MTR: THE MULTI-TASKING ROVER
A New Concept in Rover Design

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Keywords: Mobility, Internal/External Re-configurability, Modularity, Upgradeability.

Abstract: In this paper we present the novel concepts incorporated in a planetary surface exploration rover design that is currently under development. The Multitasking Rover (MTR) aims to demonstrate functionality that will cover many of the current and future needs such as rough-terrain mobility, modularity and upgradeability. The rover system has enhanced mobility characteristics. It operates in conjunction with Science Packs (SPs) and Tool Packs (TPs) – modules attached to the main frame of the rover, which are either special tools or science instruments and alter the operation capabilities of the system.

1 INTRODUCTION

On July 4, 1997 a new era for space robotics and the exploration of Mars began when the Pathfinder mission successfully delivered the Sojourner rover to the Red Planet. Following that, in 2005 the two MER rovers, Spirit and Opportunity, traversed many kilometres and took hundreds of pictures giving much more information than their ancestor. All three missions are the initial phase of a plan with the ambition of the eventual human habitation of Mars.

So far the increasing numbers of missions to Mars have provided important information about the Martian climate and geology. Scientists are using this information to locate areas of interest in the surface of the planet and following that, robotic rovers can be deployed to obtain ground truth (NASA Mars Exploration Study Team, 1998). Areas of interest are often very difficult to reach requiring a rover to have increased rough terrain mobility capabilities (Schenker, et al, 2000). The return of samples to Earth for further examination with equipment which is too sensitive to be sent to space is also necessary (Garvin, 2003), (Huntsberger, et al, 1999). After a number of sites have been evaluated, the best in terms of recourses and topographic location will be selected for the construction of habitats to support human presence on the Red Planet. Mobile rovers will be used throughout these missions.

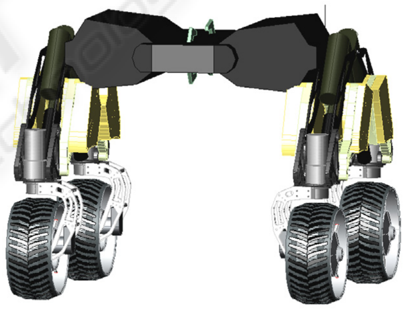
Figure 1: The Multi-Tasking Rover. (MTR).

In order to carry out the tasks mentioned above, different robotic mechanisms and rover designs need to be employed. In this paper we propose a novel new concept for robotic rovers, namely the Multi-Tasking Rover (MTR). The idea behind the design of the MTR is the fusion of all these systems into one. This is accomplished with the construction of a main rover system (Fig. 1), with enhanced mobility and re-configuration capabilities, which will be the carrier of different modules each dedicated to a specific task. The rover will not only offer mobility to these modules, but in combination with a particular module will acquire unique characteristics transforming its role and functionality. The modules can be either Science Packs (SPs) or Tool Packs (TPs) - the current design supports the deployment of two Packs on each MTR.

For example a Science Pack can be a particular type of spectrometer and a Tool Pack a scoop mechanism. A scenario could be the transportation

Bouloubasis A., Mckee G., Sharkey P. and Tolson P. (2006).
MTR: THE MULTI-TASKING ROVER - A New Concept in Rover Design.
In *Proceedings of the Third International Conference on Informatics in Control, Automation and Robotics*, pages 176-181
DOI: 10.5220/0001218401760181
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of the packs to a selected site, the acquisition of samples using the scoop and in situ testing by the spectrometer. Now assume that samples are needed from a particular depth under the Martian surface. The MTR will re-configure by placing the Spectrometer and the Scoop Packs to a storage location, pick-up two TPs, a robotic mole and a deployable solar panel, move them to the desired location, deploy them, connect them such that the solar panels provide power continuously to the robotic mole and leave them to that location until the samples are taken.

The MTR approach assumes that the packs have in-built control systems and can operate once deployed independently from the rover. Communication links between the packs and the MTR will be established when required. The advantage of this approach is that instead of sending a large number of different rovers to perform a variety of tasks, a smaller number of MTRs could be deployed with a large number of different SPs and TPs, offering greater functionality at a reduced payload.

The remainder of the paper is organized as follows. Section II describes the electromechanical design of the MTR system. Section III outlines the rover electronic and sensory systems. Section IV gives a description of the behaviours that will be implemented and the architecture, under which they will be integrated. Finally, section V provides a summary and conclusions.

2 ELECTROMECHANICAL SYSTEMS

A key element in the development of a modular, re-configurable, multitasking system like the MTR is the development of complex mechanisms that will enable the principles of operation to be demonstrated. The MTR requires a total of 14 motorized actuators. It comprises of the following subsystems: drive/steering system, active suspension and base unit. An SP and/or a TP will be constructed as well so that fundamental principles of operation are demonstrated. According to the nature of the Pack, this may introduce further axes of control. A stereo camera system will also be integrated in the design at a later stage.

The four-wheeled rover will achieve a maximum speed of 7cm/sec, which is delivered through a motor/gearbox combination incorporated within each wheel. The aluminium wheels measure 175mm in diameter and the rims are covered with a rubber tire for maximum traction. Each of the wheels is independently steered 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.

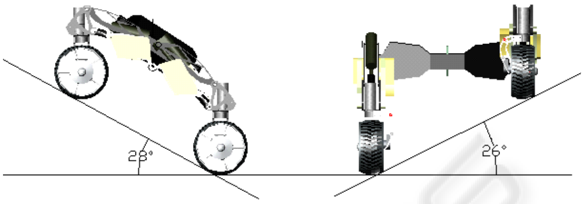

Figure 2: Demonstrating internal re-configurability of the Carrier.

The Active Suspension Mechanism (ASM) serves as means of not only providing rough terrain stability, by re-allocating the vehicle's centre of mass (Figure 2), but also gives the basic mobility to the main body for reaching, grasping and deploying any of the Science/Tool Packs that need to be employed for a given task. The ASM comprises of a pair of shoulders and each of these in turn comprises a pair of legs; at the end of each leg is a steerable wheel. Each shoulder's angle is adjustable between 0 to 188 degrees allowing the main body to move up/down (300mm travel) and modify its roll angle (±26 degrees). This is accomplished using a linear actuator located within each leg. If so desired the shoulder's angle can be adjusted by altering the configuration of only one of the legs.

Figure 3a, illustrates a 3-D model one of the shoulders fully extended (lower position) and Figure 3b shows an assembly of all of the parts that have been made to date. This configuration gives unique motion characteristics to the rover's body, enhancing internal re-configurability. Each leg also houses a Lithium-Polymer (Lipoly) battery and the associated low-level controller. The four Lipoly packs situated on the legs in conjunction with four more located inside the chassis of the MTR give a total power capacity of 22V at 9 Ah.

The topology of the MTR's suspension is similar to that of JPL's SRR2K (Schenker, et al, 2000), but configuration and functionally differ greatly. The two shoulders are linked via an active differential drive mechanism in order to obtain contact of all four wheels with the ground. This is accomplished with the Main Frame Rotation Mechanism (MFRM). The main body resides between the two shoulders, houses the differential mechanism, the on-board high level controller and provides means of support for the deployment of two Packs. The axis that links

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the two shoulders through the differential is also the axis of rotation of the body. The MFRM comprises two actuators which provide the ability to adjust the pitch angle (±720 degrees rotation) of the body of the MTR in order to maintain a constant orientation to the horizontal when needed. The MFRM mechanism also offers centre of mass re-allocation for extra stability and body pitch angle adjustment for the sake of operation of any Packs (a TP might have to operate vertically or at an angle e.g. a drill). Finally the MFRM gives the ability to the main frame to pick-up a Pack no matter its orientation; the roll angle can be controlled via the suspension and the yaw angle can be determined through the steering/drive system. Twelve actuators in total control the subsystems mentioned above.

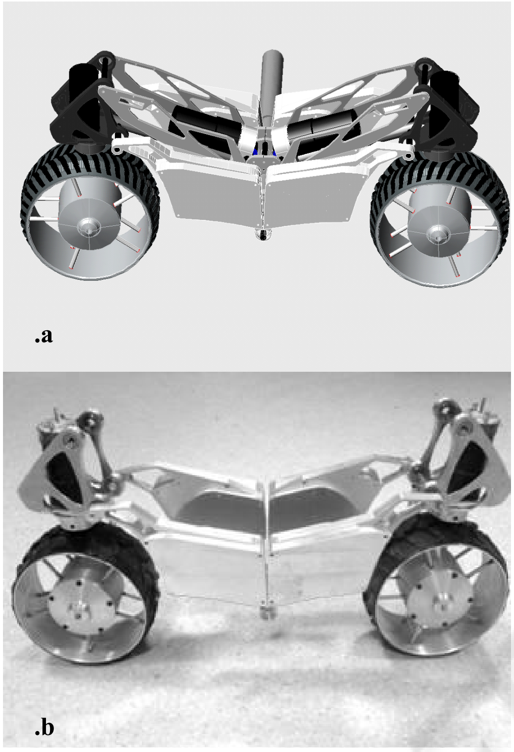


Figure 3: Three-dimensional model of the ‘shoulder’ (a), and the parts that have been currently made (b).

The mechanisms or instruments that can be incorporated within a Pack are limited by the maximum allowable size of the Pack and the lifting/transportation capability of the MTR. The maximum volume for a Pack is limited to 5litres and its weight should not exceed 3kgs. Nonetheless this configuration offers great external re-configurability since an appreciable number of devices can be deployed within the given constraints.

The MTR provides a set of mounting points on its body to support two Packs. In order to simplify the MTR design, each Pack encapsulates a locking mechanism, necessary for stabilising it on the rover’s body. Another advantage is the upgradeability of the system since by sending new Packs future needs of space exploration can be satisfied. An absolute necessity is of course a standard interface between the MTR and the modules.

3 ELECTRONICS AND SENSING

The electronics system comprises two subsystems. 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 utilised by local, low-level behavioural loops, or the higher-level controller (the second subsystem) when necessary.

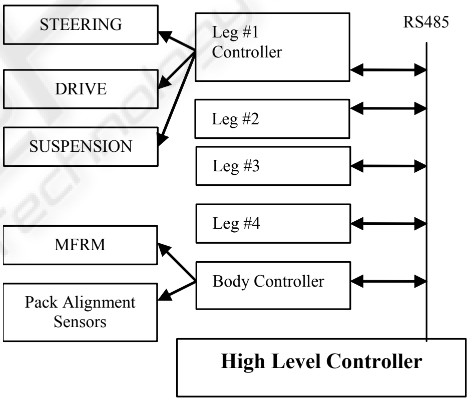


Figure 4: Electronic & Electromechanical Subsystems on the Carrier.

Modularity is a key design goal. The low-level controller is divided into five smaller subsystems. Each leg will comprise a small network of five PICs, three motion controllers and two additional general purpose controllers that will be used for functions like A/D conversion, sonar reading and other low-level functions that may be required. The 5th subsystem is located in the body of the MTR and will be in charge of the actuators that govern the operation of the MFRM (active differential and body rotation). This controller will provide all the necessary feedback for alignment of the MTR with respect to a Pack.

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 platform that will be employed to perform the high-level control functions is still under investigation. The options range from the Nano-ITX and the Soekris, to the very small Gumstix. The basic topology of the high and low-level controllers, together with the main electromechanical systems is shown in Figure 4.

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 TP/SP with enhanced processing capabilities. A wireless Ethernet connection will offer a fast data communication path between the Control Station, the MTR and any of the Packs (Figure 5).

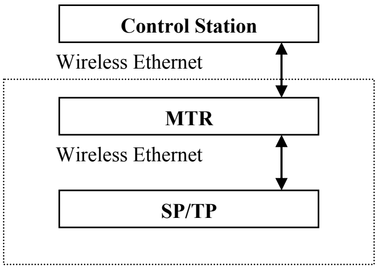


Figure 5: The Complete System.

A variety of different sensors must be employed so as to obtain all the required feedback and assist the function of the two subsystems. Two-channel quadrature encoders will be employed for the PID control of the rotating elements. Temperature sensors will inform the controllers on the status of the motor driver chips and current sensing will provide the necessary force feedback. Strain gauges incorporated within the steering system of each wheel will monitor the contact forces with respect to the ground and assist the operation of rough terrain stability behaviours.

Sonar sensors, also based on the steering brackets, as well as on the MTR's body, will utilize the pan rotation of the wheels and the tilt rotation of the frame (MFRM) to support obstacle avoidance behaviours. A two-axis inclinometer will provide feedback on the roll and pitch of the vehicle. A pair of GPS receivers will be employed (one on the MTR and one on the Pack) in order to obtain rough estimates for the position of the vehicle with respect to the Pack. An RF receiver on the MTR will work in combination with an RF transmitter on the Pack to enable it to approach the Pack. Alignment and grasping of the Pack will be performed using infrared receiver/transmitter pairs, in conjunction with digital compasses on both the MTR and the Pack.

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.

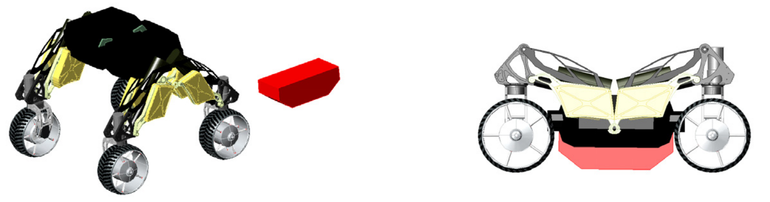
4 BEHAVIOUR & CONTROL SYSTEM ARCHITECTURE

Many functions of the system will be behaviour-supported as this offers fast response times and simplifies the overall control task. In avoiding hazardous situations e.g. tipping over whilst traversing on the sides of a crater in order to acquire samples, or while cooperatively transporting an extended payload (Bouloubasis, et al, 2005), reflexive responses can be employed. Direct control of the fourteen actuators would necessitate enormous processing power and is not considered as an option.

The MTR offers many opportunities for behaviour based control. The Obstacle Avoidance Behaviour (OAB) will utilise the ultrasonic sensors' output to provide collision-free traversal when enabled. In combination with an on-board digital compass the maintenance of the course of traversal will be ensured in case the vehicle must deviate from its original path to avoid a collision.

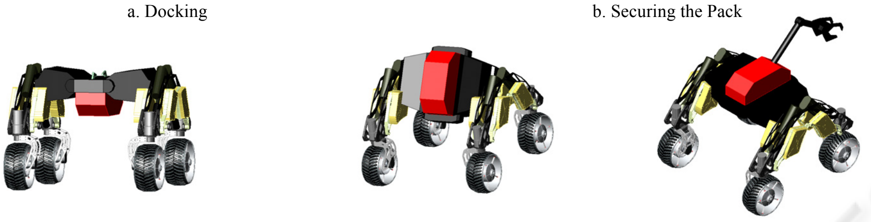
As mentioned above, internal re-configurability by means of re-allocating the rover's centre of mass through the suspension system (ASM) and the frame's rotation around the axis that links the two suspension shoulders (MFRM) aims to offer rough terrain stability. The Stability Enhancement Behaviour (SEB) will obtain feedback from the strain gauges located in the steering system and the two-axis inclinometer to decide whether the shoulder angle and/or the base pitch need to adjust to accommodate differential altitude changes in the rover's local terrain.

In some cases it may be required e.g. for the operation of a SP/TP, to maintain a particular orientation of the body with respect to the horizontal. The Orientation Maintenance Behaviour (OMB), using the information obtained from the inclinometer, will adjust the pitch angle of the body to ensure that the desired orientation is maintained during traversal of varying slope terrains.



a. Docking

b. Securing the Pack



c. Lifting the Pack

d. Rotating the frame

e. The Manipulator TP is deployed

Figure 6: The MTR deploys the Manipulator Tool Pack.

The approach to a Pack remote from the MTR will be accomplished using an RF beacon. Once enabled, the Pack Approach Behaviour (PAB) will alter the rover's velocity vector to point towards the RF source. Following that the Pack Docking Behaviour (PDB) will align the rover's body with the Pack. This will be established using a pair of digital compasses in conjunction with infrared transmitter/receiver pairs situated on the contact faces of the MTR and the Pack. Once alignment is verified, the ASM module will lower the body of the MTR so as to obtain contact with the Pack. Once contact is established the Pack will utilise the mounting points offered by the MTR and physically couple the two systems (Figures 6a-b).

The integration of a Pack may introduce additional behaviours in the control system. For example a Tool Pack may contain a manipulator used for the cooperative transportation of extended payloads (Bouloubasis, et al, 2003). It has been demonstrated that a number of behaviours and specialized sensory systems can be incorporated for the completion of such a task (Bouloubasis, et al, 2005). Figures 6a-e shows a typical sequence of actions that the MTR must perform in order to acquire and utilize the Manipulator TP: dock to the Pack, acquire contact and grasp it, lift it and rotate it to the desired height and angle of operation, and finally deploy it.

A single architecture must integrate all the behaviours mentioned above and more importantly any new behaviours introduced to serve the operation of any SP/TPs. A multilayered architecture (Brooks, 1986) assumes the addition of 'levels of competence' to the existing ones, to achieve further functionality. In an upgradeable, multi-functional system like the MTR, this translates to either a very complex hierarchical structure at the low level, capable of accommodating additions in the higher level of the architecture, or new levels that suppress the lower ones. The designer cannot possibly predict the behaviours that future Packs may require to operate and therefore cannot predict ways that these will interact with the existing MTR.

The single-layered Ego Behaviour Architecture (EBA), (Lewis, et al 1997) is comprised of a number of behaviours, which operate autonomously and independently of each other. Each behaviour is developed separately, tested and then integrated into the existing architecture using an elementary summation function (Fig 7). This facilitates the design and suits the operation of the MTR since it fulfils the need for uncomplicated assimilation of new behaviours in the existing architecture. Another advantage of the EBA is that the arbitration mechanism allows cooperation or competition of two or more behaviours, the emergent response being the resultant effect rather than a single behaviour. For example if PAB, OAB and SEB are enabled, the rover will traverse towards the Pack (RF source), change the velocity vector to avoid any obstacles, maintain course, and at the same time adjust its centre of mass through ASM and MFRM systems to account for rough terrain.

Each Behaviour has an associated Ego (Figure 7). The behaviour takes as input its current Ego Status (Active or Inactive) together with any system variables, e.g. sensory information, commands from control station, etc. and produces a Desired Response. A Desired Status signal, which depends on a number of constrains, is also produced, indicating whether the behaviour should be active or inactive. The Ego of a behaviour compares the system's emergent response to that of the associated behaviour and changes the Ego-controller gains in order to gain control. When a behaviour fails to gain control it becomes inactive (resigns).

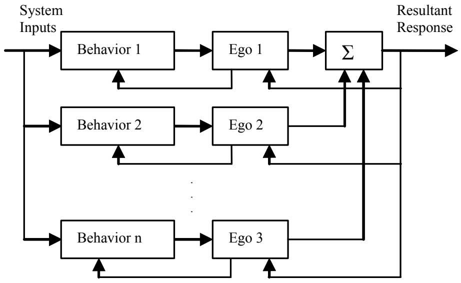


Figure 7: The Ego-Behaviour Architecture.

The EBA is based on the concept that a number of behaviours can work cooperatively and/or competitively at the same time. In the example mentioned, three behaviours are enabled to assist the completion of a task, namely the safe approach to a Pack. The PAB when enabled will direct the rover towards the Pack. This works competitively with OAB which will alter the vehicle's direction when an obstacle is detected. The sonar sensors' input to the behaviour will change the Desired Status to Active. In this case the gain of the OAB Ego-controller will be higher than that of the PAB and so OAB will take over. When the obstacle has been bypassed the behaviour will indicate a Desired Status of Inactive; the Ego-controller of OAB will resign giving the control back to PAB. In the same example OAB and SEB will work cooperatively towards safe traversal of the rover to the target area.

5 SUMMARY & CONCLUSIONS

The work presented in this paper outlines innovative rover systems design concepts which could be integrated to existing or future planetary surface exploration rover designs. Emphasis has been given in this paper to the overall design of the Multi-Tasking Rover system. The MTR focuses mainly on modularity and upgradeability, which are enhanced by re-configurability (internal & external) of the structure. Science Packs (SPs) and Tool Packs (TPs) provide varying functionality to the MTR system. Figure 8 shows the MTR equipped with two Packs: a Manipulator TP that lifts small rocks and a Spectrometer SP that examines soil underneath.

Our current work focuses on the design and construction of mechanical and electronic systems for the MTR. A Pack is also being designed in order to demonstrate the fundamental principles of operation of the MTR. The integration of the EBA with the associated behaviours will follow the completion of the electronics architecture. Further developments will include incorporation of a stereo camera system and vision-guided navigation.

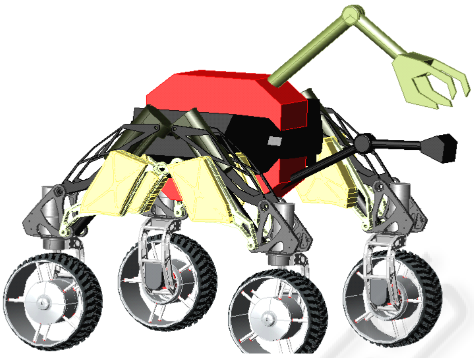


Figure 8: A Manipulator TP is used in combination with a Spectrometer SP to examine areas of interest under small rocks.

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