Preventing the Risks of Inadequate Human-Computer Interaction (HCI) Systems in Manned Spacecraft Missions: Toward an International Public Policy Framework Proposal

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Stojchevska, Stefani and Sami Mehmeti (2024) Preventing the Risks of Inadequate Human-Computer Interaction (HCI) Systems in Manned Spacecraft Missions: Toward an International Public Policy Framework Proposal. *Advanced Space Law*, Volume 13, 51-63. https://doi.org/10.29202/asl/13/5

This scientific research paper analyzes the link between space technology and space law through specifically designed Human-Computer Interaction (HCI) systems applied in manned spacecraft missions, notably by the National Aeronautics and Space Administration (NASA). The risk of inadequate HCI systems may lead to a wide range of undesired consequences, including risks of error or failure of mission objectives, wrongly displayed information, unavailable data and confusion of the data presented, this potentially putting astronauts aboard the spacecraft in life-threatening circumstanced within their extraterrestrial working environment. Consequently, the blame is put on the lack of appropriate policies addressing the regulation of space-related HCI systems. Hence, an international public policy framework is proposed in order to ultimately ensure astronauts' safety in space exploration, as well as minimizing the risk of space-related accidents occurring during manned spacecraft missions.

Keywords: Space Law; HCI; Space Technology; Public Policy; International Regulation.

Received: 15 May 2024 / Accepted: 20 June 2024 / Published: 1 July 2024

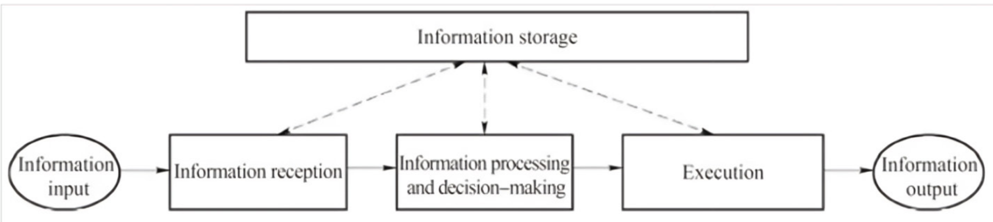
Introduction

The meaning of advanced space-related technology and its continuous developments within the space industry represents a very important question in which humankind should be relatively interested. As Professor Svetla Ben-Itzhak speculates how space technology would have multidimensional impacts upon our thriving society, including such from a political aspect, where relations between States are further classified (or rather challenged) at three primary levels: (1) the *individual* level, (2) the *state* level and (3) the *system* level (Ben-Itzhak, 2022: 1). Be that as it may, Ben-Itzhak notably describes the political interests of space-faring nations from the prism of global space economy and the formation of space alliances for achievements which seem fairly futuristic and accompanied with highly advanced technological outcomes against the background of the current technologically developed state of our society. Therefore, the political interests of space-faring nations are included in a manner that such separate classifications, as emphasized above, do not demonstrate a direct and strong correlation with space-related technology developments. This would already indicate the fine lines of discrepancy between the practical implementations of space-related technology and the theoretical adaptations of space law, policies and regulations. Nevertheless, it is within the common knowledge of every space lawyer and legal practitioner that the legal branch of space law was established particularly due to the burgeoning outer space technology (Maitin, 2022: 229; Launius, 1999). By following this legal trend, space law would expectedly advance in a parallel manner with the developments in space exploration and space-related technology. For that matter, important issues related to the further development of space law must be raised within a timely manner. However, we may simultaneously notice the unfortunate absence of space regulation being largely evident as technologies continue to rapidly advance, particularly considering their extensive magnitude and scope within the space industry. Furthermore, the challenge of providing a clear and unambiguous understanding in regards to the unbreakable link between space technology and space law could also be described as very complex and dynamic when taking into account manned spacecraft missions and space exploration itself, generally speaking. One might even claim the both concepts are "locked" within a constant state of interdependence. In other words, contemporary developments in space technology had always represented a struggle for the legal regime of international space law, where interdisciplinary collaboration would often be necessary in regards to solving such interrelated issues. At this moment, the space industry must ask itself what the further development and advancement of space-related technology means for legal or regulatory objectives. While advancements in space technology would undoubtedly have a significant impact upon multiple aspects in our human society, it is almost needless for us to additionally point out that such advancements manifest the requirement for new policies and regulations (Pagallo et al., 2023: 23). As Steven Freeland argues, appropriate legislatures and regulatory policies must accept the advancements in space-related technology due to the demand of adapted legal reviews over limited periods of time (Freeland et al., 2018: 129). Given the rather broad scope of space-related technology as implemented in manned space missions, the purpose of this scientific research paper is to attempt to improve the developments of space law through the prism of human performance in consideration of working with space-related HCI systems.

Critical analysis

Enthusiastic space actors from all over the globe – be they space-faring States or private spaceflight companies – strive toward the continuous advancement of space technology as implemented within manned spaceflight missions. One of them undoubtedly represents Human-Computer Interaction (HCI) systems, given that they play an essential role by primarily encompassing interfaces between astronauts and computers or other machines, automation and controls. Such increasingly sophisticated systems are designed for ensuring the deployment of new manned spacecraft mission systems and technology (Thompson, 2011). The incorporation of HCI within the space industry in practice is not a new occurrence, but rather dates back several decades. Namely, there have been discussions about HCI on space stations even during the late 1980s, where it is emphasized how far-reaching requirements also take into consideration their implication (Hayes, 1987: 151). This seems logical enough, as we bear in mind that HCI only had emerged in the early 1980s as an area of research and practice. More importantly, the focal points upon certain changes regarding space station interfaces was deemed necessary even for that period of time – by citing the reasoning behind such expectation of changes, as well as the ways of planning for it (Hayes, 1987: 172). At the National Aeronautics and Space Administration (NASA), HCI refers to the design, evaluation, and implementation of interactive systems that are efficient and easy to use (NASA, n.d.), which had also strived toward its numerous benefits immediately after its appearance in the then-contemporary world of technology. One evident demonstration of such interest was NASA's establishment of the Human-Computer Interaction Laboratory (HCIL) in 1984 which, among other research objectives, had aimed toward designing spacecraft computer-based workstations and HCI's, as well as research developments resulting in specific guidelines for space station human-computer interface (Rudisill & Gillan, 1989: 55). In addition, it had also considered intense efforts in testing HCI in virtual (or synthetic) environments (Noor, 1996: 2). And even after several decades later, it could be confirmed that there is still an on-going interest in HCI addressing the purposes of space exploration and manned spacecraft missions in recent years, such as NASA's contemporary Ames HCI Group (NASA, n.d.) Other researchers have also been enthusiastic for addressing HCI for space explorations through the annual Space CHI Conferences (MIT Media Lab, n.d.), while some have specifically focused on developing various types of HCI systems which are designed to support human's physical and mental performance in extraterrestrial environments (Pataranutaporn et al., 2021). For instance, Wanling Li and Hongjing Cheng have analyzed the requirements HCI systems of manned spacecrafts in deep space exploration (Li & Cheng, 2021), while on the other hand Dr. Simon B. Thompson believes that newly received interests and advances in space technology have contributed for the use of established knowledge in HCI fields and in medicine, which is invaluable in order to progress further in space exploration (Thompson, 2011). The truth of such assertion may be further confirmed by taking into account the implementation of health care informatics in space science (Djorgovski et al., 2015: 2959), as well as the technological role of health care informatics in medical devices and the field of healthcare in general (Acharya, 2010: 2957). Hence, in order for future manned spacecraft operations and missions to be best supported on a global scale, collaborative research between HCI and other areas of research is crucial (Thompson, 2011). One of such other areas of research includes space law, regulations and policies for regulating manned spacecraft missions, given that HCI is a critical component of any space-based system (Heinrich et al., 2023: 11). One question that should often be debated by space lawyers and legal practitioners is that of what policies should be adopted for HCI systems implemented in manned spacecraft missions. Considering that HCI significantly contributes towards the success of the manned spacecraft mission, simultaneously challenges space law (Pagallo et al, 2023: 7). However, academic discussions revolving around policy-making of HCI systems in manned spacecraft missions are, unfortunately, relatively scarce. Scholars had already discussed about how the Outer Space Treaties no longer provide an adequate framework to regulate the increasing use of space in regards to new technologies (de Zwart, 2018). Hence, drastic changes in space law and regulations are expected due to advancements in outer space technology (Martinez, 2021: 322). Another important aspect in the midst of emerging space-related technologies such as HCI systems in manned spacecraft missions, regulations must address their effects on safety and security, as well as sustainability (Legal Vidhiya, 2023). The development of space technology increases in a continuous manner along with human activity in outer space, where it is suggested the importance of establishing laws that would regulate HCI in manned spacecraft missions due to the risks of various legal problems, including the safety of astronauts regarding potential space-related accidents (Ruhaeni & Izadi, 2019: 369). Namely, the risks and benefits of HCI systems in manned spacecraft missions include the safety and security standards that all manned spacecraft missions should meet and guarantee. This becomes a problematic issue not only in the public sector, as *"government policy is incapable of moving fast enough to stay in front of where investment is leading us,"* but in the private sector as well, where the stark contrast between the speed of technological developments and the slowness of regulations is the main cause for "friction" experienced firsthand by industry leaders (Goessler, 2022). As further argued by Steven Freeland, manned spacecraft missions operating in high altitudes would represent yet another challenge in terms of defining the holder of responsibility for regulations stemming from manned space flight (Freeland, n.d.), where implications of both national and international legal principles as well as governing structures must consider the function and application of HCI systems of manned spacecraft. Appropriately, this scientific research paper analyzes requirements of HCI systems in deep space exploration missions, predicts the development trend of HCI systems in future manned deep space exploration mission, puts forward the conceptual model and architecture design of HCI systems based on deep space exploration mission, and discusses the implement approach. For that matter, we adopt a comparative analysis approach by adapting designs of HCI systems in manned spacecrafts in order to build up a policy framework proposal.

Figure 1: Basic Function Diagram of Human-Computer Interaction System



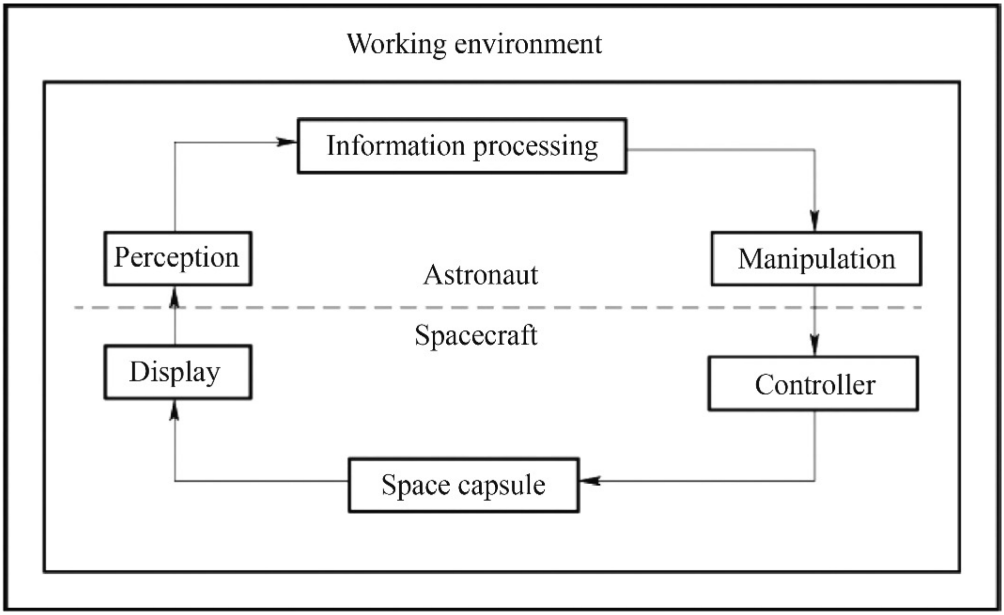
Note. Adapted from "Manned Spacecraft Technologies" (p.51) by H. Yang, 2020, Springer Nature.

The starting point of our comparative analysis begins with discussions on the basic functions of HCI systems as depicted by the "Basic Function Diagram of Human-Computer Interaction System" in Figure 1, where the entire process of "information storage" is consisted of five main components, those being the following:

1) Information input;
2) Information reception;
3) Information processing and decision-making;
4) Execution; and
5) Information output;

However, the information storage is not simultaneously reciprocal with the beginning process of information input and the ending process of the information output, because both components do not represent the astronauts' overall participation in the mental processing of the given information by the HCI system. Namely, the "information input" means that the HCI systems is receiving signals and/or commands from outer sources, while the "information output" means that the HCI system is performing and/or sending the processed information. On the other hand, information storage is simultaneously reciprocal with information reception, information processing, decision-making, and execution. Firstly, through the "information reception" component, the astronaut enters the role of the reader and makes an individual reception or interpretation of the information input displayed by the HCI system. This component is consequently followed by the astronaut's psychological approach to processing, storing and retrieving the information input displayed by the HCI system through the use of both his or her senses and previously acquired knowledge. Once the astronaut mentally assesses the alternative solutions offered by the HCI system in order to address a certain issue, he or she enters the process of making a choice through making a single decision – either rational or irrational – which represents the "information processing and decision-making" component. Lastly, for the astronaut to visually see his or her decision being completed, it is necessary to practically perform or conduct such previously made decision, which represents the "execution" component prior to the HCI system manifesting the information output, thus rounding off the entire "information storage" process, respectively. Even though the basic functions of an HCI system would seem straightforward and comprehensible for astronauts, there are some additional components identified within applicable HCI systems operating within manned spacecraft missions. Namely, when particularly discussing within the context of preventing space-related accidents, circumstances of inadequate HCI systems must be appropriately addressed by regulations aimed at preventing addressing the potential risk or endangerment of astronauts. According to the NASA Report titled *"Evidence Report: Risk of Inadequate Human-Computer Interaction,"* for instance, the risk of inadequate HCI among other core contributing factors, includes requirements, policies and design processes (Holden et al., 2013: 3). Hence, our comparative analysis continues with discussions on the HCI system in manned spacecraft missions, as depicted by the "Schematic Diagram of Human-Compute Interaction System in Manned Spacecraft" in Figure 2, where within an extraterrestrial surrounding, the "information storage" represents the main product of a continuous cycle being consisted of five interrelated components, which are simultaneously divided between each other.

Figure 2: Schematic Diagram of Human-Computer Interaction System in Manned Spacecraft



Note. Adapted from "Manned Spacecraft Technologies" (p.53) by H. Yang, 2020, Springer Nature.

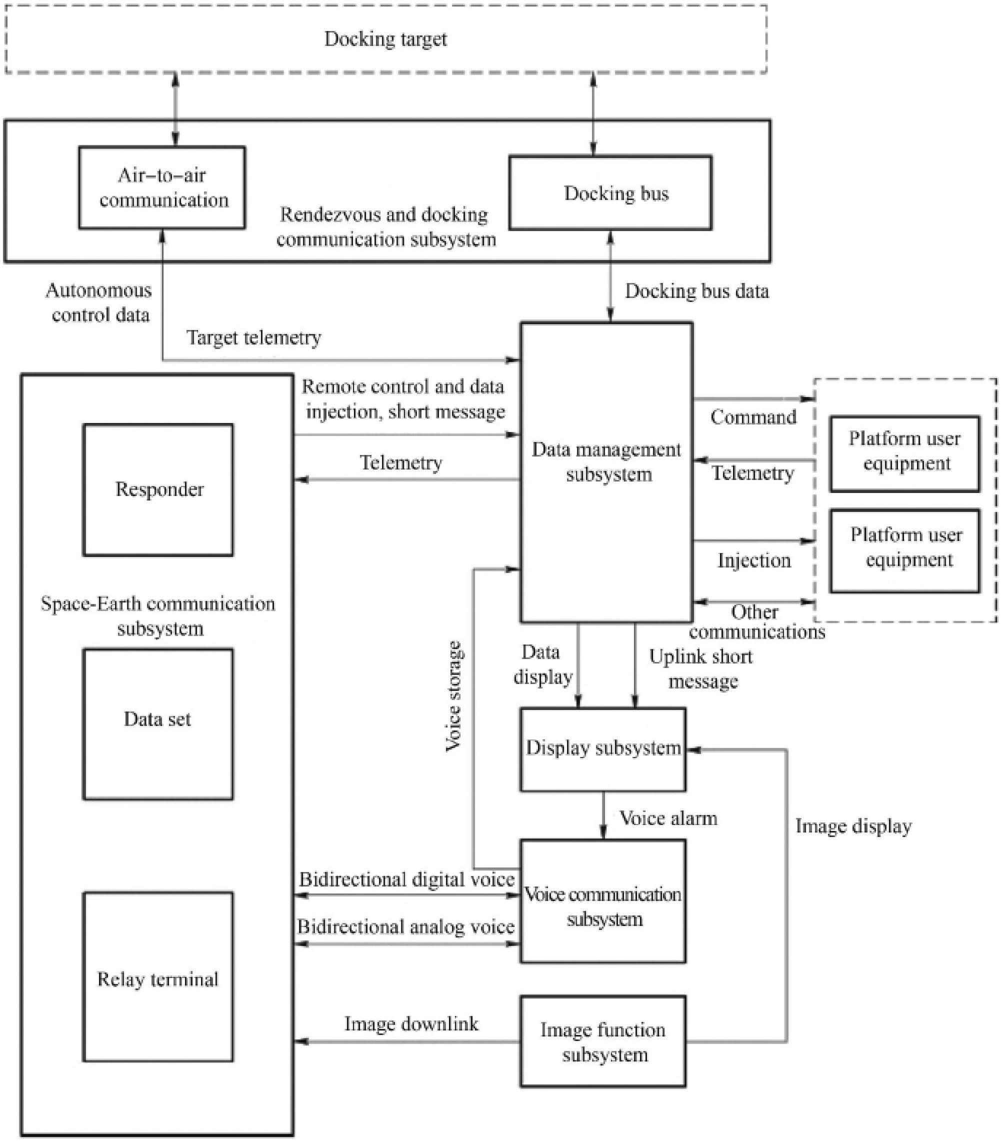
Namely, the astronaut's working environment is strictly located within the spacecraft, where an easily distinguishable division between the "astronaut" segment and the "spacecraft" segment may be simultaneously observed within the entire process of how the HCI system is designed to operate for the purposes of a manned spacecraft mission. We first begin analyzing the "astronaut" segment, which is consisted of the following components: (1) *perception;* (2) *information processing;* and (3) *manipulation*. The components obviously represent the astronauts' participation in the mental processing of the given information by the HCI system. For instance, with the astronaut becoming aware of and interpreting the signals and/or commands received by the HCI systems from outer sources through neurophysiological processes of seeing and/or hearing such signals and/or commands, represents the "perception" component. Or, the astronaut being said to use his or her cognitive processes in order to simultaneously acquire, store and use knowledge previously obtained for the purposes of the astronaut mentally assessing the alternative solutions offered by the HCI system in order to address a certain issue deemed necessary for the success of the manned spacecraft mission, represents the "information processing" component. On the other hand, the "spacecraft" segment is consisted of the following components: (1) *controller*; (2) *space capsule*; and (3) *display*. The components obviously represent the HCI's design features for the astronaut's proper use and operation during the manned spacecraft mission. For instance, the "display" component would represent the HCI system's output device displaying the signals and/or commands received from outer sources, as well as the performance and/or sending the processed information – most commonly in textual and/or pictorial form – with which the astronaut directly comes into contact through his or her senses. Altogether, the "astronaut" and "spacecraft" segments should constitute the entire operation process of an HCI system designed for and simultaneously applied in manned spacecraft missions. Nevertheless, the acceptance of error-prone HCI systems otherwise deemed workable by uncertain astronauts pulls down the risk of life-threatening endangerments and jeopardizing the entire manned spacecraft mission along with it. Unfortunately, NASA had also reported such high-risk occurrences due to the presumed lack of proper regulations addressing HCI-related issues. In other words, the displacement of both HCI regulations and astronauts' abstracted perceptions of HCI systems only increases the risk of inadequate HCI creating unsafe circumstances within extraterrestrial working environments (Holden et al., 2013: 9-10). With the priority of space flight safety, the primary goal of designing the manned spacecraft mission has to be to maximize this objective whilst achieving mission success (Shayler, 2009: 47). Hence, we emphasize once more that it would be preferable for researchers working on space-related HCI systems for manned spacecraft missions to cooperate with policymakers without either getting lost in translation (Spaa et al., 2019: 1). By further considering a socio-technical perspective toward our comparative analysis, manned spacecraft missions include yet another significant aspect – namely, the information systems which are also a crucial component for the anatomization of space-related HCI systems. The composition of the information system is shown in Figure 3 below. Generally speaking, the information systems of a manned spacecraft may be divided into six functional subsystems, where they cooperate with each other for the purpose of performing the functions of information systems:

(1) Data management subsystem;
(2) Display subsystem;
(3) Image subsystem;
(4) Voice communication;
(5) Space-Earth communication subsystem; and
(6) Rendezvous and docking communication subsystem;

The involvement of HCI within information systems is reflected in its task of manifesting interrelated collaboration between the above-mentioned subsystems for the purpose of maintain control of the spacecraft (Yang, 2020: 22) characterized by crew autonomy through a human-machine interface (HMI) allowing the astronauts aboard the spacecraft to send commands to their vehicle and review essential subsystems (Campan et al., 2022: 473).

Operating a spacecraft by the principle of crew autonomy, however, is a complicated process similar to the operation of a spacecraft by ground control, due to the fact that modern spacecraft are complex machines with more and more sophisticated software (Faller & Schmidhuber, 2022: 118). While communication is a key success element within the crew aboard the spacecraft (Uhlig & Söllner, 2022: 157), astronauts may act spontaneously to events and act less deterministically that computers (Göttfert et al., 2022: 325). This is due to the design of the spacecraft, and consequently the way how to operate them, being defined by their manufacturer (Faller & Schmidhuber, 2022: 118). This alone raises separate liability-related issues of manufacturers who specifically design space-related HCI systems in manned spacecraft missions (Vershchetin, 1990: 13). And even if there are already established policies addressing HCI development efforts, their impracticality (including such from a financial aspect), are often prone to being either waivers or entirely ignored (Holden et al., 2013: 12). At the same time, international cooperation which is developing on a broad scale in the field of exploration and use of outer space also requires an improvement of its judicial mechanism (Vereshchetin, 1990: 12).

Figure 3: Composition of Information System



Note. Adapted from "Manned Spacecraft Technologies" (p.23) by H. Yang, 2020, Springer Nature.

Conclusions

Space-related technology, including HCI systems specifically designed and applied in manned spacecraft missions, as well as space exploration in general, offer continuous advancements to our thriving society (Magagula & Witten, 2019: 813). Unfortunately, such advancements have often been built upon risks and endangerments which may lead to life-threatening consequences for astronauts(Shayler, 2000: 3). The blame could be partially placed upon the lack of appropriate public policies and regulations – on national, international and even commercial levels – addressing space-related HCI systems. In addition, given that fact that there are multiple space-faring nations currently possessing the technological capacities to launch spacecrafts and other similar objects into orbit, it would be fair enough to consider proposing an international public policy as a result of the potential cooperation between both space lawyers and HCI scientists, even though the latter had not contributed significantly in the area of policymaking before (Lazar et al., 2015: 71). The belief of this cooperation being crucial lies in the necessity for space lawyers to properly comprehend the regulatory requirements of space-related HCI systems (Freeland, n.d.).Namely, an international public policy framework regulating space-related HCI systems, especially designed and applied in manned spacecraft missions should be envisioned as a multidisciplinary (Kaneria & Pandey, 2024: 34). Meanwhile, the term "public policy" would consider both government and non-governmental aspects (Lazar, 2015: 69), as reflected in Lazar's statement that *"taken broadly, public policy includes not only laws, regulation, enforcement actions, lawsuits, and court actions, but human rights treaties, international technical standards, non-governmental organizations, and multinational organizations"* (Thomas, 2017: 474). However, it must also be understood that providing an international public policy framework regarding the proper regulation of HCI systems in manned spacecraft missions can be particularly challenging due to some obstacles that were present even in the early days of establishing space regulations parallel to outer space exploration, including the lack of political will of leading space-faring nations or the international community, as well as the disproportional developments between space technology and space law (Perek, 1990: 19). In other words, international space-related policies regulating HCI systems in manned spacecraft missions may need to evolve so that technology does not outpace it (Schrepferman, 2020). Hence, it is firmly believed that the importance of this scientific research paper may be further reflected upon technology policy and the space industry, as we acknowledge that any space flight represents some degree of risk and working in space, as in aviation, comports some hazards. When envisioning that suddenly and at any time during a mission, a situation may occur that will threaten the life of the astronauts or radically alter the flight plan, it is thus critical to the success of the mission and security of the crew is the complex process of interaction between astronauts and their spacecraft, not only in routine operation, but also in unforeseen, unplanned, and life-threatening situations.

🕮 References

Acharya, Chitra, Thimbleby, Harold and Oladimeji, Patrick (2010) Human Computer Interaction and Medical Devices. In *Proceedings of the 2010 British Computer Society Conference on Human-Computer Interaction*. Edited by Tom McEwan and Lachlan McKinnon. ACM, 2957-2959. https://doi.org/10.14236/ewic/HCI2010.22

Ames HCI Group (n.d.) (2024) *National Aeronautics and Space Administration (NASA)*. Available online: https://hci.arc.nasa.gov/

Ben-Itzhak, Svetla (2022) The Future of Space Technology and How It May Benefit Humanity. *Challenges and Opportunities at the Dawn of the New Space Age*, Spring 2022, 1-16. Available online: https://global.upenn.edu/sites/default/files/perry-world-house/space-ben-itzhakthoughtpiece.pdf

Campan, Jerome, Uhlig, Thomas, Herrmann, Dennis and Sabath, Dieter (2022) Human Spaceflight Operations. In *Spacecraft Operations (Second Edition)*. Edited by Florian Sellmair, Thomas Uhlig and Michael Schmidhuber. Springer, 473-490.

de Zwart, Melissa (2018) Outer Space. In *New Technologies and the Law in War and Peace*. Edited by William H. Boothby. Cambridge University Press, 338-358. https://doi.org/10.1017/9781108609388

Djorgovski, S., George, Mahabal, Ashish A, Crichton, Daniel J, and Chaudhry, Bushra (2015) From Stars to Patients: Lessons from Space Science and Astrophysics for Health Care Informatics. In *IEEI International Conference on Big Data*. Edited by Howard Ho, Beng Chin Ooi, Mohammed J. Zaki, Xiaohua Hu, Laura Haas, Vipin Kumar, SudarsanRachuri, ShipengYu, Morris Hui-I Hsiao, Jian Li, Feng Luo, SaumyadiptaPyne and KemaforOgan. Institute of Electrical and Electronic Engineers, 2957-2959. Available online: https://arxiv.org/pdf/1512.05272

Faller, Ralf and Schmidhuber, Michael (2022) Flight Procedures. In *Spacecraft Operations (Second Edition)*. Edited by Florian Sellmair, Thomas Uhlig and Michael Schmidhuber. Springer, 117-134.

Freeland, Steven, Hutchinson, Kirsty, and Sim, Val (2018) How Technology Drives Space Law Down Under: The Australian and New Zealand Experience. *Air and Space Law*, Vol. 43, No.2, 129-147. https://doi.org/10.54648/aila2018010

Freeland, Steven (n.d.) Following the technology: questions relevant to the future regulation of space activities. *International Bar Association*. Available online: https://www.ibanet.org/article/3E009779-2438-4C90-9E2E-554D6EDFA178

Goessler, Alyssa (2022) The Private Sector's Assessment of U.S. Space Policy and Law. *Center for Strategic and International Studies*. Available online: https://aerospace.csis.org/the-private-sectors-assessment-of-u-s-space-policy-and-law/

Göttfert, Tobias, Prüfer,Sven, and Mrowka, Falk (2022) Mission Planning for Unmanned Systems. In *Spacecraft Operations (Second Edition)*. Edited by Florian Sellmair, Thomas Uhlig and Michael Schmidhuber. Springer, 325-334.

Hayes, Phillip J. (1987) Change in Human-Computer Interfaces in the Space Station: Why it Needs to Happen and How to Plan for it. In *Human Factors in Automated and Robotic Space Systems: Proceedings of a Symposium*. Edited by the National Research Council. The National Academies Press (NAP), 151-464. Available online:https://nap.nationalacademies.org/read/792/chapter/17

Heinrich, David G.I., McAndrew, Ian, and Pretty, Jeremy (2023) Automation, Alarm Management, and Human-Computer Interaction in Space Operation Environments. *International Journal of Applied Technology and Leadership*, Volume 2, 1-15. Available online:https://www.ijatl.org/wp-content/uploads/journal/published_paper/volume-2/issue-1/article_XKc3xrk1.pdf

Holden, Kritina, Ezer, Neta and Vos, Gordon (2013) *Evidence Report: Risk of Inadequate Human-Computer Interaction*. National Aeronautics and Space Administration (NASA). Available online: https://humanresearchroadmap.nasa.gov/evidence/other/HCI.pdf

Kaneria, Bansi and Pandey, Shivam Kumar (2024) Interplay Between Technology and Law in Space Exploration. *Journal of Environmental Science, Toxicology and Food Technology*, Volume 18, 31-46.

Launius, Roger D (1999) NASA History and the Challenge of Keeping the Contemporary Past. *The National Council on Public History: Reflections on a Twentieth Anniversary (Summer 1999)*, Vol. 21, No.3, 63-81. https://doi.org/10.2307/3378961

Lazar, Johnathan (2015) Public Policy and HCI: making an impact in the future. *Interactions,* Vol.22. No.5, 69-71. https://doi.org/10.1145/2807916

Lazar, Johnathan, Abascal, Julio, Barbosa, Simone, Barksdale, Jeremy, Friedman, Batya, Grossklags, Jens, Gulliksen, Jan, Johnson, Jeff, McEwan, Tom, Martinez-Normand, Loic, Michalk, Wibke, Tsai, Janice, van der Veer, Gerrit, von Axelson, Hans, Walldius, Ake, Whitney, Gill, Winckler, Marco, Wulf, Volker, Churchill, Elizabeth F, Cranor, Lorrie, Davis, Janet, Hedge, Alan, Hochheiser, Harry, Hourcade, Juan Pablo, Lewis, Clayton, Nathan, Lisa, Paterno, Fabio, Reid, Blake, Quesenbery, Whitney, Selker, Ted and Wentz, Brian (2015) Human-Computer Interaction and International Public Policymaking: A Framework for Understanding and Taking Future Actions. *Foundations and Trends in Human-Computer Interaction*, Volume 9, Issue 2, 69-149. https://doi.org/10.1561/1100000062

Li, Wanling and Cheng, Hongjing (2021) Requirements and Architecture Design of Human Computer Interaction System for Manned Spacecraft Based on Deep Space Exploration Mission. *2021 2nd International Conference on Intelligence Computing and Human-Computer Interaction (ICHCI)*. Available online: https://ieeexplore.ieee.org/document/9708675/authors#authors

Magagula, S.G. and Witten, J (2019) Space Education and Awareness in South Africa – Programmes, Initiatives, Achievements, Challenges and Issues. In *Space Operations: Inspiring Humankind's Future*. Edited by Helene Pasquier, Craig A. Cruzen, Michael Schmid Huber and Young H. Lee. Springer Nature, 811-826.

Maitin, Ananya (2022) Growth of Space Law and Its Implications: Outer Space and International Law. *Indian Journal of Integrated Research in Law*, Vol. II, No. II, 228-240. Available online: https://ijirl.com/wp-content/uploads/2022/03/GROWTH-OF-SPACE-LAW-AND-ITS-IMPLICATIONS-OUTER-SPACE-AND-INTERNATIONAL-LAW.pdf

Martinez, Katherine Latimer (2021) Lost in Space: An Exploration of Current Gaps in Space Law. *Seattle Journal of Technology, Environmental & Innovation Law*, Vol. 11, No.2, 322-349. Available online: https://digitalcommons.law.seattleu.edu/cgi/viewcontent.cgi?article=1022&context=sjteil

Noor, Ahmed K. (1996) *Human-Computer Interactions and Virtual Environments*. The National Aeronautics and Space Administration (NASA).

Pagallo, Ugo, Bassi, Eleonora and Durante, Massimo (2023) The Normative Changes of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards. *Philosophy & Technology*, Vol. 36, No.23, 1-23. Available online: https://link.springer.com/content/pdf/10.1007/s13347-023-00626-7.pdf

Pataranutaporn, Pat, Sumini, Valentina, Ekblaw, Ariel, Yashar, Melodie, Häuplik-Meusburger, Sandra, Testa, Susanna, Obrist, Marianna, Donoviel, Dorit, Paradiso, Joseph, and Maes, Pattie (2021) SpaceCHI: Designing Human-Computer Interaction Systems for Space Exploration. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. Edited by Yoshifumi Kitamura, Aaron Quigley, Katherine Isbister and Takeo Igarashi. ACM Press, 1-6.

Payette, Julie (1994) Advancing Human-Computer Interface and Voice Processing Applications in Space. In *Human Language Technology: Proceedings of a Workshop Held at*

Plainsboro, New Jersey, March 8-11, 1994. Edited by the Defense Advanced Research Projects Agency (DARPA). Morgan Kaufmann Publishers, 416-420. Available online: https://aclanthology.org/H94-1083.pdf

Perek, Lubos (1990) Interaction between Space Technology and Space Law. *Journal of Space Law*, Vol.18, No.1, 19-30. Available online: https://airandspacelaw.olemiss.edu/pdfs/jsl-18-1.pdf

Rudisill, Marianne, and Gillan, Douglas J (1989) Human-Computer Interaction NASA Johnson Space Center. *ACM SIGCHI Bulletin*, 55-56. Available online: https://dl.acm.org/doi/pdf/10.1145/67450.67462

Ruhaeni, Neni, and Izadi, FarizFarikh (2019) The Outer Space Exploration Under International Space Law: An Islamic Point of View. *Advances in Social Science, Education and Humanities Research*, Volume 409, 369-372. Available online: file:///C:/Users/USER/Downloads/125935257%20(1).pdf

Schrepferman, Will (2020) To Make a New Framework in Space, We Have to Planet. *Harvard International Review*. Available online: https://hir.harvard.edu/to-make-a-new-legal-framework-in-space-we-have-to-planet/

Shayler, David J (2000) *Disasters and Accidents in Manned Spaceflight*. Springer-Praxis.

Shayler, David J (2009) *Space Rescue: Ensuring the Safety of Manned Spaceflight*. Springer-Praxis.

Spaa, Anne, Durrant, Abigail, Elsden, Chris and Vines, John (2019) Understanding the Boundaries between Policymaking and HCI. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Edited by Stephen Brewster and Geraldine Fitzpatrick. ACM, 1-15. Available online: http://nrl.northumbria.ac.uk/id/eprint/38369/1/Spaa%20et%20al%20-%20Understanding%20the%20Boundaries%20between%20Policymaking%20and%20HCI%20AAM.pdf

SpaceCHI (n.d.) *MIT Media Lab*. Available online: https://spacechi.media.mit.edu/

Space Law & Policy: Critical Study on International Legal Regulation (2023) *Legal Vidhiya.* Available online: https://legalvidhiya.com/space-law-policy-critical-study-of-international-legal-regulation/

The Future Regulation of Space Technologies: Plugging the gaps in space (2024) *Regulatory Horizons Council.* Available online: https://assets.publishing.service.gov.uk/media/6620cf9a77a30aa0c4757d35/rhc_report_on_the_future_regulation_of_space_technologies.pdf

Thomas, Vanessa, Remy, Christian, Hazas, Mike and Bates, Oliver (2017) HCI and Environmental Public Policy: Opportunities for Engagement. In *CHI '17: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. Edited by Gloria Mark. ACM, 6986-6992. Available online: https://eprints.lancs.ac.uk/id/eprint/84117/1/HCI_and_EPP_3.pdf

Thompson, Simon B (2011) Space Medicine. Not as we Know it. Human-computer Interaction, Night Nurses Paralysis and Space Technology. *Webmed Central*. Available online: http://static.webmedcentral.com/article_view/1749

Uhlig, Thomas and Söllner, Gerd (2022) Human Factors in Spaceflight Operations. In *Spacecraft Operations (Second Edition)*. Edited by Florian Sellmair, Thomas Uhlig and Michael Schmidhuber. Springer, 135-159.

Vereschetin, V.S. (1990) Legal Regulation of Space Activities: Which Way Will It Advance Further? *Journal of Space Law*, Vol.18, No.1, 11-18. Available online: https://airandspacelaw.olemiss.edu/pdfs/jsl-18-1.pdf

What is HCI? (n.d.) *Human-Computer Interaction Group*. Available online: https://hci.arc.nasa.gov/about/hci.html

Yang, Hong (2020) *Manned Spacecraft Technologies*. Springer Nature.