Artificial Intelligence (AI) in Space Missions: Investigating Legal Challenges

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Abstract

Artificial intelligence (AI) is an emerging and impactful technology across different sectors. AI has been particularly significant for improving efficiency and accuracy in operations. One of the areas that AI has had a huge impact is in space exploration. However, the emergence of AI in space exploration has come with difficulties and challenges, particularly in assigning fault in situations where the use of AI systems cause harm. This paper examines the impact of the widespread AI usage in space exploration, analyzing the legal challenges that the use of autonomous AI technologies in space objects may entail, particularly in determination of liability.

Keywords: Artificial intelligence, Space Exploration, Liability, Legal challenges, Autonomous AI

الذكاء الاصطناعي في المهمات الفضائية: دراسة للتحديات القانونية

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ملخص

تُعد تقنيات الذكاء الاصطناعي من التقنيات الناشئة والفعّالة في مختلف القطاعات. وقد كان لها تأثير كبير في تحسين الكفاءة والدقة في العمليات. ومن أبرز المجالات التي أثّر فيها الذكاء الاصطناعي بشكل كبير هو مجال استكشاف الفضاء. ومع ذلك، فإن ظهور الذكاء الاصطناعي في استكشاف الفضاء صاحبه العديد من التحديات، خاصة فيما يتعلق بتحديد المسؤولية في الحالات التي يُسبب فيها استخدام أنظمة الذكاء الاصطناعي ضرراً. تهدف هذه الورقة إلى دراسة تأثير الاستخدام الواسع للذكاء الاصطناعي

في مجال الفضاء، وتحليل التحديات القانونية الناتجة عن استخدام تقنيات الذكاء الاصطناعي الذاتية في الأجسام الفضائية، لا سيما في ما يتعلق بتحديد المسؤولية.

الكلمات المفتاحيّة: الذكاء الاصطناعي، استكشاف الفضاء، المسؤولية، التحديات القانونية، الذكاء الاصطناعي الذاتي.

Introduction

The past few years have seen two notable, related trends in the tech field. The first is the acceleration in terms of exploration of space. There have been notable steps taken, supported by technological improvements, to show the world what is out there in the universe. In 2022, for instance, the National Aeronautics and Space Administration's (NASA) James Webb Telescope released its first images of thousands of distant stars, planets and galaxies, including images of the farthest galaxy ever detected[1]. This is just an example of several excursions and steps taken when it comes to the exploration of space. The space sector has expanded, driven largely by commercialization and investments in both launch technologies and satellite services. Companies like Space X have invested heavily in space exploration and in initiatives that will enable further exploration. For context, according to the Dow Chemicals company, 2023 alone saw up to $7 billion spent on launch services for up to 2300 satellite services[2]. In total, the spending on satellite builds reached up to $15.8 billion[3]. Improvements in technology have seen satellites improve, reducing in size and improving in levels of efficiency. The bulk of these are focused on communication, but there are satellites that are focused on cargo and reconnaissance. These changes and trends in both satellite technologies and space exploration have seen international and commercial tensions rise.

Space exploration has become one of the biggest areas of international and commercial competition. Countries like the United States and companies like Space X face immense competition in their quest for space exploration and push for spacecraft and colonization[4]. This is why the second trend is also important, the influence of new age technologies in space exploration. With technologies rapidly growing, the world has entered what is being referred to as the 4th

industrial revolution. The 4th industrial revolution is characterized by the fusion and combination of technologies that transcend the biological, physical and technological spheres of influence. The disruptive effects of these technologies have been found to have the capacity to improve the quality of life across the world[5]. One of the areas where there is potential for such improvements and changes is the field of space exploration. The potential for AI use in space exploration and missions has grown over the past few decades.

The emergence of AI technologies and capabilities in the sphere of space exploration has promoted space exploration through AI-powered and equipped space objects. Theoretically, the modern-AI, both as it is now, and its promise into the future, offer convenient solutions to some of the biggest problems that have always been faced in space exploration. First, AI has the potential to redefine human roles in space exploration. Today, spaceflight still relies on astronaut skills and teamwork. However, AI has the capacity to replace many of these human capabilities, and could potentially either replace or significantly reduce human reliance[6]. This is especially the case given the stakes that are involved in space travel. Decisions in space can quickly escalate or regenerate into situations that are safety-critical. Incidences in the past few months and years point to this truth. For instance, it is only recently that astronauts Suni Williams and Butch Wilmore had to extend their stay in space to almost 9 months, a stay that was supposed to be much shorter. NASA had initially decided that flying the astronauts home aboard their Boeing Starliner capsule would be too risky, with NASA instead deciding to have the crew join the international space station[7]. Such situations raise the stakes for the potential use of AI going into the future.

AI also has potential for improvements in training of astronauts. AI offers a transformative role in the training process, offering such technologies as augmented and virtual reality. AI models provide realistic simulations that help astronauts train in environments that closely mimic the space environment. AI-related technologies like digital twins also offer virtual representations of mission environments that help in planning, maintenance and management of risks[8]. Granted, humans have become indispensable for some tasks in space exploration that are beyond the reach

of technology. However, the pace at which AI technologies are improving is so fast that there is a possibility of it advancing to overshadow humans in many areas. This is especially the case given how costly and risky it might be to maintain human health and safety in space travel and exploration.

Study Justification

The use of AI, with all the promise it brings in enhancing space missions, does not come without potential challenges. The large number of possibilities and the challenges that arise when it comes to the use of AI in space exploration make this topic important to study. Some of the biggest issues that arise here include legal challenges, particularly those involving liability assignment. The increasing role of AI in space missions has not yet been fully examined by international law. AI systems that work independently in space by controlling satellites, maintaining them and analyzing a lot of information are now facing problems with the existing laws developed during an earlier time.[9] It is also important to consider the novelty of these issues. First, AI is a unique technology in that it is often associated with predictability, opacity and autonomy. Despite these advantages, AI offers unprecedented challenges with accidents and issues that might arise from biased input and AI systems that might not necessarily be up to task. This raises the second novelty issue here[10]. One of the reasons why AI might offer legal challenges as a result of novelty is the uniqueness of outer space. The intersection of these to challenges, in a world where international and commercial competition is tight, makes it particularly important to study the legal challenges associated with the use of AI in outer space. In particular, the problem is liability is likely to become a big issue. When damage is done by autonomous or semi-autonomous systems, liability can be difficult to prove, especially given that such actions can be difficult to predict or prevent by the developers themselves. However, given the stakes that are involved in space exploration, particularly with the intense international and commercial competition, this is a too a big a problem to brush aside, legally or otherwise. The topic of AI use in space missions was selected to investigate the challenges and unclear laws related to issues of liability in autonomous AI particularly in space operations. There is an increasing concern

about if existing space treaties such as the Liability Convention and the Outer Space Treaty, can handle the new challenges from AI-assisted missions. As AI plays an important role in exploration, research should be done to evaluate if the existing laws can adapt as quickly as technology changes.

Importance of the Study

The study adds to efforts around the world to update space law by considering the role of AI in space activities. It outlines the current challenges and recommendations for policymakers, legal scholars, and space agencies on the legal problems caused by autonomous systems in space.

Research Issue

The fast growth of AI in space has left international laws behind, so it is now unclear who is responsible, how data privacy is protected and who owns AI-generated intellectual property. The Liability Convention and other space law treaties, have not taken into full consideration the challenges that emanate from the use of autonomous systems. This research investigates whether it is necessary to modify laws that control AI in space exploration so as to guarantee its responsible and ethical use by every party involved.

Research Objectives

1. To examine the international laws with regards to liability in space and determine their applicability to autonomous AI systems.
2. To examine the challenges of deciding who is responsible for decisions made by AI in outer space missions.
3. To offer suggestions for a global legal framework that establishes rules for liability in artificial intelligence for use in space.

Research Methodology

This study used a qualitative research design as it enabled in-depth exploration of complex legal issues which cannot be quantified or experimentally

tested. Primary sources used included international treaties, legal instruments, and relevant soft law documents governing outer space and digital technologies. Secondary sources that were used included; academic articles, as well as legal commentaries and publications from organizations such as the United Nations Office for Outer Space Affairs (UNOOSA) and the European Space Agency (ESA). Three important topics were investigated in this research: (1) liability for any damage caused by AI, (2) protecting data and privacy rights and (3) intellectual property rights to AI-produced outcomes in outer space. This methodology makes it possible to understand the changing rules by studying expert views, current laws and policy materials, but case law involving space and AI is not available to support its findings.

Results

The results focus on addressing the research objectives/research questions of this research. More importantly, each of the headings and subheading in this section focuses on addressing the specific research objectives that were to be met in this study as follows;

Objective 1: To examine the international laws with regards to liability in space and determine their applicability to autonomous AI systems.

AI use in Space

The past few years have seen an exponential growth in the use of AI in space. A wide range of AI functionalities have emerged in the space realm. For instance, AI is now being used in satellite systems that enable them to avoid collisions, as well as in systems that can help humans find and remove space junk[11]. For instance, the space mission ClearSpace-1 of the European Space Agency has famously incorporates AI systems as the first debris removal mission from startup. Clearspace-1 will rendezvous, capture and return with debris from space for re-entry, particularly focusing on the upper part of a Vega Secondary Payload Adapter (VESPA) that was used with the Vega launcher. This is an object that was initially left in gradual disposal orbit in compliance with space debris mitigation regulations in 2013[12]. Some of the AI-enabled capabilities on

this mission include advance guidance systems, navigation and control systems and vision-based AI systems which would allow the satellite to safely close on the target on an autonomous basis and then use robotic arms to achieve capture. As technology evolves and need increase on the earth's surface, new space-based AI technologies are emerging.

Another new class of AI technologies include the space-based services, like the global navigation satellite systems. These are satellite systems that provide signals which support the functioning of self-driving cars, emergency response services, drones, maritime and agricultural services[13]. Furthermore, AI is now being used to evaluate satellite data in ways that then offer valuable insights. AI is already being used to control mega-constellations, and to evaluate and review the data that is collected by such satellites. Mega-constellations are large satellite constellations that gather and disseminate data in autonomous ways[14]. This has further raised the stakes in AI use, with AI now having the capability of changing the way satellites are manufactured, and therefore how the data is generated from their space objects. In the manufacturing phase, AI can be used to perform various repetitive tasks without human intervention. These could include the cleaning and updating of the health status of the different components[15]. When they are eventually launched into space, AI systems can be used to gather more accurate space data, while reducing the overall costs involved in the gathering of data.

Apart from the fully autonomous systems, AI is also now being used to provide assistance to humans that are exploring space. While explaining how space travel affects humans, suggestions are that there are some tasks, at least at the moment, that humans are indispensable for[16]. However, AI offers important assistance to these astronauts. For instance, there is a new generation of autonomous astronaut assistants, for example the Crew Interactive Mobile Companion (CIMON). This is a system that enables voice-controlled access to media and documents, navigating the astronauts through repair and operational processes. These systems are now also being used in planetary exploration processes, especially in conditions that might be too dangerous or prohibitive for humans[17]. The possibilities for use of AI in space are huge and constantly expanding. However, this unfortunately also raises

important issues, especially with regard to the law and liability issues. The biggest issues here include space law problems and contradictions, the liability laws and norms to be followed, and the overall procedures that might be followed in case damages occur, either in outer space or down on earth[18]. All this is happening in an environment where the current pillars and the legal framework that governs space travel, including the international treaties, continue to fall short and lag behind in dealing with the challenges that AI poses[19]. In order to understand the current legal framework and find the gaps in dealing with liability with respect to the use of AI in space, one must first outline the actual pillars of space law.

Space Law and Liability Issues with AI in Space

The branch of law that deals with activities in outer space is aptly named space law. The bulk of these laws were or are based on treaties that were signed in the 1960s and 1970s[20]. Granted, this was a period when there was increased movement in the exploration of space, at least in comparison to the years before then. This advancement was also supported by the significant growth in computational power and technologies. However, compared to what is available today, the change is huge. For context, the technologies that were used to power the systems that conducted missions in 1969 can be compared to what was in an iPhone 5 more than a decades ago[21]. The main pillar of international space law is the international space treaty of 1967[22]. Under this treaty, three specific arguments or statements specify the provisions of the outer space treaty under the United Nations. The first is the statement that focuses on the rescue of astronauts from 1968 and agreements on their return to earth, together with the return or objects that are launched into outer space. The second is based on the outcomes of the liability convention of 1972 which deals with damage caused by space objects. The third is the registration convention of 1976, which focuses on the registration of objects that are launched into outer space[23]. Furthermore, countries have also developed their own internal and regulatory frameworks for space-related activities. For instance, in Luxembourg, the country approved its own laws for the exploration of space and the use of space resources in 2017. The laws in countries like Germany are even more relevant to the subject matter at hand. Germany's law protects against security

risks that arise from the dissemination of high-grade earth and remote-sensing data, and was passed on 2007[24]. The 1967 treaty was passed under the UN, which was then followed by different countries each coming up with their own laws and regulations[25]. The architecture of the laws governing space can be summed up as being state-centric laws that are built around the principles of sovereignty and the UN legal framework.

An evaluation of these three arguments within the context of the circumstances in which the 1967 international space treaty was signed, as well as the national laws and their effects, reveal weaknesses that have been exacerbated by the growing trend of AI use in artificial intelligence. That the architecture of the laws was designed as it is, is understandable given the fact that these laws were passed in 1967 when states had a dominance of space activities, and the principles of law were largely based on sovereignty[26]. However, things have changed in ways that raise two important issues, particularly when it comes to the use of AI in space exploration and arising matters of liability. The first issue when it comes to liability and AI use in space is the clash between national and international law. According to article VI of the Outer Space Treaty, states are responsible for national activities in outer space. Article VII on the other hand, establishes the international liability of the states that launch, or states that procure the launching of objects in outer space and the damages that might result from such launch to other states and their legal and natural persons. The liability mentioned here is either absolute or based on fault. Even though the convention provides a formal process for the resolution of these disputes, it can be difficult to determine whether a state has incurred fault or whether the damages covered include indirect damages. The concept of indirect damages in this context refers to the situation where space accidents could trigger a chain of events that cause long-term indirect outcomes such as the loss of revenues as a consequence of interruptions of business operations, loss of profits, or loss of services.[27] The compensation of these indirect damages remains a challenge because different countries hold varied perspectives on how they should be approached. Rulings that happen in the international court of justice and the fault standards that are set by the Corfu Channel case leave several open problems with

respect to liability[28]. The general problem is that the international space law's liability convention provides a mechanism for compensation for the injured state. To do this, the convention requires that there be proof of state fault for the liability to arise. However, it does not define this liability, or even establish a standard of care for which this liability can be defined. In fact, this is the only fault-based liability regime in international law. with AI now seemingly a mainstay in space exploration, the effects of such ambiguities become even more serious when it comes to matters of liability in a state-based legal system.

AI legal regulation can be divided into two categories – the traditional UN legal documents that regulate responsibility for wrongful acts and special legal documents that specifically regulate question arising under space law. Notably, none of these legal documents enshrines separate provisions on AI employment in space and what is the role of human inputs while determining the scope of liability for caused damage. Liability involves three key aspects: an accident, the person or thing that is damaged because of it, and the clear link between the two, and it is typically connected to an operator in charge.[29] Therefore, the most problematic issue that has not yet been resolved is the liability for caused damages that may occur as a result of autonomous AI activities in space. Moreover, in other industries where AI is also successfully applied, such as self-driving cars industry, many incidents have already occurred.[30] Importantly, Article 1 of the Liability Convention interprets the concept of a space object as an object that includes component parts of a space object, as wells as its launch vehicle and parts thereof.[31] Thus, the term is not limited to one particular notion, and "space object" includes human-made objects physically brought into outer space and their AI-equipped parts that enable the autonomy of space objects, forming indispensable technical features. Still, even when AI-equipped space objects fall within the meaning of basic term of 'space object', it is necessary to resolve the liability problem of autonomous space objects. The liability problem of autonomous space objects refers to the potential compensation that launching countries are expected to pay for the damage emanating from its space objects on the surface of the earth or to aircraft.[32] The liability of autonomous objects are mainly linked to the launching country's faults in space. Thus, while launching

autonomous objects, it is fundamental for countries to recognize potential faults and liabilities that they are exposed to.

The Liability Convention indicates the grounds and list of agents to whom wrongdoings are attributable. In this regard it is worth noting that Article 2 of the Liability Convention indicates that "A launching State shall be absolute liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft in the sky"[33] Article 1(a) interprets "damage" as "loss of life, personal injury or other impairment of health; or loss of or damage to property of States or of persons, natural or juridical, or property of international intergovernmental organizations."[34] The language of the Liability Convention distinguishes "liability" and "responsibility" concepts even though they are interrelated in some manner. When the question arises regarding consequences for caused damages resulting from space-related activities, it applies to the notion of "liability". In other words, this term refers to already-occurred adverse results, and the guilty state should pay compensation for committed wrongdoings in outer space. With regards to "responsibility," it refers to obligations imposed on people and institutions who are supposed to perform certain activities. For instance, the duty of due diligence requires the launching state to act reasonably and prevent all possible negative consequences (act with duty of care). Still, this Article does not address the matter of responsibility for damages caused by AI systems integrated in space objects while being engaged in space mission operations.

Another unsettled issue is the concept of 'fault' in terms of liability for caused damages in result of AI activities, such as damages caused to property, assets, or people. Under international space law, the notion of "fault" means any failure of a launching state to act in appropriate manner and to use due care in a particular situation.[35] According to the Outer Space Treaty and Liability Convention that contains provisions on responsibility issues in space, the concept of "fault" applies only to the fault of state or fault of persons.[36] Fault mainly focuses on the actions of the launching state that result into damage or loss against other states in the outer space. However, there is some lack of clarity

concerning the whole issue of fault, as it is not directly defined in the Liability Convention 1972. The meaning here is that it may be difficult to substantially directly reference a fault emanating from the launching state and the damages that are supposed to be paid. States may find themselves in situations where they are not able to claim fault damages because of the lack of clarity in fault liability by launching states.[37] Therefore, whereas the attribution of committed wrongdoings in space to a state or person is apparent, the attribution of actions to autonomous space objects is not obvious. Compared to human supervision, where a particular person is responsible for making decisions, AI systems are operated with autonomous decision-making that causes significant uncertainty with the issue of attribution for committed wrongdoings.[38] For example, a satellite with an AI collision-avoidance system may autonomously modify its orbit to prevent a perceived threat, but in doing so, accidentally hits with another state's satellite, causing extensive damage. With no human intervention involved in the decision, determining who or what is legally responsible becomes a challenge. Thus, now it is rather difficult to imagine how it would be possible to apply the notion of "fault" to an autonomous space object that made a wrongful decision.

Accordingly, in today's space realm, it is becoming increasingly relevant to settle the question of the legal personality of intelligent space objects and the scope of responsibility when automatic intelligent systems make decisions without human supervision and input. In the process of negotiations on granting legal personality to AI, the European Commission took a straightforward position that there is currently no need to give a legal personality to emerging digital technologies, such as AI.[39] It means that space objects cannot be liable for making autonomous decisions in the course of space-related missions, and the notion of "fault" is not attributable to AI-equipped space objects in their direct meaning. The discussions of whether it is appropriate to grant a legal personality status to AI-equipped autonomous space objects raises reasonable concerns among space scholars due to the unpredictability it may entail for law enforcement and its consequences.

Objective 2: To examine the challenges of deciding who is responsible for decisions made by AI in outer space missions.

The difficulties in defining fault in international law are exacerbated by the use of AI, especially when it is as widespread and likely to continue as it is in the space sector. First, given that the development of AI cannot typically anticipate the resultant problems or situations that AI will solve, establishing what constitutes fault is difficult[40]. The ideal situation where fault would be easy to establish would involve individuals using AI systems to cause harm deliberately. However, proving fault is difficult for situation where there is unintended harm. AI systems are generally unpredictable, and the lack of control that users might have of the directions they take means that these AI systems pose unique problems in a fault-based regime. One of the examples of fault on the side of the users is the failure to maintain the automated system or oversee the functioning. It is important to note, though, that defining fault like this starts from the premise that AI is primarily a tool[41]. However, if AI is to be seen as an autonomous decision-making system, then simply putting it in operation cannot be seen as a negligent step if the system then causes harm. Operationally, especially in the space sector, it is rarely ever the case that astronauts completely hand over control to the AI systems. Instead, most AI systems are decision-assistance systems, which are designed to offer support and recommendations to human decision system. For instance, the AI system CIMON enables decision support through voice-controlled access to media and documents, while helping navigate the astronauts through repair and operational process. If an astronaut were to rely on recommendations from the AI system to make a decision, which then leads to harm, it is difficult to consider them negligent. Finding the individuals at fault essentially disconnects accountability from the locus of control, which is unfair[42]. These problems with liability raise issues when it comes to the division of responsibility between manufacturers and users, which then leads the discussion to the second issue, which is the emergence of privatization.

There has been a rapid growth in democratization of outer space. This has come as a result of a dramatic reduction of costs and access to the materials and

technologies that are used to develop spacecraft and go for space missions[43]. As a result, there has been an incredible push by the private sector into the space environment. The bulk of activity in the space sector has always been driven by the private sector. For context, in the 2010s, up to 70% of space activity was driven by the private sector[44]. Reports by the UN predict that the space business is likely to generate trillions of dollars by 2040. The critical role of private sector players has been described as the new space[45]. These growing trends in the participation of the public sector in space further reveals weaknesses in liability law, especially when it comes to the use of AI. These state-centric laws make it difficult to navigate matters of liability where these private entities are involved. First, in a state centric system, one of the first issues to establish is the jurisdiction. Given the democratization of technology and the growing dominance of the private sector, it is likely that different facets of the AI technology could be developed in different countries. Furthermore, where a private company is incorporated in one country and launches in another country, then uses technologies that are developed in different countries, the determination of fault could be difficult.

The emergence of the private sector also adds to the division of responsibility problem when it comes to liability and AI use in space. The division of responsibility between AI manufacturers and users creates problems when it comes to the establishment of liability. When looking to establish harm, it might be unclear if the harm is the result of a product defect, or the harm is the result of improper use and can at least be partially attributed to the system. The fact that these AI systems are autonomous seems to shift responsibility towards the manufacturer side[46]. The question that arises, though, is where the line can be drawn for the autonomous systems. For instance, one of the difficult legal issues that might arise is the question of whether any and all harmful actions are the responsibility and fault of the manufacturer, or whether there is a general acceptance that these autonomous systems will, even with the best efforts of the manufacturer, cause harm from time to time. The developers of the AI that is used in space could argue that it was made without any defects that could cause faults while the users could also argue that they followed the user manuals in the use of AI in space. This could make it more

challenging to determine the exact person to pay for the damages resulting from negative outcomes of the application of AI. The damage caused by non-human factors is also difficult to determine, especially because the AI could malfunction without interference.[47] With such ambiguity in the law, the allocation of liability to the developers and users of AI becomes a challenge. Further, problems might arise when dividing responsibility among the manufacturers and other stakeholders that might be involved in the functionality of the product[48]. The work of an AI system requires the complex computational elements, and the data models on which it is built. This means that if the responsibility for the harm were to fall on the manufacturer, then at the very least some of the blame should fall on the data providers.

To take things a step further, the establishment of causality could be challenging, and for two reasons. First, in a world where there is a lot of competition and a lucrative industry, most of these AI systems are opaque. Without the proper understanding of how input might lead to output, injured parties might not even in the first place realize that they have been harmed as a result of the AI systems that were used[49]. Secondly, there is the question of what level of safety is expected from AI systems that are supposed to either make decisions or offer decision support. Without clarity on what constitutes the standard of care, then it might be difficult to determine what exactly constitutes a defect that would then start off the process of establishing liability and pinning it on the producers or manufacturers of the AI systems[50]. Finally, as the AI systems become autonomous, it becomes even more difficult to draw a line back to any human actors and decisions, and as a result attribute any responsibility to any particular actor. This autonomy that is being celebrated as a step in the right direction given the risks and rangers of space exploration shifts control away from users, and in some cases even from the manufacturers themselves. Furthermore, it is also important to note that the operation of an AI system is not necessarily predictable in the same way the classic engineering systems would be. The implication here is that manufacturers often cannot see the full picture of how AI systems can act or make decisions once they are placed in the market. Consequently, it might be impossible to hold these manufacturers

responsible for the AI and how they cause harm[51]. The flip side is that as they become more autonomous, users become less able to control their operations. The overall effect is an inherent difficulty in establishing liability, particularly in a legal regime that is fault based.

Objective 3: To offer suggestions for a global legal framework that establishes rules for liability in artificial intelligence for use in space.

The answer to this objective is anchored on the following notable recommendations;

- It is recommended that the aspects of strict liability and fault-based liability be developed further to capture the emerging applicability of AI in space missions. Currently, strict liability and fault-based liability in the Liability Convention explains the extent to which states are liable for damages caused by space objects on the surface of the earth or damage occurring in space. However, the Liability Convention needs to be developed further by countries to recognize AI and the parties that will be strictly liable or liable by fault. In this case, both developers of AI and the user of AI in space missions will understand their levels of responsibility and the liability that they are bound to bear. Consequently, there will be less confusion on who is supposed to be held liability under strict liability or fault-based liability in cases of damages.
- Additionally, it is recommended that the international community should work on a unified AI framework for its applicability in space to create a safe space for space exploration. To avoid increased incidences of liability for different member states, it is fundamental that all countries work on a collaborative framework that recognizes the extent of AI application and the quality of AI technologies that should be applied to space objects. Using a unified approach will help reduce cases of both direct and indirect damages and claims of liability across countries worldwide.
- More so, there needs to be development of the ways of how and the extent to which both producers of AI technologies for space missions and users of AI for space missions are held accountable for their actions. At the bare

minimum, liability rules have to be able to induce both the manufacturers or developers and the users to take required care in the design, testing and employment of these AI systems in space exploration. This will play a vital role in reducing cases of negligence and ensuring that everyone is highly responsible for their actions while using AI.

- Finally, education and retraining on the rules related to AI use in space missions has to be an ongoing process across all countries. Given the speed at which AI is evolving, there needs to be frequent training especially for space missions to lessen the potential liability arising from damages. While mistakes may be made in the initial phases of using AI in space missions, frequent trainings will help mitigate potential faults and reduce liability claims in the future.

Discussion

Due to the issue of legal personality of AI-equipped autonomous space objects, this paper recommends that national states should continue to bear liability for space activities involving AI technologies, regardless of the level of autonomy exhibited by the space object. Moreover, private organizations should be allowed to engage in space missions only under state authorization and continuous oversight. Where a corporation or joint venture is launching an AI-enabled object, it should be liable for any damages suffered, in accordance with the liability of the state overseeing the operation. This recommendation aligns with the Liability Convention, which holds launching states liable for damage caused by their space objects on Earth, in airspace, or in outer space, irrespective of whether the activity was carried out by a government body or a private organization under its jurisdiction.[52] This would ensure that both private companies and states are held responsible in case of damages caused by AI-enabled systems in space.

This paper recommends that new international regulations governing AI use in the space industry include specific provisions to address the complex issue of intellectual property (IP) protection for AI-generated innovations. Given the legal

uncertainty around patent eligibility for AI-created inventions and the limitations of trade secret protection, it is crucial to develop a harmonized legal framework that recognizes AI's role in the inventive process. This framework should clearly define ownership rights for AI-generated outputs and establish criteria for patentability that accommodate non-human inventors. To ensure global coherence, cooperation is required between international organizations such as the World Intellectual Property Organization (WIPO), the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), and the International Telecommunication Union (ITU). These bodies should collaborate to create binding guidelines and model laws that member states can adopt, thereby safeguarding AI-driven innovation in space while promoting legal certainty and cross-border enforcement of IP rights.

Even though there is no internationally unified regulation on AI regime in space yet, future legislation should primarily be based on general international law principles applicable to outer space activities. It means that space exploration with AI space-related techniques must be performed in the interests of all states and realized peacefully, and space activities must be carried out in compliance with international law promoting international cooperation and mutual assistance.[53] As stated in the Outer Space Treaty, "the exploration and use of outer space... shall be carried out for the benefit and in the interests of all countries" and "shall be the province of all mankind," while "States Parties... shall carry on activities in the exploration and use of outer space... in accordance with international law... in the interest of maintaining international peace and security" (Articles I and III), and "not place in orbit any objects carrying nuclear weapons or any other kinds of weapons of mass destruction" (Article IV).[54] Therefore, any future regulatory framework for AI in outer space must be grounded in these long-standing principles of peaceful use, benefit-sharing, and international cooperation.

To ensure the safe and responsible future of space exploration, the international community must urgently collaborate to create unified legal standards for AI in space. As intelligent technologies evolve beyond current frameworks, proactive and cooperative regulation is essential. Only through global commitment can AI-driven space activities remain transparent, accountable, and beneficial to

all humankind—aligning innovation with shared ethical and legal values that secure the future of space for generations to come.

There has to be decisions made on the appropriateness of strict versus fault-based liability. Several relevant points have to be taken into account when making this decision. First, there have to be consideration of the balance between costs and incentives for the provision of information for the victim. Under the fault-based system, the owner of the AI system would be held liable if they failed to take safety precautions that are demanded by a certain standard of care. The owner is therefore encouraged to take action if the courts and lawmakers determine this standard of care. If the bar is either set too high or too low, then the owner of the system is incentivized to take reduced levels of care and precautions. Given the mention circumstances surrounding the use, understanding and control of these systems once they have been deployed for use in space, the situation could very well force the manufacturers and owners to tend towards a tradeoff between the safety of AI and its levels of sophistication[55]. The flip side when it comes to strict liability, on the other hand, is that the lawmaker does not necessarily require information on what is regarded as the optimal level of precaution. Strict liability rules require the owners to take the optimal levels of precaution as it then shifts all the responsibility and costs towards them. However, in a perfect situation, a strict liability rule has the owner and manufacturer bearing all the costs, failing to then have the users take appropriate care, even in situations where they, too, could be partly responsible for an accident[56]. For the future of liability to be determined as AI continues to become a mainstay in the space exploration sector, then this double moral hazard problem has to be solved.

The balance between restrictions in the levels of activity and sophistication and innovation should also be observed. It is impossible to ignore the fact that commercialization drives much of the innovation today, even in the space exploration field that has for a long time been dominated by nation-states. When looking for the perfect middle ground for liability law, there has to be a consideration of how these las might either incentivize or disincentivize innovation, given that a lot of the actions and steps that are being taken in outer space have

been proven important to the daily lives of the average citizen[57]. The strict liability rule shifts all the weight and responsibility to the manufacturer or owner of these systems that use AI in space, pushing them to observe the optimal levels of care that are possible, as they pursue the optimal levels of activity and innovation that they can. However, the use of AI, even in space, has been noted to be inherently risky, as AI and autonomous systems cannot always be controlled or their outcomes predicted[58]. In such a situation where an event can be harmful even with the best of precautions, the typical reaction often is to stop the manufacturers from engaging in the said activity completely. This would especially be ideal given that the harmful effects of AI use in space have rea-life consequences even for individuals on the earth's surface. This could be why many jurisdictions have the strict liability rules for driving cars. Fault-based regimes do not have this, as the manufacturer and owner, as the injuring party here, could avoid paying costs of their activity if they can prove that they took the required amounts of care. The problem here is that the potential wrongdoer might end up becoming too careful. The activities of those that develop these AI systems for space benefit the whole of society. However, not all the benefit that society gets trickle down to them, given the levels of risk that they take. This might lead to them being too careful, and operating below the optimum levels of activity or efficiency. This is a negative outcome because of the clear benefits of AI use in space, as well as the potential that AI use in space could have for other industries and sectors. In the end, the approach to liability should be one that does not stifle innovation in this sector, but also pushes the organizations towards risk-mitigating technologies and stop-gaps.

The development of AI systems, for space exploration or otherwise, is often an endeavor that requires multiple individuals or parties involved in the actual manufacture. The implication here is that multiple parties affect the risk of harm, and therefore liability laws and approaches should consider this. Ideally, the least-cost avoider should be the one that should be targeted by the liability rule[59]. This is the individual or party that can minimize harm at the lowest costs to them. The question of damage could be provable in a court. However, the question of who

should bear the costs of the damage should also be adjudicated. As a result, it is important to understand how the actions of various parties would result in failures. The laws have to differentiate between situations where care is complementary, such that all the parties have to take care, and situations where the care by one party is perfect substitute of the care that would be provided by another party.

Finally, there has to be ways to decide how, to what extent and when to hold both the producers of the AI technologies and the users responsible for the harm that results from their overall actions. At the bare minimum, liability rules have to be able to induce both the manufacturers or developers and the users to take required care in the design, testing and employment of these AI systems in space exploration.

Conclusion

The development of AI technologies has improved possibilities in space exploration and travel. There are multiple advantages of AI use in space missions, especially given the stakes involved. AI has the potential for reducing mistakes and missteps in the space missions, including unanticipated issues that might result in astronauts getting stuck in space or in disastrous outcomes. AI can also be useful in manufacturing and training processes, simulating the environments that resemble the space environment and improving manufacturing outcomes. Overall, AI technologies have made the whole ecosystem of space missions faster, more efficient and cheaper. However, the use of AI raises legal issues, particularly the problem of liability assignment. The current legal framework is not adequate to deal with the issues that the continued use of AI raises. Going forward, a balance has to be struck to come up with a liability regime that deals with the new liability and fault challenges that are raised by AI.

Endnotes

(1) Landry Signé, and Hanna Dooley. *How space exploration is fueling the Fourth Industrial Revolution.* March 28, 2023. https://www.brookings.edu/articles/how-space-exploration-is-fueling-the-fourth-industrial-revolution/ (accessed July 7, 2025).

(2) Materion. 6 Key trends in shaping space technology in 2025 and beyond. January 30, 2025. https://www.materion.com/en/insights/blog/six-key-trends-shaping-space-technology (accessed July 6, 2025)

(3) Ibid

(4) ibid

(5) Ndung'u Njuguna, and Landry Signé. *The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse.* January 8, 2020. https://www.brookings.edu/articles/the-fourth-industrial-revolution-and-digitization-will-transform-africa-into-a-global-powerhouse/ (accessed July 6, 2025).

(6) Ilaria Cinelli, *Will AI redefine human roles in space exploration?* January 28, 2025. https://spacenews.com/will-ai-redefine-human-roles-in-space-exploration/ (accessed July 7, 2025).

(7) Jackie Wattles, and Ashley Strickland. *NASA's Suni Williams and Butch Wilmore finally return home after more than nine months in space.* March 18, 2025. https://edition.cnn.com/2025/03/18/science/spacex-crew-9-astronauts-space (accessed July 6, 2025).

(8) Laura. *The power of AI in space exploration.* December 20, 2024. https://blogs.esa.int/exploration/the-power-of-ai-in-space-exploration/ (accessed July 7, 2025).

(9) George Anthony Gal et al., "Artificial Intelligence in Space," *arXiv* (2020)

(10) HLEG. *Liability for Artificial Intelligence and Other Emerging Technologies.* European Commission's Group of Experts on Liability and New Technologies, 2019.

(11) ESA, *ESA purchases world-first debris removal mission from start-up.* December 1, 2020.https://www.esa.int/Space_Safety/ESA_purchases_world-first_debris_removal_mission_from_start-up (accessed July 7, 2025).

(12) ibid

(13) Ugo Pagallo, Eleonora Bassi, and Massimo Durante. "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards." *Philosophy & Technology* , 2023.

(14) ESA. *Artificial intelligence in space.* August 3, 2023. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space (accessed July 7, 2025).
(15) Giovanni Tricco, et al. "The protection of AI-based space systems from a data-driven governance perspective." *Acta Astronautica*, 2025: 73-86.
(16) Marcin Tomsia, et al. "Long-term space missions' effects on the human organism: what we do know and what requires further research." *Frontiers in Psychology*, 2024.
(17) ibid
(18) Bratu, I, A R Lodder, and T Van der Linden. "Autonomous space objects and international space law: Navigating the liability gap." *Indonesian Journal of International Law*, 2021: 423–446.
(19) Martin, A, and Freeland S. "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges." *Space Policy*, 2021: 101408.
(20) ibid
(21) ibid
(22) Ugo Pagallo, Eleonora Bassi, and Massimo Durante. "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards." Philosophy & Technology, 2023.
(23) ibid
(24) Gracie Nacimento, *A general introduction to Space Law in Germany.* 2023. https://www.lexology.com/library/detail.aspx?g=8fcb085a-8145-4622-901f-098ef2298af9 (accessed July 7, 2025).
(25) Ugo Pagallo, Eleonora Bassi, and Massimo Durante. "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards." Philosophy & Technology, 2023
(26) Ugo Pagallo, Eleonora Bassi, and Massimo Durante. "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards." Philosophy & Technology, 2023
(27) Mohamed Abdelhamid, and Guoyu Wang. "Addressing the Liability Regime in the Space Convention: A Legal Reformation of the Concept of Damage and Its Application to Private Entities." *US-China Law Review*, 2024, 21, no. 2 (February). https://doi.org/10.17265/1548-6605/2024.02.001
(28) Dennerley, J A. "State liability for space object collisions: The proper interpretation of 'fault' for the purposes of international space law." *European Journal of International Law*, 2018: 281–301.

(29) Maryam Altamimi and Mohammad Farooqui, "The Extent of Space Carrier's Liability for Damages," *University of Sharjah Journal of Law Sciences* 21, no. 1 (2024): 560.
(30) Ioana Bratu et al., "Autonomous Space Objects and International Space Law: Navigating the Liability Gap," *Indonesian Journal of International Law* 18, no. 3 (2021): 424.
(31) United Nations, "Convention on International Liability for Damage Caused by Space Objects," *UN Office for Outer Space Affairs*, 1971. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html, accessed March 30, 2022.
(32) The UN, "Convention on International Liability for Damage Caused by Space Objects," *UN Office for Outer Space Affairs*, 1971. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html, accessed March 30, 2022.
(33) The UN, "Convention on International Liability for Damage Caused by Space Objects," *UN Office for Outer Space Affairs*, 1971. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html, accessed March 30, 2022.
(34) Ibid
(35) Michael Chatzipanagiotis, "Whose Fault is it? Artificial Intelligence and Liability in International Space Law" (conference paper, The CyberSpace Edition, 2020): 2.
(36) Anne-Sophie Martin and Steven Freeland, "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges," *Space Policy* 55 (2021): 2.
(37) Arnanda Yusliwidaka, Kholis Roisah, and Joko Setiyono. "State Liability for the Fault Causing Damage in Outer Space." *JED (Jurnal Etika Demokrasi)*, 2023, 8, no. 3 (August): 326–33. https://doi.org/10.26618/jed.v8i3.11398
(38) Ibid
(39) Ioana Bratu et al., "Autonomous Space Objects and International Space Law: Navigating the Liability Gap," *Indonesian Journal of International Law* 18, no. 3 (2021): 437.
(40) William D. Smart, Cindy Grimm, and Woodrow Hartzog. "An education theory of fault for autonomous systems." *Notre Dame Journal on Emerging Technologies*, 2021: 35-55.
(41) Selbst, Andrew. "Negligence and AI's human users." *Boston University Law Review*, 2020: 1315-1320.

(42) Smith, H, and K Fotheringham. "Artificial intelligence in clinical decision-making: Rethinking liability." *Medical Law International*, 2020: 131.
(43) Lyall, F, and P B Larsen. *Space Law: A Treatise*. Routledge, 2017.
(44) Vernile, A. *The Rise of Private Actors in the Space Sector*. Springer, 2018.
(45) ibid
(46) Selbst 2020
(47) Buiten, Miriam, Alexandre De Streel, and Martin Peitz. "The law and economics of AI liability." *Computer Law & Security Review*, 2023.
(48) Buiten, Miriam, Alexandre De Streel, and Martin Peitz. "The law and economics of AI liability." *Computer Law & Security Review*, 2023.
(49) Martin Ebers, "Regulating AI and Robotics." In *Algorithms and Law*, by Martin Ebers , & Sussana Navas , 44. Cambridge University Press, 2020.
(50) See *Buiten* 37
(51) Hannah Sullivan, and Scott Schweikart. "Are current tort liability doctrines adequate for addressing injury caused by AI?" *AMA journal of ethics*, 2019: 2
(52) United Nations, *Convention on International Liability for Damage Caused by Space Objects* (UN Office for Outer Space Affairs, 1973), https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/liability-convention.html, accessed May 10, 2025.
(53) Ibid
(54) United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty)*, opened for signature January 27, 1967, Japan Aerospace Exploration Agency (JAXA), https://www.jaxa.jp/library/space_law/chapter_1/1-2-2-5_e.html? accessed March 30, 2022.
(55) ibid
(56) Ugo Pagallo et. al., (2023)
(57) Buiten, De Streel and Peitz (2023)
(58) HLEG. *Liability for Artificial Intelligence and Other Emerging Technologies.* European Commission's Group of Experts on Liability and New Technologies, 2019.
(59) Jack Solowey. "AI Providers Should Not Be Liable for Users' Securities Violations" 2024 https://www.cato.org/commentary/ai-providers-should-not-be-liable-users-securities-violations

References

- Anne-Sophie Martin and Steven Freeland, "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges" p. 5.
- Arnanda Yusliwidaka, Kholis Roisah, and Joko Setiyono. "State Liability for the Fault Causing Damage in Outer Space." *JED (Jurnal Etika Demokrasi)*, 2023, 8, no. 3 (August): 326–33. https://doi.org/10.26618/jed.v8i3.11398.
- Bratu, I, A R Lodder, and T Van der Linden. "Autonomous space objects and international space law: Navigating the liability gap." *Indonesian Journal of International Law*, 2021: 423–446.
- Buiten, Miriam, Alexandre De Streel, and Martin Peitz. "The law and economics of AI liability." *Computer Law & Security Review*, 2023.
- Cinelli, Ilaria. *Will AI redefine human roles in space exploration?* January 28, 2025. https://spacenews.com/will-ai-redefine-human-roles-in-space-exploration/ (accessed July 7, 2025).
- Dennerley, J A. "State liability for space object collisions: The proper interpretation of 'fault' for the purposes of international space law." *European Journal of International Law*, 2018: 281–301.
- Ebers, Martin. "Regulating AI and Robotics." In *Algorithms and Law* , by Martin Ebers , & Sussana Navas , 44. Cambridge University Press, 2020.
- ESA. *Artificial intelligence in space.* August 3, 2023. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space (accessed July 7, 2025).
- ———. *ESA purchases world-first debris removal mission from start-up*. December 1, 2020.https://www.esa.int/Space_Safety/ESA_purchases_world first_debris_removal_mission_from_start-up (accessed July 7, 2025).
- Freeland, S, and D Ireland-Piper. "Space law, human rights and corporate accountability." *UCLA Journal of International Law and Foreign Affairs*, 2022: 1-34.
- Maryam Altamimi and Mohammad Farooqui, "The Extent of Space Carrier's Liability for Damages," *University of Sharjah Journal of Law Sciences* 21, no. 1 (2024): 560.
- George Anthony Gal et al., "Artificial Intelligence in Space," *arXiv* (2020)
- HLEG. *Liability for Artificial Intelligence and Other Emerging Technologies.* European Commission's Group of Experts on Liability and New Technologies , 2019.

- Ioana Bratu et al., "Autonomous Space Objects and International Space Law: Navigating the Liability Gap," *Indonesian Journal of International Law* 18, no. 3 (2021): 437.
- Laura. *The power of AI in space exploration.* December 20, 2024. https://blogs.esa.int/exploration/the-power-of-ai-in-space-exploration/ (accessed July 7, 2025).
- Lyall, F, and P B Larsen. *Space Law: A Treatise.* Routledge, 2017.
- Martin, A, and S Freeland. "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges." *Space Policy*, 2021: 101408.
- Materion. *6 Key trends in shaping space technology in 2025 and beyond.* January 30, 2025. https://www.materion.com/en/insights/blog/six-key-trends-shaping-space-technology (accessed July 6, 2025).
- Mohamed Abdelhamid, and Guoyu Wang. "Addressing the Liability Regime in the Space Convention: A Legal Reformation of the Concept of Damage and Its Application to Private Entities." *US-China Law Review*, 2024, 21, no. 2 (February). https://doi.org/10.17265/1548-6605/2024.02.001.
- Nacimento, Gracie. *A general introduction to Space Law in Germany.* 2023. https://www.lexology.com/library/detail.aspx?g=8fcb085a-8145-4622-901f-098ef2298af9 (accessed July 7, 2025).
- Ndung'u , Njuguna, and Landry Signé. *The Fourth Industrial Revolution and digitization will transform Africa into a global powerhouse.* January 8, 2020. https://www.brookings.edu/articles/the-fourth-industrial-revolution-and-digitization-will-transform-africa-into-a-global-powerhouse/ (accessed July 6, 2025).
- Pagallo, Ugo, Eleonora Bassi, and Massimo Durante. "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards." *Philosophy & Technology* , 2023.
- Selbst, Andrew. "Negligence and AI's human users." *Boston University Law Review*, 2020: 1315-1320.
- Signé, Landry, and Hanna Dooley. *How space exploration is fueling the Fourth Industrial Revolution.* March 28, 2023. https://www.brookings.edu/articles/how-space-exploration-is-fueling-the-fourth-industrial-revolution/ (accessed July 7, 2025).
- Smart, William D, Cindy Grimm, and Woodrow Hartzog. "An education theory of fault for autonomous systems." *Notre Dame Journal on Emerging Technologies*, 2021: 35-55.

- Smith, H, and K Fotheringham. "Artificial intelligence in clinical decision-making: Rethinking liability." *Medical Law International*, 2020: 131.
- Solowey, Jack. "AI Providers Should Not Be Liable for Users' Securities Violations" 2024 https://www.cato.org/commentary/ai-providers-should-not-be-liable-users-securities-violations
- Sullivan, Hannah, and Scott Schweikart. "Are current tort liability doctrines adequate for addressing injury caused by AI?" *AMA journal of ethics* , 2019: 2.
- Tomsia, Marcin, et al. "Long-term space missions' effects on the human organism: what we do know and what requires further research." *Frontiers in Psychology*, 2024.
- Tricco, Giovanni, et al. "The protection of AI-based space systems from a data-driven governance perspective." *Acta Astronautica*, 2025: 73-86.
- Vernile, A. *The Rise of Private Actors in the Space Sector.* Springer, 2018.
- Wattles, Jackie, and Ashley Strickland. *NASA's Suni Williams and Butch Wilmore finally return home after more than nine months in space.* March 18, 2025. https://edition.cnn.com/2025/03/18/science/spacex-crew-9-astronauts-space (accessed July 6, 2025).