AI in Space Exploration: How NASA and SpaceX are Leveraging Artificial Intelligence

In this modern era, there is much excitement associated with space exploration. This excitement is mostly derived from the opportunities it offers to "expand on human knowledge, discover new resources and empower or inspire future generations." However, space exploration also presents significant challenges that need to be met in order for the field to progress. "High costs, technological limitations and the need to address ethical and legal concerns" are challenges related to AI used in space exploration.

There is no denying the transformative effect artificial intelligence has had on the aerospace industry. Notably, machine learning algorithms can "analyze thousands of design variations and simulate performance under numerous conditions. This allows for the identification of optimal configurations human engineers might discover." AI is also being used in the manufacturing process to detect tiny defects invisible to human eyes. This ensures that spacecraft and aircraft are the highest quality possible and reduces the likelihood of any kind of mechanical or engineering failure.

AI plays a critical role in enhancing space exploration capabilities from mission planning to autonomous navigation and system maintenance. This essay will explore how NASA and SpaceX Are utilizing AI to advance missions, improve safety and enable autonomous decision making.

The role of AI in modern space missions

In the context of space exploration AI is defined as machine learning, robotics, computer vision an autonomous system. These models are used to, "simulate the actions of human pilots" with the result that we can now "achieve missions that were once beyond human capability."

There are several reasons why AI is essential to the field of space exploration. Firstly, the long delays experienced when communicating with earth from space. To achieve this, advanced algorithms and neural networks are used to, "allow mission systems to operate semi independently in space" reducing their dependency on human operators.

An example of how AI could be used to facilitate communication from space is seen in the "Earth to Mars communication lag." This refers to the amount of time it takes to send a signal from earth to Mars, typically, "four to 24 minutes for a one-way signal." AI reduces this time delay so that it is possible to achieve instantaneous communication between the two planets.

There is also the issue of having a limited human presence in deep space. Human astronauts and human powered spacecraft don't have the capacity to venture into deep space. However, with autonomous AI powered spacecraft we will soon have the capability to send spacecraft into areas no human has ever been before and gather new information we've never had the wherewithal to gather.

In the above scenario, space vessels going into deep space would have to be completely autonomous given humans lack the ability and possibly the willingness to venture so far into space. AI powered space capsules have the capacity to venture into deep space and send instantaneous communications and reports back to earth. Which is why they are essential for the expansion of our understanding of the universe.

How NASA Uses AI

There are several ways in which NASA leverages AI to help with its goals and missions. One of these is mission planning and simulation. Tools like machine learning are used to schedule and optimize mission tasks such as checking satellites for anomalies and to "analyze data, reveal trends and patterns and develop systems capable of supporting spacecraft and aircraft autonomously."

There is also the Deep Space Network. This is "a global system of radio antennas" that enables spacecraft exploring "the solar system and beyond" to communicate. It transmits commands, receives data and images and tracks spacecraft. It is made-up of "three main facilities located strategically around the world to maintain continuous communication with spacecraft as the earth rotates."

This network uses machine learning models to increase the speed and accuracy of data analysis. For example, these models can, "analyse light curves to predict events like supernova and gamma ray bursts." AI can also identify gravitational waves, speeding up the analysis of data from labs like the Laser Interferometer Gravitational-Wave Observatory and Virgo.

NASA's Mars Rovers, *Perseverance* and *Curiosity* use AI for autonomous navigation and hazard avoidance. These robots rely heavily on AI for their ability to navigate the surface of Mars on their own without being damaged. They are equipped with a special instrument that uses AI to "search for signs of ancient life by testing and analyzing rock samples based on collected data from previous missions." The Rover known as *Curiosity* has an AI powered laser which it uses to independently pick up items that can be analyzed for chemicals. This task is critical to our understanding of the surface of Mars.

Another lucrative and useful way in which NASA leverages artificial intelligence is for the purpose of satellite and image data analysis. They do this by employing their AI models to analyze satellite images from their massive data sets to "uncover patterns of information that would be too time consuming or impossible for humans to detect." The model that does this is what's known as a, "deep learning model." These are deep neural networks that can mine years of accumulated data and pick up on even subtle relationships. NASA also uses machine learning to identify geological features and track climate change.

Another use to which NASA puts its artificial intelligence is health monitoring and predictive maintenance. Predictive maintenance is a term used to describe the process of an AI model using datasets of past mistakes to predict possible upcoming failures in hopes of preventing them before they occur. It is well known that AI models are not subject to human shortcomings like mood changes or unreliable lighting. This gives them the capacity to pick up on things human inspectors might miss, allowing for a better chance of obtaining a solid fix. It is essential for NASA to be able to correct potential failings on earth rather than from a distance.

How SpaceX Uses AI

SpaceX also has several important ways it has used and uses AI. Perhaps the most notable is autonomous rocket landing. For example, their Falcon 9 rocket made a vertical landing

thanks to AI driven decision making. All of SpaceX's rockets, including Falcon 9, are equipped with, "advanced sensors, including accelerometers, gyroscopes, and GPS systems." These AI power tools collect vast amounts of data on the altitude speed and trajectory of the rocket which makes it possible for it to land on its own without any human assistance.

SpaceX also uses computer vision and reinforcement learning for precision. Computer vision enables the rocket to have a view of its surroundings and, "adjust its dissent." Meanwhile, reinforcement learning gives it the capacity to learn from previous landings and "improve its control algorithms over time.

One of SpaceX's proudest achievements is, no doubt, the Dragon Capsule. It can, "carry up to 7 passengers into earth's orbit and beyond" and it is the only spacecraft currently active that can return "significant amounts of cargo to earth." On top of that, it is the first private spacecraft to take humans to the International Space Station.

Predictably, this cutting-edge spacecraft uses AI to navigate and to dock at the International Space Station. It does this by means of AI powered autopilot systems which, "leverage real time sensor data and predictive analytics." The Dragon Capsule also uses AI to detect potential failures in its on-board systems before they occur and to sense space debris and avoid collisions. This is done using real time data that tracks potential threats to the craft.

SpaceX also plans to carry out future Starship missions to Mars that will depend heavily on autonomous systems. It will need these systems for rocket landings, robotic operations on Mars and, "building a self-sustaining city." They are planning unmanned missions as well as human landings with the goal of, "establishing infrastructure and robotic support for future human exploration." AI powered autonomous systems will be essential for humans to explore the surface of Mars safely and efficiently.

Another use SpaceX has found for AI models is long duration mission planning and risk assessment. This is done using machine learning algorithms that, "analyse vast amounts of

data, predict potential issues and optimize mission trajectories." The models do this by detecting anomalies through predictive maintenance and handling energy.

SpaceX uses AI for its manufacturing operations. AI models are mainly employed in supply chain optimization, component quality assurance and for predictive maintenance of reusable rockets. These processes as well as design optimization and testing acceleration are done by machine learning models. The models analyze vast amounts of data from past launches to predict potential failures as well as develop new material.

Case Studies

Mars Rover (NASA)

Since 2009, Nasa has been using Autonomous Exploration for Gathering Increased Science (AEGIS) on rovers Opportunity and Curiosity to explore, and photograph select targets on Mars. First, on Opportunity rover (2009) and subsequently on the Curiosity rover (2016). AEGIS is an artificial intelligence software system developed by NASA's Jet Propulsion Laboratory (JPL). With it, the Curiosity rover can autonomously analyse soil samples using image analysis made by the Chemcam. The analysis can determine the chemical makeup of rocks and soil to identify any traces of past water or habitability. This is particularly important when communication with scientists on earth is unreliable. The precision with which AEGIS targets and analyse soil samples (approximately 93 per cent) on Mars radically increases the pace of data collection.

Another example of artificial intelligence as used by NASA is, Terrain Relative Navigation (TRN). TNR is a vision-based navigation system that helps a spacecraft "see" the landing area, compare it to onboard maps, and make instant decisions about where it is safe to land. TNR is equipped with pre-loaded maps to indicate hazards and descent imaging cameras that photograph the surface at the time of landing. If the original landing spot unsafe, TRN autonomously guides the spacecraft to a safer spot.

TRN, first used during Perseverance' landing mission on Mars in 2020, was able to land in the hazardous and scientifically interesting Jezero Crater. Without the help of TNR this landing would have been quite unlikely.

Falcon 9 Rocket Landings (SpaceX)

As already mentioned, SpaceX's Falcon 9 Rocket is another example highlighting the contribution of AI to the field of space exploration. It's first stage landing is a model of AI-driven adaptive control. It adapts in real-time to changing weather, wind, fuel loads, mass distributions, and even hardware wear, ensuring a safe touchdown. Falcon 9 relies on adaptive algorithms, model predictive control (MPC), and data-driven tuning based on machine learning performed between flights. MPC forecasts future system states like trajectory and fuel use. With the sensor data generated in each flight, machine learning models are trained offline, between flights to detect engine wear and refine predictive models for next launches and improve landing precision.

Ethical and Technical Concerns

As with any implementation of AI, there are ethical concerns that need to be addressed before a company decides that AI is right for them. First and foremost is decision making accountability in autonomous systems. It is important to understand how an AI model has made its decisions. If the model makes a decision based on biased or faulty data, the user of the model is likely to pay for it with bad information, a faulty technical report or something of that nature. The key to succeeding with an autonomous system is to find the right balance between autonomy and human control. "Too much human control defeats the purpose of autonomous systems, but too little can have unintended consequences," states Michael Umanski, co-founder and CEO of SmythOS.

The appropriate level of human control depends on the tasks the model is being asked to perform. For example, an AI chat bot might need very little control, but an autonomous weapon would need much more. It follows that an unmanned spacecraft would need an amount of control somewhere between those two extremes, enough control to know where it was going and to fix itself but not so much control that it mishandles information or bring back faulty reports. Human oversight would, of course, be essential in mission critical operations.

With AI powered spacecraft, there are technical concerns that must also be addressed. The first of these is, data limitations in space environments. Factors like extreme temperatures, radiation and limited storage and processing power make it difficult for AI

models to store data in space. To ensure that the space AI model is as reliable as possible, it must be as robust and secure as possible.

The Future of AI in Space Exploration

As you can imagine, there are many exciting innovations to be on the lookout for in the future of space exploration and AI. Firstly, there are expected to be more instances of humans collaborating with AI for lunar and Martian missions. This will enhance deep space exploration capacity. AI will, "act as a copilot assisting with tasks like data analysis common navigation and resource management." This will reduce the pressure space exploration causes human scientists and perhaps incite them to take fewer risks. AI models or autonomous systems will handle things like emergency responses and habitat management allowing human astronauts to concentrate more of their efforts on exploration and science. With this human, AI collaboration, NASA hopes to, "thrive on Mars and create a sustained human presence beyond earth."

Fully autonomous missions are also on the horizon. Soon, AI is expected to manage all the operations of a spacecraft. Already, there are some spacecrafts in existence capable of, "performing tasks or making decisions without human intervention. These craft are making it possible to explore further into deep space than ever before, greatly expanding the possibilities for exploration and discovery.

In conclusion, AI is playing a major role in the work being done by both NASA and SpaceX. NASA uses it for spacecraft maintenance, communication satellite data analysis and to create fully autonomous spacecraft such as their Mars Rovers. Meanwhile, SpaceX also has autonomous rockets that employ various kinds of AI models for navigation and other decision-making. AI is also a prominent feature of its passenger space capsule that can transport up to seven people.

Added to this, SpaceX is planning to carry out various missions into space and to Mars that will employ entirely autonomous spacecraft. These missions include building a, "self-sustaining city" on the Red Planet. SpaceX also uses AI for long term mission planning, using models to analyze data from previous missions to help create new ones. Both companies also use AI models to manufacture their spacecraft, notably predictive

maintenance and machine learning. AI is not just an assistant, but a necessary partner in expanding human presence in space.