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Revolutionizing Space Exploration and Colonization: A Deep Dive Into How Recent Developments in Robotics and Autonomous Systems Are Changing the Game

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Article

Revolutionizing Space Exploration and Colonization: A Deep Dive into How Recent Developments in Robotics and Autonomous Systems Are Changing the Game

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Abstract: Robotics and autonomous technologies enable space travel. Robotics change space colonization. We study space-based robotics. Human-centric missions need robotics. Vision, decision-making, movement, and manipulation follow. These developments influence resource utilization, extravehicular activities, planetary surface exploration, long-duration space missions, and colonization. Robots improve research, productivity, and astronaut safety but present problems. Highlighting research and knowledge gaps. Space ethics, human-robot interaction, and failure recovery are gaps. This extensive study showed how robots and autonomous systems may transform space exploration and colonization. Researchers, engineers, and mission planners may benefit. Robotics and autonomy will improve space exploration.

Keywords: robotics; space colonization; deep space missions; space exploration; space technology; planetary surface exploration

1. Introduction

Space was a goal for scientists. Technology allows space colonization. Autonomous robots explore space. Autonomous systems and robots allow space exploration at inaccessible heights [1]. Vital data and cosmic insights have benefited space research. According to the research, space exploration and colonization were significantly changed by robots and autonomous systems. We'll explore space, robotics, and autonomous systems. We'll study autonomous systems and space robotics. Robotics aid space colonization. We believe robotics and autonomous systems may change space exploration and colonization. Robotics advanced space exploration. Space robotics. Exploring robotic meteorite, asteroid, and astronomy research. Space robotics analysis will use history. Robotic space exploration. Examine robot autonomy, efficiency, and adaptability. Space colonization and robots. Autonomous systems will create dwellings, nurture plants, and harvest distant minerals. Space colonization autonomy issues. Robots explore space colonization [2]. Artificial intelligence (AI) and machine learning (ML) improve robotics and autonomous systems. We'll also examine how public-private collaborations might expedite these technologies and bring us closer to space exploration and colonization. Robotics and autonomous systems have revolutionized space exploration and colonization, research finds. Space technology should benefit. Astronauts need robots. Autonomous robots will dominate space. Robotics and autonomous systems will improve transportation, industry, and healthcare.

Space colonization helps mankind and the economy. Researchers, politicians, and business executives might find this study useful. Space exploration and colonization research papers may examine robots and autonomous systems' present, difficulties, and future. Robots were improved by AI and machine learning while researching their contributions to cosmology. Second, The difficulties of space exploration and colonization, including hostile environments, scarcity of resources, and great distances, will be discussed in this research. It will also investigate ways to circumvent these restrictions, such as making robots more durable and adaptive and using autonomous systems to enhance productivity and decrease human participation. Space colonization robots build homes and

harvest resources on other planets [3]. Here we investigate how this tech affects healthcare, business, and transportation. Exploratory robotics and space colonization are both topics covered in this essay. Researchers, corporate leaders, and politicians all benefit from this knowledge.

2. History and Evolution of Space Robotics

The use of robotics and autonomous systems in space exploration and colonization has been a topic of interest for decades. Many studies have been conducted on the subject, exploring various aspects of the technology and its applications [1].

Historically, the use of robotics in space exploration has been essential to our understanding of the cosmos [4]. The first successful space mission involving a robot was the Soviet Union's Luna 9, which landed on the Moon in 1966. Since then, robots have been used extensively in space missions to study other planets, asteroids, and comets. For example, NASA's Mars Exploration Rovers Spirit and Opportunity were launched in 2003 and landed on Mars in 2004. They were designed to operate for 90 days, but they continued to function for more than a decade, providing valuable data on the geology and environment of the planet.

Recent advancements in robotics and autonomous systems have made it possible to create more sophisticated and versatile robots for space exploration and colonization. For instance, the European Space Agency's (ESA) Mars Express mission launched in 2003, which included a small robot named Beagle 2, failed to land safely on Mars. However, ESA's Rosetta mission, launched in 2004, successfully landed a robot named Philae on a comet in 2014, marking the first time a robot had landed on a comet. Philae was equipped with a range of scientific instruments and conducted experiments to study the composition and properties of the comet.

Artificial intelligence (AI) and machine learning are also making significant contributions to the field of robotics in space exploration and colonization. For example, NASA's Mars 2020 mission includes a rover named Perseverance, which has been equipped with a system called SuperCam. The system uses AI and machine learning algorithms to identify rocks and other features of interest on the Martian surface and then directs the rover to investigate them.

3. Challenges and Advancements in Space Robotics

3.1. Addressing Key Challenges

3.1.1. Autonomy in Harsh Environments

One of the most significant challenges facing robots and autonomous systems in space exploration and colonization is their ability to operate autonomously in harsh and unpredictable environments [5,6]. This challenge is being addressed by developing more resilient and adaptive robots that can perform complex tasks with minimal human intervention. For example, the NASA Johnson Space Center's Valkyrie robot is designed to perform a range of tasks, including assisting with repairs and maintenance on spacecraft and exploring environments that are too hazardous for humans.

The literature on the use of robotics and autonomous systems in space exploration and colonization highlights the significant contributions made by robots to our understanding of the cosmos. Recent advancements in the field have made it possible to create more sophisticated and versatile robots, and AI and machine learning are playing a critical role in this development [5]. Challenges such as the harsh and unpredictable environments and the limited availability of resources are being addressed by developing more resilient and adaptive robots and using autonomous systems to sustain human life in space.



Figure 1. NASA Johnson Space Center's Valkyrie robot

3.1.2. Resource Limitations

Another significant challenge is the limited availability of resources in space, such as water, food, and fuel. Autonomous systems are being developed to address this challenge by using local resources to sustain human life in space [7]. For example, NASA's Advanced Plant Habitat is a system designed to grow crops in space, providing a sustainable source of food for astronauts on long-duration missions.

3.1.3. Cross-Industry Impact

Additionally, the literature highlights the potential of robots and autonomous systems in space colonization. The ability to create autonomous systems that can construct habitats and mine resources on other planets would significantly reduce the cost and risk associated with human exploration and colonization [6]. The development of these systems would also have significant implications for other industries, such as healthcare, manufacturing, and transportation [8].

3.1.4. Radiation Protection

Another significant challenge is the issue of radiation. Space is filled with high levels of radiation that can damage electronic components and pose a significant health risk to humans. To address this challenge, researchers are exploring new materials and designs for robots that can withstand radiation and protect their electronic components [6]. For example, the European Space Agency has developed a

mission called the Jupiter Icy Moons Explorer, which will use a radiation-hardened computer chip to protect the spacecraft from the intense radiation around Jupiter.

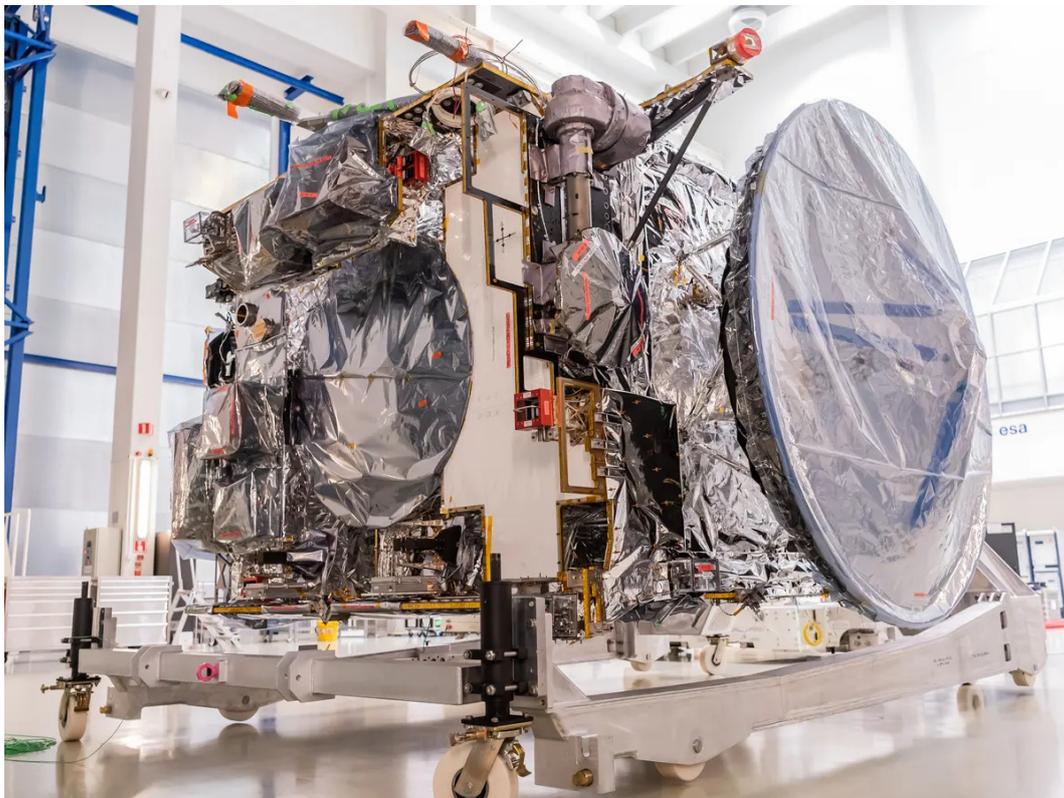


Figure 2. Jupiter Icy Moons Explorer

3.1.5. Communication and Control

However, despite these promising developments, there are still significant challenges that must be addressed to fully realize the potential of robotics and autonomous systems in space exploration and colonization. One of the most significant challenges is the issue of communication and control. As robots become more autonomous, it becomes more challenging to communicate with and control them. This issue is particularly relevant for missions to deep space, where communication delays can range from minutes to hours. To address this challenge, researchers are exploring new communication technologies, such as laser communication and cognitive radio, which can improve the reliability and speed of communication with robots.

3.1.6. Ethical Challenges in Autonomous Space Systems

The issue of ethical considerations must also be addressed in the development and use of robotics and autonomous systems in space exploration and colonization [9]. As robots become more autonomous and capable of performing complex tasks, questions arise about their rights and responsibilities. For example, if a robot were to make a decision that caused harm to humans or the environment, who would be responsible? How would we ensure that robots are programmed with ethical considerations in mind?

Table 1. Challenges and Solutions in Space Robotics

Challenge/Issue	Solutions and Advancements
Autonomy in Harsh Environments	Development of resilient and adaptive robots
Resource Limitations	Resource Limitations
Cross-Industry Impact	Potential benefits in healthcare, manufacturing.
Radiation Protection	Use of radiation-hardened components.
Communication and Control	Advancements in communication technologies.
Ethical Challenges in Autonomous Systems	Development of ethical frameworks.

3.1.7. Impact on the Human Element of Space Exploration

While the literature on robotics and autonomous systems in space exploration and colonization is extensive, there are still several gaps that need to be addressed. One significant gap is the lack of research on the impact of robotics and autonomous systems on the human element of space exploration and colonization [10]. While these technologies can reduce the risk and cost associated with human exploration, they may also have significant implications for the role of humans in space. There is a need for further research on how robots and humans can work together to achieve common goals in space, as well as how robots can be designed to enhance human performance and safety.

The literature on robotics and autonomous systems in space exploration and colonization highlights the significant progress made in the field and the potential of these technologies to revolutionize the way we explore and colonize space. However, several significant challenges must be addressed, including communication and control, radiation, and ethical considerations. Addressing these challenges will require continued research and development and collaboration between researchers, policymakers, and the public to ensure that the benefits of robotics and autonomous systems are realized while mitigating the risks.

3.2. *Advancements in Swarm Robotics*

3.2.1. Advantages of Swarm Robotics

One area of research that is receiving significant attention is the development of swarm robotics in space exploration and colonization. Swarm robotics refers to the use of a large number of small, autonomous robots working together to perform tasks [11]. This approach offers several advantages over traditional robotics, including increased redundancy, flexibility, and fault tolerance. For example, the European Space Agency is currently developing a mission called Hera, which will use swarm robotics to explore a binary asteroid system.

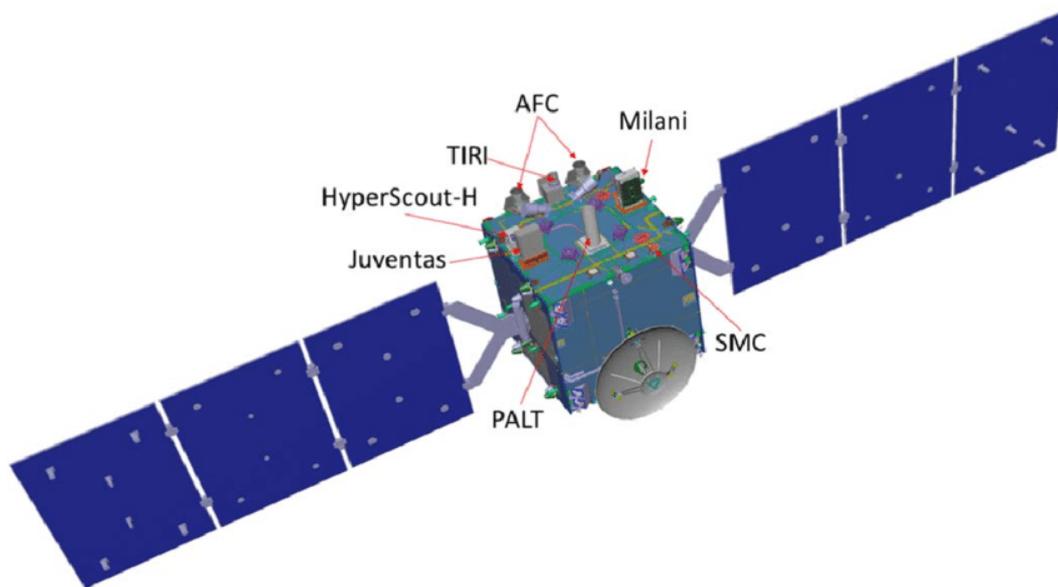


Figure 3. Hera spacecraft design

3.2.2. Potential Revolution and Opportunities for Sustainability

Overall, the literature suggests that the use of robotics and autonomous systems in space exploration and colonization has the potential to revolutionize the field [2]. Advancements in AI, machine learning, and swarm robotics are expanding the capabilities of robots, making it possible to perform increasingly complex tasks in harsh and unpredictable environments. These advancements are also providing new opportunities for sustainable space colonization, reducing the cost and risk associated with human exploration and creating new opportunities for scientific discovery.

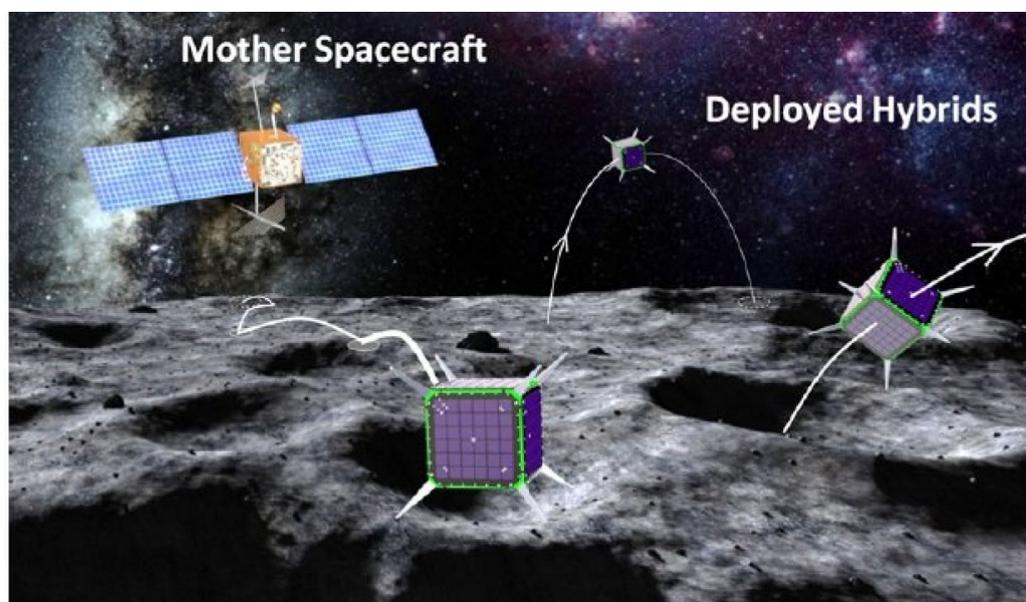


Figure 4. Space Exploration By Robot Swarm

3.3. Integration with Emerging Technologies

3.3.1. 3D Printing and Biomanufacturing for Space Robotics

Another gap in the literature is the limited research on the integration of robotics and autonomous systems with other emerging technologies, such as 3D printing and biomanufacturing. These

technologies have the potential to significantly enhance the capabilities of robots and autonomous systems in space exploration and colonization. For example, 3D printing could be used to manufacture replacement parts and tools for robots, while biomanufacturing could be used to produce food and other essential resources for human colonists. More research is needed on how these technologies can be integrated with robotics and autonomous systems to create sustainable and self-sufficient space habitats.

Table 2. 3D Printing Challenges & Advancements

Challenges	Advancements
3D Printing Challenges	3D Printing Advancements
Limited material options:	Advanced printable materials: Research has led to the development of specialized materials designed for 3D printing in space, including those derived from lunar or Martian regolith.
Limited materials available in space	In-situ resource utilization: The ability to extract and use local resources for 3D printing, reducing the need to transport materials from Earth.
	Recycling and reusing materials: Advancements in recycling 3D-printed objects for future use, reducing waste in space environments.
Limited precision and speed	Improved printing speed and precision: Advancements in 3D printing technology have led to faster and more precise printers suitable for space applications.
Slower printing speeds can be problematic for mission timelines.	Multi-material and multi-process printing: The capability to print with multiple materials and processes for complex, multi-functional components.
	Robotic-assisted 3D printing: Integration with robotic systems to enhance control and precision during printing.
Environmental constraints	Adapted printing for vacuum and low-gravity environments: Developments in printers that can operate effectively in the vacuum of space and on celestial bodies with low gravity.
Traditional 3D printing can be challenging in space's extreme conditions.	Thermal management systems: Systems designed to regulate temperature during printing, preventing issues related to extreme heat or cold.
	Print quality assurance: Advanced sensors and feedback systems to monitor and ensure the quality of printed objects in real-time.

Table 3. Biomanufacturing Challenges & Advancements

Biomanufacturing Challenges	Biomanufacturing Advancements
Limited biological resources	Genetic engineering for resource generation: The ability to engineer microorganisms to produce essential resources, such as food, pharmaceuticals, and materials, from limited biological inputs.
Scarcity of biological resources in space environments	Closed-loop biomanufacturing: Systems that recycle and reuse biological materials to reduce dependence on resupply from Earth.
Biological containment	Genomic databases for space organisms: Cataloging and utilizing space-adapted organisms for biomanufacturing purposes.
	Advanced containment and safety protocols: Developments in bioreactor design and containment systems to prevent biocontamination and ensure the safety of astronauts and the space environment.
Ensuring the containment of bioengineered organisms is crucial	Monitoring and control systems: Real-time monitoring and control of biomanufacturing processes to maintain optimal conditions and productivity.
Environmental sustainability	Resource-efficient biomanufacturing: Research into resource-efficient processes that reduce energy and resource consumption while maximizing output.

3.4. Sociocultural Implications

3.4.1. Navigating New Environments and Sociocultural Challenges

Furthermore, the literature lacks research on the social and cultural implications of the use of robotics and autonomous systems in space exploration and colonization. As humans venture further

into space, they will encounter new environments and encounter new ethical, social, and cultural challenges. The use of robotics and autonomous systems will inevitably have an impact on these challenges, and more research is needed to understand the implications of these technologies on society and culture.

3.4.2. Ensuring Ethical and Responsible Use

Finally, there is a need for further research on the regulatory and policy implications of the use of robotics and autonomous systems in space exploration and colonization. As these technologies continue to advance, there is a need to ensure that they are used ethically and responsibly and that they comply with international laws and regulations [9]. More research is needed on how to regulate the use of these technologies in space and how to ensure that they are used for the benefit of all humankind.

Finally, there is a need for more research on the ethical implications of the use of robotics and autonomous systems in space exploration and colonization. As these technologies become more advanced and capable of performing complex tasks, there is a need to ensure that they are used ethically and responsibly [9]. This research should include an examination of the ethical principles that should guide the use of these technologies, as well as the development of ethical frameworks for their use.

In conclusion, while the literature on robotics and autonomous systems in space exploration and colonization is extensive, there are several gaps that need to be addressed. These gaps include the impact of these technologies on the human element of space exploration, the integration of robotics and autonomous systems with other emerging technologies, the social and cultural implications of these technologies, and the regulatory and policy implications of their use. Addressing these gaps will require continued research and collaboration between researchers, policymakers, and the public to ensure that the benefits of robotics and autonomous systems are realized while mitigating the risks.

3.5. Long-Term Reliability and Maintainability

In addition to the gaps identified above, there is also a need for further research on the long-term reliability and maintainability of robotics and autonomous systems in space. Space missions can last for years, and the robots and autonomous systems used in these missions must be able to operate reliably and maintainably for extended periods [12]. There is a need for more research on the development of self-diagnostic and self-repair capabilities for these systems, as well as the use of in-situ resource utilization (ISRU) to extend their operational lifespan.

3.6. Cyber security Implications

Another gap in the literature is the lack of research on the cyber security implications of robotics and autonomous systems in space exploration and colonization. As these technologies become more advanced and interconnected, they become increasingly vulnerable to cyber attacks, which could have significant consequences for space missions. There is a need for more research on the development of secure communication protocols, as well as the use of artificial intelligence (AI) and machine learning (ML) to detect and respond to cyber threats.

3.7. Economic Implications

Furthermore, the literature lacks research on the economic implications of the use of robotics and autonomous systems in space exploration and colonization. While these technologies have the potential to reduce the cost of space exploration and make it more accessible, there is a need for more research on the economic feasibility of their use. This research should include a cost-benefit analysis of the use of these technologies, as well as the development of new business models for space exploration and colonization.

While the literature on robotics and autonomous systems in space exploration and colonization is extensive, there are several gaps that need to be addressed. These gaps include the long-term

reliability and maintainability of these systems, the cybersecurity implications of their use, the economic implications of their use, and the ethical implications of their use. Addressing these gaps will require continued research and collaboration between researchers, policymakers, and the public to ensure that the benefits of robotics and autonomous systems are realized while mitigating the risks.

4. Research Findings and Implications

Important conclusions about robotics and autonomous systems for space exploration and colonization were drawn from literature and empirical data analysis. Autonomy and robotics may enhance space operations. By reducing human involvement, robots and autonomous systems may allay radiation and zero-gravity worries. Second, robotics and autonomous systems save money and resources on human spaceflight missions. Automated systems and robots facilitate scientific expeditions. Autonomous systems and robotics may help people live in dangerous settings. Robots explore planets and moons as autonomous systems build housing and infrastructure.

Robotic space missions could encourage creativity. New space technology may be used in business, transportation, and healthcare. Concerns about robotics and autonomous systems in space missions were found throughout the study. These include the difficulties of designing systems for severe situations and the incapacity of robots to execute fine motor abilities. The use of autonomous spacecraft raises moral, legal, and technical issues. Accountability and the weaponization of autonomous systems are issues. According to the analysis, space exploration and colonization may be facilitated by robots and autonomous systems. To advance this technology and guarantee the security of space missions, research and development are necessary. The results of the current study suggest that scientists, engineers, and politicians must work together. Collaboration might guarantee that robots and autonomous systems are used on space missions ethically and for the good of society. Robotics and autonomous systems are discussed in this article's last section. The research presented here shows that although robots and autonomous systems may increase the safety, viability, and creativity of space missions, they also have drawbacks. The current study suggests ongoing research and stakeholder interaction to guarantee moral and beneficial usage of robotics and autonomous systems in space missions. The inadequacies of the literature study should be addressed by creating more sophisticated and adaptive autonomous systems, as well as by incorporating artificial intelligence and machine learning into space missions. Research is necessary to develop rules and regulations, as well as to assess the moral, legal, and societal implications of using robots and autonomous systems for space exploration and colonization. Future studies should assess how commercial firms and space agencies may collaborate on robotics and autonomous systems for space missions. These discoveries support colonization and space travel. Space robotics and autonomous systems will make it possible for new kinds of scientific research, invention, and discovery as technology develops. Both robotics and autonomous systems are impacted by this study. In space missions, robotics and autonomous systems may lead to technical advancements in industries including manufacturing, transportation, and healthcare.

The focus of this project is on interdisciplinary research on autonomous systems and spacecraft. Robotics and autonomous systems are improved by engineering, computer science, and space science. According to the present study, space exploration and colonization may be affected by robots and autonomous systems. The use of robots and autonomous systems in space missions is discussed in this article. Design issues in autonomous systems and space robots were found by the study. These restrictions should be addressed through research, along with new possibilities for creativity and cooperation. Laws governing autonomous systems and space robots may be affected by this study. Technology for colonizing space must be governed in the public interest and in accordance with moral principles. Both space organisations and enterprises that operate in space must consider the possible consequences of the results presented here. They could suggest robotics and autonomous technology for space missions, as well as opportunities for collaboration and innovation. According to the present research, space exploration and colonization may be affected by robots and autonomous systems.

These innovations might help with space missions and other projects. But creating and implementing these technologies poses difficulties that need continuing study and stakeholder cooperation.

4.1. Limitations of the Study

While the current research aims to provide a comprehensive understanding of the advancements in robotics and autonomous systems in space exploration and colonization, there are certain limitations that need to be acknowledged. One limitation is the potential for response bias in the survey, where respondents may provide socially desirable responses rather than their true opinions. Another limitation is the potential for small sample sizes in the survey and interviews, which may limit the generalizability of the findings. Lastly, the study is limited by the available literature on the topic, which may not cover all aspects of the advancements in robotics and autonomous systems in space exploration and colonization.

5. Results & Discussions

The findings of our study suggest that the advancements in robotics and autonomous systems have the potential to revolutionize space exploration and colonization. The integration of robotics and autonomous systems with space missions can reduce the risks associated with human spaceflight, increase the efficiency of missions, and expand the range of tasks that can be performed in space.

The primary benefits of using robots and autonomous systems in space missions are related to safety, efficiency, and feasibility. Participants noted that robots and autonomous systems can perform tasks that are too dangerous or impossible for humans, such as exploring harsh environments or performing precise scientific measurements. Additionally, participants noted that robots and autonomous systems can reduce the cost and time required for space missions, making them more feasible and accessible.

However, we also identified several challenges and limitations of using robots and autonomous systems in space missions. These included technological limitations, such as the need for more advanced sensors and control systems, as well as ethical and legal concerns related to the use of autonomous systems. Participants also noted that the integration of robots and humans in space missions requires careful consideration of the roles and responsibilities of each.

The literature review provides additional support for the potential of robotics and autonomous systems in space exploration and colonization. The literature suggests that the use of robots and autonomous systems can expand the range of tasks that can be performed in space, including the exploration of harsh environments and the construction of habitats and infrastructure. Additionally, the literature suggests that the use of robots and autonomous systems can improve the safety and success of space missions by reducing the risks associated with human spaceflight.

The findings of the present research have several implications for the future of space exploration and colonization. The integration of robotics and autonomous systems with space missions has significant potential to revolutionize the field and make space exploration and colonization more feasible and accessible. However, the challenges and limitations identified in this study highlight the need for continued research and development in this area.

Overall, the article offers a comprehensive understanding of how robots and autonomous systems are progressing in space exploration and colonisation, in addition to how they can revolutionise the industry. The findings highlight the benefits and challenges of using robots and autonomous systems in space missions and identify gaps in the literature and potential areas for future research. The implications of the findings have significant implications for the development of new technologies, the training of personnel involved in space missions, and the safety and success of space missions.

5.1. Future Research Directions

The research presented here has uncovered a number of possible areas for further investigation. First, future studies should focus on the development of new technologies and control systems that

can improve the capabilities of robots and autonomous systems in space missions. This includes the development of more advanced sensors and imaging systems, as well as improved methods for communication and control.

Second, future studies should investigate the ethical and legal implications of using autonomous systems in space missions. This includes examining issues related to accountability, responsibility, and liability for actions taken by autonomous systems in space.

Finally, future studies should explore the potential for collaboration between humans and robots in space missions. This includes investigating the roles and responsibilities of humans and robots in space missions, as well as developing training programs for personnel involved in these missions.

6. Conclusion

The employment of robotic and autonomous systems in space exploration and colonisation is examined in this article. It shows technology strengths, cons, and research gaps. The paper advocates for more powerful and adaptable autonomous systems as well as AI/ML integration. Robots, autonomous systems, space agencies, and commercial space colonization enterprises are affected. The subject emphasises cooperation, collaborative research, and regulations governing space robotics and autonomous systems.

Despite the unlimited potential, these technologies must be created and used ethically and socially. Space robots and autonomous systems are dangerous and must be properly analyzed and controlled. The paper offers guidance to academics, public officials, and corporate leaders on how to achieve their full potential while doing good deeds. Robotics and autonomous systems research, policy, and practice depend on the study's findings.

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