The Metaverse and Space Informatics

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First published October 2024

Publisher: PolyU Press
Hunghom, Kowloon, Hong Kong SAR China

ISBN 978-962-367-893-3

Contents

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Preface

In recent years, one of the most intriguing research fields has been space informatics. The use of AI, robots, IoT systems and theories in the design and development of spacecraft, operation of space systems, and their related technologies are known as space informatics. Many space exploration and exploitation missions are in part sustained by the growing informatics approach, in aspects that include design, prediction, planning, navigation and control of ground stations, satellites, spacecraft, and robotics. Space informatics requires hardware and software integration, as well as various computer architectures with sensors, networks, and apps, among other things, for simulation and optimisation, decision-support methods and algorithms. Furthermore, given the sophisticated, high cost, and high-risk characteristics of space missions and the systems associated with spacecraft, improved technologies in 3D modelling, computer simulation, workflow optimisation, and decision-support approaches are necessary to increase safety, reliability, efficiency, and effectiveness in deep space exploration and exploitation. The challenges involved have given us the motivation to write a book that relates to state-of-the-art space informatics with metaverse technologies and their integration. This book outlines the latest research and cutting-edge space exploration and metaverse technologies, with the goal of contributing to current and future space missions and spaceflight development.

Deep space exploration and exploitation refer to the integration of various disciplines including astronomy, astronautics, and space technology needed for exploring the distant regions from the Moon and beyond. Deep space exploration is challenging partly due to the large amount of resources and the complexity of the technologies involved. A more economic and efficient approach is to be based on computer simulations with mixed reality. Computer simulations enable outer space experiments to be conducted in the digital or metaverse environment to simulate the many complex situations and scenarios by modelling for evaluation. With the wider adoption of virtual reality (VR), the results from simulations can be visualised, modified, and interacted with. The metaverse offers a network of interconnected virtual worlds that enhance a single virtual space, usually provided by VR. Each digital context in the metaverse can be designed and managed independently and allows users to move freely from one virtual space environment to another. This book aims to provide researchers, engineers, designers, practitioners, and others with a wide range of methods and tools for control and collaboration when conducting deep space exploration experiments, verifying safety measurements, maintenance and settings in the spaceship, robots, man and machine, and astronauts and machines, that are important in deep space exploration.

Ir Prof. Yung Kai-leung

Ir Prof. Andrew Ip Wai-hung

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Chapter 1

Metaverse-Enabling Technologies in Deep Space Exploration Applications

Abstract

Deep space exploration and exploitation refers to astronomy, astronautics, and space technology that is involved with exploring the distant regions of outer space. However, deep space exploration is difficult due to the large amount of resources and the complexity of the technologies involved. A more economic and efficient approach is based on computer simulations. Computer simulations enable outer space experiments to be conducted in the digital environment, while many complex situations and scenarios can also be modelled for evaluation. With the wider adoption of virtual reality (VR), the results from the simulations can be visualised, modified, and interacted with. The metaverse offers a network of interconnected virtual worlds that enhances the single virtual space that is usually provided by VR. Each digital context in the metaverse can be designed and managed independently, and allows users to move freely from one virtual space environment to another.

This provides stakeholders with a wide range of control and collaboration opportunities for deep space exploration and other collaborative tasks such as conducting experiments, verifying safety measurements, maintenance and settings in the spaceship that are particularly important in many deep space activities. This chapter introduces the recent literature as well as the metaverse paradigm in deep space exploration.

Keywords: metaverse, deep space exploration, deep space mission

1 Introduction

The emerging metaverse paradigm promises to transform domains ranging from social connection to professional collaboration. This transformation is enabled by the metaverse's integration of extended reality, pervasive networking, blockchain architectures, and artificial intelligence. While early metaverse applications targeted entertainment and virtual economies, the potential to enhance specialised technical fields is gaining increasing attention.

One domain ripe for metaverse disruption is deep space science and exploration. Defined as the realm spanning from beyond low Earth orbit to the farthest reaches of the solar system, deep space represents humanity's next frontier. Realising ambitious initiatives in deep space will require advances across key capabilities including communication, autonomous operations, human-machine collaboration, and integrated modelling. The metaverse offers convergence potential to enhance these areas through immersion, persistent connectivity, intelligent automation, and unified data integration.

This literature review synthesises early research at the intersection of metaverse technologies and deep space applications. The objective is to extract insights from contributions across diverse disciplines, and to assess the potential benefits and challenges of applying the metaverse paradigm to space systems. Trends in the findings reveal a burgeoning research nexus between established aerospace engineering foundations and ascendant digital transformation trends. Strategic investment in this synergistic relationship promises to unlock deep space's next frontiers by leveraging metaverse technology capabilities to profoundly augment the human experience.

2 Literature Review

The metaverse, a term that has gained significant attention in recent years, represents a collective virtual shared space created by the convergence of physical and virtual reality. This space is not just a representation of the world as we know it, but is a world fully built and populated by the creativity of its inhabitants, enabled by a range of key technologies. Meanwhile, deep space exploration represents humanity's quest to learn more about our universe, expanding our knowledge and presence beyond the confines of our planet.

2.1 Defining the Metaverse

The metaverse is an expansive network of digital experiences and assets that are interoperable and accessible across different hardware platforms (Ritterbusch & Teichmann, 2023). It represents a collective virtual shared space that is created by the fusion of virtually enhanced physical reality and physically persistent virtual reality, converging in a shared online space that is persistent, spans the digital and physical worlds, incorporates a fully functioning economy, and is populated by "users and Ais" (Gao et al., 2023).

2.2 Key Technologies Enabling the Metaverse

Artificial Intelligence (AI) plays a crucial role in the metaverse, with subsets such as Machine Learning (ML), Natural Language Processing, and Computer Vision being integral components. AI enables personalised experiences, automates processes, and drives interactivity in the metaverse (Saritas & Topraklikoglu, 2022).

Technologies such as 5G/6G, the Internet of Things (IoT), Cloud Computing, and Edge Computing are vital to the functioning of the metaverse. They ensure the high-speed data transfer, ubiquitous connectivity, and real-time processing required for immersive and seamless metaverse experiences.

Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Brain-Computer-Interface (BCI), is the foundation of the metaverse. These technologies enable the creation of immersive digital environments and interactions (Gao et al., 2023).

Blockchain, Smart Contracts, and Cryptocurrency underpin the economy of the metaverse, facilitating secure and transparent transactions of digital assets and services (Ritterbusch & Teichmann, 2023).

Digital Twins, Computational Simulation, Asset Twins, System Twins, and Avatars enable the creation of digital representations of physical entities and environments in the metaverse, facilitating interaction and experimentation (Saritas & Topraklikoglu, 2022).

2.3 Deep Space Exploration

Deep space exploration involves the investigation of cosmic bodies beyond the Earth's moon, including other planets, asteroids, and exoplanets (Wu et al., 2012). Activities in this field include the deployment of spacecraft, satellites, and astronauts for various missions aimed at better understanding the universe.

2.4 Research Questions

Given the expansive capabilities of the metaverse and the vast potential of deep space exploration, several key research questions arise:

1. What are the applications of the metaverse in the deep space industry?
2. What are the impacts of key enabling technologies in the metaverse on the deep space industry?
3. How is the metaverse's development challenge and future opportunity in the deep space industry?

Exploring these questions will provide valuable insights into how the metaverse can be leveraged for advancements in deep space exploration, potentially facilitating new discoveries, enhancing efficiency, and opening novel opportunities in the field.

3 Methodology

In the pursuit of a comprehensive and systematic review of the literature related to the metaverse's applications in deep space exploration, we employed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. PRISMA is a renowned approach for conducting systematic reviews and meta-analyses, and it offers a robust framework to ensure the transparency and completeness of the review.

Our sources for this study were three of the most respected academic databases: Web of Science, IEEE Xplore, and ScienceDirect. We used the PRISMA flow diagram to guide our methodology, offering, as it does, a clear visual representation of the process we undertook in the identification, screening, eligibility assessment, and final inclusion of studies in this review.

3.1 Identification

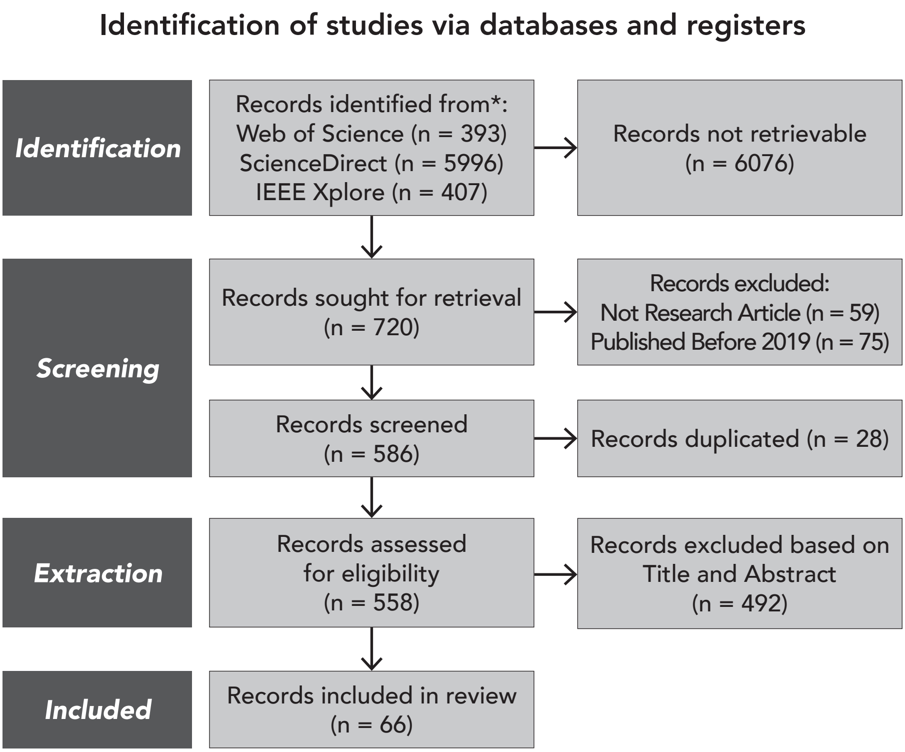

Figure 1. PRISMA Analysis Flowchart

Table 1. The Search Query Used in Three Databases Searching

Database	Search Query
Web of Science	(“Metaverse” OR “Metaverses” OR “Artificial Intelligence” OR “Machine Learning” OR “Natural Language Processing” OR “Computer Vision” OR “Networking” OR “5G” OR “6G” OR “Internet of Things” OR “Cloud Computing” OR “Edge Computing” OR “Extended Reality” OR “Virtual Reality” OR “Augmented Reality” OR “Mixed Reality” OR “Blockchain” OR “Smart Contracts” OR “Digital Twins” OR “Simulation” OR “Virtual Environment”) AND (“deep space” OR “deep space exploration” OR “deep space mission” OR “space exploration” OR “human space exploration” OR “space mission” OR “aerospace” OR “astronaut” OR “satellite” OR “asteroid” OR “space vehicle” OR “exoplanet” OR “spacecraft” OR “earth observation”), Open Access, Document Types: Article, Publication Years: 2019 or 2020 or 2021 or 2022 or 2023
Science Direct	(“Metaverse” OR “Metaverses” OR “Artificial Intelligence” OR “Machine Learning” OR “Natural Language Processing” OR “Computer Vision” OR “Networking” OR “5G” OR “6G” OR “Internet of Things” OR “Cloud Computing” OR “Edge Computing” OR “Extended Reality” OR “Virtual Reality” OR “Augmented Reality” OR “Mixed Reality” OR “Blockchain” OR “Smart Contracts” OR “Digital Twins” OR “Simulation” OR “Virtual Environment”) AND (“deep space” OR “deep space exploration” OR “deep space mission” OR “space exploration” OR “human space exploration” OR “space mission” OR “aerospace” OR “astronaut” OR “satellite” OR “asteroid” OR “space vehicle” OR “exoplanet” OR “spacecraft” OR “earth observation”)
IEEE Xplore	(“All Metadata”:“Metaverse” OR “All Metadata”: “Metaverses” OR “All Metadata”:“Artificial Intelligence” OR “All Metadata”:“Machine Learning” OR “All Metadata”:“Natural Language Processing” OR “All Metadata”:“Computer Vision” OR “All Metadata”:“Networking” OR “All Metadata”:“5G” OR “All Metadata”:“6G” OR “All Metadata”:“Internet of Things” OR “All Metadata”:“Cloud Computing” OR “All Metadata”:“Edge Computing” OR “All Metadata”:“Extended Reality” OR “All Metadata”:“Virtual Reality” OR “All Metadata”:“Augmented Reality” OR “All Metadata”:“Mixed Reality” OR “All Metadata”:“Blockchain” OR “All Metadata”:“Smart Contracts” OR “All Metadata”:“Digital Twins” OR “All Metadata”:“Simulation” OR “All Metadata”:“Virtual Environment”) AND (“All Metadata”:“deep space” OR “All Metadata”:“deep space exploration” OR “All Metadata”:“deep space mission” OR “All Metadata”:“space exploration” OR “All Metadata”:“human space exploration” OR “All Metadata”:“space mission” OR “All Metadata”:“aerospace” OR “All Metadata”:“astronaut” OR “All Metadata”:“satellite” OR “All Metadata”:“asteroid” OR “All Metadata”:“space vehicle” OR “All Metadata”:“exoplanet” OR “All Metadata”:“spacecraft” OR “All Metadata”:“earth observation”)

To start with the identification phase, we divided our search terms into two primary categories. The first category focused on the metaverse and its key technologies, including terms such as "Artificial Intelligence", "Machine Learning", "Natural Language Processing", "Computer Vision", "Networking", "5G", "6G", "Internet of Things", "Cloud Computing", "Edge Computing", "Extended Reality", "Virtual Reality", "Augmented Reality", "Mixed Reality", "Blockchain", "Smart Contracts", "Digital Twins", "Simulation", and "Virtual Environment".

The second category of terms we searched for was related to deep space missions. These terms included "deep space", "deep space exploration", "deep space mission", "space exploration", "human space exploration", "space mission", "aerospace", "astronaut", "satellite", "asteroid", "space vehicle", "exoplanet", "spacecraft", and "earth observation".

Our initial search across the three databases yielded 393 records from Web of Science, 5,996 records from ScienceDirect, and 407 records from IEEE Xplore.

3.2 Screening

Following the identification stage, we moved on to the screening of the identified records. The criteria for inclusion in our study were that the paper must be available in full text, must be related to the metaverse and deep space, must be written in English, and must have been published in or after 2019.

Exclusion criteria were also established to further refine our search. We excluded records if the full text was not available, if the paper was not related to the metaverse and deep space, if the paper was written in a language other than English, and if the paper was published before 2019.

We also defined eligibility criteria to ensure the quality of our sources. To be eligible, a document had to be an original research paper published in an academic journal or conference, it had to be a complete research paper presenting the research issue, process, and results, and it had to address a research topic related to virtual commerce.

The application of these criteria resulted in the exclusion of 6,076 records that were not retrievable, 59 records that were not research articles, 75 records that were published before 2019, and 28 records that were duplicated.

3.3 Extraction

The records that passed our screening phase were then subjected to an extraction process. At this stage, we examined the titles and abstracts of the remaining papers to ensure they were relevant to our study. This resulted in the exclusion of an additional 492 records that did not meet our inclusion criteria.

After this rigorous process, we were left with a total of 66 papers. These papers, carefully extracted from thousands, form the basis of our literature review. They present a comprehensive overview of the application of metaverse technologies in deep space exploration and offer valuable insights into the challenges and opportunities in the field.

The use of AI, robots, IoT systems and theories in the design and development of spacecraft, operation of space systems, and their related technologies are known as space informatics. This book relates to state-of-the-art space informatics with metaverse technologies and their integration. It also outlines the latest research and cutting-edge space exploration and metaverse technologies, with the goal of contributing to current and future space missions and spaceflight development.

This book aims to provide researchers, engineers, designers, practitioners, and others with a wide range of methods and tools for control and collaboration when conducting deep space exploration experiments, verifying safety measurements, maintenance and settings in the spaceship, robots, man and machine, and astronauts and machines, that are important in deep space exploration.

PolyU Press
香港理工大學出版社

ISBN: 978-962-367-893-3

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HKD $338