Space Robotics & Deep Space Communication

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Abstract- *Outer space is an ultimate field for the application of robotics technology. As outer space is a harsh environment with extreme temperatures, vacuum, radiation, gravity, and great distances, human access is very difficult and hazardous and is therefore limited. To assist human activities in space for constructing and maintaining space modules and structures, robotic manipulators have been playing essential roles in orbital operations. Moreover, expanding the horizons of exploration beyond the areas of human access, robots that land and travel on planetary surfaces have been greatly contributing to our knowledge of the solar system. New challenges are expected in the future. This article consists of three parts. In the first part, what is space robotics and importance of space robotics are reviewed, highlighting the fundamental research challenges. In the second part, some of the selected topics of planetary robotics from the field robotics research point of view are described. Finally, technological challenges to asteroid robotics are discussed. When designing a robot to explore the surface of an asteroid, microgravity raises an interesting problem of how to stick and move on the surface. Some ideas to address these questions are introduced.*

Keywords- Asteroid robots, Free-flying robots, Localization, Mapping, Space robotics.

I. INTRODUCTION

Space robotics is the development of general purpose machines that are capable of surviving (for a time, at least) the rigors of the space environment, and performing exploration, assembly, construction, maintenance, servicing or other tasks that may or may not have been fully understood at the time of the design of the robot. Humans control space robots from either a "local" control console (e.g. with essentially zero speed-of-light delay, as in the case of the Space Shuttle robot arm (Figure 1.1) controlled by astronauts inside the pressurized cabin) or "remotely" (e.g. with non-negligible speed-of-light delays, as in the case of the Mars Exploration Rovers (Figure 1.2) controlled from human operators on Earth). Space robots are generally designed to do multiple tasks, including unanticipated tasks, within a broad sphere of competence (e.g. payload deployment, retrieval, or inspection; planetary exploration).

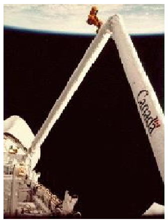


FIGURE 1.1


FIGURE 1.2

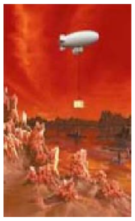


FIGURE 1.3

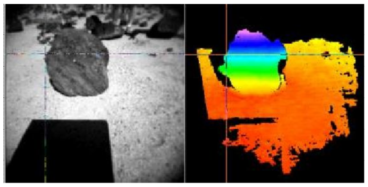
II. IMPORTANCE OF SPACE ROBOTICS

Space robots are important to our overall ability to operate in space because they can perform tasks less expensively or on an accelerated schedule, with less risk and occasionally with improved performance over humans doing the same tasks. They operate for long durations, often "asleep" for long periods before their operational mission begins. They can be sent into situations that are so risky that humans would not be allowed to go. Indeed, every space robot mission beyond Earth orbit has been a "suicide mission" in that the robot is left in place when it stops operating, since the cost of return-to-Earth is (literally) astronomical (and that cost would be better spent in return of scientific samples in almost every case). Missions to distant targets such as Titan (a moon of Saturn thought to have liquid methane lakes or rivers) presently require a substantial fraction of a human lifetime during the transit from Earth to the destination. Access to space is expensive (currently about $10,000 for every kilogram lofted into Low Earth Orbit (LEO)), implying that, for certain jobs, robots that are smaller than a human and require much less infrastructure (e.g. life support) makes them very attractive for broad classes of missions.


Figure 2.1. Artist's conception of "Robonaut" (an "astronaut-equivalent" robot) performing space assembly.

III. FUNDAMENTAL RESEARCH CHALLENGES

Fundamental research challenges for space robotics include solving the basic questions of mobility: Where am I, where is the "goal," where are the obstacles or hazards, and how can I get from where I am to where I want to be? Figure 3.1 shows some results from stereo correlation, a process where images taken from stereoscopic cameras are matched together to calculate the range to each point in the image. This range map, along with the known camera viewing geometry, can be transformed into an elevation map that is used to identify obstacles and other forms of hazards. Defining a coordinate frame in which hazards and objects of scientific interest can be localized is an important decision. With the original Mars rover Sojourner, the coordinate frame was fixed to the lander, and the rover always moved within sight of the lander mastmounted cameras. However, with the MER rovers, the landers were left far behind and could serve as a stationary reference point. So it is very important to accurately measure the motion of each vehicle so that the updated position of previously-seen objects can be estimated. In Figure 3.2 is shown a result from "visual odometry," a process where distinctive points in an image are located and tracked from frame to frame so that the motion of the camera in a stationary scene can be accurately estimated. Vehicle "dead reckoning" (e.g. using only its compass and odometer to navigate) typically results in errors of about 10% of distance traveled in estimating its new position. With visual odometry, this error drops to well under 1%. Shown in Figure 3.3 is "Purgatory Dune," a soft soil formation of Mars where the rover Opportunity got stuck for five weeks in the spring of 2005. Shown in Figure 3.4 are the tracks leading into Purgatory Dune, showing that the visual appearance of Purgatory Dune was not distinctively different from that of the small dunes which had been successfully traversed for many kilometers previously. Detecting very soft soil conditions requires additional research and may require specialized sensors.



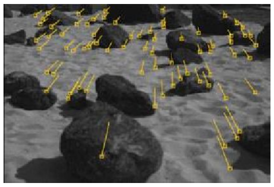
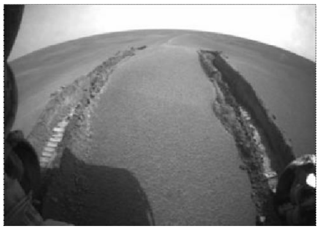


Figure 3.1. Stereo correlation example. Figure 3.2. Visual odometry example.



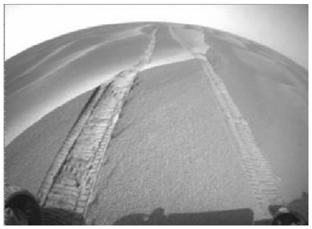


Figure 3.3. Opportunity rover image of Purgatory Dune. Figure 3.4. Opportunity image of rover track leading into Purgatory Dune.

Another area of fundamental research for space robotics relates to manipulation. Traditional industrial robots move to precise pre-planned locations to grasp tools or workpieces, and generally they do not carefully manage the forces they impart on those objects. However, space hardware is usually very delicate, and its position is often only approximately known in terms of the workspace of the arm. Large volumes of the workspace may be occupied by natural terrain, by spacecraft components, or by astronauts. If the robot arm is strong enough to perform useful tasks, and is fast enough to work cooperatively with human astronauts, then it represents a tremendous danger to the spacecraft components, the human astronauts, and to itself. Advanced sensing is needed to identify and keep track of which parts of the work volume are occupied and where workpieces are to be grasped. Whole-arm sensing of impending collisions may be required. A major advance in safety protocols is needed to allow humans to occupy the work volume of swift and strong robots—something that is not now permitted in industry.

Time delay is a particular challenge for manipulation in space robotics. Industries that routinely use teleoperation, such as the nuclear industry, generally use "master-slave" teleoperators that mimic at the "slave" arm any motion of the "master" arm as maneuvered by the human. This approach only works well if the time-delay round trip between the master and slave is a very small fraction of a second. When delays of a few seconds are encountered, human operators are very poor at managing the contact forces that the slave arm imparts on the workplace. For these cases, which include many or most that are of interest in space robotics, it is more appropriate for the human to command the slave arm by way of "supervisory control." In supervisory control, the contact forces are rapidly measured and controlled directly by the electronics at the slave arm, so that the time delay back to the human operator doesn't result in overshoot or oscillation of the slave arm. The human gives commands for motions that can include contact with elements of the worksite, but those contact forces are managed within a preplanned nominal range by the remote-site electronics independent of the motion of the master. Figure 3.6 shows an artist's conception of a submarine robot exploring the putative liquid water ocean thought to exist under the surface ice on Europa, a moon of Jupiter. The speed-of-light round trip for control of such a device would be at least hours, and practically it may only be possible to send commands to such a vehicle once every few days.

Figure 3.5 Dextrous arm

Figure 3.6. Artist's concept of a submarine robot of mars in the sub-liquid water ocean Europa, a moon of Jupiter.

Figure 3.7. Artist's conception of exploration rover thought to exist on.

IV. PLANETARY ROBOTICS

For the exploration of the moon and other planets, robots have been contributing to expand the frontier of scientific knowledge and human access. The first robot that traveled on the surface of extraterrestrial body was Lunokhod (1970), developed by former Soviet Union. It was remotely operated from Earth and traversed more than 10.5 km on the moon. The following Lunokhod-2 (1973) was also successful in 37 km of teleoperated traversal. On the other hand, the Lunar Roving Vehicle (LRV) or moon buggy was used in the NASA’s Apollo program (Apollo 15, 16, and 17, during 1971–1972). The moon buggy was an electrically driven four-wheel cart that can carry two astronauts and can be manually driven like a golf cart. It was useful to expand the area of human expedition from the landing sites.

As for the exploration of Mars, the first successful landers are NASA’s Viking 1 and 2 (landed 1976). Although they were static landers, they have a robotic arm to collect soil samples and conduct in situ analysis. A recent mission, NASA’s Phoenix lander, was also successful in landing at the Martian arctic region. It is equipped with a 2.4-m long, 4-DoF manipulator arm that has the capability of carrying out dexterous tasks to interact with the terrain, such as digging, scraping, and sample acquisition [26]. In situ analysis of the soils confirmed the existence of water ice at present, and a possibly warmer and waterrich climate in the past was strongly suggested.

As for mobile robots (rovers) on Mars, the Sojourner rover in the Mars Pathfinder mission (1997) and Sprit and Opportunity in Mars Exploration Rover (MER) mission (2004–2009, see Figure 4) have had remarkable success. The benefits of mobility in remote exploration mission have been strongly highlighted in these missions with rich scientific returns. The ESA’s ExoMars mission should be added as a planned rover mission. From a robotics technology point of view, interesting issues are the design of mobility mechanisms and the algorithms for navigation control in natural rough terrain. In particular, the wheel slip and traction issue in a loose soil environment were highlighted by Opportunity during exploration of Meridiani Planum. In late April 2005, Opportunity got stuck in a soft sand dune (named Purgatory Dune), and due to significant wheel slip, it took many weeks until it finally got back onto firm ground in early June 2005 [27]. Wheel slippage also degrades the accuracy of odometric measurement of the vehicle, and improved methods for robot odometry have been developed.

Phoenix and ExoMars missions will be elaborated in this issue. This article provides a short review of wheeled robots for surface locomotion, with highlights on the technologies for environment mapping, odometric measurement, and slip and traction control.

V. ROBONAUT

A Robonaut is a dexterous humanoid robot built and designed at NASA Johnson Space Center in Houston, Texas. Our challenge is to build machines that can help humans work and explore in space. Working side by side with humans, or going where the risks are too great for people, Robonauts will expand our ability for construction and discovery. Central to that effort is a capability we call dexterous manipulation, embodied by an ability to use one's hand to do work, and our challenge has been to build machines with dexterity that exceeds that of a suited astronaut.

There are currently four Robonauts, with others currently in development. This allows us to study various types of mobility, control methods, and task applications. The value of a humanoid over the other kind of designs is the ability to use the same workspace and tools - not only does this improve efficiency in the types of tools, but also removes the need for specialized robotic connectors. Robonauts are essential to NASA's future as we go beyond low earth orbit and continue to explore the vast wonder that is space.

Robonaut 2 or R2, launched to the International

Space Station on space shuttle Discovery as part of the STS-133 mission, it is the first dexterous humanoid robot in space, and the first US-built robot at the space station. But that was just one small step for a robot and one giant leap for robot-kind.

Initially R2 will be deployed on a fixed pedestal inside the ISS. Next steps include a leg for climbing through the corridors of the Space Station, upgrades for R2 to go outside into the vacuum of space, and then future lower bodies like legs and wheels to propel the R2 across Lunar and Martian terrain. A four wheeled rover called Centaur 2 is being evaluated at the 2010 Desert Field Test in Arizona as an example of these future lower bodies for R2.

Figure 5.1 A robonaut

VI. ROBONAUT 2

In the current iteration of Robonaut, Robonaut 2 or R2, NASA and General Motors are working together with assistance from Oceaneering Space Systems engineers to accelerate development of the next generation of robots and related technologies for use in the automotive and aerospace industries. Robonaut 2 (R2) is a state of the art highly dexterous anthropomorphic robot. Like its predecessor Robonaut 1 (R1), R2 is capable of handling a wide range of EVA tools and interfaces, but R2 is a significant advancement over its predecessor. R2 is capable of speeds more than four times faster than R1, is more compact, is more dexterous, and includes a deeper and wider range of sensing. Advanced technology spans the entire R2 system and includes: optimized overlapping dual arm dexterous workspace, series elastic joint technology, extended finger and thumb travel, miniaturized 6-axis load cells, redundant force sensing, ultra-high speed joint controllers, extreme neck travel, and high resolution camera and IR systems. The dexterity of R2 allows it to use the same tools that astronauts currently use and removes the need for specialized tools just for robots.

One advantage of a humanoid design is that Robonaut can take over simple, repetitive, or especially dangerous tasks on places such as the International Space Station. Because R2 is approaching human dexterity, tasks such as changing out an air filter can be performed without modifications to the existing design.

Another way this might be beneficial is during a robotic precursor mission. R2 would bring one set of tools for the precursor mission, such as setup and geologic investigation. Not only does this improve efficiency in the types of tools, but also removes the need for specialized robotic connectors. Future missions could then supply a new set of tools and use the existing tools already on location.

Figure 6.1 A robonaut 2

VII. MOBILITY

NASA JSC has developed a series of Centaur rovers to carry the Robonaut upper bodies and other payloads. Centaur 1 was developed for work with the Robonaut R1B humanoid upper torso in 2006. Centaur 2 rover was developed in 2010 by the Human Robotics Systems (HRS) Project as part of the Exploration Technology Development and Demonstration Programs, and has now been integrated with the Robonaut R2A torso. This combination mixes state-of-the-art robotic mobility with the world’s most advanced dexterous manipulation system. Hybrid rover/arm systems, commonly referred to as mobile manipulation, represent a new domain of robotics research. Mobile manipulation is an important new Space Technology with multiple applications for improving life here on Earth. NASA's new Centaur2/Robonaut2 system is an ideal testbed for this research and positions the agency as the technological leader.

Centaur 2 has several advanced technologies including a new active suspension system using force control, body articulation, high performance (330V, 30 Amp) embedded motor controllers, thermal/dust isolation of embedded avionics in the legs, line replacement unit body avionics for EVA or robotic maintenance, in-hub wheel actuation, and a new configuration of crab style steering. These Space Technologies are important for future NASA rovers, as well as terrestrial applications in electric vehicles and robotic vehicles.

Centaur 2 was delivered for a "shake out cruise" at the Desert Rats 2010 field test in August 2010. Fitted with a digging implement developed by the HRS engineers working at GRC, Centaur 2 was shown to be a rugged and agile new rover. The Robonaut 2 torso has now been integrated as a new payload, and integrated with the electrical and data systems of the Centaur 2 rover. Combined, this new mobile manipulation system was integrated in time to support KSC launch activities of the Robonaut unit R2B on STS -133. Future lower bodies for the Robonaut 2 series include zero gravity climbing legs for performing EVA tasks on the ISS. Future payloads for Centaur 2 include prospecting sensors, deeper excavation implements and devices for converting into usables

Figure 7.1 Example of robonaut in explaining mobility

VIII. THE STATE-OF-THE-ART IN SPACE ROBOTICS

The current state-of-the-art in "flown" space robotics is defined by MER, the Canadian Shuttle and Station arms, the German DLR experiment Rotex (1993) and the experimental arm ROKVISS on the Station right now, and the Japanese experiment ETS-VII (1999). A number of systems are waiting to fly on the Space Station, such as the Canadian Special Purpose Dexterous Manipulator and the Japanese Main Arm and Small Fine Arm . Investments in R&D for space robotics worldwide have been greatly reduced in the past decade as compared to the decade before that; the drop in the U.S. has been greater than in Japan or Germany. Programs such as the NASA Mars Technology Program (MTP) and Astrobiology Science and Technology for Exploring Planets (ASTEP), as well as the recent NASA Exploration Systems Research and Technology (ESRT) programs represent an exception to the generally low level of investment over the past decade. However, some or all of these programs are expected to be scaled back as NASA seeks to make funds available to pursue the Vision for Space Exploration of the moon and Mars. An artist conception of a Robonaut-derived vehicle analogous to the mythical ancient Greek Centaurs, with the upper body of a human for sensing and manipulation, but with the lower body of a rover for mobility.A comparison between the first two autonomous planetary rovers flown, Sojourner (or actually the flight spare, Marie Curie) and Spirit. In Asia, the Japanese have consolidated most space robotics work at NEC/Toshiba, who have several proposals submitted but no currently funded space robotics follow-ons to the MFD, ETS-VII, or JEMRMS. The Japanese have developed several mission concepts that include lunar rovers. The South Koreans have essentially no work going on in space robotics. Both China and India are reported to be supporting a significant level of indigenous development of future lunar missions that may involve robotics. Figure 8.1 shows a model at the Chinese Pavilion at the Hannover Expo 2000 depicting Chinese astronauts with a lunar rover planting the flag of the People's Republic of China's on the lunar surface while Figure 8.2 shows a prototype of a lunar rover developed by the Japanese for the SELENE-II mission. In Europe, the Germans are planning a general-purpose satellite rendezvous, capture, reboost and stabilization system to go after the market in commercial satellite life extension. In the U.S., the Defense Advanced Research Projects Agency (DARPA) has a similar technology development called Spacecraft for the Unmanned Modification of Orbits (SUMO). The French are proposing a major role in a Mars Rover as part of the ESA ExoMars project. The French Space Agency CNES and the research organization LAAS/CNRS have significant capability for rover hazard avoidance, roughly comparable to the U.S. MER and planned Mars Science Laboratory (MSL) rovers. Neither the British nor the Italians have a defined program that is specific to Space Robotics, although there are relevant university efforts. Figure 8.3 shows an artist conception of a future ESA astronaut examining and retrieving an old ExoMars rover.

Figure 8.1. Model at the Chinese Pavilion, Hannover Expo 2000 showing Chinese astronauts with lunar rover planting.

Figure 8.2. Development model of a lunar rover for the Japanese mission SELENE-II.

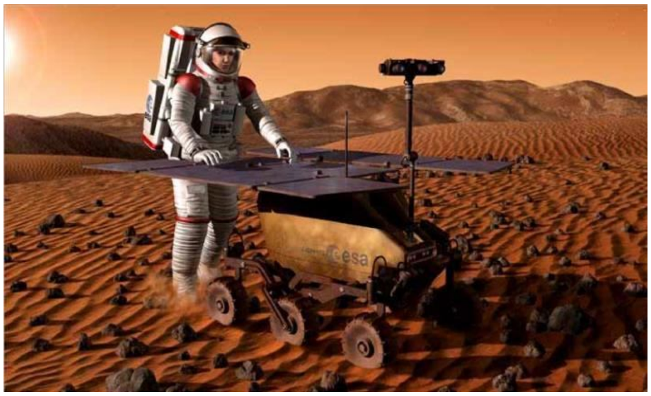


Figure 8.3. Artist's conception of a future European Space Agency astronaut examining the ExoMars rover.

Table 8.1. A qualitative comparison between different regions and their relative strengths in space robotics

	U.S.	Canada	Japan	Europe
Basic:				
Mobility	****	*	**	***
Manipulation	**	***	***	***
Extreme Environment	***	**	**	**
Power, Comm, etc.	***	*	**	**
Applications:				
Rovers	****	*	**	***
Large Manipulators	*	****	****	*
Dexterous Manipulators	***	****	***	****
Free-Flyers	***	*	***	**

There are no clearly identified funded or soon-to-be-funded missions for robotics except for the current manipulation systems for the Space Station, the planned U.S. and European Mars rovers, and a possible Japanese lunar rover. There is no current plan by any nation to use robots for in-space assembly of a large structure, for example. The role of robotics in the NASA “vision” outlined in the speech by President Bush in January 2004 is not defined yet, but may be substantial. Table 3.1 gives a qualitative comparison between the different regions of the world and the relative strength of their respective activities in Space Robotics. One star means that there is very little activity going on in this area; four stars means there is a deep body of expertise.

Future trends in Space Robotics are expected to lead to planetary rovers that can operate many days without commands, and can approach and analyze science targets from a substantial distance with only a single command, and robots that can assemble/construct, maintain, and service space hardware using very precise force control, dexterous hands, despite multi-second time delay.

IX. INTERNATIONAL EFFORTS IN SPACE ROBOTICS

Other nations have not been idle in developing space robotics. Many recognize that robotic systems offer extreme advantages over alternative approaches to certain space missions. Figures 9.7-8 show a series of images of the Japanese ETS-VII (the seventh of the Engineering Technology Satellites), which demonstrated in a flight in 1999 a number of advanced robotic capabilities in space. ETS-VII consisted of two satellites named “Chaser” and “Target.” Each satellite was separated in space after launching and a rendezvous docking experiment was conducted twice, where the Chaser satellite was automatically controlled and the Target was being remotely piloted. In addition, there were multiple space robot manipulation experiments which included manipulation of small parts and propellant replenishment by using the robot arms installed on the Chaser.

Figure 9.1Phoenix arm, developed by the Jet Propulsion Laboratory for the Phoenix mission led by P.I. Peter Smith of the University of Arizona for use on the lander system developed by Lockheed-Martin of Denver

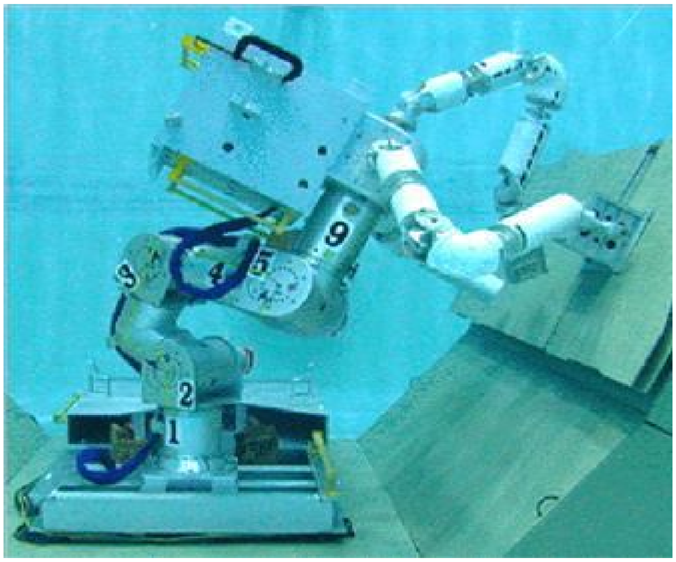


Figure 9.2. Ranger Manipulator

The Japanese have also developed advanced robotic elements for the Japanese Experiment Module (JEM) of the International Space Station. The Remote Manipulator System, or RMS, consists of two robotic arms that support operations on the outside of JEM. The Main Arm can handle up to 7 metric tons (15,000 pounds) of hardware and the Small Fine Arm (SFA), when attached to the Main Arm, handles more delicate operations. Each arm has six joints that mimic the movements of a human arm. Astronauts operate the robot arms from a remote computer console inside the Pressurized Module and watch external images from a camera attached to the Main Arm on a television monitor at the RMS console.

The arms are specifically used to exchange experiment payloads or hardware through a scientific airlock, support maintenance tasks of JEM and handle orbital replacement units. The operations of a prototype SFA were evaluated as part of the Manipulator Flight Demonstration (MFD) experiment conducted during the STS-85 Space Shuttle mission in 1997. The Main Arm measures 9.9 meters (32.5 feet) long, and the SFA measures 1.9 meters (6.2 feet). Figure 9.9 shows the SFA, which is awaiting launch.

Figure 9.3. Special-purpose dexterous effector by McDonall-Detwiler Robotics for Canadian Space Agency.

Figure 9.4. Mars Exploration Rover robot arm, end-effector, developed by developed by Alliance Spacesystems, Inc.,

Figure 9.5. AERcam-sprint

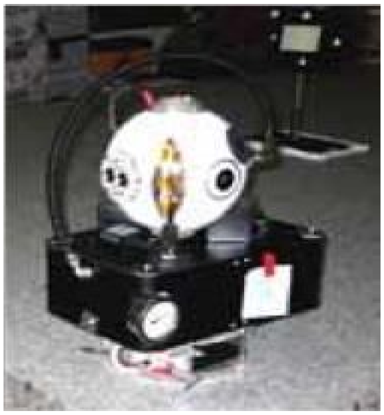


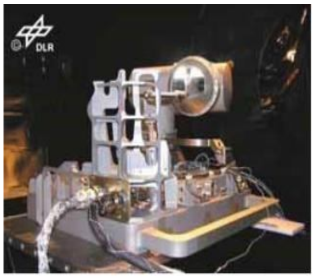
Figure 9.6. Mini-AEM CAM

The Japanese MUSES-C asteroid sample return mission has several robotic elements. This mission (renamed after launch, in the Japanese tradition, to “Hayabusa,” meaning “Falcon”) approached in late 2005 the asteroid 25143 Itokowa, named after a Japanese rocketry pioneer. Hayabusa made only momentary contact with its target. It descended to the surface of the asteroid, and immediately fired a small (5 gram) projectile into the surface at a speed of about 300 m/s, causing small fragments from the surface to be collected by a sample collection horn. This is a funnel which guides the fragments into a collection chamber. After less than a second on the surface, Hayabusa fired its rocket engines to lift off again. During the first descent to fire a pellet into the surface, a small surface hopper, called Minerva, was to be eased slowly onto the asteroid's surface, but the timing was not right and the Minerva was lost. For one to two days it was supposed to slowly leap about the asteroid taking surface temperature measurements and high-resolution images with each of its three miniature cameras. Minerva is shown in Figure 9.10

Figure 9.7 ETS-VII RENDEZVOUS

Figure 9.8. Docking adapter test
Figure 9.10 Japanese FINE arm

European researchers have also been active in space robotics. ROTEX is an experiment developed by the German Aerospace Center (DLR) near Munich that was flown in a cabinet on the SPACELAB module in the Space Shuttle in 1993 (Figure 9.9). One of the most important successful experiments was the catching of a freely floating and tumbling cube. A key element of the system was the “predictive display,” which allowed human operators on the ground to see what was projected to occur one speed-of-light-round-trip in the future based on the commands given to the manipulator and the laws of physics applied to the motion of free objects. The system included a high-precision six-axis manipulator (robot arm) with grippers, tipped with distance, force, moment, and touch sensors that could be controlled (using stereoscopic vision) either from onboard the shuttle or from ground operators at DLR. More recently, DLR has developed ROKVISS (RObot Komponent Verification on ISS). ROKVISS (Figure 9.7) is a German technology experiment for testing the operation of the highly integrated, modular robotic components in microgravity. It is mounted on the exterior of the International Space Station, with a modular arm with a single finger used for force-control experiments. Stereo cameras are used to permit remote visualization of the worksite, and a direct radio link with the command center is used when the ISS flies over Germany. The purpose of ROKVISS is to validate the space qualification of the newest lightweight robot joint technologies developed in DLR’s lab, which are to form a basis for a new generation of ultra-light, impedance controllable and soft arms (Figure 9.9), which, combined with DLR’s newest articulated four-fingered hands (Figure 9.10), are the essential components for future “robonaut” systems. The main goals of the ROKVISS experiment are the demonstration and verification of light-weight robotics components, under realistic mission conditions, as well as the verification of direct telemanipulation to show the feasibility of applying telepresence methods for further satellite servicing tasks. It became operational in January of 2005. Figure 9.8 shows the Spacecraft Life Extension System (SLES), which will use a DLR capture mechanism to grapple, stabilize, and refuel commercial communications satellites.



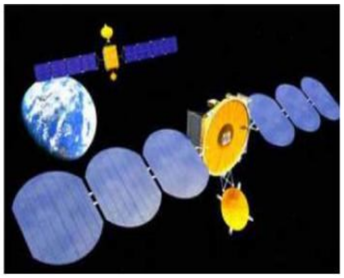


Figure 9.11. ROKVISS experiment
Figure 9.12 Spacecraft Life extension

Figure 9.13 Dexterous Multiplier

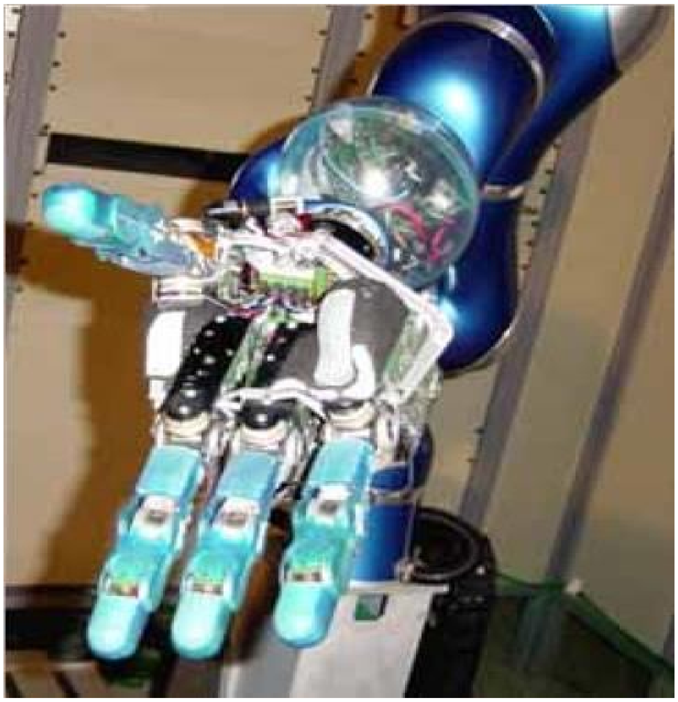


Figure 9.14 Four Fingered Dexterous Multiplier

Figure 9.15 Beagle 2 Mars Lander
Figure 9.16 ExoMars Rover

Figure 9.15 shows the Beagle 2 Mars lander, which had a robot arm built by a collaboration of British industry and academia for use in sampling soil and rocks. Figure 9.16 shows a proposed Mars Rover that is conceived for the ExoMars mission that the European Space Agency is considering for launch at about the end of this decade. French research centers at Toulouse (Centre National d'Etudes Spatiales (CNES) and Laboratoire d’Analyse et d’Architecture des Systèmes/Centre National de la Recherche Scientifique (LAAS/CNRS)) have developed substantial expertise in rover autonomy in a series of research projects over the past 15 years. They have proposed a major role in developing the control algorithms for the ExoMars rover.

Figure 9.17 Special Purpose Dexterous Multiplier

X. CONCLUSION AND RESULT

Some of the selected topics of planetary robotics that are motivated by the field robotics research point of view were described. Recent achievements in the author’s laboratory were presented as illustrative examples. Finally, technological challenges to asteroid robotics were discussed. When designing a robot to explore the surface of an asteroid, microgravity raises an interesting problem of how to stick and how to move on the surface. Some ideas to this question were introduced.Thus the above mentioned concept can be brought into real world application. As robonauts are in its final stages of R&D, we add on a feature to its armoury via artificial intelligence. We can feed certain set of instruction into a chip and that can be placed inside a robonaut so that the user from earth or from far distance can operate the robonaut. Also the user can operate by means of cloud were it will act as an interface between the robonaut and the user. Thus the predefined instructions stored in cloud on the command of the user will facilitate the robonaut to do actions on its own. Also by this technique malfunctioning of a robonaut can be solved by itself based on the commands of user by the platform called cloud. Thus the efficiency of robonaut can be increased by using these techniques which reduces the cost of the project which is the primary aspect.For further reading, the following text books would provide basic theories for modeling and control of space robots and their application examples: Space Robotics:Dynamics and Control (1992) [52], An Introduction to Space Robotics (2000) [23], Intelligence for Space Robotics (2006) [54], and Handbook of Robotics (2008) [25].

XI. FUTURE ENHANCEMENTS

Robonauts can be updated in mere future in such a way that they are capable of constructing satellites and space stations in the space and can operate by themselves such that there is no human intervention inorder to launch the satellites from the earth. This will be a great advancement in the field of space science. But this feature faces a hinderance in the domain of deep space wireless communication.

ACKNOWLEGEMENTS

The author thanks Dr. Rick Wagner at Northrop Grumman Space Technology and Dr. Richard Volpe at JPL for their editorial assistance, and Dr. Kaiji Nagatani and Mr. Keisuke Sato for providing the navigation data of El Dorado-II rover in ICRA 2009 Planetary Exploration Challenge.

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