returned valuable information about the Martian environment. Mars Science Laboratory (MSL) [Naderi, 2006] is a highly instrumented rover that will be deployed on the Red Planet sometime in October 2010 and used to perform more detailed remote-field geology. NASA's scenarios for a planetary outpost [Drake, 1998] include the deployment of 3 un-pressurized rover vehicles. ESA's Exomars mission, planned for 2012, will deliver the Pasteur rover whose equipment includes an on-board drill system [Jorge, 2006].

The Multi-Tasking Rover (MTR) presented here and depicted in Fig. 1, is an experimental robotic platform, which incorporates advanced mobility features. In order to account for local terrain irregularities, the rover employs one passive and two active suspension systems. It can shift its centre of mass accordingly, to obtain stability enhancing traversability when so required. The MTR incorporates a novel suspension system to promote significant advantages over traditional rover designs. Its real strength however, lies in providing a multitasking robotic platform rather than a dedicated system that can only be engaged in specific, pre-defined scenarios. To do so the rover operates in conjunction with Tool and Science Packs (TP/SP).

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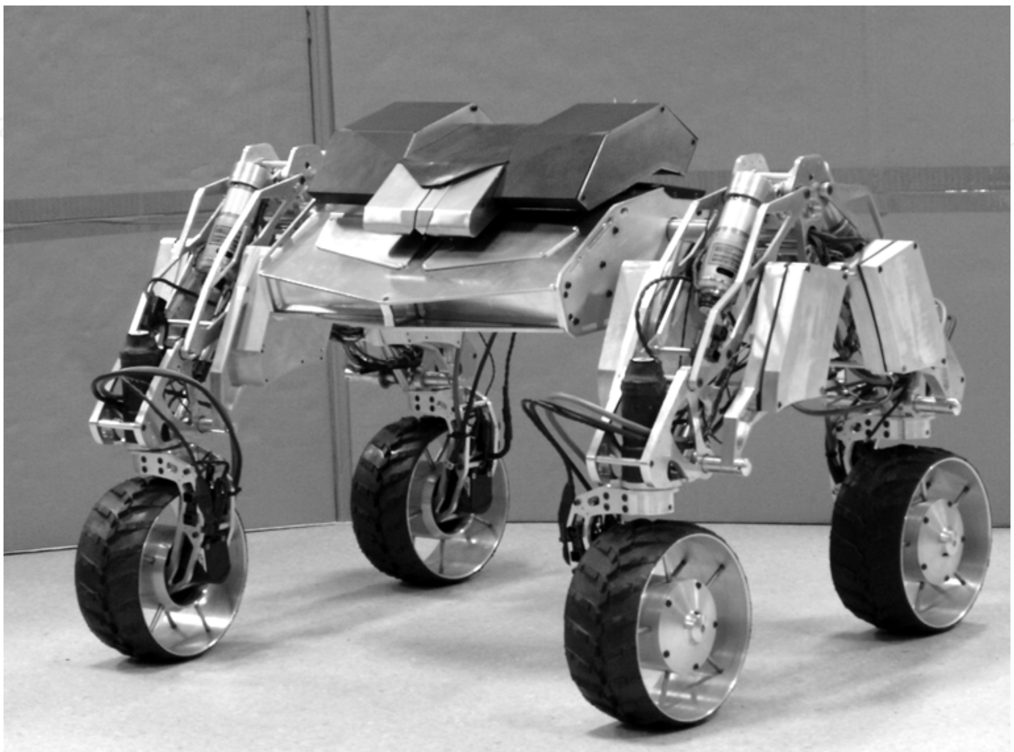


Figure 1. The MTR equipped with a Battery Pack

The MTR is not equipped with any scientific instruments or tools. These are encapsulated in Packs. A Pack effectively encapsulates the functionality required to perform a certain task. The Packs are interchangeable and thus the MTR can be engaged in a variety of tasks. The units are deployed from the Pack Cargo Bay (PCB) and according to their function they can either have an entirely symbiotic relationship with the rover or operate independently. For example, a Scoop Pack used for the transportation of Martian or Lunar soil could not operate on its own. Alternatively, a robotic Mole Pack would just utilize the MTR's mobility to deliver it to a target and once deployed, operate unsupervised. Each Pack contains the necessary control electronics and additional energy sources to support its operation. The rover can carry a maximum of two Packs.

This chapter gives an overview of the MTR system. The next section looks briefly into some of the challenges and requirements, imposed on rover system design by the demanding terrestrial exploration of the accessible celestial bodies of our Solar System and demonstrates how these can addressed with the MTR approach. Following this, a description of the rover's mechanical sub-systems is given, emphasizing on mobility and re-configurability. An outline of the generic principles that govern the design and operation of a Pack are then discussed together with a description of a Battery Pack, currently under development. Section 5 outlines the electronics architecture design needed to support the operation of the rover and the integration of Packs. Associated sensors, together with their topology and operation are also presented here. Section 6 gives a description of the approach incorporated in order to locate and acquire a Pack together with a number of behaviours developed to support the operation of the mobile platform. Following that, section 7 depicts the preliminary assembly of the MTR subjected to early testing. Finally, section 8 provides a summary and conclusions.

2. Requirements and System Operational Description

Robotic rover systems are an invaluable tool for the scientific community since they replace the eyes and hands of the researchers and reach hostile places that humans currently cannot. These systems are not intended only for exploration. Numerous scenarios are being exploited covering different aspects of operation such as re-configurability [Iagnemma, 2000], cooperation [Trebi-Ollennu, 2002] [Bouloubasis, 2003] [Mumm, 2004], transportation [Bouloubasis, 2005] and sample recovery and return [Huntsberger, 1999]. Enhanced mobility is a characteristic required for all of these scenarios since the rovers need to traverse unstructured natural terrain.

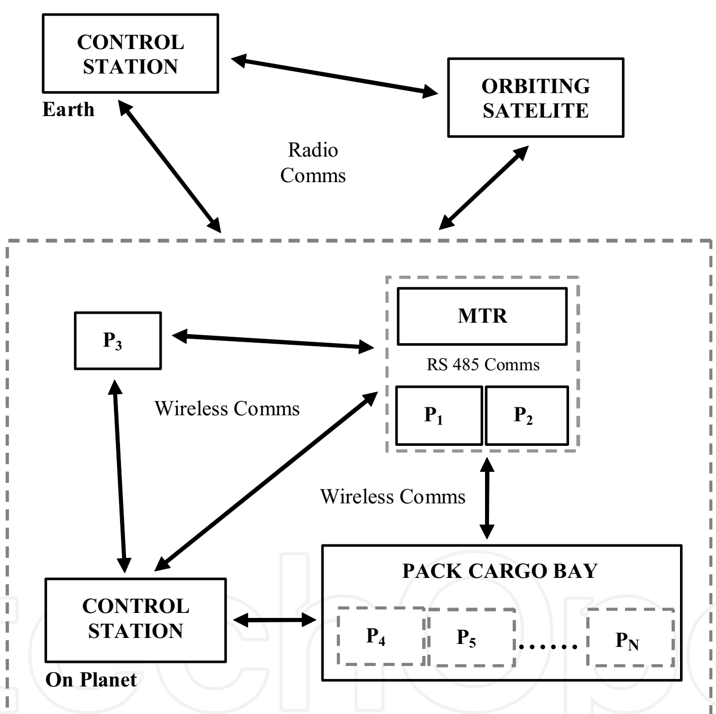


Figure 2. The operational context for the MTR. A variety of different Packs is stored inside the Pack Cargo Bay (PCB). The on-planet control station would not be available in the initial stages

The scientific payload weighs only a small fraction of the total mass of a rover system. Furthermore the associated colossal costs per unit mass combined with the availability of space impose major restrictions in the design of a mission. Modular, multi-functional systems offer an elegant approach to account for those factors. A system like the one in discussion, once deployed, can offer multiples of the functionality compared to that of traditional rover designs. Additionally, since the task-level functionality of the MTR is provided by upon Pack sub-systems, the designer need not to consider future needs imposed by planetary exploration and colonization because these could be satisfied by new Packs sent in later stages of the mission. In short, the functionality of the MTR is upgradeable.

Figure 2 shows a possible operational scenario. The MTR is delivered on the planetary surface with a number of Packs encapsulated in the PCB. The PCB could arrive on the planet separately. Much like in current approaches, the rover is supervised by a Control Station; as exploration progresses this could be further supported by a Lunar or Martian Station. This operational snapshot shows the MTR equipped with Packs P1 and P2. These were acquired previously from the PCB. The selection of the specific Pack is task dependant. For example P1 could be a Mole Pack and P2 a Solar Array Pack that the rover could deploy and interconnect, such that the robotic mole is powered sufficiently to carry out its task. In the same figure P3 could be a weather station that has been deployed at an earlier stage. The PCB holds additional Packs to be employed if and when necessary.

As mentioned above the rover accounts for stability using a number of different sub-systems both active and passive. These are also employed for the acquisition, operation and discharge of any Packs. The following section describes the suspension and mobility systems in more detail, such that the operational capabilities of the system can be realised.

3. Rover Mechanics

Adaptability has been the driving force behind the mechanical design of the MTR. The overall design 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.

3.1 Generic Mobility – 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. The MTR can traverse forward/backward, turn on the spot, take hard/soft turns and crab to any direction whilst maintaining or adjusting its heading. The rotation of each of the wheels is restricted to ±182 degrees by limit switches. Absolute as well as relative wheel position information is available through navigational sensory systems.

3.2 Adjusting Leg Configuration – Shoulder Articulation System (SAS)

Each leg assembly comprises of the six main elements shown in figure 3. The steering system section 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. A cooling system is also incorporated within each electronics compartment to reduce the temperature due to heat dissipated from the motor drivers.

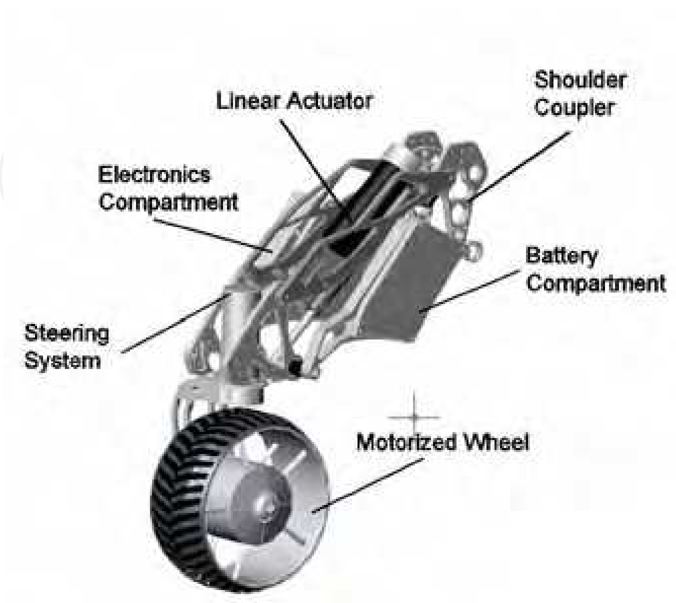


Figure 3. A CAD illustration, showing the main elements of a leg

A 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. This is illustrated in figure 4. In this series of pictures the MTR is using solely the SAS to re-configure and shift its centre of mass.

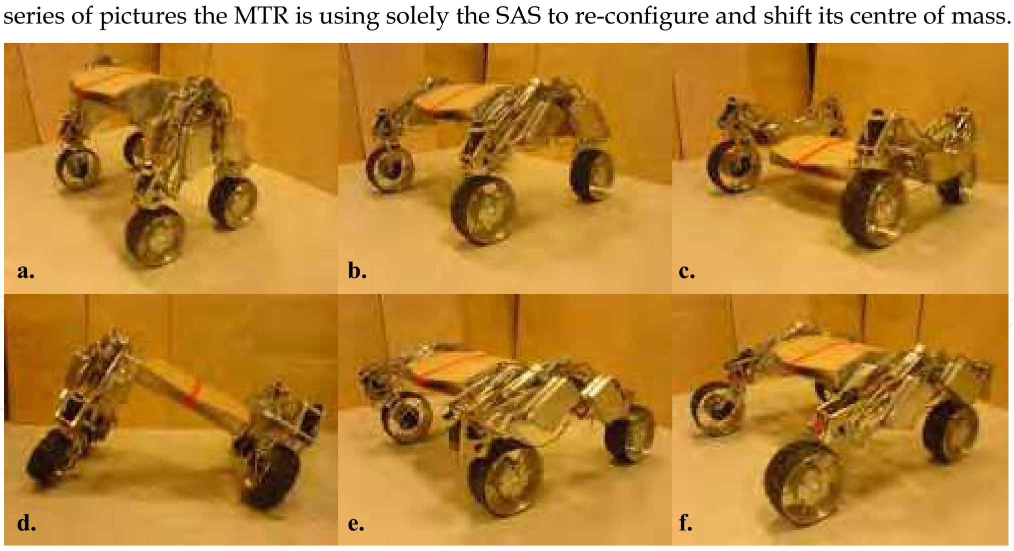


Figure 4. Using the Shoulder Articulation System (SAS) to alter the configuration of the MTR

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 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 Packs.
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 still 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. The adaptability of the vehicle to local terrain irregularities can be increased further, by linking the two shoulders with a differential mechanism.

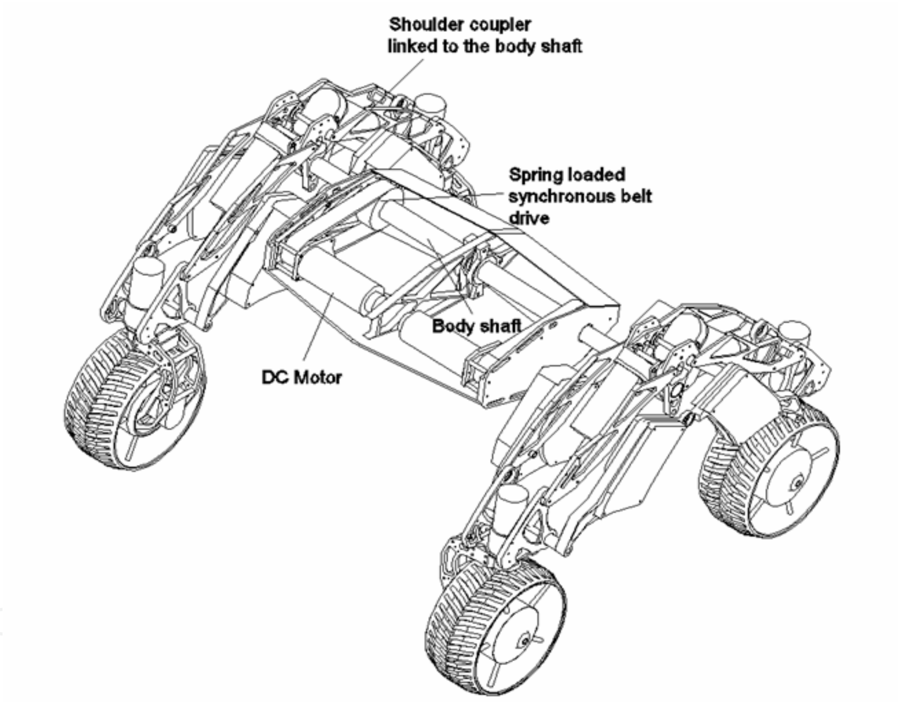


Figure 5. The key elements of the Active Compliant Differential System (ACDS)

3.3 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 employ a passive differential suspension mechanism [Volpe, 1996]. This allows all wheels to stay in contact with the ground. 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. The shaft is linked to a DC motor-gearbox combination via a pulley drive that provides control of rotation. 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.

There is a certain amount of deflection that the suspension can cope with passively, before the 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 mechanism was initially 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. The two spring-loaded pulley drives act both actively or passively to account for the differential suspension drive.

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. Four custom-made electrical rotary unions (explained in more detail in the following section) are used for the transmission of signals and power between the two shoulders and the main body. 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.

3.4 Combined Operation

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. 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.

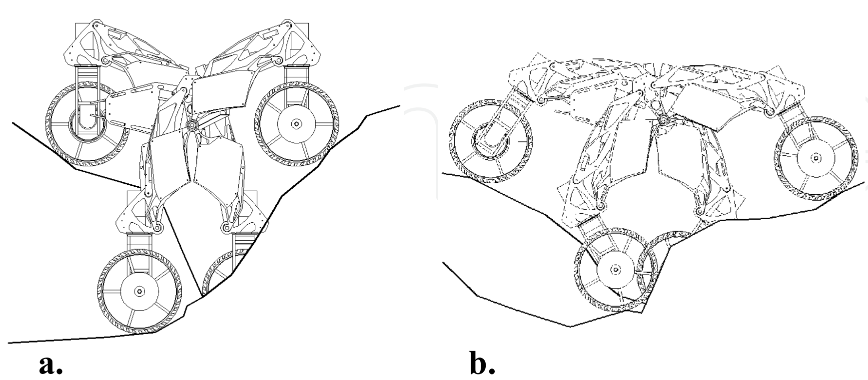


Figure 6. The SAS (a) and the ACDS (b) engaged in rough terrain

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.

The SAS and ACDS together enable the MTR to cope with rough terrain irregularities. This is illustrated in figure 6**.** In order to exemplify, two different cases are considered where the rover engages the SAS (Fig. 6a) and the ACDS (Fig. 6b) in order to traverse over anomalous ground maintaining stability. In the first instance the SAS is used to account for stability enhancement by re-configuring each of the rover's legs and bringing the body to the horizontal and the steering axes parallel to the gravity vector, whilst at the same time maintaining contact between the wheels and the ground. In the second configuration the ACDS is engaged instead. The two shoulders rotate by equal and opposite amounts about the rover's body pitch axis allowing all wheels to be in contact with the ground. The steering axes remain perpendicular to the plane of traversal. Note that in this particular scenario the ramp inclination is excessive mainly for illustration purposes. The ACDS alone could not cope with large altitude differentials between the two shoulders without the assistance of SAS since it is only associated with pitch-angle control of the body section and re-configurability of the shoulders. Even though the SAS can be employed to account for large local terrain differentials, the ACDS is a more economical method in terms of power, of accounting for smaller anomalies in the terrain (1 – 1½ wheel diameter in height).

4. Science and Tool Packs

The presentation of the MTR up to this point focused on the mobility aspects of the rover system. The real superiority of the MTR over existing rover designs comes from its ability to work cooperatively with other sub-systems called Packs. These can be integrated to and alter the operational characteristics of the MTR. They can also utilize the rover's advanced mobility and once deployed can act autonomously and independently of the MTR.

4.1 Candidate Packs

The approach allows the rover to be engaged in a variety of tasks ranging from planetary surface exploration to supporting infrastructure development of a self-sustainable Lunar or Martian colony. Examples of Packs include:

Manipulator Pack – used for manipulation and assembly of structural elements.

Scoop Pack – used for the transportation of raw materials.

Communications Pack – used to extend communications beyond the line of sight of the station. Multiple CPs could be deployed in an 'optical daisy chain' configuration.

PV Array Pack – photovoltaic array which could power other subsystems, e.g. an autonomous robotic mole.

Spectrometer Pack – for measuring wavelengths or indexes of refraction of planetary minerals and gases and effectively determining their composition.

Rocket Pack – used for sample return operations.

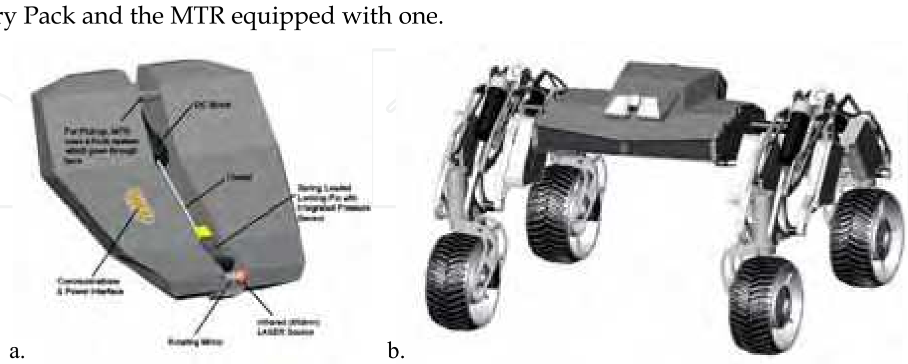
Weather Pack – used for monitoring and recording weather.

Robotic Mole Pack – used for automated sub-surface sampling aiming in the discovery of past or present life on Mars.

Steep Slope Descent Pack – employing a winch in combination with a hook system used to allow safe descent to a crater's basin.
Future needs would most likely require additional Packs to be deployed. Additionally, advances in technology would allow further systems integration under a single Pack. A major advantage of the approach is that these could be send later and when necessary, evolving the functionality of the MTR accordingly. The technical aspects together with some of the design constraints are discussed in more detail below.

4.2 Pack Specifics

The main body of the MTR resides between the two shoulders, houses the ACDS, the on-board high level controller and provides two Pack Docking Stations (PDS), located on the top and bottom faces of the body. These allow the mechanical and electrical coupling between the Packs and the MTR. The Packs 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 MTR design upon completion to be around 18kgs, 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 variety of devices can be deployed.
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. The rover equipped with a Battery Pack is depicted in figure 1. The body of the rover will offer a set of mounting points with which a spring loaded locking pin on the Pack will be engaged 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 – one on top of the other, 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 7 below, illustrates an early CAD model of the Battery Pack and the MTR equipped with one.



a. b.

Figure 7. The main elements of the Battery Pack (a), and the MTR equipped with the Pack (b)

5. Electrics/Electronics and Sensing

5.1 Rover System – Low-level Controller

The electronics system for the MTR comprises two subsystems (fig. 8.). The first, the low-level controller, is built around the Microchip PIC controller and a number of different peripherals. It has the responsibility of motor PID-servo control, as well as obtaining the sensors' feedback to be utilized by local, low-level behavioural loops, or the higher-level controller (the second subsystem) when necessary. Modularity is a key design goal. The low-level controller is divided into five smaller subsystems. Each leg will comprise a small network of four PICs, three motion controllers and one additional general-purpose controller. Each leg has a number of sensors associated with it.

Apart from optical encoders, limit switches and potentiometers, which are employed for the control of the motors, infrared range finders and motion detectors, are mounted on the steering brackets of each wheel. Another range finder is positioned at the side of the leg together with a pair of infrared detectors. The latter are used during the Pack Pick-Up Sequence so that the presence of a Pack is detected; as explained below, the Pack emits an infrared beam, which the rover uses in order to align with it. Other low-level functions may be required and therefore both I2C and RS-485 communication buses are utilised so that additional controllers/sensors can be added in a plug-and-play fashion.

The fifth low-level subsystem is located inside the body of the MTR and will be in charge of the actuators that govern the operation of the ACDS. It is also used to obtain sensor information and report back to the high-level controller. Sensors located on the body include: a 3-axis accelerometer; a GPS receiver; a digital compass; two stereo-camera systems (front and rear); ultrasonic sensors located at the front and rear faces of the body; infrared distance sensors at the top and bottom faces of the body; force sensors, encoders and potentiometers for the operation of the ACDS; a series of infrared detectors located at the top and bottom faces of the body for detecting the infrared LASER beam emitted by a source on the Pack and aligning with it; opto-reflectors to verify positioning of the Pack with respect to the body; and finally motion detectors situated at the front and rear faces of the body, to aid the navigation of the MTR in dynamic environments.

Note that many of the sensory devices mentioned above cannot operate in a space environment. Nonetheless alternatives exist that do. Usage of cheaper systems allows the principles of operation of the MTR system to be demonstrated.

5.2 High-level Controller

The second subsystem, an on-board high-level controller, will be connected with all the modules through an RS485 bus allowing a sufficiently large number of devices to be part of the loop. The Gumstix/Verdex has been selected as the most appropriate platform. It uses an Intel XScale PXA-270, running at 400MHz, with 64MB of RAM and 16MB of flash. It provides many peripherals on a single board – Bluetooth, access to a 32-Bit External bus, CompactFlash/PCMCIA interfaces, a CMOS/CCD image sensor input, MSL (up to 416 Mbps), I2C, SPI, SD Card and Memory Stick , USB Host/Device. The unit measures 80 x 20 mm and consumes as little as 650 mW. Many expansion boards also exist.

The high-level controller, which is located within the body, needs to exchange information via a full-duplex RS-485 communications bus, with the low-level controller, which is distributed over both shoulders and the body. Furthermore 8 Lithium-Polymer battery cells are distributed over both shoulders and the body of the rover. If uniform discharge is desired, these have to be linked. Also if a Battery Pack is going to be used for long traversals, it will have to be able to power all sub-systems. Another point to make is that the ACDS uses pressure sensors placed onto the body-rotation shafts, which are linked to the shoulders and therefore the sensors have to rotate with respect to the main frame. To account for communications, power distribution and the ACDS pressure sensor signals, two electrical rotary unions are employed.

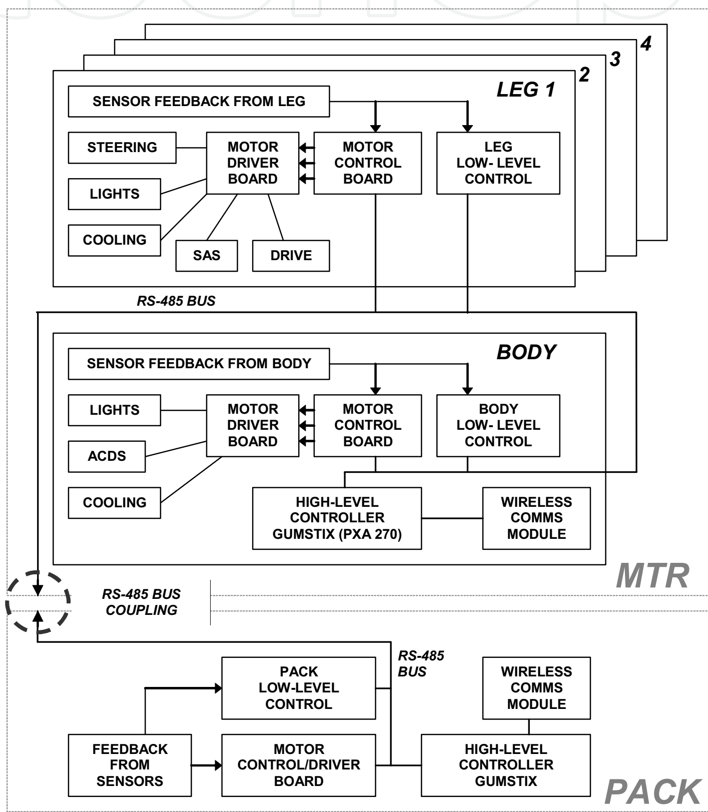


Figure 8. An overview of the electronics architecture for the MTR and a Pack. Note that the rover can accommodate a maximum of two Packs

Both rotary unions are custom made to suit the availability of space requirements that are imposed by the compactness of the design. Each rotary union comprises a set of brass slip-rings and brushes and is situated at the base of the body rotation shaft. Care has been taken to minimize electrical resistance between the rotating contact points. In the case of battery power connections, the resistance has to be exceptionally small so as to maximize the amount of power delivered to the sub-systems. Moreover decreasing the path resistance ensures uniform discharge between battery cells. The motor power connections have a resistance on the order of 12-15 mΩ each. The rotary connections to power logic and the ACDS pressure sensors each have resistance of about 40-50 mΩ each. All slip-rings are connected with cables which run inside the body rotation shafts and terminate at the shoulder couplers. An exception to the rule is the ACDS cables, which come out half way down each shaft in order to connect to the pressure sensors of each pulley drive.

5.3 Pack Electronics

A Pack can have a controller of equivalent or higher processing power, as the situation and functionality demands. De-centralized control has been the basis for fast response through parallel processing and is not limited within the physical boundaries of the MTR. If more processing power is required in order to carry out a given task, it can be obtained from a Pack with enhanced processing capabilities. At this instance, wireless Ethernet connection will offer a data communication path between the Control Station(s) the MTR(s) and the Packs.

The incorporation of a Pack will introduce additional sub-systems. For example the integration of a 5-DOF Manipulator TP will require low-level control electronics for five extra axes of motion and feedback acquisition, together with a high-level controller. These have to be contained within the Pack, which should also come with its own power resources. A Science Pack might introduce additional data manipulation/storage requirements. Pack systems should preferably come with their own high-level controller; they might use the rover's resources if the task they are engaged is not computationally expensive.

The top and bottom faces of the body of the rover accommodate physical connection points so that a power and data exchange link is accomplished between the MTR and a Pack. A standard power and communications bus is provided. It comprises three smaller busses: a 5V bus for logic, a 22.2Vfor power drivers and a RS-485 communications bus.

6. Pack Acquisition Scenario

The MTR will use a Pack to alter its functionality and accomplish different tasks. Therefore, some of the associated behaviours that govern the operation of the overall system will be Pack dependant. Reflexive behaviours will be employed to control the ACDS and SAS sub-systems according to the scenario in which the rover is engaged. In order to use a Pack the rover must first locate it, pick it up and secure it onto its body. Since a Pack must be interchangeable, a release sequence must be incorporated as well. A combination of different sub-systems both at the computational as well as the physical level must be employed to achieve this. An arbitration architecture to orchestrate this must be employed. An option is the EBA [Lewis, 1996], which presents a modular approach to the control architecture, suited to the operation of the rover system [Bouloubasis, 2006]. It could be implemented – or some of its characteristics – in the final control system.

The approach and orientation phases assume the availability of a GPS and digital compass on both rover and Pack systems. In a real space application these would be normally substituted by an on-orbit support system and/or identifiable through the vision system landmarks. The overall technology employed to demonstrate the concepts behind the operation of this innovative rover design is based on commercially available sub-systems, whose integration is relatively easy and their functionality can be also obtained by space-graded components.

The sequence of events required for Pack deployment and operation have been carefully planned to ensure minimal number of additional actuation elements and maximum utilization of the ones available. Figure 9 illustrates the three phases incorporated for the completion of the task. As mentioned, the rover can carry a maximum of two different Packs. The description here assumes there is at least one Pack Docking Station (PDS) available on the rover. The MTR would otherwise need to re–configure by placing one of its two Packs to a storage location, prior to engaging itself to the pick-up sequence described below.

6.1 Approach and Pick-up Sequence

During the first phase of the Pack Pick-up operation, the rover traverses to a location near the candidate Pack. To do so, the rover must identify roughly the location of the Pack. This information is delivered to the rover system by the Pack itself. The Pack's on-board GPS receiver informs its controller of its location and the controller transmits that by means of wireless communication to the rover.

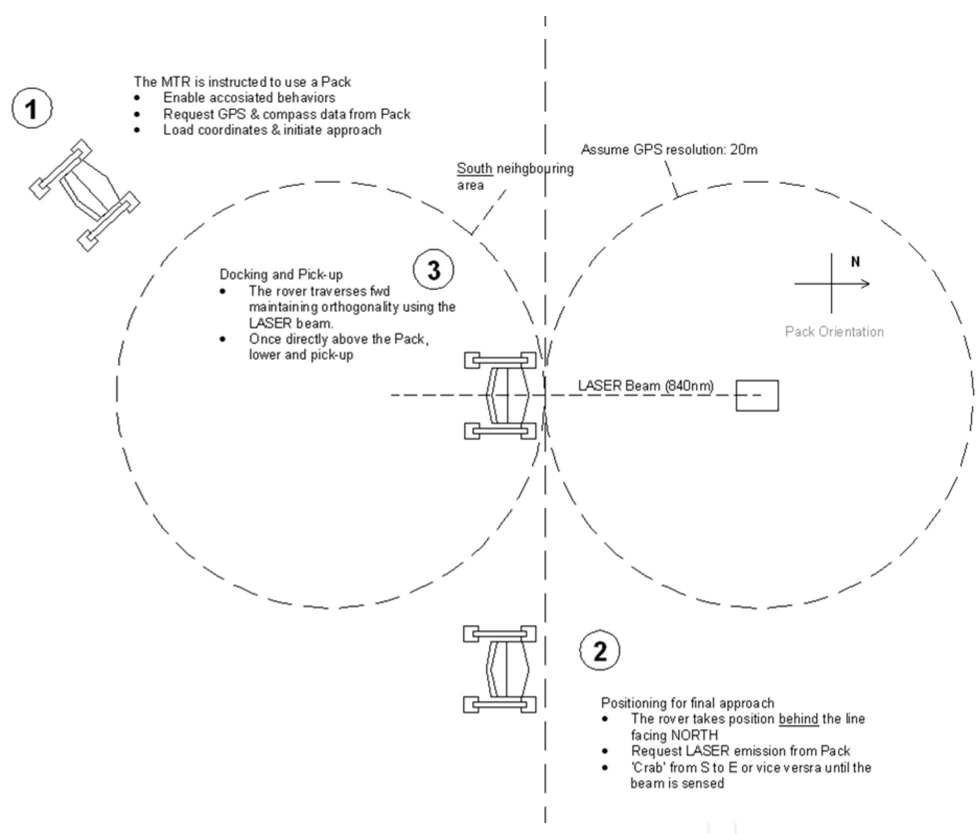


Figure 9. Sequence of events required for the acquisition of a Pack

The rover is also equipped with a GPS receiver module so that it can iteratively compare its position to that of the Pack while it traverses towards it. The Pack also transmits information concerning its orientation. Even though the pick-up strategy incorporates a fixed (South to

North) orientation for the Pack, an on-board digital compass is employed to verify this. This orientation is used in order to avoid facing the Sun directly during approach to a Pack, since that could interfere with the sensor systems used to align the rover. To conclude, during this phase the MTR, once instructed, acquires the Pack's coordinates, enables traversal and stability assisting behaviours and aims to get within a close range to the Pack (±10m). This range is effectively GPS resolution dependant.

Once it is within range, the second phase commences. Following figure 9, the rover will position itself on the boundary line of the south-neighbouring area to the one the pack is located. The reason for doing so is because of the uncertainty imposed by the resolution limitations of the GPS module(s). For a S to N Pack orientation the rover would have to start this second phase by placing itself to the boundary line of the north-neighbouring area. Once the system has reached that position, it will attain the same orientation as the Pack. The on-board digital compass will provide the necessary feedback to achieve this. The Pack will then be instructed by the MTR to initiate LASER emission so that the latter can align to it. The rover will then start moving laterally, what is commonly referred to as 'crabbing', until the infrared (840nm) LASER beam is sensed by the on-board receptors. This would complete the second phase.

A number of infrared sensors, situated on the rover's body combined with the mobility capabilities of the system will ensure alignment of the MTR with respect to the Pack. As mentioned earlier the ACDS, by rotating the main body section about the axis that links the two shoulders, provides the capability of accommodating two Packs per MTR system. Therefore the infrared receptors are duplicated over both top and bottom sides of the body since with the acquisition of the first Pack the alignment sensors used are physically covered by the Pack itself, and thus disabled. The ACDS is also employed in order to ensure that the right set of sensors is exposed to the LASER beam emitted from the Pack and also that the angle of the body with respect to the horizontal allows good visibility of the beam by the sensors.

Upon completion of the second phase the rover is facing the Pack from a distance that is effectively GPS resolution dependant. Once the third phase is initiated, the rover by manoeuvring accordingly will centre itself to the LASER beam and begin its traversal towards the Pack. A pair of infrared LEDs of the same frequency as the LASER source situated on the Pack and arranged vertical to the direction of traversal of the rover will be used so that the MTR can stop directly above the Pack. Once in position the SAS will lower the body until it is in contact with the Pack. The MTR will then instruct the Pack to activate its locking mechanism so that it is secured onto the rover's body. The rover is now ready to utilize the Pack.

7. Summary & Conclusions

To conclude, the MTR is an advanced surface mobility system, which presents a high degree of internal and external re-configurability to account for rough terrain stability and multi-functionality. The operational capability of the MTR is enclosed inside Packs, and is interchangeable and upgradeable. The numbers of robotic Tools and/or Science instruments that can be utilized by the rover are limited only by the exploration needs.

The approach aims to bring down the cost versus functionality ratio by offering mobility according to demand to smaller modules with dedicated, well-defined operational characteristics. This reduces the overheads imposed by the necessity of having a dedicated mobility for each of the functions that may be required for each of the different exploration phases. Instead of sending a large number of rovers to perform a variety of tasks, a small team of MTR units could be deployed with a large number of Packs, offering multiples of the functionality at a fraction of the payload. Apart from mission costs, this also decreases the probability of mission failure, since if a rover malfunctions, its operations could be performed by any of its fellow robotic-workers. By offering mobility according to demand, to dedicated tools, the productivity of a robotic colony could be maximized, reducing running and maintenance costs.

Furthermore the capabilities of an MTR robotic team would be upgradeable since new Packs could be send that would enclose any additional science instruments and/or tools that may be required for the completion of the next part of the mission. Once on the surface of the Moon or Mars, the MTR could stay and serve mankind for many generations.

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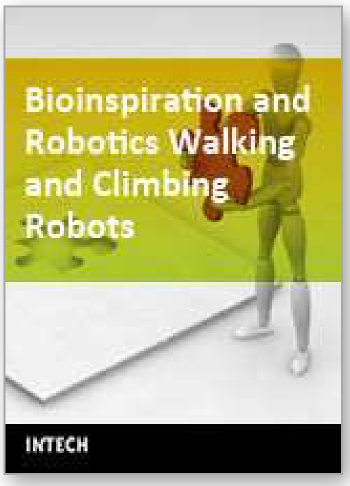

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Nature has always been a source of inspiration and ideas for the robotics community. New solutions and technologies are required and hence this book is coming out to address and deal with the main challenges facing walking and climbing robots, and contributes with innovative solutions, designs, technologies and techniques. This book reports on the state of the art research and development findings and results. The content of the book has been structured into 5 technical research sections with total of 30 chapters written by well recognized researchers worldwide.

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