Navam G. Welihinda
Human Biology 001: Life on Mars
Prof. Jay C. Buckey, Jr., Prof. Mukul Sharma, Prof. Laurence J. Davies,

The Feasibility of Autonomous Exploration of Mars

Abstract

One of the principle arguments NASA and the ESA faces in the exploration of the solar system is the feasibility of manned missions as opposed robotic / telerobotic missions. The brute force method of sending humans gather intelligence is now obsolete in most cases. Technology is now at a sufficiently advanced stage, thus we can now think of faster, better and more risk averse methods of achieving our goal of exploring mars.

This paper will take an objective look at the current means of exploring mars. The past, future, and current missions of both unmanned and manned spaceflight for exploratory needs is reviewed, based on the track record of these missions and by the benefit of the returns, we will attempt to weigh the problems of manned space travel and discuss how unmanned missions will overcome these problems.

The paper will finally describe an implementation strategy for autonomous exploration of mars based on the current research of various teams in MIT, Dartmouth, NASA and Carnegie Mellon.

Introduction

Exploration is a human trait which is apparent throughout human history. Be it the search for new land, diving the depths of the ocean floor where our creation the Titanic lies sunken, the conquest of the icy peak of Everest, or walking on the earths desolate moon, humankind has strived to explore the unexplored and as the saying goes "boldly go where no man has ever gone before." Given our very curious habit, it is no surprise that the next logical step is to outdo all our previous feats and plan to conquer and walk on the ominous Red Planet. However, as the human race moves forward, we must question our decisions, learn from our common history, and go through a process of "behavioral Darwinism" to select our best traits and discard the rest.

Having an exploratory nature does not mean that one should blindly pursue a goal incurring whatever cost one comes to bear. One must question the relevance of human exploration to Mars, one must objectively dissect the reasons for traveling to the red planet, how the mission could be made possible, and most importantly we must look into the alternative scenarios to sending a manned mission. Clearly it is to our advantage to discover, both for the betterment of humanity and the satisfaction of our innate curiosity. However, if we are on a quest for knowledge there are more efficient ways of gaining the knowledge we seek through alternative means, rather than the brute force method of traveling to mars and "seeing what we could see". The clear alternative at this point of time is the exploration of Mars through mobile robots. This paper will compare human and autonomous exploration of space, and investigate the feasibility of autonomous exploration of the planet mars.

Robotic Exploration

There are two kinds of robotic missions that can be deployed to explore the planet mars. The uses of the technology varies, both of which could be used effectively as means to two different ends.

1. Autonomous Exploration
2. Telerobotic Exploration

The term "autonomous exploration" in the context of this paper, is used to describe the exploration of a surface or space without human intervention. It differs of current telerobotic missions, in the aspect of control. Telerobotics require a human being to issue instructions to a robot, which in turn follows the given instructions to achieve a goal. Autonomous robots can be deployed with a preprogrammed task and eliminates the need for a human to be in the control loop, the robot then performs by negotiating obstacles and unforeseen events as they arise. The level of autonomy may vary, certainly we do not want a robot to be fully autonomous and reject human instructions.

The use of autonomous robots eliminates the problem of communication between the two planets. "The large distances of between the Earth and the bodies to be explored create signal delays that restrict the intensity of the interaction and limit the human role in providing local intelligence and control. For exploring the Moon the corresponding time delays are only a few seconds; when exploring Mars, the time delays can range from six minutes half an hour." (http://esapub.esrin.esa.it/pff/pffv6n1/wubv6n1.htm) This communication delay is one of the primary arguments against sending robotic missions to mars. The time it takes for a human operator to issue commands to the robot and the robot to acknowledge would be unacceptable due to the time lag of communication. Robot autonomy would eliminate this problem. By designing algorithms that mimic intelligence for many given situations, we can program a computer to react accordingly for any given situation.

Autonomy also allows for humans to deploy robots to mars that can investigate at their own will and report back to base when needed. This strategy allows for a more long term presence on mars.

For now, a certain degree of human intervention is needed for robot control. An autonomous robot that performs tasks in a complex environment is a goal of the future. All current robots usually perform complex tasks in simple environments or simple tasks in complex environments (Daniella Rus, 2001) . The inability to perform complex tasks in complex environments is certainly a problem we will have to overcome if we are to use autonomous robots to explore Mars.

NASA Missions

In order to select the best mode of exploration we now weigh the performances of manned missions and robotic missions that have been designed specifically for the purpose of exploration.

Robotic Mission Summary

(http://spaceflight.nasa.gov/mars/advance_scouts/robotic/)

Robotic Mission Sites

MISSION
OBJECTIVE
LAUNCH
ORBIT/LANDING

Mars Polar Lander
Study climate and geology near Martian South Pole. Probes will search for water below the surface.
Orbiter:
Dec. 11, 1998
LOST
Sept. 24, 1999

Lander:
Jan. 3, 1999
LOST
Dec. 3, 1999

Mars Program Independent Assessment Team Report

Mars Global Surveyor
High resolution imaging of the surface
Nov. 7, 1996
Sept. 11, 1997 (Mars orbit)

Mars Odyssey 2001

Mapping chemical elements, looking for water, analyzing the radiation environment

April 7, 2001
Oct. 24, 2001

Mars Surveyor 2001
Global studies, surface exploration and resource production
Orbiter:
March 30, 2001
(scheduled)
Oct. 20, 2001 (scheduled Mars orbit)

Lander:
cancelled
cancelled

Mars Surveyor 2003
Mars rover, ascent vehicle and sample collection

May-June 2003
Under review

Mars Surveyor 2005
Mars rover, ascent vehicle and sample return mission
July-Aug 2005
Under review

Mars Pathfinder
First Mars rover
Dec. 4, 1996
July 4, 1997

Viking II
Global studies and surface exploration
Sept. 9, 1975
Orbiter:
Aug. 7, 1976

Lander:
Sept. 3, 1976

Viking I
Global studies and surface exploration
Aug. 20, 1975

Orbiter:
June 19, 1976

Lander:
July 20, 1976

Mariner IX
First spacecraft to orbit another planet
May 30, 1971
Nov. 17, 1971

Mariner VII
Atmospheric and geologic studies
March 27, 1969
Aug. 4, 1969 (Mars fly-by)

Mariner VI
Atmospheric and geologic studies
Feb. 24, 1969
July 31, 1969 (Mars fly-by)

Mariner IV
First glimpse of Mars at close range
Nov. 28, 1964

July 14, 1965 (Mars fly-by)

Human Exploration

Let us now focus on the relevant manned missions that are relevant and comparable to a mission to mars. The only significant human exploration performed my NASA or any other space agency have been the Apollo Lunar Landings. Most other manned missions have been concentrated on missions close to the earth.

The 1969 Lunar Landing by Apollo took the first men to the moon. The peak budget during the Apollo mission was 5.7% of the federal budget (today 0.7%) (http://www.cnn.com/TECH/specials/apollo/stories/nasa.then.and.now/index.html). "Twelve astronauts in six Apollo missions landed on and explored the nearside of the Moon between 1969 and 1972. The six landing sites were chosen to explore different geologic terrains." (NASA Spacelink, Exploring the Moon) Since these missions, the worlds interest has waned in the moon, and no further missions were sent to the moon in recent years. Following these several successful lunar landings, the worlds attention is focused on mars, drawing from the success of the lunar missions we now arrive at the Mars Reference mission: a daring plan to put humans on Mars.

The Mars Reference Mission is the current strategy for sending humans to mars. The mission involves a near term Mars Precursor strategy and eventually a human exploration mission. The first stage would set the groundwork for later human exploration by sending cargo missions on minimum energy trajectories to mars, the cargo would include a a fully fuelled ERV and a nuclear power plant. The later stages will deliver to crew to mars, where they can live off the cargo produce that was initially launched (The Mars Reference Mission – NASA).

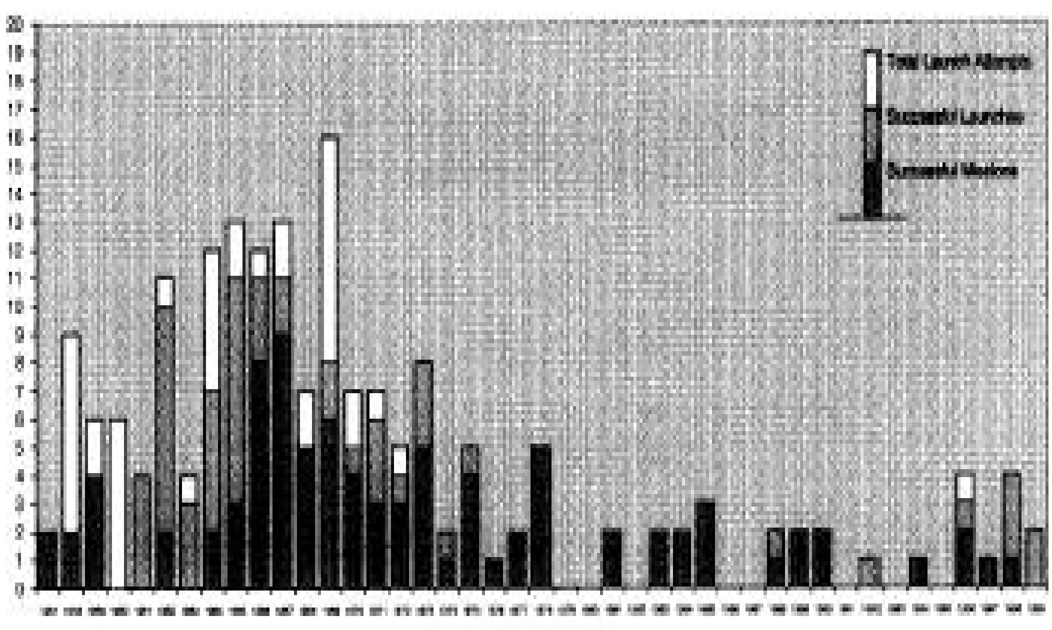
Humans Vs. Robots.

Cursory observation of the past human and robotic mission shown above show that we have acquired far more experience at sending probes to different planets than we have humans. We can also see the gradual development of the standard of robotic probes we have sent to other planets, as opposed to the proposed sporadic jump of sending a human to the moon and then sending a human to mars. Manned space-flight to mars will be a large gamble, with much risk involved due to the lack of preliminary missions. Sending more robotic missions would simply amount to more experience in general leading to less mistakes and bigger benefits.

Another complexity of sending a crew to mars is the payload weight. Sending a manned mission would envisage lifting a far greater weight into space than a robotic mission. Most proposed robotic probes are lightweight and do not require a large lifting thrust. A human mission on the other hand would be much heavier due to the weight of the crew, the supplies, and the life support systems. Historical data suggest that heavier missions are less likely to be flown whereas lighter missions are flown more frequently.

This is a definite negative aspect of flying a manned mission because we are likely to prematurely stop the program due to budgetary reasons and ignore a more stable long-term presence in mars. “(If we take) a look at the history of planetary exploration, the launch rate appears to be inversely related to spacecraft size and weight; particularly in he U. S. (see Figure 1). As missions grew in size launch rate declined. There were many factors which influenced growth in mission size and weight. Probably the most important desire to acquire the most science from each of the very limited opportunities to explore the solar system…Smaller more focused mission were being developed at a fraction of

Figure 1: Planetary Mission Summary



Note: Some spacecraft launched in 1996-99 have yet to complete their mission objectives.

the cost of the previous missions at a much faster pace.”(Exploring the solar system)

Human beings are very fragile in a hazardous environment such as space. The primary concern of sending humans to mars is the safety of the crew. The level of crew safety observed in a manned mission is not so much a concern in a unmanned mission. Long duration flight involves much strain on the human system. “In weightlessness, the bones of the lower body are not subject to constant stress, so the regulatory mechanisms of the body begin to break down bone material, thus reducing compact bone mass. This process begins immediately after entering microgravity and continues until return to Earth” (NASA Life Sciences Data Archive). The body is also susceptible to harm due to hazardous radiation in space. (Prof. Jay Buckey, Dartmouth College, 2001)

The Next Step – So what do we do?

The principle plan of exploring mars should be to look at the current successes and expand the scope of those missions. The most successful missions have been robotic missions, and the missions that have returned us the most data have been unmanned missions. The more reliable method to uncover questions regarding the Arian terrain climate would be to continue to use unmanned probes and robotic missions. As the complexity of missions grow the use of autonomous robots would probably be the most beneficial for handling uncertainty.

Arguably the most dramatic and successful mission that involved exploring another planet to date has been the Mars Pathfinder and Sojourner Rover. The pathfinder mission can serve as a reference point and a platform to build better robots for the purpose of exploration. Pathfinder landed on Mars successfully on July 1997. “The total cost of the Pathfinder mission was approximately $265 Million” (Touching Mars 1998)

(fig 1: The Soujourner Rover : http://www.channel4000.com/news/stories/news-970729-143459.html)

More importantly the mission exemplified the following capabilities. (Touching Mars 1998)

- A low cost, descent and landing system
- Solar Powered rover and lander surface operations
- Remote operation of an automated mobile machine
- Utility of a small rover for scientific investigations

(Touching Mars, 1998)

Pathfinder exemplifies what is capable of being achieved with current robotic technology. Considering these facts we can conclude that robotic exploration to Mars is possible, feasible and has been demonstrated. Starting from the relatively "simple" platform of the rover we can incorporate current Robotic ideas to form more robust systems.

Technology – Building the Autonomous Robot.

If we accept the hypothesis that robotic missions are more viable for the exploration of mars, we now must examine the question of how we are to design a perfect autonomous system that will meet our needs. By re-evaluating the past missions and extrapolating to meet the needs of the future we can deduce that technological advancement is needed in order to have a successful mission to mars. But the rate of technological growth for an unmanned mission is not unattainable. If we compare the technological growth required to safely initiate the Mars Reference mission we can clearly see that unmanned missions are more realistic to meet the current needs of finding life on mars.

The key to having a robust system mars is to incorporate very high level intelligence into current machines. The current level of mechanical sophistication is adequate to meet our needs, however, much development is needed in the software that drives the machines. Thus, Artificial Intelligence will have to play a major role in building a successful and robust system of robot explorers

Exploring a rough terrain like mars requires a robot that can perform complex tasks in a complex environment. The most relevant architecture to perform this task is the subsumptionist system designed by Rodney Brookes of MIT.

Subsumptionism

The subsumptionist system is a layered system of robotic control. The lower layers are used for lower level processes such as object avoidance and roaming, the higher levels are used for reasoning and perception. The layers are built with inhibitors, so that any higher level operation can inhibit a lower level operation, also lower level operations take precedence over higher level operations. (Elephants Don’t Play Chess, Rodney A. Brooks). The architecture can be thought of as the layered behavior a human being possesses, for example, as you are reading this paper, if you notice a large object moving towards you, you will stop your higher level operation of language comprehension and reasoning, and let your lower level object avoidance reflexes take precedence over your actions.

This multi-level performance in a machine is necessary because a robot should be capable of self preservation from natural hazards even while it is in the process of evaluating a higher level function like analyzing a soil sample. The reaction time of a classical robot would be too slow for an unknown environment.

Even though subsumption architecture requires much advance in technology, robotics in it's present form, or telerobotics can serve for preliminary missions until the mission payload gets more complex as to require the subsumptionist architecture.

Picking the perfect control architecture is only part of complexity of sending an autonomous robot. The second important feature of a autonomous system is the method of locomotion for the robot.

Locomotion

Locomotion is one of the most important aspects of a robot design. Picking the right locomotion system for a robot we send to mars will be pivotal in the mission success.

The main ideas we have to keep in mind while sending a robot to mars is that the terrain is unknown. We may have large maps of the planet, that show us rocky mare like terrain or a dusty surface, but when sending a robot to explore, it has limited intelligence to negotiate little obstacles that are unmapped. If the robot does not know that there is a specific boulder at a specific place, it might get stuck much like what happened to the Soujurner rover in the Pathfinder mission.

The easiest method of overcoming this obstacle is to pick a locomotion method that does not rely on knowing if the terrain is smooth or picking the best path. A Six-Legged robot with a tripod gait is probably one of the most stable robots on a rough terrain. Carnegie Mellon University's Dante robot, exemplifies the capabilities of six legged locomotion. Dante has been used to explore the rough uncharted terrain of the inside of the active crater of Mt. Spurr in Alaska, a similar system should be able to handle the arian terrain.

(http://nctn.hq.nasa.gov/innovation/Innovation25/DanteII.html)

(Fig 3: Carnegie Mellon's Dante II exploring Mt. Spurr

http://volcano.und.nodak.edu/vwdocs/vw_news/dante.html)

The second method of locomotion- Dartmouth's Self Reconfiguring Robots- would probably be the best option for robotic exploration in the future. "A self-reconfiguring robot consists of a set of identical modules that can dynamically and autonomously reconfigure in a variety of shapes, to best fit the terrain, environment, and task. Self-reconfiguration leads to versatile robots that can support multiple modalities of locomotion and manipulation. For example, a self-reconfiguring robot can aggregate as a snake to traverse a tunnel and then reconfigure as a six-legged robot to traverse rough terrain, such as a lunar surface, and change shape again to climb stairs and enter a building." (http://www.cs.dartmouth.edu/~robotlab/robotlab/robots/molecule) This robot is still in it's formative stages and may not be available for exploratory use until further research has been done and advances have been made in this technology.

fig 2: Example of a very simple molecule robot. This single molecule has two "atoms" and a "bond"(http://www.cs.dartmouth.edu/~robotlab)

Conclusion

During the course of this paper we have observed that

- Most non shuttle missions flown have been unmanned, and most relavant discoveries and data have been returned by probes from unmanned missions to mars and other planets in the solar system. Thus we have far more experience in sending unmanned missions for exploration than we have in sending manned mission.

- The budgetary involved in sending unmanned missions to space is miniscule compared to the manned mission.

- Unmanned missions are far lighter than manned missions, thus are much cheaper to launch than manned mission. A lighter unmanned program is also easier to sustain than a manned mission.

- The use of Autonomous robots can take the place of humans for decision making in uncertain environments, thus it would free the program from requiring a human in the control loop.

- The subsumption architecture, is a very feasible method of introducing robust autonomy to machines.

- The rough terrain can easily be traversed using self reconfiguring robots or six legged locomotion systems.

The only reason humans wish to set foot on mars is to prove it’s superiority as a means of technological muscle flexing. This muscle flexing is a very costly exercise in futility. If our principle goal is knowledge and the betterment of all humankind, then we must approach the prospect of exploring mars with a more open mind, and devise more ingenious ways of learning about the Red Planet, by sending our mechanical agents to hoard information and relay it to earth in a true “faster, better, and cheaper” sense. Reviewing these observations we can clearly conclude that an autonomous system sent to mars would not only be feasible but also a superior choice than a manned mission.

REFERENCES

- Brooks, Rodney A, Elephants Don't Play Chess
- Brooks, Rodney A. , Flynn, Anita M, Fast, Cheap and out of Control: A Robot Invasion of the solar system, (http://www.ai.mit.edu/people/brooks/papers/fast-cheap.pdf)
- Prof. Jay C. Buckey, Jr., Prof. Mukul Sharma, Prof. Laurence J. Davies; Class lectures and notes, Dartmouth College, Hanover NH, Spring 2001
- Rus, Daniella : Dartmouth College, Hanover NH. Spring 2001
- Dartmouth Robotics Lab: (http://www.cs.dartmouth.edu/~robotlab/index.html) accessed 4/12/01
- Huckins III, Dr Earle K.; Elachi, Dr Charles; Woods, Mr Dan; Exploring the Solar System a current overview.
- Mars Reference Mission- HUBI 1 Reader.
- NASA Life Sciences Data Archive: http://lsda.jsc.nasa.gov/overview.cfm
- NASA SpaceLink Exploring the Moon Accessed 5/28/2001

http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Exploring.the.Moon/Exploring.The.Moon.pdf

- NASA Human Space Flight (http://spaceflight.nasa.gov/mars/advance_scouts/robotic/) Accessed 5/22/01
- Ockels, Wubbo J. , RISE- Remote/Robotic Interactive Space Exploration (Tele-exploration) http://esapub.esrin.esa.it/pff/pffv6n1/wubv6n1.htm accessed 5/13/01
- Shirley, Donna, Touching Mars: 1998 Status of the Mars Robotic Exploration Program
- Space Technology Innovation: Volume 2, Number 5 September/October 1994 (http://nctn.hq.nasa.gov/innovation/Innovation25/DanteII.html) Accessed 5/28/2001