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SPACE ROBOTICS

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Abstract

Space robotics represents key enablers to a wide range of future robotic and crewed space missions. They enable missions to be less expensive and more accessible, allowing for more complex missions farther from Earth. They have been used in exploring every planet in our solar system. They are used to aid, augment, and substitute for the astronauts to do difficult tasks in dangerous environments. Sending robots to space is cheaper than sending a human or an astronaut. This paper reviews space robotics and their applications.

Keywords: robots, robotics, space robotics.

INTRODUCTION

We live in the world of robots that have positively impacted our lives. Robotics is a branch of engineering that involves the conception, design, manufacture, and operation of robots. It involves other disciplines such as electronics, computer science, artificial intelligence, mechatronics, and bioengineering. A while ago, space robots were science fiction, appearing in comic books and Hollywood movies. Today, space robots are a reality. Space robots are used in exploring other planets like the moon or Mars. They have enabled humans to extend their reach in space. They cover all types of robotics for the exploration of a planet as well as those used in orbits. They have been instrumental to space exploration by enabling scientific breakthroughs and by fulfilling human ambition to conquer new worlds.

The universe has been a mystery to mankind from the beginning of time. The exploration of space by mankind is an expression of one of our finest aspects - curiosity. The exploration of space is deemed necessary to figure out some of the most fundamental questions of science related to the origin of the universe. The desire to widen the horizons of our knowledge of space is more than ever [1]. To meet the long-term need for exploration and science, a variety of robotic missions concepts, involving efforts from both academia and industry, have been proposed and studied by the international space community. The new generation of space exploration has traveled further into the solar system to tackle more ambitious scientific and exploration goals. Space agencies around the world have been using robotic probes and explorers to visit other planets and celestial bodies and learn more about our universe.

North America is a leading participant in the space robot market due to the presence of national organizations, including NASA and CSA, that are actively working toward the development of space robots. In the US, National Aeronautics and Space Administration (NASA) has been at the frontier of

Mars science through a series of successful planetary missions. NASA is an exploration agency, and there are currently several competing ideas as to what their destination should be. In spite of successful missions performed to date, space robotic systems have only scratched the surface [2].

WHAT ARE ROBOTS?

The word "robot" was coined by Czechriter Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots [3]:

(1) Robots must never harm human beings,

(2) Robots must follow instructions from humans without violating rule 1,

(3) Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [4,5]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing. Figure 1 indicates that robotics is one of the branches of artificial intelligence.

Special forms of robots in common use include drones and chatbots. Drones are flying robots, a type of robots, that are poised to proliferate in certain commercial sectors. Drones can help utility crews after a storm by quickly and safely identifying areas in need of repair. Drones can also help with maintenance tasks, such as surveying solar panels for damage.

Chatbots have empowered the banks and other financial institutions by simplifying the complex processes. We interact with Facebook Messenger bots all the time. Messenger bots are revolutionizing the small business world. Messenger bots can answer customers' questions, collect user's info, organize meetings, reduce overhead costs, and engage in other business tasks. Big companies like Walmart, Alibaba, and Amazon have been benefitting the help of bots.

SPACE ROBOTICS

A space robot essentially consists of a controller, actuators, sensors, the power supply, and the radio communications. The sensors provide information about the robot and its environment, and the controller processes the information from the sensors, the ground control provides instructions, and it sends appropriate command signals to the actuators which convert the command into actions [6]. Although space are expensive to make, it is cheaper to send a robot to space than a human. Robots do not need to eat or rest.

They can survive in space for many years and endure harsh atmospheric conditions. They robots do not require need food to survive like humans. Without robots, scientists and astronauts cannot complete their daily tasks [7]. With planned missions to a number of planets in the coming decades, space robot designs need to account for extreme differences in temperature, pressure, chemical environments, gravity, and radiation.

Space mechanisms are frequently designed and debugged in ground environments and operated in space microgravity environments.

Soft robots have great potential for space applications. They are typically composed of soft materials. Compared with traditional space (rigid) robots, soft robots have apparent advantages of flexibility, dexterity, robustness, and safety, and exhibit better adaptability to space environments. They are lightweight, multiflexible, and robust, resulting in excellent potential for space missions. Common technologies for fabricating soft robots include 3D printing, injection molding, transfer printing, lamination manufacturing, and soft lithography. Sensing and control are the key interactions between soft robots and their environment. Soft robots must adapt to changes in space exploration and environment. In some space missions, soft robots have exhibited potential applications with high adaptability. Soft robots used in space should satisfy the special requirements of space environments. A harsh space environment dictates stricter requirements for the design, fabrication, actuation, sensing, and

control of soft space robots. Soft space robots must adapt to the space environment to ensure normal operation. Soft robots in Earth's orbit float freely in space. Based on the gravity of the Earth, atmospheric pressure gradually decreases with an increase in altitude [8].

The following list of historical missions defines the state of the practice in orbital robotics [9]:

- ✓ DLR ROTEX (1993) – 6 DOF autonomous manipulation experiment on ISS
- ✓ JAXA ETS-VII (1997-1999) – first satellite to be equipped with a robotic arm.
- ✓ CSA Canadarm 2 (2001) – service crane for the ISS assembly and maintenance.
- ✓ DLR ROKVISS (2005-2010) – a 2 DOF manipulation hardware test bed outside ISS
- ✓ MIT SPHERES (2006-present) – internal microsatellite testbeds aboard ISS.
- ✓ JAXA JEM-RMS (2009) – service arm on ISS.
- ✓ DARPA Orbital Express (2007) – autonomous satellite grappling.
- ✓ CSA Dextre (2008-present) – dual-armed external support system on ISS
- ✓ NASA JSC Robonaut 2 (2010-present) – dual-armed experimental system internal to ISS
- ✓ NASA GSFC Robotic Refueling Mission (2013) – ISS manipulation experiments.
- ✓ NASA Raven (2016) – ISS autonomous navigation and guidance system technology demonstrator.
- ✓ NASA Restore-L (2020) –satellite refueling mission.
- ✓ DARPA Phoenix Mission (2020) – multiple satellite repairs.

EXAMPLES OF ROBOTS IN SPACE

Space robotics refers to the development of general purpose machines that are capable of surviving the rigors of the space environment, and performing exploration, assembly, construction, maintenance, servicing or other tasks. 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 [10]. Space robots come in different shapes and sizes. They perform different functions and work automatically or by remote control.

Humans have developed various space robots for scientific experiments, extravehicular operations, space exploration, and other activities. Humans have launched several robots in space. We will consider four examples here.

1. *Robonaut 2:* This is a legless robot that lives on the International Space Station. It has a camera on its head, and doesn't need constant supervision. Robonaut 2 follows in the steps of Robonaut 1, a ground-based prototype intended to help astronauts on spacewalks. Shown in Figure 2, Robonaut 2 was launched in 2011 and performed experiments in a stationary position [11].
2. *Dextre:* This is a Canadian-built space robot. Canadian Space Association launched Dextre, a robotic arm designed to install and replace small equipment such as exterior cameras or the 100-kg batteries used on the Space Station, and to test new tools and robotics techniques. It is shown in Figure 3 [12].
3. *Spirit:* Spirit and its sister, Opportunity are equipped robot geologists, designed by NASA. Both rovers are packed with sensors and cameras. They have been revealing Mars in unprecedented detail. The robots have been exploring Mars since January 2004. They studied the history of climate and water at sites on Mars where conditions may once have been favorable to life. Spirit is shown in Figure 4 [13].
4. *Sojourner:* This is the name given to the first robotic roving vehicle to be sent to the planet Mars. Sojourner was built by NASA. It was an experimental vehicle whose main mission was to test in the Martian environment technical solutions that were developed by NASA engineers. It is a

robotic Mars rover that landed in the Ares Vallis channel. It is shown in Figure 5 [14].

APPLICATIONS

Robots do significant work on the International Space Station. Space agencies around the world have been using robotic probes and explorers to visit other planets and celestial bodies to learn more about our universe. The application of space robots undoubtedly reduces the risk and cost of space activities. Common areas of applications of space robots include the following [7,15]:

- *Telerobotics:* Astronauts remotely operate space robots on a planet's surface while floating in orbit. This is both cheaper and substantially better than plans to put people on the ground. A telerobotic mission would only require one vehicle -- the same spacecraft takes people to another planet, keeps them in orbit, and then returns them to Earth.
- *Aircraft Robotics:* Many businesses are investing significantly in creating cutting-edge technologies for the aircraft robotics sector. Airbus is one such business that has been working on many autonomous technology for its airplanes. It integrates several aircraft technologies to increase passenger enjoyment and safety.
- *Aerospace:* Robotics plays a crucial role in the aerospace sector. Using collaborative robots (cobot) is one of the most important trends in the aerospace robotics sector. Since cobots are designed to operate alongside humans, production processes for aerospace benefit from their affordability, flexibility, and efficiency. The usage of drones in the aerospace industry has grown substantially. They complete difficult jobs more effectively as consumer demand for drone technology grows.
- *Space Exploration:* Space exploration of our solar system is important to top-level science and to answer many fundamental scientific questions, including the formation of the universe, the origin of Earth, the evolution of life, and the existence of life beyond Earth. Space robots find applications in exploration missions to the Moon, Mars, Mercury, comets, asteroids, and other celestial bodies. Space exploration relies on the development of on-orbit robotic capabilities for tasks such as servicing of satellites, removing of orbital debris, or construction and maintenance of orbital assets. Space robots are perfect for exploring other planets. They basically assist humans. They complete manual tasks and provide astronauts with assistance in many ways. Some carry astronauts and provide them with life support systems. They take care of things that are too dangerous for astronauts. NASA is investing in space robots that could provide engineers and scientists with new insights into the Solar System and beyond. Lockheed Martin is the only company that has built a spacecraft that has successfully landed on Mars and they have done it four times. Their probes provide the data that impact our understanding of planets and other celestial bodies as well as measure the properties of space.

BENEFTIS

Space robotics is regarded as one of the most promising approaches for on-orbit servicing missions such as refueling, repairing, upgrading, transporting, rescuing, and orbital debris removal. The primary benefit of space robot and space exploration is the ability of the robots to gather data without the need for human astronauts. We can send robots to explore space without worrying much about their safety.

Space robot are devices used to aid, augment, and substitute for the astronauts to do difficult tasks. They can operate autonomously, meaning they can be programmed to carry out tasks without human intervention. They can collect data and samples from other planets. The use of robotics in space exploration missions has been a game-changer for the space industry [16].

Although space robots are expensive to design and produce, their loss in space is always better than the loss of astronauts. Space robots have been deployed in space science experiments, extravehicular operations, and deep space exploration. Robotic space exploration has the potential to revolutionize the way we explore the universe. The involvement of government space organizations have increased competition in the market for space robotics.

CHALLENGES

As with any new technology, there are both benefits and challenges associated with space robots and space exploration. A major challenge is the cost. Robotic probes are much more expensive than human missions, and the cost of building and launching them can be prohibitive. They are not capable of making decisions or taking action in the event of an emergency, and they cannot repair themselves if something goes wrong. The space environment (radiation, contamination sensitivity, thermal extremes, etc.) poses unique challenges to space robot and robot algorithms. A major challenging requirement to the robotics for surface exploration relates to energy availability, both in terms of amount and duration. Soft robots are typically unsuitable for sustaining strong loads, which may limit their space application. Controlling soft space robots with precision is a major challenge based on the complexity of the space environment and high dimensionality of soft robots. For the same reason, it is difficult to establish an accurate mathematical model of a system. Robotic servicing of a non-cooperative satellite is still an open research area facing many technical challenges. One of the greatest challenges is to ensure the servicing spacecraft safely and reliably docks with the target spacecraft [17]. Time delay is another challenge for manipulation in space robotics.

CONCLUSION

Robots are an important part of humanity's future. As robots continue to evolve, they are at the forefront of space exploration. Space robotics is a relatively new field of engineering that was developed as an answer to growing needs of space exploration and space missions. Space robots are capable of performing complex tasks in extreme environments, making them ideal for space exploration. Robotic space exploration has the potential to revolutionize the way we explore the universe, enabling us to go farther and explore more than ever before.

Space robots will continue to help scientists and astronauts with their space missions. Future space applications can be classified as exploration, global information services, or utilization of space. They all require intelligent action and manipulation in space. Space robotics provides the infrastructure for a new space economy. As technology develops, there will be an endless possibilities for space robots in the future. For more information about space robotics, one should consult the books in [18-28] and the following related journals devoted to robotics:

- ✓ *Robotica*
- ✓ *Robitics and Autonomous*
- ✓ *Robotics and Computer-Integrated Manufacturing,*
- ✓ *Advanced Robotics*
- ✓ *Autonomous Robots*
- ✓ *Journal of Robotics*
- ✓ *Journal of Robotic Systems*
- ✓ *Journal of Robotic Surgery*
- ✓ *Journal of Robotics and Mechatronics*
- ✓ *Journal of Intelligent & Robotic Systems*
- ✓ *Journal of Mechanisms and Robotics-Transactions of the ASME*
- ✓ *Journal of Automation, Mobile Robotics and Intelligent Systems*
- ✓ *Journal of Future Robot Life*
- ✓ *IEEE Robotics and Automation Letters*
- ✓ *IEEE Transactions on Robotics and Automation*
- ✓ *International Journal of Medical Robotics and Computer Assisted Surgery*

- ✓ *International Journal of Robotics Research*
- ✓ *International Journal of Social Robotics*
- ✓ *International Journal of Humanoid Robotics*
- ✓ *International Journal of Advanced Robotic Systems*

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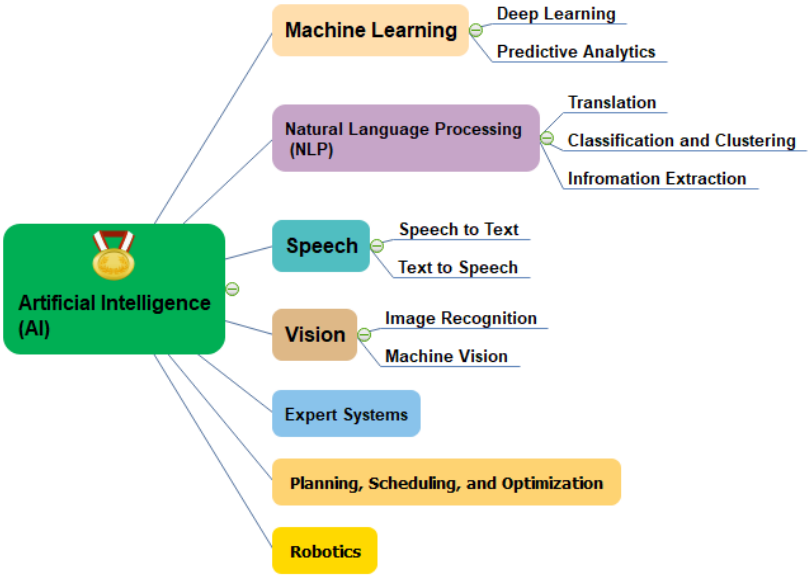

Figure 1. Robotics is one of the branches of artificial intelligence.

Figure 2. Robonaut 2 [11].

Figure 3. A Canadian-built space robot, Dextre [12].

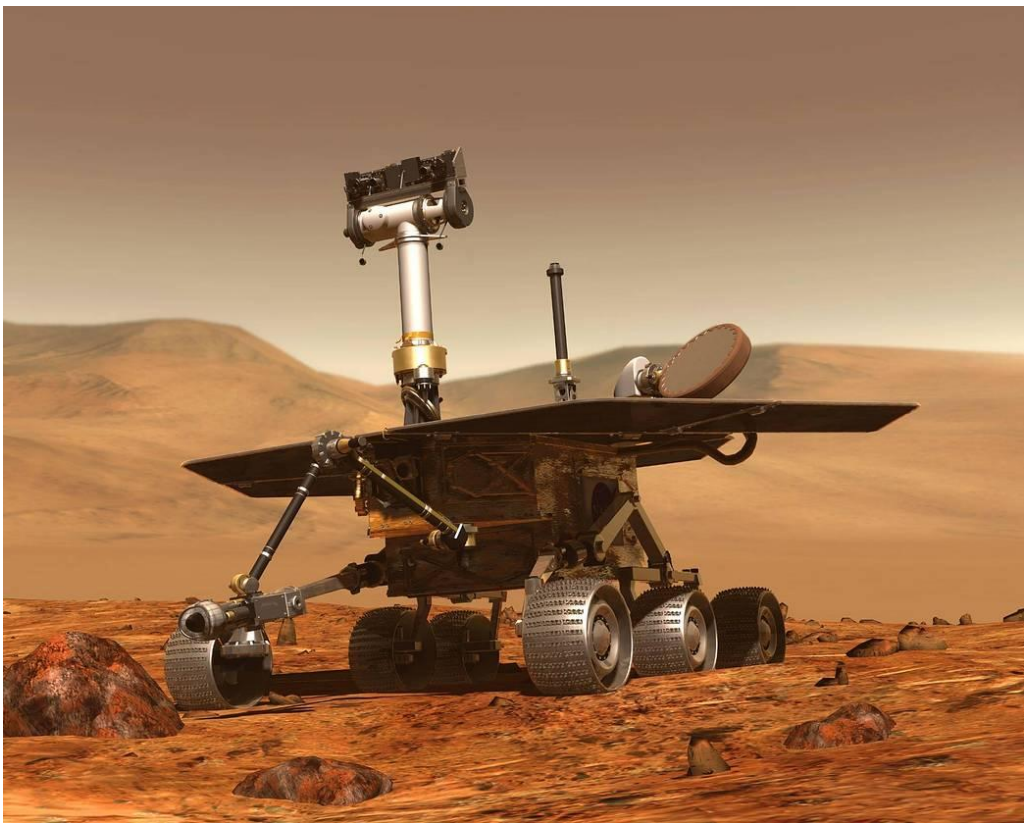

Figure 4. NASA space robot Spirit [13].

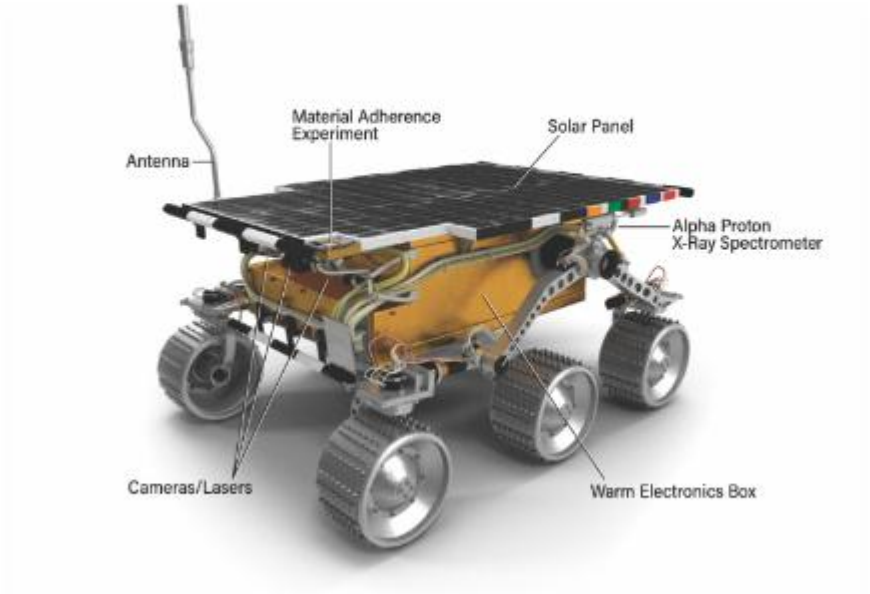

Figure 5. Sojourner built by NASA [14].