PENNSTATE

Modular Research Rover and Gesture Control System for EVA

Submitted by the Penn State Mars Society pursuant to the NASA 2002 RASC-AL Forum

Student Team Co-Leaders

Joel Richter (jdr212@psu.edu) & Kevin Sloan (kfs113@psu.edu)

Student Team

Elizabeth Barnwell, Adrienne Benski, Amy Blank, Kevin Clark,
Lisa Legget, Steve McGuire, Nima Moshtagh, Paul Smidansky,
Ryan Swanson, Andy Summerville, Sandy Toh, Jeff Weiss

Student Team Faculty Advisor

Mike Jacobs

1. Abstract

As technology and computing power increases at extraordinary rates, our ability to effectively explore our solar system increases to new levels. The immediate future will see the continual development of robotic exploration as our primary means of exploring other planets. Once the time does arise for mankind to again push his frontiers to new limits, our definition of space exploration will be completely redefined. However, human exploration of our solar system cannot happen without the assistance of our robotic counterparts which helped blaze the trail into space. This transition to human exploration will see astronauts beyond the immediate communication reaches of Earth being forced to work with equipment that was at one time controlled by large teams of scientists and engineers with immediate access to significant computing resources.

In order to deal with these problems, the Penn State Mars Society is developing a new method of robotic control that allows an astronaut in the field on the surface of Mars to be able to directly control any robotic equipment that he could potentially be working with. By integrating virtual reality (VR) gloves into an astronaut's space suit gloves, his hands now become an accurately measurable and rather versatile input device. Gloves of this nature are rather small and unobtrusive, and as such, can very easily be incorporated into the gloves that an astronaut would be wearing. The gloves as an input system will remain passive until activated by a command from the user. At this point, they begin to actively monitor the hand's motion. They would relay this information to a computer on-board the rover, which would in turn convert this complex hand model into a command to execute. When the user is ready to free himself from the input state, another unique gesture can be used to deactivate the control system.

This method of interfacing with a computer will require refinement and testing, and for that purpose a rover is being built. As well as providing a test subject for the control system, the rover highlights another unique feature of our project. One issue that mission planners will surely face with a manned mission (as well as they do for all missions, human or robotic) is the trade-off of reducing overall cost and weight, while still sending ample equipment. Most rovers and other robotic equipment sent will be optimized for one specific portion of the mission, and will consequently lay idle for lengthy periods of time. To solve this issue, we are designing a modular research rover, which will maximize the versatility of the available equipment. The idea behind this rover is a standard rover base which will provide all of the major systems, including power, computing, locomotion, navigation, and communications. Separate modules will be able to be attached both mechanically and electrically to the base, allowing vast expansion of the base rover. The base will accept a few modules at a time; however these units will be able to be interchanged with great ease throughout the course of the mission. Since individual modules will be significantly smaller and cheaper than entire rovers, they will clearly be a better option from a mission logistics standpoint.

2. Introduction

When the first manned missions are sent to Mars, the teams will require an extremely high level of self sufficiency. With communication delays to Earth as long as forty minutes, they will be virtually isolated. Despite their circumstances, they will still be expected to perform as though in an ideal setting. In order for these explorers to be able to maximize their time, and produce large quantities of data, new methods for planetary exploration must be developed.

One scenario that needs improvement is a small team of astronauts (or possibly even a single astronaut) conducting field work far away from their base. This seemingly commonplace scenario will find team members out facing the elements and conducting research. It seems only natural for research rovers to accompany the team into the field. However, having to deal with robotic equipment while in a pressure suit presents several issues, the main one being control. By incorporating virtual reality glove technology into the astronaut's gloves, his hands become a quick, easy and effective input device. A simple hand command can activate the gloves, and the rover begins to respond to hand gestures, which are interpreted as commands. Our stranded astronaut now has complete flexibility in the control over all of the different robotic equipment and machines that will be in the field with him.

All plausible mission outlines for the first manned missions to Mars entail the crew collecting extraordinary amounts of data in many different areas. Most of the field work would be conducted with research rovers such as those described above, each specializing in a different task. The amount of rovers to be sent will quickly add up. A much smaller fleet of modular rovers allows for mission flexibility while significantly cutting back on overall mission cost and weight. These modular rover bases, which will accept a wide variety of scientific units, will operate on a very standard platform. Because all of the equipment will have interchangeable components, the astronauts will be able to effectively

handle most basic problems that could arise in the field. This modularity, coupled with the simplicity of the glove input, tackles many of the difficulties that an astronaut would face in the field that would otherwise severely restrict his productivity.

3. Approach

Members of the Penn State Mars Society participated in the two previous HEDS-UP competitions sponsored by LPI (Lunar and Planetary Institute) and NASA. From the experience that we were able to gain during those two years a plan for the future started to mature. The first goal was to work on a project that was more than a paper concept; it had to be something that could be developed, built and tested. By keeping a design simply on paper, there is no room for refinement, nor any validation of the design. There was much more to be learned by taking a design past the concept phase to a final product.

A second objective was to steer away from the one year projects of the past. One of the inherent difficulties that was faced each year was sitting down and finding a new problem to solve. Furthermore, this narrow time frame never allowed us to do more than an initial investigation into a solution, much less work on an actual product. This also will give incentive for people to stay in the project for multiple years, because there has been a very high turnover rate each year for the three years since this group was formed.

Another aim was to work on something unique; yet be within the scope on an undergraduate student group. Selecting such a topic was difficult because NASA and the space industry has been around for a rather long time, and most interesting projects that are not extremely advanced have been thoroughly studied.

With those as the motivating factors behind the search for a project, options were discussed. The reason the astronaut/computer interface was chosen was because it was an area that appeared to be totally unexplored. The reason it has been unexamined so far is that as long as real-time communication with Earth is possible, it is not necessary. Mission control can assist an astronaut through every step of every mission. Once humans venture out of the Earth-Moon system and communication delays emerge due to the extremely long distances traveled, a computer interface for astronauts will become necessary.

The decision to pick gesture recognition as the method of control to be tested was made after many other options were considered. No other option provided the same flexibility and seamless integration that VR gloves did. Once this decision was made, it became clear that the project would fit the other two objectives. The gesture control system needed a test subject, leading to the second part of this project. A rover fit that requirement perfectly as it was something that could be expected to be controlled by an astronaut in a space suit on Mars. It also provided a great opportunity learn about design and construction of a sophisticated combination of machinery and electronics. This forced the project to be multidisciplinary, and has lead to the formation of a balanced team consisting of aerospace, mechanical, electrical and computer engineers.

The large scope of the project, building a rover and defining and implementing a gesture recognition and control system, lends itself to drawing out the project over multiple years. Both parts can be greatly improved even once they are fully functional. Because the rover is being designed with modularity in mind, much work can be devoted to adding capability and features to the rover after the chassis is completed. Additionally, the gloves can be improved by modifying them to add more degrees of freedom and possibly implementing some sort of force feedback. This project has excellent possibilities for future work, and the future course will be determined by evaluating the past progress to address shortcomings and improve on strengths.

4. Results
4.1 Prototype

Initial investigations into the different systems of our design showed that our team would be best served by beginning work on a scaled down prototype. In our case scaled down refers not to the size of our prototype, rather its complexity. Our work was divided up into two separate areas: the glove and gesture recognition software, and the rover.

Glove and Gesture Recognition Software

Fundamentally, the system developed to interpret gestures has three major components: input filtering, gesture recognition, and device-specific output. Each of these components runs in a separate thread of execution, exchanging data through buffer queues. By multithreading the processing jobs, the overall program can process data without depending on the complexity of individual components.

Compared to other commercially available input devices, we feel that a virtual reality glove is the best candidate to be adapted to use while wearing a pressure suit. In order to use a keyboard, the individual keys would need to be large enough to be reached without trouble from bulky gloves. If the key size were to be scaled appropriately, the overall size of the keyboard would be ungainly. A traditional

joystick is limited by the number of input dimensions; generally, only two degrees of freedom are present through the manipulation of the stalk, with additional degrees provided by trigger buttons or other small actuators. Even if the additional buttons were to be scaled to be usable from a pressure glove, there simply are insufficient degrees of freedom available for general-purpose tasks. Although we do not describe alternative input devices, designed for the impaired or for fully immersive environments, we are looking at novel user interfaces that might be adaptable to an outer space or planetary environment.

We begin with a description of the input devices available for our use. For this project, we have obtained two 5DT Technologies, Inc. virtual reality gloves, each with a serial interface to the host machine. These gloves have five finger sensors, and then an auxiliary roll and pitch sensor. Each finger sensor consists of an optical fiber that wraps around the length of the digit, such that the flexion of a finger bends the fiber. In an electronics package attached to the body of the glove, a light source emits light, and photosensors observe the transmission through the fiber. The glove is calibrated based on the principle that as an optical fiber flexes, the intensity of a transmitted light will vary as a linear function of the flexion. This flexion is represented as a single 8-bit byte value to the host. The roll and pitch sensors also produce 8-bit accurate results. After opening each device, we are ready to sample data.

In order to submit a sample to the processing pipeline, we must first read the data stream coming from the glove(s), and then assign the sample to the processing pipeline. To interpret the raw glove data, we utilize a vendor-supplied library function that returns the actual value measured by the glove hardware. Since our project was designed to have the option of using multiple gloves, we keep track of the mapping between samples and gloves. From the input module's point of view, there is no more work to be done, and so the next sample is obtained.

Once a sample has been provided to the processing pipeline, the next stage is a simple exponential filter that serves to regulate noisy input data from the gloves. This stage was added after initial testing indicated that users have slightly shaky hands; after filtering, the data is much smoother and appropriate to use in a decision process.

After data filtering, logical gestures may be interpreted out of the physical data. We define a gesture to be a region of flexion for each digit. In practice, we have found that the output of the gloves can be divided into only three or four "zones", due to the fact that a human cannot repeat gestures with exact precision. Assuming that each finger was capable of producing each position independently, there are a maximum of 1024 gestures; this number is entirely too optimistic. For example, as a limitation of the design of the individual gloves that we are using, the thumb measurement only has two zones; we have also found that users are not as comfortable with intermediate positions of the thumb as with positions of the fingers. Secondly, most people cannot move their pinky finger without incurring some movement in the ring finger; in the same vein, the ring finger generally implies a movement in the middle finger. Truly independent movement is only possible for the index and middle fingers. We divide the limitations into two categories: extrinsic for those limitations such as the thumb movement that are a result of the manufacture of the glove, and intrinsic for those limitations such as the non-independent movement of the pinky finger. Extrinsic constraints may be mitigated by investing in higher-quality gear; for our purposes, however, the performance of our gloves is adequate.

Since the virtual reality gloves are measuring one of the user's primary world interaction mechanisms, there may be situations where a user does not want his gestures to be interpreted. Similarly, a user may direct his gestures toward different targets. To accommodate these requirements, we represent the gesture recognition engine as a Mealy finite state machine, with glove data driving both transitions and outputs. Glove data is monitored for transition events, and then transformed into an output value appropriate for the device. We envision a future system in which there exists a hierarchy of states such that an initial gesture selects a device to control, and then subsequent gestures navigate the state space for a given device. In our testbed, we have only one controllable device with one interpretation of glove data; thus, we have the two states illustrated in Figure 1. This single interpretation is a "direct-drive" state; the user's hand movements are directly interpreted into motion of the target. In more advanced control layouts, this direct drive state would be a child state of a general device selection state. For our purposes, this representation is appropriate for our prototype.
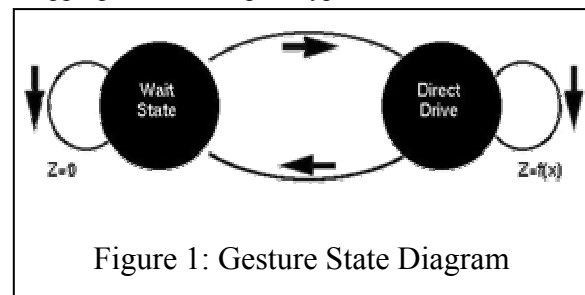

Figure 1: Gesture State Diagram

If any device output is necessary, the gesture engine passes a request off to an appropriate output processing thread for the device at hand. Since both of our devices are locomotion devices, we have only one output thread. Depending on the capabilities of the controlled devices, different formats are supported. For our prototype device, we chose a basic serial format that can accommodate translational and rotational movement commands.

To facilitate the independent development of software from the underlying hardware, we opted to use a network robot hardware simulator. Called "Player/Stage", this simulator is designed to allow a controller to be developed under simulation, and then use the same binary code on the real hardware. One of our group members is employed at a mobile robotics laboratory on campus, and his managers have graciously allowed us to test the gesture control system on real robots. These robots are ActivMedia Pioneer 2-AT class devices; one under glove control is pictured in Figure 2. This image is a clip from a movie that shows the range of motion of the glove control system; the rover is put through a series of maneuvers combining forward and reverse rotational and translational movement.

Figure 2: Pioneer Robot and Glove

For obvious reasons it is desirable to have a functional platform on which to display the glove input technology, especially one small and portable. With this desire in mind, we have interfaced the glove control with a standard rc car. These simple toys are not only effective visual tools, but at the same time are very easy to interface with. For simplicity we connected a microcontroller directly to the remote unit, allowing us to use the already existing wireless components. The four output pins used by the microcontroller are connected to the four different contacts in the remote; forward, reverse, left and right. In addition to providing us with a valuable demonstration tool, it also served as a solid instruction tool for newer members in dealing with

microcontrollers and interfacing with different inputs and outputs.

Rover Prototype

During the spring of 2002, the Penn State Mars Society built a rover prototype in order to become familiar with basic construction techniques and learn likely issues that would be encountered when building the actual rover. The other benefit from the prototype construction was to gain experience in group design work and also learn what parts were available for purchase, which turned out to be a substantial limiting factor on the design. Many problems arose during the prototype construction that were not anticipated in the design stages; thus construction of a prototype proved valuable in bringing these problems to the forefront and allowed for design modifications to the next rover in order to eliminate these problems, which are outlined in Table 1.

Problem	Action
Bolted construction - joints of very poor quality, rover lacked sufficient stiffness, joints were not square, and poor craftsmanship	Welded construction will be used on future designs
Wheel struts were extremely weak	Struts will be eliminated, dramatically increasing strength
Wheels did not allow for traversing major obstacles	Treads will be used on future designs
Round axles were difficult to epoxy to wheels	Axles will be welded to wheels

Table 1, Lessons Learned

The basic design of the rover was chosen to meet short time deadlines and to be cost effective. The design consisted of a box constructed out of aluminum square stock. Because no member of the team was proficient in welding at that time, the box had to be bolted together using aluminum angles to fasten each corner. Aluminum struts were bent into an upside-down U shape then bolted on the base of the rover to serve as the holders for the wheels and motors. Wheels were used because they are cheap and simple to attach, as opposed to treads which the next design will eventually employ. A box style frame was chosen because of the ease of construction and to mimic the storage capacity of the future rover. Constructing the rover prototype proved to be a very valuable experience and will allow future rovers to be

better designed as well as significantly easier to build.

4.2 Product Design for Future Work
Gloves and Gesture Control System
Gloves Overview

As described above, we are currently using five sensor Data Gloves developed by 5DT (Fifth Dimension Technologies), on loan from the Computer Science and Engineering Department at Pennsylvania State University which measures finger flexure (one sensor per finger) and the orientation (pitch and roll) of the user's hand. However, gloves that contain additional sensors can allow for greater customization in regard to commands that may be created for instructing the rover. 5DT's fourteen sensor gloves not only measure finger flexure with two sensors per finger, and hand orientation; they can also measure the degree of abduction between the fingers, allowing for even greater expandability of the command processes, accounting for an analysis of finger-finger interactions. Furthermore, the gloves that 5DT develops are also offered in wireless models. This becomes very convenient for the astronaut. For example, it would decrease the need to lug a laptop on his/her back. The commands can be sent directly to the rover, from the gloves, where all the processing of those commands can be performed on the rover's onboard computer.

Immersion, another major producer, offers a very impressive line of gloves. Branded "CyberGlove," they are offered in eighteen and twenty-two sensor models, and they can perform every function that 5DT's Data Gloves can, and can measure additional movements, such as thumb crossover, palm arch, wrist flexion, and wrist abduction. The only difference between the eighteen and twenty-two sensor gloves is that the twenty-two sensor gloves contain three sensors to measure finger flexion instead of two, one sensor per each joint on the finger. Unfortunately, they do not offer wireless transmission of the commands. This leaves virtually no possibility of free movement without an accompanying backpack computer. All data transfer is done through a single cable that can be bought in ten foot or twenty-five foot lengths. However, to the degree that these gloves can measure hand movement, the number of commands that can be programmed is virtually limitless, thus offering optimal convenience in that regard.

With all of the impressive gloves on the market, there become natural trade-offs with the level of accuracy in modeling desires versus cost. As alluded to previously, there is a natural point at which accuracy in hand modeling becomes irrelevant as it surpasses the ability of a human to control his own hand. The gloves above which measure different types of hand movements, as opposed to adding accuracy, are probably the most desirable.

At this point it would seem prudent to discuss the field practicality of our glove control system. As noted previously, the gloves are hard wired to the serial input on a computer. This limitation is one that we are facing due to the model of gloves that we have been provided. Although wireless gloves are commercially available; they are naturally more expensive. Despite the need for the gloves to be physically connected to a computer, this does not limit their application to a laboratory setting. Our implementation of this control system will eventually entail a small, lightweight laptop that can be worn in a backpack. The glove-end laptop will communicate to the rover via wireless Ethernet. By connecting through the laptop, the range of the gloves would be drastically improved, due to the nature of the two different styles of communications systems. This modification will allow us to effectively simulate a wireless glove control system.

Gesture Recognition Control Expansion

In our current prototype, there are many more degrees of freedom in the controller than the device. Since one of the future goals of the project is to have glove control over several devices, we expect to take advantage of the excess freedom. However, a complicated control system will lead to human confusion and error. To make the gesture language easier to learn and apply, we will be adding a second glove to the system. In this extension, a gesture state transition can use one or both gloves for data input.

The use of two hands will make a system easier to interact with, but also raises the concern that a user will not be able to carry or hold anything while performing a two-handed gesture. In response to this issue, a complete backup gesture system could be implemented such that no command is impossible to perform without two fully functional gloves. The two-handed state transition could serve merely as a convenient shortcut to the same destination state as a series of single-handed transitions.

To experiment with two-handed control, a rudimentary case in which the second glove controls an independent device has been implemented. This independent device is the gripper/lift combination on the front of the Pioneer robots; this device is only used to test out the capabilities of the gesture recognition system while our final project is under construction.

In the discussion regarding the hardware system of the virtual reality glove hardware, it was noted that

each glove requires a serial port for communications. With our available computer resources, we were unable to run both gloves using the same host; the solution to this problem came through the previously mentioned Player robot server. Since both glove-host machines were on the same network as the robot, each could control its device independently. The point of this extension was to show that the same binary code could interpret gestures independently, as opposed to having a left-hand controller and a right-hand controller.

Although this scheme works as a proof of concept, we expect to use a host that is capable of driving both gloves simultaneously. The use of a robot server does point out a possible source of redundancy; if the gesture-based primary control system were to fail in the field, less efficient but functional alternatives could be engaged to complete the mission.

Our approach is extensible in terms of the gesture control hierarchy; one need only define an entrance transition, an optional output as a function of the current state and current inputs, and an optional exit transition. We have chosen a simple initial model to serve as a proof of concept for a more complex control system; since the device to be controlled is a simple model, a simple controller will suffice. As we expand the function of our rover device, states may be added to the controller to control these additional hardware capabilities.

We expect that new devices to be added will conform to one of a few standard controllable classes of devices. Dividing the devices into such categories as actuators, locomotion, or sensors will allow a generic implementation of both computer code and gesture language. The upshot is that any locomotor base can be controlled by the same gestures, assuming that an appropriate hardware interface has been developed to the standard specifications. In this fashion, a gesture control system is not limited to a single robotic platform; such a limitation would be very inconvenient from a user's perspective in terms of training, storage and maintenance. By abstracting out device specifics, we can integrate a wide variety of peripheral devices without having to change the standard gesture engine. We refer to this prospect as a "universal language", since the user need not be concerned with the physical characteristics of the device.

Every device that is to be controlled by the gesture recognition system may have one or more operating modes. For example, a sensor will have two modes: data output and configuration input. To accommodate these different operations, one can simply add states into the device hierarchy for each possible mode of operation, defining the same three characteristics: entrance transition, output, and exit transition. This construction is evident in our very simple state diagram referred to earlier in the paper; there are two operating points for the rover: direct control and off. We envision a third point: autonomous operations.

To add an autonomous controller to the gesture engine, we must augment the state hierarchy. First, we must add a state where the position device is selected, but no outputs are modified. The purpose of this state is to allow a user to choose a device with which to interact. The second additional state is a configuration state that permits a user to select an autonomous action, to be activated on exit. In setting up the transitions, we note that a direct control state should override the autonomous action; this contention should be addressed in the output routines. The fundamental idea is that the gesture engine could allow a manual intervention, resuming autonomy when the user has moved on to another task. This addition is straightforward when considered in the context of our described framework.

Previously, it was mentioned that a group member works at a mobile robotics laboratory. This laboratory is the Applied Research Laboratory at Penn State; the laboratory performs contract research within the areas of interest of its research fellows. In the process of developing the gesture control system, our member's manager has taken an interest in further developing some of the control strategies described within as applicable to Discrete Event Control systems and robotic autonomy. In addition to rover robots, there is shared interest in six degree of freedom controllers for robotic vehicles such as submarines and dirigibles. We look forward to developing our system in conjunction with the Applied Research Lab's support.

Rover Design
Size

The first design decision that had to be made once the purpose of the rover was defined was its size. The key considerations were payload size, usefulness in the field, cost, and ease of construction. Some of these considerations pointed to different sizes, so compromise was necessary. A small rover is most useful when accompanying a person because it can navigate small crevasse and caves which would not permit human investigation. If the rover is operating away from humans, a large size would be more useful because that would allow it to collect more samples and travel faster and farther. Obstacles would also prove less difficult to avoid with a larger rover.

The largest factor in determining the size of the rover being constructed is the payload it is going to

carry. In order to have reasonable usefulness, it must carry an on-board computer. This became the largest size constraint because a laptop was chosen based on low cost and easy availability. The rover also had to carry motors and a battery, which occupy a large portion of the volume of the vehicle. There are many additional components which take up a small amount of space, but did not dictate the design of the rover. In order to accommodate a laptop and have sufficiently powerful motors to travel at a desired speed, a minimum size became apparent.

The rover under construction is 24" long, 16" wide and the main compartment is 10" high. This compartment will sit about 8" off the ground suspended by shock absorbers on a bottom plate containing the motors and axles. The wheels chosen will be 10" in diameter. See figure 3 for an overview of the rover design.
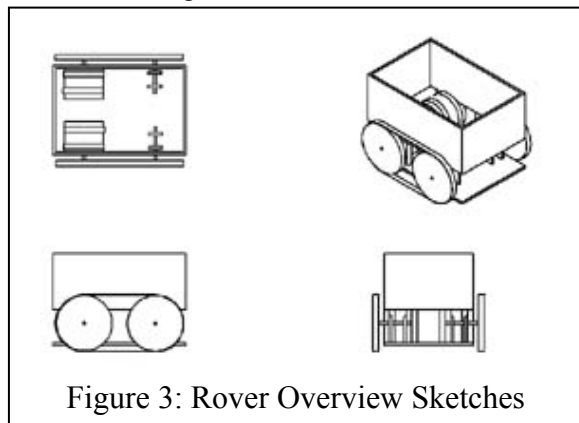

Figure 3: Rover Overview Sketches

While choosing a laptop as the computing payload determined the size, there were several other reasons this size was the best choice. Constructing a much smaller rover would have been very difficult because parts would have to be machined to more stringent tolerances and assembly would have required more precision. In addition, the electronic components small enough to fit on a smaller rover are very expensive. If the rover was much larger, components such as the frame, battery and motors would become very expensive as the design approached the size of an ATV.

Locomotion

Perhaps one of the most crucial aspects of the rover, selection of motors and design of the drive system has proven to be a challenge. Design problems in these areas include matching motor power consumption ratings with available batteries, selecting motors with enough torque and appropriate revolution rates, and weighing the respective merits of treads versus wheels.

For the rover under construction, the electric motor must have sufficient power to propel an 80 lb (with $g=32.2ft/s^2$) rover, which is the proposed weight. We have preliminarily estimated the necessity of a 1/8 horsepower minimum output to obtain the speed desired. Additionally, the need for a gearbox to reduce the shaft revolutions and boost torque is obvious. Given the time and resource constraints of our project, a motor with a combined, pre-built gearbox would be highly desirable. However, most 1/8 horsepower motors with attached gearboxes operate on 90V, in contrast to our desired 12V based on typical battery output.

The question of wheels versus treads has been quite difficult to solve. The advantage to treads is improved operation on rugged terrain, but it comes at a cost of reduced motor efficiency and greater difficult in construction. Because tracks would be more useful in the field, the decision was made to include tracks in the final design. However, anticipated difficulties in construction have led us to decide to build the rover which wheels which could be converted to tracks at a future time. This will keep the track option available while allowing the rover to be constructed to a working state more quickly.

Suspension

Suspension is an important aspect of any mechanical vehicle or rover because of vibrations and obstacles that will be encountered. The amount of external interference depends a great deal on the type of terrain the rover is designed to scale. Obstacles must be anticipated for the rover, along with normal vibrations from small irregularities in the ground. The suspension on the rover is also necessary because of internal vibrations from the motor. These vibrations and other obstacles make suspension necessary because of their effect on the solid structure of the rover as well as the equipment on it. Vibrations affect the structure of the rover because they can loosen bolts and other connections. The primary concern is weakening of welded joints, although this is less of a concern that the loosening of bolts as occurred in the prototype. Vibrations have a negative affect on the equipment on board, such as computers, modules, and electrical wiring, as well. Any wiring has a chance of coming lose while undergoing vibrations and electronics can be damaged if shaken too hard.

For these reasons the decision was made to develop a suspensions system for our rover. The motors and wheels will be mounted to a separate base level, which will be attached to the main frame of the rover by shock absorbers. This base level is the only part of the rover directly exposed to the main causes

of vibration: that caused by the ground upon the wheels and that caused by the motors. By this design, the vibration will not directly affect the rest of the rover. Two shock absorbers, each measuring approximately four inches long, will connect each corner of the base level to the equipment bay. The pin joints attaching them to the frame will be offset so that the each one of a corner pair will allow for small movement in the direction perpendicular to the other, as shown in figure 4. This will account for motion other than that which is directed up and down. To provide additional stiffness in the forward/backward, left/right directions, tubes will be attached to the base level that fit into holes drilled in the equipment bay, allowing for unrestrained up/down motion, but restrict motion in the other four directions.
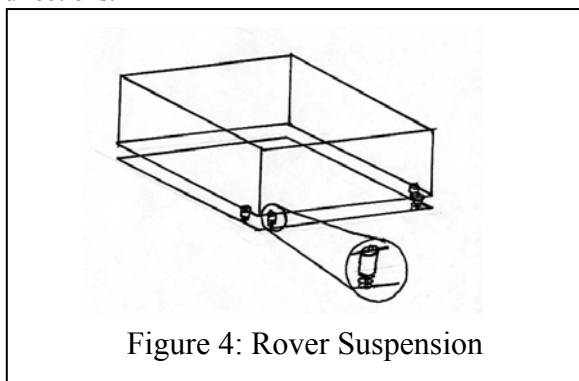

Figure 4: Rover Suspension

On Board Computing/Electronics

When looking into the on board computing requirements, there are two main directions to take. The first follows along with most commercial rovers, and involves single board computers, also referred to as PC104. PC 104 is highly powerful, versatile and expandable, which is why it is preferred in most applications of this nature. However, all of its benefits result in it having a very large prices tag. For that reason, we have elected to utilize our second option, a laptop computer. Despite being bulky in comparison to PC104 they are much more readily attainable, and consequently much more cost effective. Having an on board laptop provides the rover with an extreme amount of flexibility, not only due to the computing power, but because of the peripheral support as well.

When considering the rover as a fully functional mobile laboratory for an astronaut working in the field, the laptop's display will also be a valuable tool. While the primary operation of the rover will not necessitate an interactive display, more advanced options will. For example, any data analysis, or complex operation of the rover will be able to be controlled through menus and other similar visual working environments.

Microcontrollers will need to be used to interface the laptop to a large majority of the on board hardware, including motors and sensors. During initial construction stages we will be using the Parallax Basic Stamp 2. This microcontroller is very simple compared to most devices of its kind. The Stamp 2 itself has 16 I/O pins plus 2 additional serial pins with which to communicate to the main rover processor. The stamp can store approximately 500-600 instructions within its on chip EEPROM, and can process these instructions at about 4,000 instructions per second. The stamp is programmed in PBasic, which is a slight variation of Basic programming language. This will be used in the prototype because of its simplicity. It is capable of handling all of the processes which will be used on the prototype and debugging any errors will be much easier to do. For the final design, the Stamp 2 will be replaced with a Motorola HC711E9 microcontroller, henceforth referred to as the HC11. This device is a much more robust controller than the Stamp 2. It is programmed in assembly language, allowing for much more user defined programming. The chip has 512 bytes of on-chip ram and EEPROM, as well as 12Kbytes of EPROM. It is also capable of running at higher speeds, which can be set by the user, than the Stamp 2, and has more than twice the I/O pin count due to having several ports. An additional component included is an 8-bit A/D converter. This microcontroller will be used on the final design because of its robustness and superiority to the Basic Stamp 2.

The on board computing resources will also allow us to do work with stereo vision. Two firewire cameras will be connected to the laptop, and can be used for a variety of autonomous navigation tasks. More basic tasks will allow the rover to keep track of where its operator is in the immediate region. Further work with this area can also be used for hazard detection and avoidance. This will be used directly in fully autonomous operation, as well as in direct drive state. The rover will have the ability to override a user's input if the operation (i.e. drive off of a cliff that the user cannot see) is deemed unadvisable.

Modularity

An issue being addressed in this rover design is long term usefulness and flexibility. Extremely specialized rovers are the most logical solution when sending single unmanned missions that will only last a period of weeks or months. When humans travel to Mars, they will most likely take numerous rovers with them, as well as spare parts to keep them running for a long time. With this being the case, it makes sense to get as much usefulness out of each

9

rover as possible. The balance between specialization for a specific goal and long term usefulness leads to one conclusion.

Rovers that are sent to Mars on a human expedition will almost certainly be modular. This will allow the rovers to serve several purposes through the duration of the mission. The idea is that a rover chassis can be built to accept payloads with standardized connectors and control implementations, as shown in figure 5. The modular system will consist of a bay in the top of the rover into which scientific instruments will dock. There will be a connection for power, data transfer to the rover computer, and mechanical connections to latch it in place. Simply by plugging in the module and connecting the latches, the new module will be ready to use. The rover chassis will provide every module with locomotion, communication back to the astronaut and habitat, and a computer to process the data collected by the module.
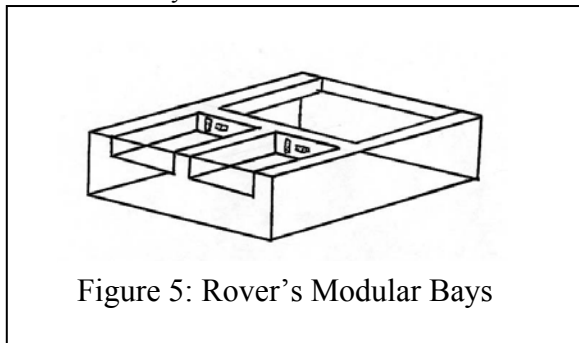

Figure 5: Rover's Modular Bays

This modularity allows for more types of science packages than there are rovers, increasing the mission capability at a lower cost than specialized rovers. Redundancy is also increased, because a failure will most likely take place on the rover chassis and not the module, due to the complexity of the drive system and the harsh Martian environment. If the chassis fails, the module can be placed in another rover with no loss of functionality.

The key to modularity is a set of standards which all electronic equipment will operate on. While this is not a new idea, it has not been widely put into practice. The need to adopt a standard is clear considering the time required to rewrite drivers and software to transfer hardware from one rover to another. One member of the Penn State Mars Society experienced this hassle while working at NASA Ames when he saw many hours spent transferring a camera designed for one rover to another. While this leads to wasted time on Earth, astronauts will not necessarily have the luxury of time to reprogram equipment. This could lead to equipment lying dormant if there is a problem on the rover carrying it. When everything costs tens of thousands of dollars per pound to deliver it to the Martian surface, this

will not be tolerable. The benefits will naturally carry over to Earth, reducing the time it takes to make hardware for one rover work with another.

Implementing modularity first requires a rover, so construction of modules is on hold until the rover is at a sufficient state of completion to allow for the use of modules. The eventual goal of this implementation of modularity is to demonstrate the simplicity of the changing modules with such a system as well as providing further features for the gesture recognition system control. The exact modules have not been decided on yet, but will likely include advanced video equipment and rangefinders. The actual modules used on Mars would naturally include packages used to study meteorological conditions, take samples of soil and rocks, and perform basic field analysis of them. Other possibilities include construction equipment such as a bulldozer blade or a crane.

5. Future Studies & Testing

Project Timeframe & Possible Extensions

By the end of 2002 designs will be finalized for the rover base, as well as plans for extensions of the glove control system. Construction will begin early in 2003 and will focus primarily on the rover base. A fully functioning mobile base, complete with on-board computing systems will be running by May of that year. In addition, this stage will see basic stereo vision applications implemented. This includes simple tasks such as locating, and driving to, an astronaut in the field. Glove control will also be expanded to a two-glove input system that will begin to allow us increased flexibility in the control of the rover. Over the course of the 2003-2004 academic year the rover base will be completely finalized and fine-tuned, and we will begin to develop different modules that can be used in field tests.

Field Testing

Once the mobile rover base has been completed, we will begin with very basic field tests. By analyzing its response to different situations and testing environments we may gain added insight that can be applied towards latter systems on the rover, including the individual modules. As we develop the rover and glove control system into a fully mature state field testing will obviously become a very logical step in this project. Because the focus of this project isn't so much the actual technology as it is the implementation of that technology, most of the knowledge to be gained will come from these experiments. An ideal testing situation would be at The Mars Society's Mars Desert Research Station

(MDRS) in southern Utah. At MDRS, Mars Society members conduct studies in manned Mars missions from an operations standpoint. More specifically, they look at many of the human factors of a manned Mars mission, including how work will be performed. The Mars Society has expressed a strong interest in local chapters testing their work at the station, and we feel that this would be an ideal situation and a beneficial partnership.

6. Conclusion

Because this project has been built with modularity in mind, there are inevitably countless extensions which could easily be explored and implemented. The stereo vision system can be expanded to perform more advanced autonomous navigation tasks. This includes hazard detection and obstacle avoidance, two very crucial abilities. Beyond even the rover we will have built, we can begin to explore team robotics to tackle even more varied situations. One such example would be a separate module which serves simply to deploy a microrover. Microrovers would be designed for the sole purpose of going where a larger rover simply cannot access. Since the glove control system is designed as a universal language, controlling an entire team of rovers would be a natural extension of the basic command language. While a plethora of possibilities exist, this outlines just a few of the possible extensions for this project.

7. References

[1] Brian P. Gerkey, Richard T. Vaughan, Kasper Støy, Andrew Howard, Gaurav S. Sukhatme, and Maja J Mataric; "Most Valuable Player: A Robot Device Server for Distributed Control;" *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001)*, pages 1226-1231, Wailea, Hawaii, October 29 - November 3, 2001.

[2] The Mars Society; "The Mars Society: Mars Desert Research Station;" http://www.marssociety.org/mdrs/index.asp

[3] Stephen McGuire, Joel Richter, Kevin Sloan; "A Modular Multi-Function Rover and Control System for EVA;" October 2000.

[4] Fifth Dimension Technologies; "Welcome to the Fifth Dimension;" http://www.5dt.com

[5] Immersion Corporation; "Immersion Corporation – Welcome to the Immersion Web Site;" http://www.immersion.com

[6] Parallax Inc.; "Parallax Inc. : BASIC Stamp Microcontrollers;" http://www.parallaxinc.com

[7] Motorola Semiconductors Products Sector; "68HC11E9 Product Summary Page;" http://e-www.motorola.com/webapp/sps/site/prod_summary.jsp?code=68HC11E9&nodeId=01M98635

[8] McMaster-Carr; "McMaster-Carr Supply Company;" http://www.mcmaster.com

8. Acknowledgements