Development of Aerial Unmanned Ground Vehicles (UGV) to Enhance Support for the ARTEMIS Lunar Mission

Gliese-514b

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Signature of the sponsoring faculty advisor verifying that he has read and reviewed the paper prior to submission to NASA.

CONTENTS

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I. Executive Summary

Team Gliese-514b introduces a groundbreaking Aerial Unmanned Ground Vehicle (AUGV) tailored for the ARTEMIS Lunar Mission. Our AUGV is designed to navigate the moon's challenging terrains, merging aerial and terrestrial capabilities for optimal exploration. Pioneering a unique approach, we utilize reconfigurable computing platforms to calculate real-time energy consumption during mode transitions. This innovative solution ensures efficient energy use, enabling extended operational duration. Our renewed team composition, with diverse expertise, commits to bridging the technological gaps in lunar exploration, enhancing mission success potential, and charting a path for future interplanetary endeavors.

II. Initial Project Schedule

The Gantt chart presented in Appendix A offers a comprehensive overview of Gliese-514b's meticulous project plan. The endeavor unfolds through three distinct phases, each marked by specific objectives and actions, meticulously structured for success:

- ***Phase 1: Research and Design*** In the initial phase, Gliese-514b embarks on an exhaustive exploration of mechanical design possibilities for the Flying UGV. This encompasses the creation of a detailed 3D model and the meticulous specification of essential components crucial for enabling both ground and aerial navigation. Simultaneously, a dedicated software development effort is set in motion to orchestrate the seamless orchestration of sensors and flight control systems.
- ***Phase 2: Assembly and Hardware Implementation*** The second phase witnesses Gliese-514b's procurement efforts as they acquire every essential hardware component required for the assembly of the Flying UGV. Furthermore, this stage is marked by the intricate integration of various peripherals, harmoniously weaving them into the fabric of the UGV. A symphony of components comes to life as they are meticulously assembled and brought together.
- ***Phase 3: Testing and Implementation*** The final leg of the journey ushers in rigorous testing and implementation efforts. Gliese-514b meticulously subjects the assembled UGV to a battery of tests, scrutinizing its performance in both ground and flight modes. This phase serves as the crucible in which the Flying UGV's capabilities are benchmarked, and refinements to the design are deftly implemented. It is the culmination of the team's efforts, where the vision becomes a tangible reality.

In these meticulously structured phases, Gliese-514b's mission unfolds, propelled by dedication, precision, and an unwavering commitment to achieving its objectives.

III. Budget Justification

Appendix B provides a comprehensive breakdown of the materials and associated costs crucial for the realization of the Gliese-514b project. Each component and resource has been carefully selected to align with the project's objectives, with an unwavering focus on efficiency and functionality.

The backbone of the Gliese-514b Flying UGV is its chassis, a critical component known for its remarkable strength, durability, and ease of fabrication. To this end, the chassis will be precision-cut from acrylic, ensuring a solid foundation for the UGV's operations. Additionally, PLA filament will be skillfully employed to craft miscellaneous parts, enhancing the overall versatility and functionality of the Flying UGV.

Powering the UGV's electrical systems will be battery units, affording the flexibility and mobility necessary for its mission. The central nervous system of the UGV comprises a Raspberry Pi, complemented by a Navio2 HAT. An intricate network of wires serves as the neural pathways connecting various components, facilitating seamless coordination and control.

The UGV's locomotion is driven by a combination of four propellers and four wheels, each meticulously powered by dedicated motors. Two sets of 4 in 1 ESCs [1] provide the precise motor control required for optimal performance. Notably, the choice of motors for the wheels prioritizes higher torque and lower RPM, a deliberate decision to meet the UGV's specific operational demands.

Communication lies at the heart of the Gliese-514b project, necessitating the integration of a telemetry radio system to maintain a robust connection between the UGV and the ground control station.

Navigation and mapping capabilities are paramount for the UGV, achieved through the inclusion of camera sensors [2] and a LiDAR sensor. While the Raspberry Pi inherently supports a single camera, Gliese-514b's multifaceted approach mandates the use of a camera port multiplexer to transcend this limitation. Furthermore, high-power infrared LEDs are enlisted to enhance visibility in low-light environments, ensuring the UGV's adaptability to various scenarios.

Lastly, an SSD storage solution accommodates the substantial volume of data generated by the LiDAR sensor and multiple cameras [3]. This storage capacity ensures that critical data can be efficiently captured, stored, and utilized throughout the mission.

In sum, Gliese-514b's material and cost allocation exemplify a meticulous selection process, guided by the team's unwavering commitment to achieving project success through precision, efficiency, and optimal functionality.

IV. Research

A. Relevant Background

The Artemis mission unfolds in three distinct phases, each marking a significant milestone in humanity's journey into space. Artemis I marked a pivotal moment with NASA successfully launching the Orion Spacecraft. This mission also involved the comprehensive development and testing of essential elements such as the space launch system rocket, the human landing system, and the exploration ground systems. Rigorous testing was conducted to fine-tune these critical utilities, ensuring their readiness for the challenges that lie ahead.

Artemis II stands as the next ambitious endeavor, set to send astronauts to the Moon in 2025, with the ultimate goal of establishing a lunar base. This mission aims to further test the endurance of astronauts, the reliability of the Orion Spacecraft, the space launch system rocket, the human landing system, and the exploration ground systems. It's a critical step toward building operational confidence and preparing for Artemis III.

Artemis III represents the pinnacle of ambition, envisioning the establishment of a lunar base that will serve as a launchpad for Mars exploration. The Moon will become a hub for scientific research and technological advancement, acting as a stepping stone toward the grander goal of Mars exploration. This mission heralds an era where a minimal human presence interacts with advanced technology, all for the betterment of humanity.

However, lunar exploration presents formidable challenges, particularly in the challenging terrain of the Moon's far side. Traditional rovers struggle to navigate uneven and rugged landscapes, highlighting a technological gap in our ability to explore efficiently. The need for swift and adaptable aerial and terrestrial navigation in these harsh conditions is evident, promising to revolutionize lunar exploration and enhance data collection.

In response to this challenge, team Gliese-514b rises to the occasion with a groundbreaking proposal—an innovative Aerial Unmanned Ground Vehicle (AUGV). This visionary creation combines the strengths of flight-capable drones and ground-based rovers, offering unparalleled agility to soar over treacherous terrains and the stability to maneuver on the ground when required.

Gliese-514b's AUGV is set to redefine lunar exploration, bridging the gap between aerial and terrestrial capabilities. It promises to revolutionize the efficiency, range, and speed of lunar missions, enabling comprehensive data collection and significantly increasing the probability of mission success. With this innovative solution, the team paves the way for a new era of lunar exploration, unlocking the mysteries of our celestial neighbor and propelling humanity toward the stars.

B. Problem Statement

The Gliese-514b team is tackling a pressing challenge in lunar exploration—bridging the technological gap for more efficient and adaptable surface exploration. Currently, the Artemis program relies heavily on orbital surveys, providing only a limited understanding of lunar landing sites. The moon's rugged terrain, marked by craters and steep slopes, presents significant challenges for traditional Unmanned Ground Vehicles (UGVs), hindering efficient surface exploration. To overcome these obstacles and enhance mission planning, the team proposes the integration of a Flying Unmanned Ground Vehicle (AUGV) with the capability to conduct detailed lunar surface surveys.

This innovative approach aims to revolutionize lunar exploration by providing a versatile solution that seamlessly transitions between aerial and terrestrial modes. The AUGV's robust propulsion system, combined with specialized wheel or track systems, enables it to , conserving energy and overcoming large obstacles. Furthermore, the team's focus on energy consumption calculation using reconfigurable computing platforms ensures real-time feedback on the AUGV's energy status, contributing to longer mission durations and enhanced exploration capabilities.

1) ***Revolutionizing Lunar Exploration: Team Gliese-514b's Innovative Approach****:* Team Gliese-514b distinguishes itself through its multidisciplinary expertise and holistic project approach. Bringing together diverse skills in aerospace dynamics, robotics, computational intelligence, and reconfigurable computing platforms, the team ensures a comprehensive solution to the problem. Their emphasis on energy consumption calculation using reconfigurable computing platforms not only benefits the current project but also paves the way for adaptable, energy-efficient systems in future lunar missions.

In conclusion, the Aerial-Terrestrial UGV proposed by team Gliese-514b addresses a critical technological gap in lunar exploration [4]. By merging aerial and terrestrial navigation capabilities, their innovative solution promises to navigate the challenging lunar terrain efficiently and adaptable. This contribution has the potential to significantly enhance the success of future lunar missions within the NASA Artemis program, optimizing unmanned lunar exploration for strategic mission planning and safe lunar surface activities.

C. Innovations

The Gliese-514b project is dedicated to the creation of a low-power, low-latency Flying Unmanned Ground Vehicle (UGV) tailored for versatile applications, with a particular focus on its role during the Artemis III mission phase. Operating under the umbrella of the Reconfigurable Space Computing Laboratory at CPP, Gliese-514b is an integral part of a pioneering initiative aimed at developing cutting-edge technology to establish a collaborative robotic environment as shown in Figure 1. This environment facilitates the seamless coordination of heterogeneous robotic elements for deep-space missions, effectively executing tasks and transmitting critical data to Earth for further analysis, as illustrated in Figure 1.

The project's core objectives revolve around the comprehensive development of both software and hardware platforms, culminating in the creation of a robust and fully integrated system optimized for lunar and Mars exploration. The overarching vision envisions the deployment of this innovative device within a collaborative robotics framework, significantly enhancing the efficiency and adaptability of exploration endeavors.

At the heart of this endeavor lies a resilient propulsion system capable of facilitating smooth transitions between flying and driving modes. This pioneering propulsion technology not only promises to deliver higher-resolution scans of the lunar surface but also positions the Flying UGV as an indispensable asset for lunar and Martian exploration missions. Furthermore, the incorporation of LiDAR sensors enhances the vehicle's navigational capabilities, allowing real-time mode adjustments based on the prevailing environmental conditions.

In tandem with the adaptable propulsion system, the Gliese-514b team is actively engaged in the development of a specialized algorithm, leveraging the potential of reconfigurable computing platforms. This algorithm serves a critical role in meticulously calculating energy consumption during transitions between flying and driving modes, providing real-time energy analysis crucial for mission planning. This ensures that the Flying UGV operates efficiently within predefined energy thresholds, opti-

Fig. 1: Collaborative Robotic Environment featuring the Gliese-514b Flying UGV

mizing resource utilization in the demanding lunar environment.

*1) **Technological Innovations:**:*

- ***Flying-to-Driving Transition:*** The AUGV boasts a robust propulsion system capable of stable hovering and dynamic flying maneuvers. Coupled with specialized wheel or track systems, this system enables seamless transitions between flight and ground modes. Such versatility ensures that the AUGV can surmount obstacles by flying and continuing its journey on the ground, optimizing energy conservation.
- ***Energy Consumption Calculation:*** Efficient energy utilization is a fundamental challenge for multi-modal vehicles. The Gliese-514b project addresses this challenge by developing a specialized algorithm on a reconfigurable computing platform to accurately compute power consumption during transitions between flying and driving modes. Real-time energy analysis aids in mission planning, ensuring that the AUGV always operates within safe energy thresholds.
- ***Terrain Adaptability:*** To navigate the capricious lunar terrain, the AUGV incorporates advanced terrain sensing capabilities. These sensors provide real-time feedback to the system, enabling it to determine the optimal mode of movement, whether flight or ground-based, depending on the prevailing environmental conditions.

D. ARTEMIS Mission

Team Gliese-514b's Aerial Unmanned Ground Vehicle (AUGV) plays a pivotal role in bolstering NASA's ARTEMIS Lunar Mission by significantly enhancing navigation capabilities across the moon's formidable terrains. By seamlessly integrating both aerial and terrestrial functionalities, the AUGV enables efficient and comprehensive exploration, particularly on the rugged and challenging dark side of the moon. Moreover, the Gliese-514b Flying UGV offers invaluable support to the Artemis Mission through its advanced navigation and terrain mapping capabilities. Equipped with LiDAR sensors, it adeptly navigates the unpredictable lunar terrain, effortlessly switching between ground and flight modes, ensuring unparalleled mobility, and generating detailed maps of the rugged lunar landscape. This multifaceted approach empowers the mission with enhanced adaptability and data collection capabilities.

V. TECHNICAL

A. Gliese-514b team

The current project is centered on setting up equipment on a flexible resin-printed chassis, aiming to enhance computational capabilities with a customized flight controller based on the F' JPL/NASA flight software. This setup includes a thermal camera for chip monitoring. Future work will focus on predicting chip failure due to intensive activities.

*B. **Project Plan***

To initiate the Flying UGV project, the primary step involves conceiving a lightweight chassis design with a minimal footprint, as illustrated in Figure 3. This updated design seamlessly accommodates all essential components required for autonomous flight, driving, and exploration, representing an improvement over the previous design showcased in Figure 2. The new design features a more robustly engineered, lightweight chassis, which will be fabricated using either laser-cut acrylic or light resin [5], with ongoing investigations to determine the ideal material for the final prototype. Once the dimensions and optimal arrangement of these components are determined, the subsequent phase involves the development of a comprehensive 3D CAD model. The chassis, as depicted in Figure 2, will be crafted from acrylic and complemented with 3D printed components. Following the fabrication of

Fig. 2: Flying UGV Prototype of Past Design

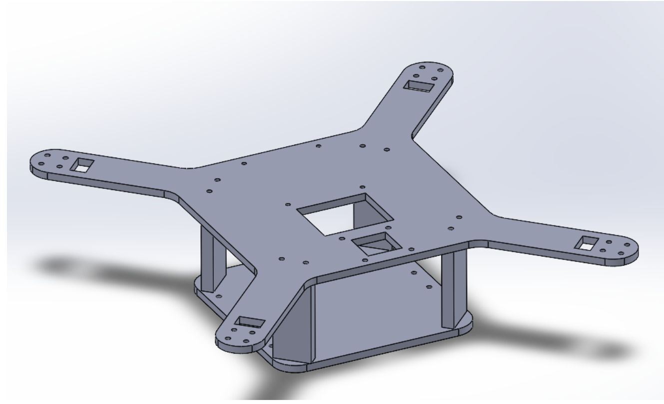

Fig. 3: CAD of Current Drone

these components, the assembly of the Flying UGV can commence.

Simultaneously, while finalizing the physical design, the software aspect of the project will be actively worked on. Team Gliese-514b will begin establishing communication protocols with the various cameras, sensors, and ESCs to ensure seamless integration and operation.

Upon the successful assembly and the establishment of seamless communication with its components, Gliese-514b will proceed to conduct a series of rigorous tests on the Flying UGV. The testing phase will commence with remote operation trials, subsequently followed by autonomous navigation testing in both ground and flight modes.

C. *Software Plan*

The software stack chosen for this project encompasses several key components to enable the Flying UGV's comprehensive exploration and mapping capabilities. It includes the PiCamera app for PiCameras, DroidCam for the potential addition of another camera through a smartphone, and LidarView to process data from the LiDAR sensor. The aim is to leverage multiple image and video-producing devices to conduct thorough scans and assess the lunar or Martian surroundings, ultimately creating detailed maps. Additionally, the LiDAR and camera inputs will facilitate the extraction of positioning information, enabling the system to calculate potential obstacles and its relative position within the observed area. The software will play a crucial role in associating the surroundings with precise coordinate references, enhancing the overall mapping process.

To enhance the Flying UGV's ability to differentiate between various materials and objects found on the Moon, computer vision capabilities will be integrated. This involves training a YOLOv8 model on cloud resources to enable the identification of different vehicles and objects [6]. Initial simulations will be conducted on Earth-based devices and objects to validate the proof of concept. The long-term vision is to train and deploy a model within the UGV itself, allowing it to avoid collisions with counterparts during missions. Additionally, teleoperation features will be added to the Flying UGV, utilizing the MediaPipe Library and potentially YOLOv8. Hand gestures will serve as the means to convey start and stop commands to the UGV, enhancing its control and interaction capabilities.

Following the creation and full integration of the software stack, Gliese-514b will proceed with rigorous testing procedures. Successful tests will pave the way for the software's utilization of the actual drones. This entails the establishment of boundary conditions, such as ensuring the Flying UGV maintains a safe distance of 1 meter from obstacles. The computer vision aspect will enable task assignment and control, making the project safe and collision-free. Moreover, it will provide astronauts with a means to assign tasks to the UGV, fostering a collaborative robotic environment where the device can receive instructions through gestures or local networks from other similar vehicles.

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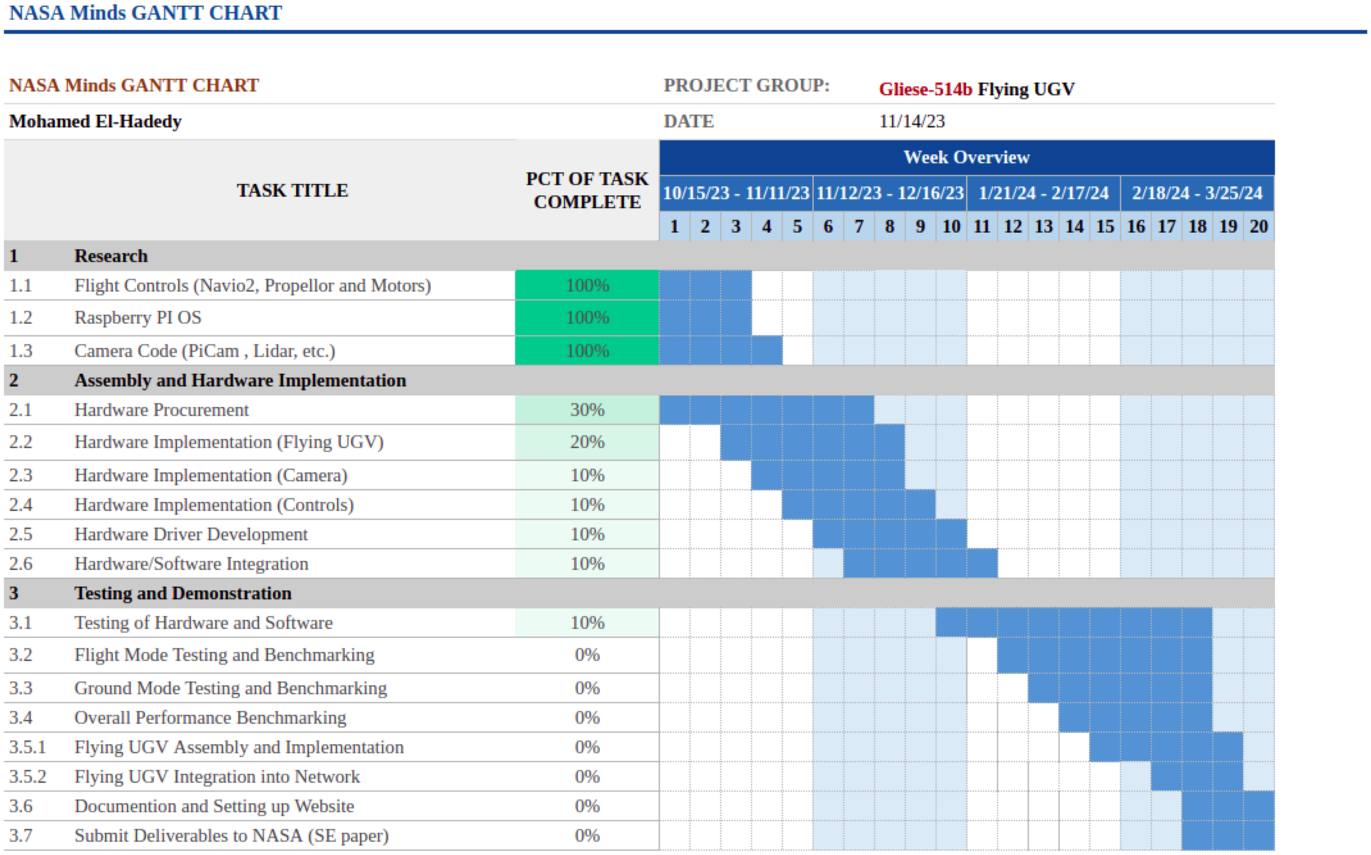
Appendix A
Gantt Chart



Gantt Chart of Scheduling

Appendix B
Cost Breakdown

Name	Cost ($)	Amount	Total Cost ($)
Acrylic sheets	32.00	2	64.00
Raspberry Pi	79.81	1	79.81
Navio2 Flight Controller	100.00	1	100.00
Propeller Motors	24.00	4	96.00
Wheel Motors	34.00	4	136
ESC	100.00	2	200.00
4s Battery	80.00	1	80.00
Telemetry Radio	90.00	1	90.00
Camera	59.99	4	239.96
PLA Filament	25.00	2	50.00
LiDAR Sensor	54.00	1	54.00
Wheels	8.25	4	33.00
Propellers	10.00	4	40.00
Multicamera adapter	29.99	1	29.99
Jumper wires	19.98	1	19.98
Infrared LEDs	8.99	4	35.96
2TB SSD	159.99	1	159.99
Total			**$1,508.69**