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ROBOTIC SAMPLING SYSTEM FOR AN UNMANNED MARS MISSION

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ABSTRACT

Major robotics opportunity for NASA will be the Mars Rover/Sample Return Mission which could be launched as early as the 1990s. The exploratory portion of this mission will include two autonomous subsystems: the rover vehicle and a sample handling system. The sample handling system is the key to the process of collecting Martian soils. This system could include a core drill, a general-purpose manipulator, tools, containers, a return canister, certification hardware and a labeling system. Integrated into a functional package, the sample handling system is analogous to a complex robotic workcell. This paper discusses the different components of the system, their interfaces, forseeable problem areas and many options based on the scientific goals of the mission.

The various interfaces in the sample handling process (component to component and handling system to rover) will be a major engineering effort. Two critical evaluation criteria that will be imposed on the system are flexibility and reliability. It needs to be flexible enough to adapt to different scenarios and environments and acquire the most desirable specimens for return to Earth. Scientists may decide to change the distribution and ratio of core samples to rock samples in the canister. The long distance and duration of this planetary mission places a reliability burden on the hardware. The communication time delay between Earth and Mars minimizes operator interaction (teleoperation, supervisory modes) with the sample handler. An "intelligent" system will be required to plan the actions, make sample choices, interpret sensor inputs, and query unknown surroundings. A combination of autonomous functions and supervised movements will be integrated into the sample handling system.

1. Introduction

In the 1990s, robotic systems will be in operation in space and especially about the space station. The specific tasks include all forms of servicing, such as assembly, inspection, module changeout, refueling. However, there is a unique task that is not servicing, i.e. exploration. In particular, the Mars Rover/Sample Return mission promises to be a unique opportunity that could be launched in the 1990s. Exploration conjures up a sense of adventure and the unknown. This uncertainty separates a structured servicing task from an unstructured exploratory task. There are many issues that make this mission unique. This paper discusses the Mars mission, sampling hardware, sampling operations, and technical issues.

2. Mars Mission

It is man's inquisitive nature that drives him to explore the surface of Mars. Mars holds answers to many scientific questions about the origin of this universe. Refer to table 1 for some facts on Mars.

Table 1 Some Mars Facts

Planet Radius	3397.2 km (equator)
Mass	6.418×10^{23} kg
Bulk Density	3.94 gm / cm^3
Gravitational Acceleration at the Surface	3.73 m / sec ^{2} (0.38 Earth G)
Maximum Temperature	288 K (At Equator)
Minimum Temperature	150 K (Polar CO_2)
Atmosphere	CO_2, N_2, Ar, O_2, CO
Mean Pressure	(.089 psi)
Wind	2 to 7 m / sec
Dust Storms	1 or 2 / year

Mars is characterized by lava flows, crevices, boulder fields, mountains, dunes and craters. The terrain varies from drift material ranging in consistency from ordinary kitchen flour[1] to jagged rocks and boulders.

The scientific goals for planetary exploration are: (1) to understand how the solar system originated, (2) to understand how the planets evolved and to understand their present state, (3) to learn what conditions led to the origin of life, and (4) to learn how physical laws work in large systems.[2] Mars is the next focus because of its accessibility and relationship to Earth. By returning samples, their analysis will determine the chemical composition and mineralogy of materials from a selected region.

In particular, the absolute age of the rock and soil can be determined. Looking at a scene of continuous rocks (Fig. 1), it is hard to imagine that a system could differentiate and pick up a unique rock.

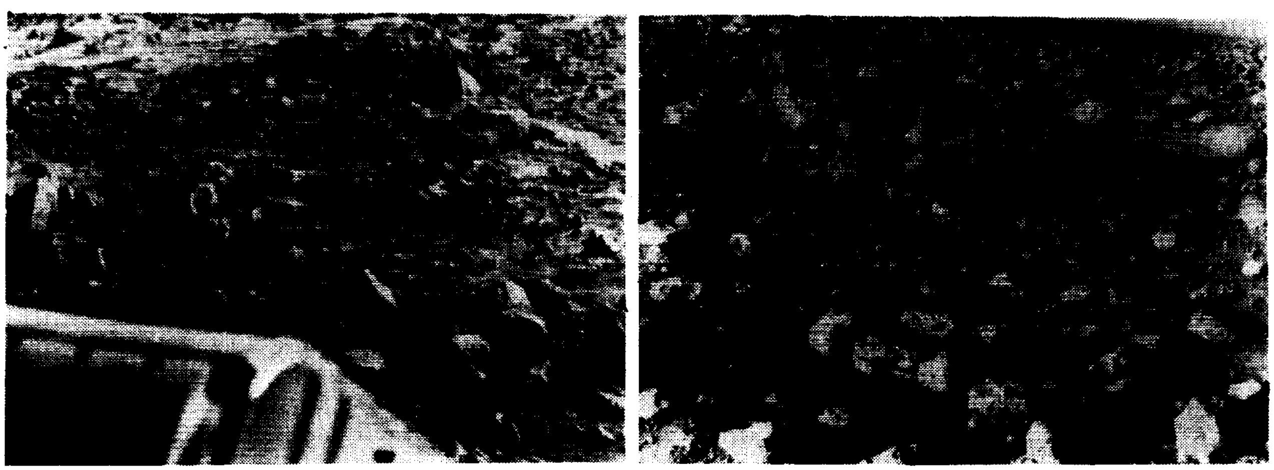

Figure 1 Photos of Rocks on the Martian Surface

3. Sampling Hardware

The functional steps of sample handing are outlined by JSC[2] and illustrated in Figure 2.

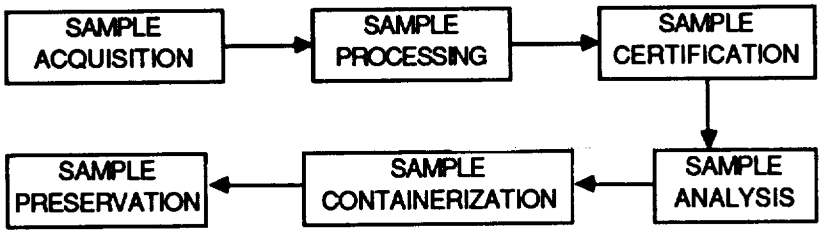

Figure 2 Sample Handling Functions

Sample acquisition is the physical interaction with the planet surface, e.g. picking up a rock or scooping loose soil. The captured sample then is transferred to processing. Processing prepares the sample for certification or analysis. In some cases, the rock sample might be too large for the test apparatus and needs to be split into smaller pieces. At other times, the soil is screened by a sieve.

Certification is the preliminary check to diagnose the character of a sample. At this point, the sample will be diagnosed from preliminary measurements to decide whether to return the sample to Earth or put it through analysis. Analysis entails further measurements and is the principal source of scientific information. The samples that are to be returned are packaged in containers and tagged with pertinent information such as location, temperature, humidity, etc. Sample preservation is the final step and protects the sample until it is received on Earth. A successful mission requires the specimen to arrive in pristine condition (no contamination, shock, or vibration damage).

The hardware for sampling is depicted in Figure 3. The subsystems shown include the manipulator, tools, and rover. The desired scientific samples dictate the tools required and the tools affect the container design that in turn drives the canister design.

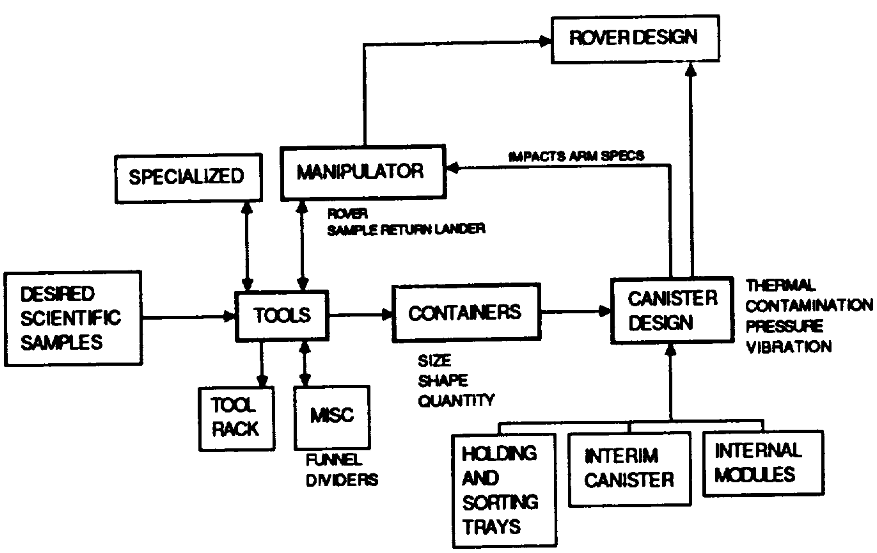

Figure 3 Hardware Interface

The current thinking is to have two manipulators: one on the rover and one on the lander. Both arms should be compatible with a common set of tools. The sample return lander manipulator is used for contingency samples at the beginning of the mission, while the second manipulator is primarily used for sample acquisition on the rover.

In addition to the above tools, a core drill is required. The drill will take samples 1m to 2m long. A rotary percussion drill requires an axial thrust of 100 lb and thus is assumed not to be held from the rover by the arm. Drilling would benefit from a stable base and the mass of the rover should be used to help the percussion motion.

There are two tool options: to be positionable by a manipulator, or to use specialized tools that do not require an manipulator. Without an arm for positioning the tool, that tool must locate itself. To an extent, the rover could be used to position a specialized tool, but the chances are good that several tools would duplicate a common positioning mechanism if there was no arm. A manipulator is desirable to acquire samples, move samples to the various processes, gimbal special sensors (similar to metal detectors) and possibly aid the rover in mobility.

The manipulator is itself a very versatile tool. By combining the arm with various acquisition tools like a gripper, the system becomes very flexible. As stated earlier, the samples determine the desired tools (except for the drill) as shown in Figure 4.

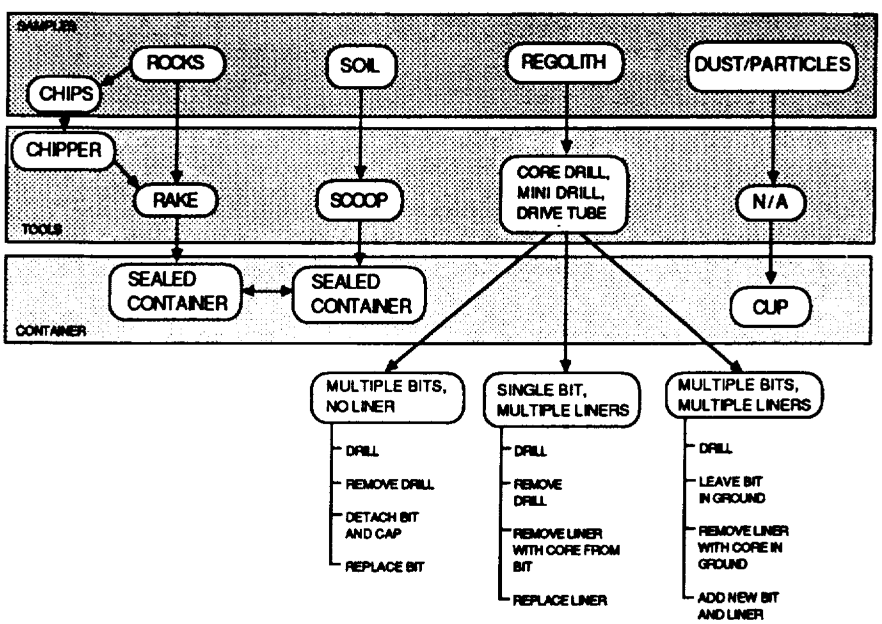

Figure 4 The Samples, Tools and Containers

The envisioned tools include a drum scoop, a chipper, a rake, a mini drill, a drive tube, and a general-purpose gripper. This list is not at all exhaustive and other tools, like a sectioning saw, a hook or additional lights and sensors are also options. The many tools require an end effector able to switch tools back and forth according to the step in the sequence.

The tools will be stored in a quick-release tool rack similar to Figure 5. In such a system, the tools will be held in an orderly manner for automated attach and detach. A compact and reliable fixture must be developed to survive launch loads and yet lock and unlock quickly and simply.

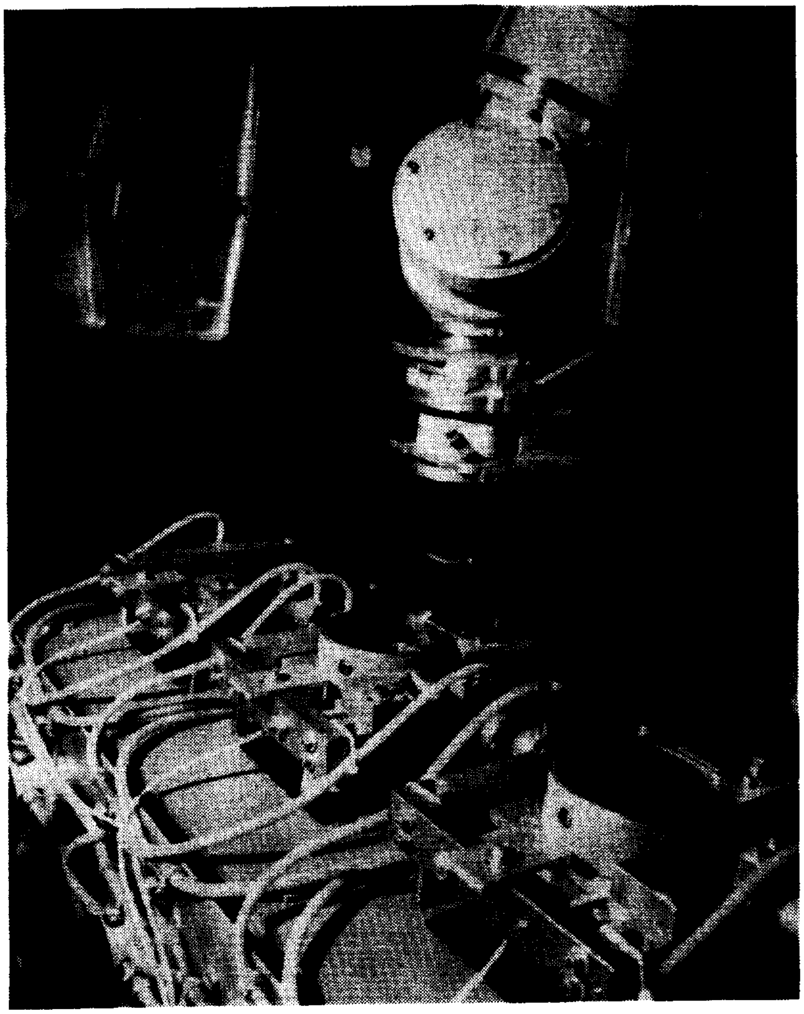

Figure 5 ITA Tool Rack

Sensors are critical to the success of this mission. The most powerful sensor is vision. Vision and possibly range imaging are needed for navigation. In addition, pictures of the environment are needed from which specimens will be picked by scientists. Another key function is the labeling of the samples.

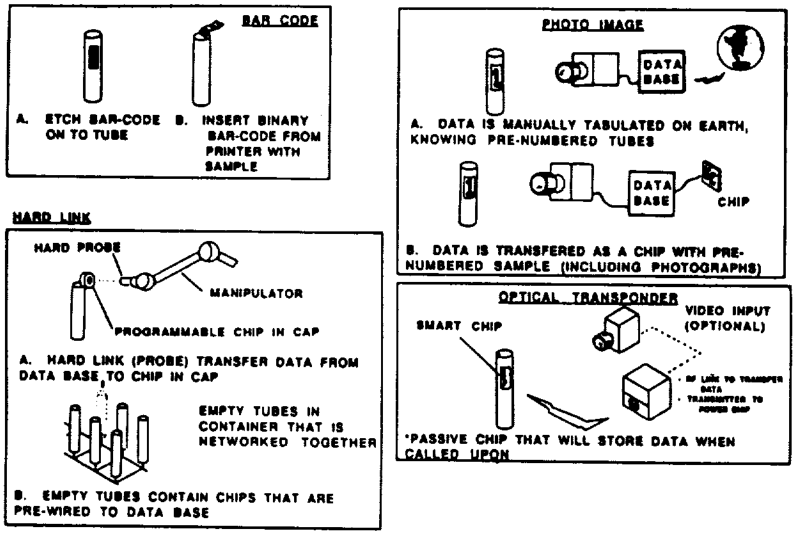

Figure 6 Labeling Options

Some examples of labeling are shown in Figure 6. The simplest method to label the individual tubes is to etch or prestamp each tube with a number or a bar code that could be read by the sampling system from all directions. It is important to identify each sample with location, temperature, preliminary certification, analysis, and local terrain conditions.

4. Sampling Operations

The manipulator is a key part of the sampling system. The goal of this mission is to return 5 kg of Martian samples. It takes a year to get there, a year for exploration and a year to return for a total of a three-year mission. The first task is to scoop 200gm of bulk material with the contingency arm prior to sending out the rover.

The rover will continue in a circular traverse to acquire a diverse sampling. The anticipated 5000 gm of samples include rocks, pebbles, soils, bulk material, regolith core, and atmosphere. The rover will be navigated to a geologically interesting site. Having studied the scene, scientists on Earth would dictate the location and type of samples to test. On their command, the manipulator will go to the required tool and proceed to acquire samples. However, the system has to be flexible enough to adapt to new and different situations.

Requirements for an exploration arm have not been defined. As opposed to servicing, many of the exploration tasks are general in nature. As a result, the arm should exhibit the most capability in a certain size package. The key is versatility and is accomplished by having a flexible system. The samples to be containerized range in diameter from 2 cm to 5 cm. This does not mean the rocks will be small. "Big Joe" in the Viking photos is approximately 1 in height. A situation could arise in which the arm would have to chip away pieces from a much larger rock.

The tasks of processing, certification, analysis, containerization and preservation are well structured and controlled. These steps can be highly automated as analogous to a robotic workcell in manufacturing or assembly. The various processing, certification, analysis and containerization equipment are carefully situated for easy access. The manipulator serves to operate in a pick-and-place condition. A robot centered cell best uses the workspace. Prior to processing, the position and orientation of the particular sample must be known. This knowledge can be obtained by vision or tactile sensing. The gripper design is general-purpose to be able to handle all samples. For an efficient workcell, the distances moved should be minimized. The cell layout is designed to reach all the stations and equipment. Considerations must be given to the movement of the end effector. Any reach aides should be minimized. Manipulator precision and accuracy is designed to meet the minimum requirements of this cell. The samples are moved sequentially from one station to another.

This manipulator is expected to perform like an assembly robot by being able to insert the samples into special tube containers. The drill also uses tubular containers for the cores. All the selected containers are gathered and transferred to the Sample Canister Assembly (SCA), which is returned to Earth.

5. Technical Issues

A technology cutoff date of 1992 is required for a 1998 launch. Rising costs and the long duration dictate that the mission and the technology must be reliable. Two important considerations are the time delay and the weight and power limitations on the system.

Light takes between 8 and 40 min to make the round trip. As a result, 20 percent of the available surface operations time is lost due to discontinuous communications[3]. Standard teleoperative control techniques would be inapplicable. Rover navigation and mobility take up additional time. Secondly, nightfall adds more restrictions in the form of downtime unless the vehicle is able to travel and work at night. High technology could help to reduce the burden.

Lighting and machine vision are important. Images of interesting sites are sent to scientists. To take full advantage of the time delay problem, they have approximately 20 min to designate an interesting area. Besides location, the type of samples desired must be input to the sampling system. The remaining sequences from acquisition to preservation should be autonomous. Periodically, scientists will have a chance to review the data of the stored samples to check their desirability. Only half the gathered samples will be returned.

Task planning algorithms will enhance the task. Force reflection will not work in this situation and intrusion detection and fault isolation will upgrade the performance of the arm. The steps from sample processing to sample preservation are hard automated (fixed). Changes in the test sequences and checks to see that the specimen will fit in the prescribed container are expected. An expert system is desirable to make decisions on the order of analysis and the overall decision to save the sample.

Greater artificial intelligence helps sampling by reducing human intervention (except for a Phobos Mission[4]). Understanding the capabilities of the sampling system as well as the environment is no small task. Assessing the situation is important. For example, the system may need to determine how deep a particular rock is lodged in a crater wall. From there, the arm attaches the appropriate tool and approaches the specimen from an optimized direction.

Sensor fusion (data correlation) will play an important role in this mission due to the many envisioned sensors in the system. Force sensing from manipulating an incorrect tool is just one example of versatility. There is always a chance to fail by immobilizing the arm or breaking the tool. There is a major problem if the drill jams or a drill bit snaps. Combining machine vision, force sensing, and possibly range data into a complete scene analysis will be computationally (power) intensive.

The sampling manipulator on the rover represents a design challenge. The challenge is to determine the amount of capability that can be built into a 32 kg (70.4 lb) arm, as reported in an early mass allocation. The arm will be designed for both pick and place and assembly specifications. An adjustable compliance wrist[5] can be applied to help satisfy both types of requirements. Packaging the arm on the rover will affect its reach and packaging in the aeroshell.

Mounted to the rover, the arm still will need a substantial reach to access everywhere. It might want to bend around a boulder and down a narrow slit to pick up a desired rock. However, the close approximations of the various sampling equipment dictate a maneuverable and dexterous manipulator. There should be no voids in the work volume. Contamination from dust storms is an issue. Bearing seals at each joint could clog or the wipers could fail. One apparent solution is to place a protective boot at each joint. The cold temperatures should minimize overheating, even if the entire structure is coated by a fine silt.

Martian gravity is .38 of Earth's gravity and consequently the 70 lb arm will be constructed from aerospace materials and advanced DC motor technology to increase performance. This could be the benchmark for a flexible manipulator. Flexible manipulators increase the load capacity of the arm without sacrificing accuracy and repeatability. Imagine the possibilities of having a long arm with the precision of an arm half its size (Fig. 7).

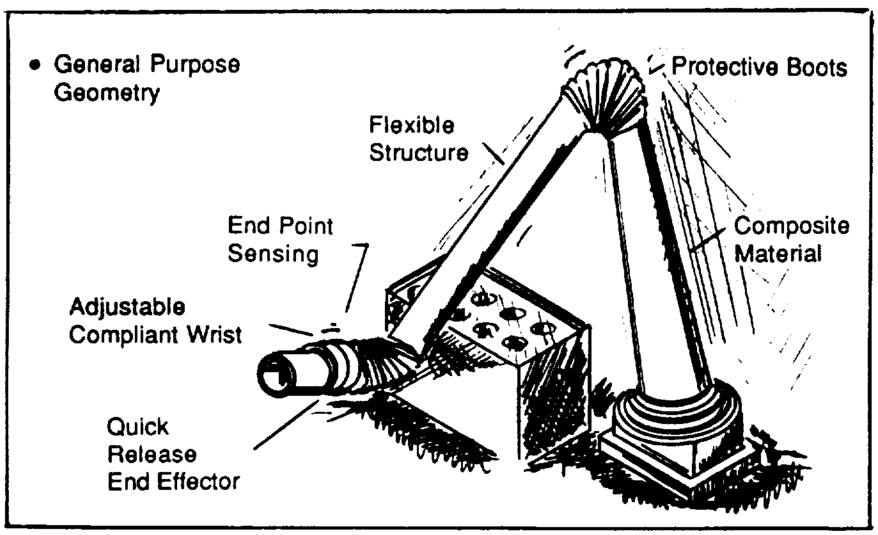

Figure 7 Anatomy of a Sampling Arm

6. Conclusion

Sampling operations would benefit from advanced robotic technologies. A cutoff date of 1992 requires a leap in research application and maturity. Long transmission delays dictate greater autonomy. Increased autonomy in terms of planning, sensor fusion, expert systems and situation assessment would enhance the system.

The manipulator could benefit from a flexible structure and still be dexterous. Adjustable compliance could aid the transition from pick-and-place tasks to assembly tasks. The most important challenge is having versatility in the system without sacrificing reliability. To obtain this versatility, advanced technologies must be developed and made mature by the technology cutoff date.

The sampling mission is harder to design for than a servicing mission. Using manufacturing specifications, exploration has some general design guidelines. The technology will have to be balanced against the reliability factor. There is no room for error when the mission is three years long. The stakes are high, but the rewards promise to be greater.

7. Acknowledgement
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8. References

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