International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 6, Nov-Dec 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Artificial Intelligence in Space Exploration

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ABSTRACT

Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. It has been making waves in recent years, enabling us to solve problems faster than traditional computing could ever allow. AI is transforming numerous industries, and space exploration is no exception. In space exploration, AI becomes critical in overcoming the challenges of long communication lags, handling massive datasets, and enabling autonomous robotic planetary exploration systems. AI has revolutionized space exploration, transforming the way we navigate and understand the cosmos. AI silently pioneers uncharted territories in space exploration. This paper examines the use of artificial intelligence in space exploration and research.

KEYWORDS: *space industry, exploration, artificial intelligence, robotics, machine learning*

How to cite this paper: Matthew N. O. Sadiku | Paul A. Adekunte | Janet O. Sadiku "Artificial Intelligence in Space Exploration" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-6, December 2024, pp.464-473, URL: www.ijtsrd.com/papers/ijtsrd71619.pdf

IJTSRD71619

INTRODUCTION

Space exploration, a realm of boundless potential, has captured human imagination for generations. Space exploration has always been a primary goal for humanity, pushing the boundaries of our understanding and opening up new frontiers. In recent years, data science has emerged as a pivotal tool, transforming the way we approach space technology. Data analytics is important in contemporary space missions, encompassing data collection, processing, analysis, and interpretation.

Space exploration generates vast amounts of data — astronomy, earth science, space weather — spacecraft now generate terabytes of information weekly. The large datasets from satellites and space vehicles are often too massive to be processed manually by humans. This is where artificial intelligence comes in; deep learning algorithms, data analytics, and image processing techniques can quickly analyze this data. The importance of artificial intelligence in space exploration is significant, just like in other aspects of life. Artificial intelligence, which makes our lives easier in every field, also provides great support while exploring space. It has emerged as a critical feature in allowing humans to better understand what we have found out in the cosmos. With the beginning of the 21st century, AI has made a steady progress in Mars exploration. The ambitions for humans to reach Mars and travel beyond into our Solar System will only be made possible with the development and use of AI for Space Exploration. AI empowers our spacecraft, telescopes, and instruments to unveil cosmic secrets. As AI advances, it expands our cosmic understanding and inspires innovation on earth.

WHAT IS ARTIFICIAL INTELLENCE?

The term "artificial intelligence" (AI) is an umbrella term John McCarthy, a computer scientist, coined in 1955 and defined as "the science and engineering of intelligent machines." It refers to the ability of a computer system to perform human tasks (such as thinking and learning) that usually can only be accomplished using human intelligence [1]. Typically, AI systems demonstrate at least some of the following human behaviors: planning, learning, reasoning, problem solving, knowledge representation, perception, speech recognition,

decision-making, language translation, motion, manipulation, intelligence, and creativity.

The 10 U.S. Code § 2358 define artificial intelligence as [2]:

1. "Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight, or that can learn from experience and improve performance when exposed to data sets.
2. An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action.
3. An artificial system designed to think or act like a human, including cognitive architectures and neural networks.
4. A set of techniques, including machine learning, that is designed to approximate a cognitive task.
5. An artificial system designed to act rationally, including an intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decision making, and acting."

AI provides tools creating intelligent machines which can behave like humans, think like humans, and make decisions like humans. The main goals of artificial intelligence are [3]:

1. Replicate human intelligence
2. Solve knowledge-intensive tasks
3. Make an intelligent connection of perception and action
4. Build a machine which can perform tasks that requires human intelligence
5. Create some system which can exhibit intelligent behavior, learn new things by itself, demonstrate, explain, and can advise to its user.

AI is not a single technology but a range of computational models and algorithms. The concept of AI is an umbrella term that encompasses many different technologies. AI is not a single technology but a collection of techniques that enables computer systems to perform tasks that would otherwise require human intelligence. The major disciplines in AI include [4]:

- *Expert systems*
- *Fuzzy logic*
- *Neural networks*
- *Machine learning (ML)*
- *Deep learning*
- *Natural Language Processors (NLP)*
- *Robots*

These computer-based tools or technologies have been used to achieve AI's goals. Each AI tool has its own advantages. Using a combination of these models, rather than a single model, is recommended. Figure 1 shows a typical expert system, while Figure 2 illustrates the AI tools. These tools are gaining momentum across every industry. Analytics can be considered a core AI capability.

SPACE EXPLORATION

Space exploration has always been of interest to scientists and governments across the globe as it holds the key to the origin of mankind and many marvelous wonders of the universe including the possibility of alien lives. Scientists and engineers have explored roughly only 4% of the visible universe, which represents the parts of space that we can see using telescopes. The visible universe is made up of planets, stars, galaxies, and other astronomical objects.

Space exploration began within human minds, long before we actually went into space, we did so in our imagination. Space is an expression of humanity's endless curiosity and exploration. Every day, various space vehicles and observation systems are used to gather information about new planets, stars, and galaxies. The commercialization of space is entering an exciting new phase with AI technology integration.

One of the main aims of NASA at the moment is to increase the exploration of space.

NASA extensively utilizes artificial intelligence and machine learning in space exploration, primarily for autonomous navigation of spacecraft, analyzing large datasets from missions, identifying patterns in planetary surfaces, and making real-time decisions on rovers (robots). NASA has been safely using artificial intelligence for decades to plan and schedule missions for planetary rovers. NASA has previously used AI in human spaceflight, scientific analysis, and autonomous systems. Currently, NASA is in the development phase of an assistant that would provide help with the process of engineering future missions. NASA has also previously developed an AI assistant named Daphne. This assistant focuses on providing instant feedback on questions and queries related to the earth. NASA's mission of exploration requires leveraging new ways to utilize and learn from the unprecedented amount of data that space-based observation platforms generate [5].

ARTIFICAL INTELLIGENCE IN SPACE EXPLORATION

The exponential rise in space data captured from satellites, telescopes, and interplanetary probes requires AI's analytical capabilities. Modern space

instruments generate terabytes of data daily - far more than scientists can examine manually. Artificial Intelligence represents a pivotal breakthrough in scientific advancement, redefining the boundaries of research and exploration. AI has the potential to revolutionize space exploration in many ways. Figure 3 illustrates AI in space exploration [6]. Some AI applications in space exploration are shown in Figure 4 [7]. Here are some of the ways that AI is being used in space exploration today [8-10]:

- *Astronaut Assistants:* Scientists and researchers are working towards creating intelligent assistants to help astronauts in their mission to Moon, Mars, and beyond. AI has become a focal point for scientists developing intelligent assistants to support astronauts in real space missions. These AI-supported assistants aim to enhance the safety and efficiency of space missions by addressing various challenges that astronauts may encounter. They are designed to understand and predict the requirements of the crew and comprehend astronauts' emotions and their mental health and take necessary actions in the case of an emergency. AI also assists with entry, descent, and landing (EDL) - the riskiest phase facing probes sent to Mars. They can detect hazardous situations such as increased carbon dioxide levels in spacecraft and provide astronauts with alerts. A typical AI-based assistant is shown in Figure 5 [11].
- *Astronaut Health Monitoring:* The mental and physical toll during missions creates a need for enhanced astronaut medical care. AI shows promise for improving future crew support systems. By integrating multi-modal data streams - from sensors tracking heart rate and skin temperature to recording exercise and sleep patterns - predictive health analytics powered by AI can enable customized interventions tailored to each astronaut. AI-based medical care can also be applied to space exploration. As humans ready themselves to leave LEO, new medical care systems that make astronauts more autonomous for delivering their own care, are highly important. Monitoring and assessing the health of astronauts on long-duration missions is a crucial challenge for space actors currently. Health is a huge barrier to overcome on deep space exploration missions to Mars. AI can be used to identify and classify health data in real-time to support the efforts of on the ground medical officers.
- *Space Debris:* The increasing amount of space debris poses a serious threat to future space missions. Space debris or space junk is any piece of machinery or debris left by humans in space. It can refer to big objects such as dead satellites that have failed or been left in the orbit at the end of their mission. The problem with space debris has reached a critical point as scientists and researchers continue to send satellites into space, which is never brought back. The major concern with these space debris is that can cause space accidents. Figure 6 shows the image released in 2013 by NASA which showed the amount of space debris we had back in 2013 [8].
- *Data Analysis:* Space exploration generates immense amounts of data across various disciplines, including astronomy, earth science, and space weather. The capability of AI to process and analyze data efficiently onboard spacecraft represents a major advancement in space research. AI can be used to analyze large amounts of data from space missions, such as images and sensor readings. This can help scientists to better understand the planets and moons that we are exploring, and to identify potential hazards. This may involve sorting through massive amounts of scientific data to find interesting or unusual discoveries that require further investigation. Since space exploration involves huge distances, it is crucial to be able to process and analyze data quickly on the spot. AI's ability to do this helps with making timely decisions, especially during critical parts of a mission. AI's ability to process vast volumes of data enables split-second threat detection and emergency responses, essential for addressing hurdles in space exploration and empowering autonomous robotic planetary systems.
- *Mission Planning:* AI can be used to plan space missions, such as determining the best trajectory for a spacecraft or the best way to land on a planet. This can help to reduce the risk of accidents and to ensure that missions are successful. AI can help us to explore new worlds, to learn more about the universe, and to ensure that our missions are safe and successful. For example, NASA is using AI to help plan future missions to Mars. Figure 7 shows the space exploration mission architecture [7].
- *Robotics:* Robotic systems have proven to be well suited for repeated tasks in harsh and hazardous environments. Robots are used for a variety of different space applications, and their function can be divided into four main categories: Rover, Arm, Sampler, or Drill. AI can be used to control robots that are exploring space, allowing them to perform tasks that would be too dangerous or

difficult for humans, such as exploring the surface of Mars. For example, the European Space Agency (ESA) is using AI to control a robot that is exploring the surface of Mars. The robot, called ExoMars, is equipped with a camera that is controlled by AI. AI-powered robotic rovers and landers such as NASA AI projects Curiosity and Perseverance navigate celestial terrains independently, gathering samples, running experiments, and snapping detailed pictures. Robots have been used for space missions for decades due to their ability to work in harsh and hazardous environments that would be unsafe for humans. Curiosity rover (robot), such as shown in Figure 8, can be sent to explore distant worlds such as Jupiter, where the lag between earth and spacecraft communications is too great to allow for a manual human operated landing [7]. The rovers are currently roaming the surface of Mars and making decisions without specific commands from the mission control.

- *Satellite Navigation:* Another area where artificial intelligence comes in handy is optimizing satellite operations, paying close attention to collision avoidance and telemetry analysis. AI is also being used to help identify rogue drones in sensitive airspace. AI's role extends to optimizing satellite operations, focusing on collision avoidance and telemetry analysis. AI for data processing can also be used for the satellites themselves. AI offers huge potential to augment in-space navigation, primarily probes exploring the extremities of our solar system. Satellites observe various regions of the planet and then submit the data to ground offices.
- *Earth Observation:* This is one area where AI is already being used more extensively. Earth observation satellites generate tremendous amounts of data. This is received by ground stations in chunks over a large period of time, and has to be pieced together before it can be analyzed. Figure 9 shows a typical earth observation [12].

BENEFITS

AI's strong points lie in its ability to handle large amounts of data quickly, identify complex patterns easily, and deal with repetitive tasks without getting tired. AI in space exploration plays a major role in enhancing efficiency, advancing scientific discovery, and ensuring the success of space missions. AI can help manage communication between space and earth by selecting the best frequencies and power levels for sending signals. AI can help establish a conversation with scientists by applying deep learning to facial recognition and speech recognition. Other benefits of AI in space exploration include [12,13]:

- *Automation:* Autonomous navigation is a key application of AI that would help us navigate around earth and other planets. Spacecraft equipped with AI capabilities can navigate space autonomously. AI automation assists with classifying and processing streams of images, sensor readings, and spectral data. AI holds immense promise for automating spectral data analysis from future missions to places like Saturn's moon Enceladus. Satellites orbiting earth also require more autonomy, as they need to make more frequent collision avoidance maneuvers to evade increasing amounts of space debris.
- *Decision Making*: AI's ability to make decisions comes into play during critical mission phases. AI can help make decisions in space missions, such as when to abort a mission or when to change course. Onboard AI can evaluate potential actions based on mission goals and choose the best response. This autonomous decision-making reduces the need for control from earth, which is crucial for deep space exploration where signal delays can be significant.
- *Anomaly Detection:* This is another area where AI proves extremely useful, helping with identifying unusual readings from instruments. By providing early warnings for potential issues, AI enhances the safety and reliability of missions.
- *Smart Space Driving:* AI helps robots and rovers drive themselves on other planets. It is like having a really smart driver who can avoid rocks and find the best paths.
- *Robot Buddies:* On space stations, AI-powered robots help astronauts with daily tasks. They are like helpful assistants who never get tired.
- *Saving Money:* Space trips are super expensive. But AI can help cut costs by doing jobs that would need lots of people or fancy equipment.
- Some of these benefits of AI in space exploration are depicted in Figure 10 [6].

CHALLENGES

Space exploration involves numerous risks and challenges, such as long-duration missions, harsh environments, and communication delays. Some promise that AI will transform society for the better, others claim it is dangerous. How are we ensuring that it is used effectively and safely in space? One obstacle is making AI algorithms compatible with harsh space environments. Other challenges of AI in space exploration include [12]:

- *Unpredictable Space Environments*: The extreme conditions of outer space can create unique situations that pre-programmed AI may not have been trained to handle. This could potentially lead to malfunctions or failures in the system.
- *Dependence Risks:* Relying too heavily on autonomous systems could result in a decline of human expertise over time, as skills weaken without regular practice.
- *Safety:* As AI continues to advance, it is important to constantly improve its capabilities alongside ensuring the safety and innovation of space exploration. Due to microgravity and special radiation environment, health issues may arise and could eventually peak in the inability to manage the spacecraft. AI contributes to the safety and well-being of astronauts during interstellar travel.
- *Sustainability:* If humanity wants to get the most out of AI-driven technologies, they need to be developed and used in an ethical and sustainable way.
- *Transparency:* Space agencies and tech companies should document and communicate the decision-making processes of AI systems. This transparency is vital not only for maintaining public trust but also for facilitating collaboration between different entities in the space sector.
- *Accountability:* There should be clear guidelines on liability and accountability when it comes to AI-driven decisions in space missions. Identifying responsible parties for AI actions can be complex, but it is crucial for addressing any unintended consequences or malfunctions.
- *Fairness:* The design of AI technologies must prevent biases that could lead to unfair outcomes. Although machine learning algorithms are as objective as the data they are trained on, ensuring fairness requires constant vigilance against skewed datasets or prejudiced assumptions.
- *Reliability:* AI is unproven in many aspects and lacks sufficient testing and proofing to be reliable. Interest in using AI in space exploration has been fueled by its increased reliability on missions and its potential cost savings. Relying on AI for critical activities during missions creates single points of failure within the system itself due to dependency. Redundancy measures must be put in place alongside fail-safe mechanisms so that these dangers can be mitigated while still ensuring the mission's success, even if something goes wrong with AI systems. AI models used for space exploration require a 100% robustness guarantee to satisfy project executives-for all remote applications the software simply cannot fail.
- *Risks of Cybersecurity:* Space-based AI systems are also prone to cyber threats and data privacy breaches. The risk of such incidents is greater with the increasing integration of artificial intelligence into space systems. The complex nature of AI algorithms and the interconnectedness of various networks within space create vulnerabilities that hackers can exploit, leading to the compromise of mission-critical operations.
- *Space Weather Forecasting:* Space weather, such as solar flares and cosmic rays, poses significant challenges to space exploration. AI algorithms can analyze space weather data and provide accurate forecasts, allowing spacecraft operators to prepare for conditions that might affect performance and astronauts can be alerted to take preventive measures.

CONCLUSION

AI's role in space exploration is transformative, processing vast data from celestial bodies and predicting risks like solar storms and space debris. The story of space exploration is being continuously rewritten by the influence of AI. AI is regarded as a game changer in the quest for knowledge and understanding of space. Concerted efforts persist in employing AI's capabilities to benefit space exploration. Space colonization and terraforming may have a bright future thanks to AI-driven innovations.

In the future, space agencies and private companies will continue to explore Mars and other planets in the solar system. AI offers huge potential to augment current and future space exploration. The future of space exploration depends on human beings working closely together with various AI capabilities. The collaboration between human ingenuity and AI capabilities promises to drive future discoveries and push the boundaries. AI is ready to fuel a new dawn of space exploration. More information on artificial intelligence in the space industry is available from the books in [15-26] and the following related journals:

- *Energy and AI*
- *The AI Journal*
- *Progress in Aerospace Sciences*

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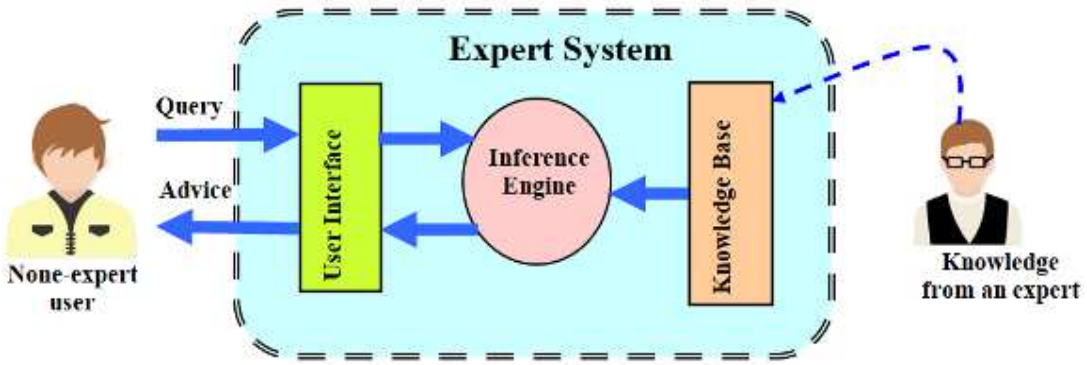

Figure 1 A typical expert system.

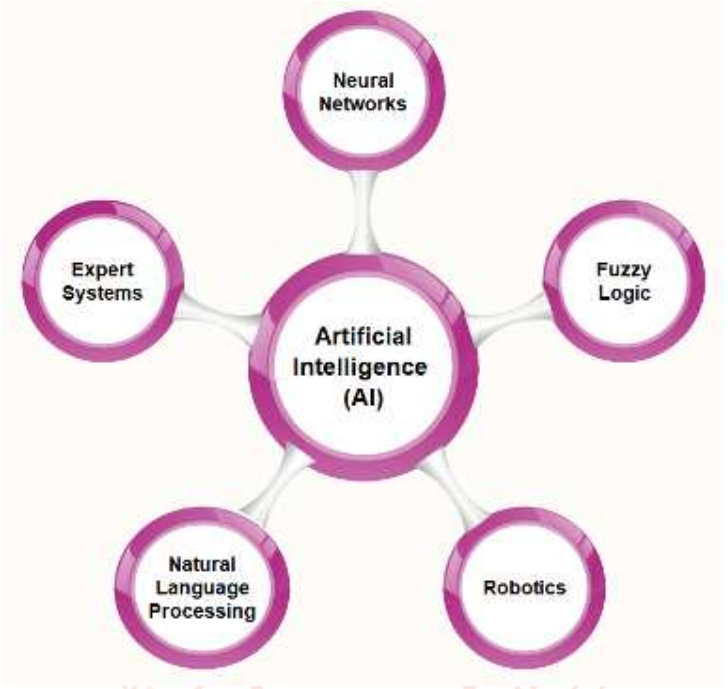

Figure 2 AI tools.

Figure 3 AI in space exploration [6].

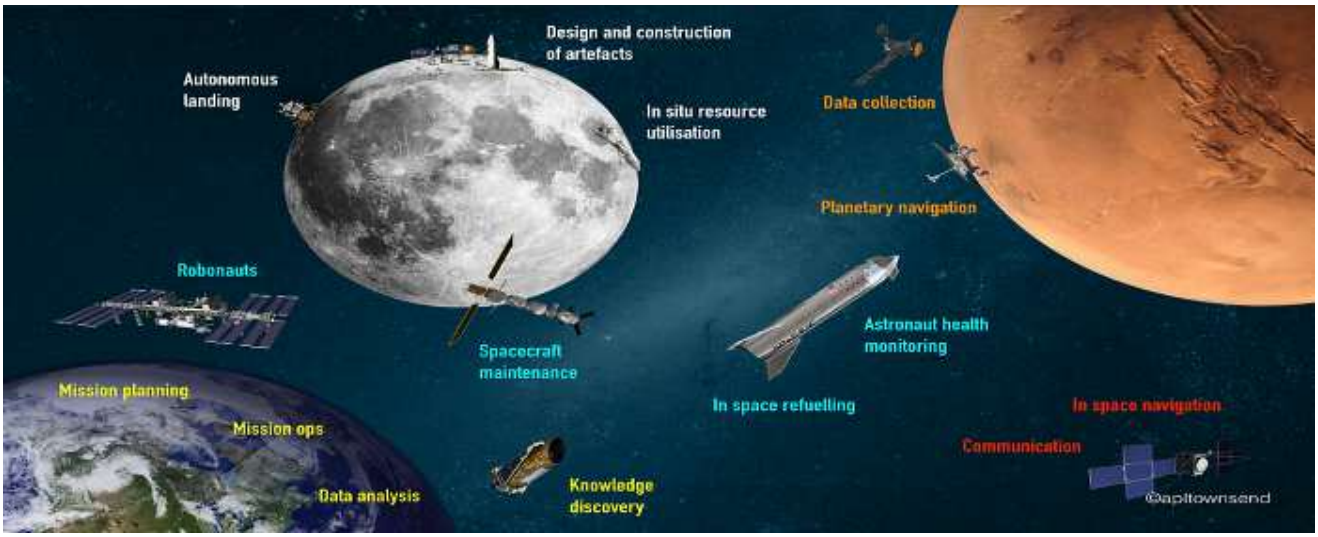

Figure 4 Some AI applications in space exploration [7].

Figure 5 A typical AI-based assistant [11].

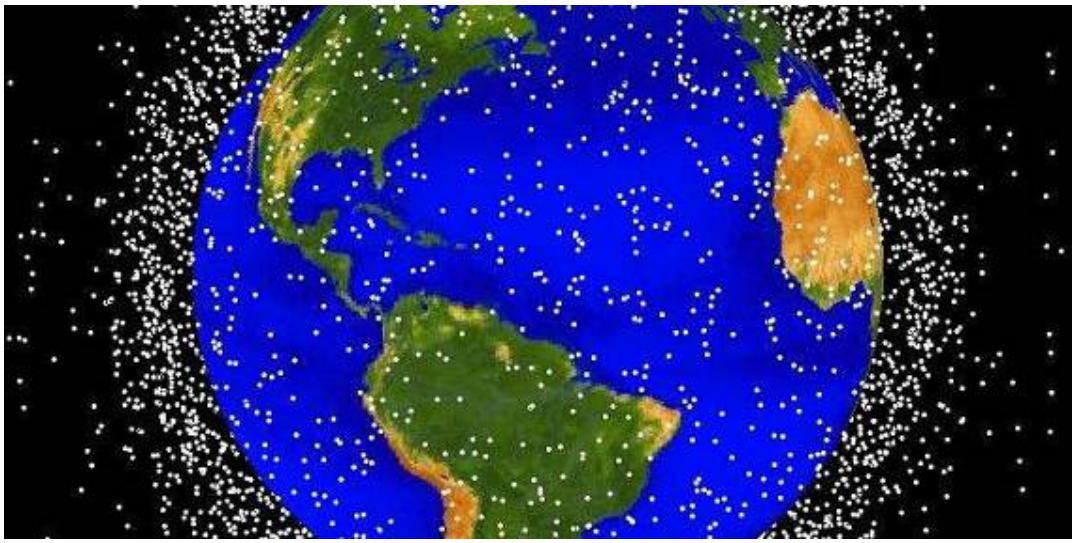

Figure 6 The amount of space debris we had back in 2013 [8].

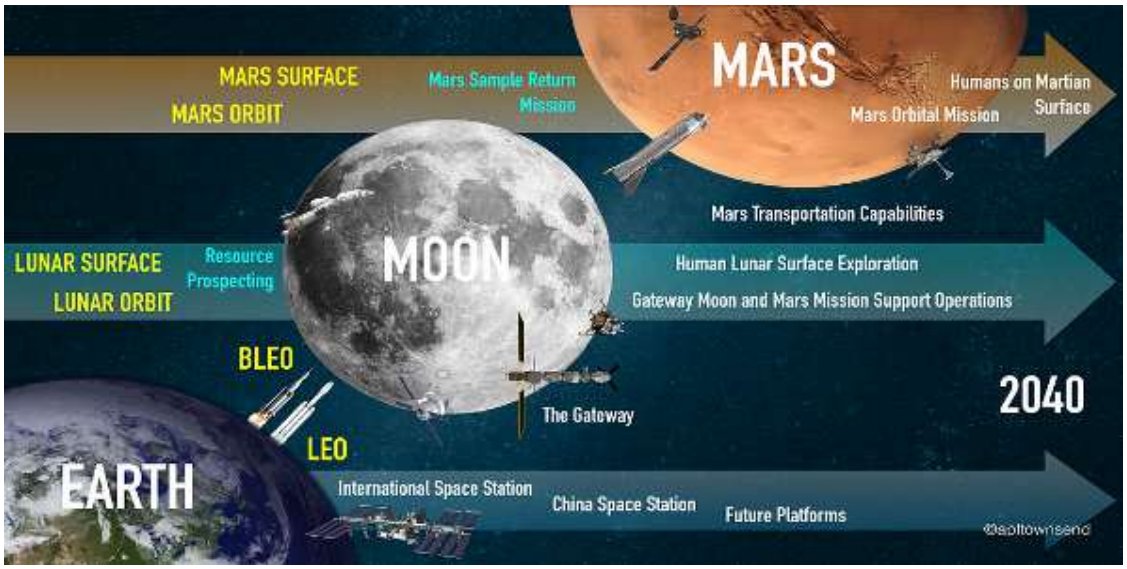

Figure 7 Space exploration mission architecture [7].

Figure 8 Curiosity rover (robot) designed by NASA [7].

Figure 9 A typical earth observation [12].

Figure 10 Some of these benefits of AI in space exploration [6].