HEDGE
Hypersonic ReEntry Deployable Glider Experiment

INTELLIGENT SYSTEMS IN MARS EXPLORATION

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Hypersonic technology (systems traveling at speeds significantly greater than Mach 5) is increasingly being invested in by the US government and private sector. (Cooper, 2022) This field of research and development has both civilian and military applications, with military applications being a short term goal. For the military, hypersonic weapons have a unique combination of speed and maneuverability that make them difficult to defend against. On the civilian side, applications include advanced, high-speed air travel and space exploration. A CubeSat, a small satellite that can be launched relatively inexpensively and designed with many commercial off the shelf parts, can be used for undergraduate education. This team of undergraduates will use a CubeSat to perform a hypersonic glider flight experiment. By using a CubeSat, university students can conduct these experiments at a lower cost, and with greater accessibility than traditional means. This technical report will explore the radio communication requirements for the ground and space segments of the HEDGE CubeSat.

A significant shift in the role of Earth-based mission control is occurring, transitioning from direct command like, HEDGE radio comms, to a more supportive role. More decisions will need to be made by astronauts without the assistance of Earth, yet we don't want to leave them completely defenseless. This research aims to understand the socio-technical implications of intelligent systems in the context of Mars missions, exploring how these systems can supplement the lost assistance caused by communication delays. These technologies may be able to support astronauts more than Earth-based mission control given adequate funding and development. This STS paper will discuss the various types of intelligent systems, their applications on Mars, and future work that will be necessary to send these systems to Mars. Additionally, it will address the following research question: " To what extent are intelligent systems catalyzing a paradigm shift in communication strategies and protocols for interplanetary missions, and how are these shifts enhancing human space exploration and the public perception of remote, autonomous communication systems?"

Technical Topic

Communications

Subsystem Design Requirements

In the field of hypersonics and radio communication, HEDGE investigates the convergence of high-velocity flight technology with advanced radio communication systems, addressing the technical intricacies that underpin efficient data transfer within the iridium satellite constellation and the earth-based ground station. The HEDGE communication subteam consists of six team members, myself, Sean Jolly, Kate Wilkins, Idriss Shively, Emmanuel Kenscoff and Tyler Spittle.

Summary of Major Elements

The communication system of the HEDGE CubeSat comprises several key components: a transceiver, relay satellites, a ground station, and an antenna. The transceiver functions as a combined transmitter and receiver, sending radio frequency (RF) signals as electromagnetic waves to the relay satellites. These relay satellites play a critical role in maintaining continuous contact with the CubeSat in orbit, eliminating the need for direct alignment with a ground station. When organized into a constellation, these orbiting satellites in Low Earth Orbit (LEO) ensure uninterrupted communication with the HEDGE CubeSat. The data transmitted to these relay satellites can then be swiftly forwarded to the ground station with minimal delay. The ground station serves as the central data collection hub on Earth, where data is stored for subsequent analysis. In the case of HEDGE, the ground station is represented by a personal computer equipped with the necessary software for data collection. The receiver component of the transceiver is employed to receive commands from the ground station, facilitated by an inter-satellite link, known as the relay satellites. A crucial subcomponent of the transceiver is the modulator, responsible for encoding collected data into RF waves for transmission and decoding received commands, converting RF waves back into usable data. The antenna's primary role is to transmit and receive RF waves between the CubeSat and relay satellites as they traverse space.

Although antennas can assume various forms, CubeSats often employ passive patch antennas. These antennas are semi-directional and require no additional power source.

Data Rate Determination

To determine the data transmission rate required based on the functional goals of the communications team, an analysis was performed. To begin it was determined that onboard the spacecraft, 4 thermocouples and 4 pressure transducers would be providing readings during the mission life of the spacecraft. Not expecting temperature or pressure measurements to exceed the integer 65535, it was determined that each measurement would be 2 bytes. With a desire to take 4 measurements per second, the data rate per sensor would be 8 bytes per second. Therefore, the entire sensor array would be collecting 64 bytes of data per second. Based on the communications functional goals, data will be transmitted once every 10 seconds. At a data collection period of 13 minutes based on reentry and burn up time, we are expecting a total of 49.92 kbytes of data transmission during reentry.

Details of Subsystem Assembly

To ensure the functionality of the communications system, the connection of the Iridium 9603 Transceiver to both the motherboard and antenna is vital. For the prototype, we will utilize the RockBLOCK 9603, which features the integrated Iridium 9603 transceiver and a patch antenna. This RockBLOCK 9603 unit will be linked to the Raspberry Pi via a 10-pin Molex-style cable. This connection to the Raspberry Pi serves the purpose of enabling the transceiver to receive commands and receive power. During the actual in-flight mission, the Taoglas IP.1621.25.4.A.02 patch antenna will be affixed to a PCB board equipped with an integrated ground plane. It will be connected to the transceiver via a U.fl cable. The Iridium 9603 Transceiver comes with a Samtec low-profile header connector, which is affixed to a Samtec header female socket. This setup allows the transceiver to be soldered to a PCB that will connect to the in-flight onboard computer.

STS TOPIC

The function of Earth-based mission control will shift as we launch human missions to Mars. Earth-based mission control, which traditionally provides real-time communication with astronauts aboard the Moon or the International Space Station (ISS), faces a unique challenge when it comes to Mars missions. The large distance between the planets introduces a significant time delay, ranging from 6 to 22 minutes in one direction. This means a 12 to 44 minute lag when waiting for a response from the Red Planet. This time delay means that astronauts on Mars cannot rely on the quick response times they're accustomed to on Earth during emergencies or time-sensitive situations. Consequently, a significant shift in the role of Earth-based mission control is occurring, transitioning from direct command to a more supportive role. Within the trajectory of space exploration, a central research question guides our exploration of this evolving landscape: "To what extent are intelligent systems catalyzing a paradigm shift in communication strategies and protocols for interplanetary missions, and how are these shifts enhancing human exploration and the public perception of remote, autonomous communication systems?" More decisions will need to be made by astronauts without the assistance of Earth, yet we don't want to leave them completely defenseless. We can send the humans to Mars with Intelligent Systems to supplement the lost assistance caused by communication delays. Robots that operate on their own, systems for augmented or virtual reality, and other AI implementations are all examples of intelligent systems. Intelligent technologies may be able to support astronauts more than Earth-based mission control given adequate funding and development.

Intelligent systems are indeed catalyzing a significant paradigm shift in communication strategies and protocols for interplanetary missions, which, in turn, have significant effects on human space exploration and the public perception of remote, autonomous communication systems. Traditionally, interplanetary communication involved the transmission of vast amounts of raw data from remote spacecraft or rovers to Earth. Human operators would then painstakingly analyze this data, making decisions based on their interpretations. This approach had several limitations, including significant time delays, resource-intensive human intervention, and the potential for data loss or misinterpretation.

Intelligent systems have revolutionized this process by automating data analysis and interpretation. These systems can process and understand large quantities of data quickly, providing astronauts and mission planners with easily discernible maps or summaries of critical information. This acceleration of data processing enables faster decision-making, route planning, resource identification, and scientific exploration on Mars and beyond. This socio-technical paradigm shift enhances human space exploration in several ways: Efficiency: Intelligent systems drastically reduce the time required to process data, enabling more agile mission planning and quicker responses to unexpected challenges. This efficiency contributes to the success and safety of interplanetary missions. Resource Conservation: By automating data analysis, the need for extensive human resources on Earth is reduced, allowing for cost savings and optimized resource allocation in space missions. Early Warning Systems: Intelligent systems can monitor the health and behavior of critical mission components, detecting anomalies before they become hazardous. This proactive approach enhances astronaut safety and mission reliability. Scientific Return on Investment: The rapid analysis and presentation of data lead to the identification of locations of scientific interest more quickly, maximizing the scientific value of missions.

The paradigm shift in communication strategies, driven by the integration of intelligent systems in the context of Mars missions, extends beyond technical efficiency to encompass profound socio-technical implications. As we journey towards human missions on Mars, Earth-based mission control undergoes a transformative evolution, necessitating a more supportive role due to significant time delays in communication. This shift prompts a closer examination of the socio-technical dynamics at play. The challenges faced by astronauts on

Mars, the integration of autonomous intelligent systems, and the resultant changes in decision-making processes collectively mark a socio-technical paradigm shift. It's not merely a technological advancement but a transformation in how technology interacts with the social fabric of space exploration. Importantly, these shifts reverberate in public perception, shaping how society views space exploration endeavors. As intelligent systems streamline communication with Mars and distant celestial bodies, the public witnesses a more dynamic, interactive, and successful space exploration narrative. This narrative extends beyond Mars missions to include hypersonics, CubeSat Communications with projects like HEDGE, and other innovative endeavors. The ability to provide real-time or near-real-time updates, coupled with engaging the public in decision-making through data visualizations and easily comprehensible information, fosters greater interest and support for space missions. The paradigm shift towards autonomous communication systems, underpinned by intelligent technology, transforms space exploration into a more accessible and engaging endeavor for the public. As interplanetary missions continue benefiting from these communication advancements, human space exploration emerges as a more integrated and collaborative effort. This collaborative ethos has the potential to inspire a new generation of scientists, engineers, and explorers. In essence, the socio-technical paradigm shift not only enhances the efficiency and safety of space missions but also actively engages and inspires the broader public, making space exploration a shared venture for humanity's future.

Conclusion

Within this exploration of hypersonic technology, CubeSat communication, and the socio-technical dimensions of interplanetary missions underscores a transformative journey at the intersection of technological innovation and societal evolution. From the high-speed field of hypersonic systems to the accessible frontiers of CubeSat experiments, and the intricate dynamics of HEDGE CubeSat communication, a common thread emerges – the pervasive influence of intelligent systems in reshaping the landscape of space exploration. As Earth-based mission control adapts to the challenges of Mars missions, the socio-technical paradigm shift becomes evident, not only as a technological progression but as a profound transformation in how society engages with the cosmos. This shift reverberates in public perception, rendering space exploration a dynamic, interactive narrative that captivates and inspires. In essence, the integration of intelligent systems propels us into a future where space exploration becomes a shared endeavor, enhancing efficiency, safety, and public involvement on the celestial journey ahead.

References

Key Texts:

First Article: Artificial Intelligence Support for Landing Site Selection on Mars

This research article outlines the challenges in selecting optimal landing sites on Mars due to increasing data volumes and the multifaceted constraints imposed by engineering and scientific considerations. The proposed AI-driven decision support system aims to empower scientists, mission designers, and engineers to explore diverse site selection choices based on available data. By utilizing fuzzy logic and rover mobility simulations, the system generates favorability maps of the Martian terrain, enabling the definition of various rover configurations and constraints. The study identifies Eastern Margaritifer Terra and Meridiani Planum as top-favorable landing sites, considering high scientific targets and easily traversable surfaces. It also demonstrates how altering mission parameters, such as landing elevation limits, can significantly expand potential exploration regions, offering crucial insights into the impact of constraints on mission exploration capabilities.

Second Article: Computer-Aided Exploration of the Martian Geology

Focusing on the significant advancements in planetary data and resolution, this article highlights the value of computer-aided decision support systems in planetary exploration, specifically in evaluating Martian geology and landing site favorability. The analysis, based on current technical capabilities, identifies Eastern Margaritifer Terra and Meridiani Planum as standout regions due to their rich scientific targets and flat terrains. However, the study also emphasizes the potential for increased landing elevations and rover speeds, providing insights into broader exploration scenarios. This research highlights the interplay between technical and scientific constraints, unveiling potential benefits for future advancements in mission capabilities.

Third Article: Analytical Framework for Space Debris Collision Avoidance Maneuver Design

Offering an analytical approach, this article presents a maneuver design framework to mitigate collisions between spacecraft and space debris. By using Gauss's planetary equations and relative motion equations, the model maps collision avoidance maneuvers at predicted close approach times. The study extends this framework to propagate changes in state between intervals, providing an optimized solution for both maximum deviation and minimum collision probability scenarios. The research compares multiple spacecraft-debris conjunction geometries and evaluates the impact of lead time on collision probability reduction, finding that uncertainties and deviations tend to grow over extended lead times. Utilizing b-plane analysis, the study dissects the effects of phasing and geometry changes in collision avoidance strategies.

Fourth Article: Human and artificial intelligence considerations for long duration space travel

This paper analyzes how instantaneous communication with ground support is crucial for ensuring the safety of crew members in space. Nevertheless, as space missions venture deeper into the cosmos, extended delays in communication become inevitable. In situations where time is of the essence and human life is at stake, it becomes imperative to rely on onboard Artificial Intelligence (AI) technology to aid in decision-making and response for anomaly mitigation. This article explores the human factors that need to be taken into account to facilitate effective problem-solving by the crew, minimize errors, and elevate safety standards during exploration-class missions.

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