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

Gliese-514b

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Abstract—**This Critical Design Report (CDR) presents Team Gliese-514's innovative development of a Unmanned Hybrid Vehicle (UHV), designed to advance terrestrial exploration and operational capabilities. The UHV integrates the functionalities of Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs), creating a versatile system optimized for complex environments on Earth, with potential applicability in extraterrestrial settings. The project emphasizes sustainable design, incorporating advanced propulsion, energy-efficient systems, and robust sensor networks to enhance performance in varied terrains and climates. Through comprehensive subsystem evaluations—including motor, Electronic Speed Control (ESC), propeller selection, and battery optimization—the UHV demonstrates exceptional adaptability and reliability. The integration of sophisticated data processing and control mechanisms further enables autonomous operations, facilitating real-time decision-making and precise navigation. Team Gliese-514's approach, combining rigorous engineering methodologies with innovative technology integration, results in a UHV that not only meets current exploration and logistical challenges but also establishes a foundation for future advancements in unmanned systems. This CDR encapsulates the team's journey in creating a groundbreaking vehicle, highlighting their commitment to pushing the boundaries of robotics and engineering for Earth and potentially beyond.**

Index Terms—**Unmanned Ground Vehicle (UGV), Unmanned Aerial Vehicle (UAV), Unmanned Hybrid Vehicle (UHV), Sensor Fusion, Edge Computing, Real-Time Data Processing, ArduPilot, Multi-Sensor Integration, ROS (Robot Operating System), SLAM (Simultaneous Localization and Mapping), MAVROS, LiDAR (Light Detection and Ranging), Collaborative Robotic Environment (CRE)**

I. KEYWORDS

1) **Unmanned Ground Vehicle (UGV)** - A vehicle that can be controlled remotely and can navigate on the ground.
2) **Unmanned Aerial Vehicle (UAV)** - A vehicle that can be controlled remotely and can navigate in the air.
3) **Unmanned Hybrid Vehicle (UHV)** - A vehicle that can be controlled remotely and can navigate on the ground or in the air.
4) **Collaborative Robotic Environment (CRE)** - An environment where robots or devices can collaborate to accomplish a task or goal.
5) **LiDAR (Light Detection and Ranging)** - A remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth, providing precise three-dimensional information about the shape of the Earth and its surface characteristics.
6) **Sensor Fusion** - The process of integrating data from multiple sensors to achieve more accurate, reliable, and comprehensive situational awareness and decision-making.
7) **Edge Computing** - A distributed computing paradigm that brings computation and data storage closer to the location where it is needed, to improve response times and save bandwidth.
8) **Real-Time Data Processing** - The capability of processing data instantaneously as it is generated or received, crucial for applications requiring immediate analysis and action.
9) **ArduPilot** - An open-source autopilot software suite used for controlling autonomous vehicles, supporting a wide range of platforms and functionalities.
10) **Multi-Sensor Integration** - Combining data from various types of sensors to enhance the functionality and decision-making capabilities of unmanned systems.
11) **ROS (Robot Operating System)** - An open-source robotics middleware suite that provides services designed for a heterogeneous computer cluster.
12) **SLAM (Simultaneous Localization and Mapping)** - A computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.
13) **MAVROS** - A ROS package that provides communication driver for various autopilots with MAVLink communication protocol support.

II. CRITICAL DESIGN REVIEW

THE Critical Design Review (CDR) for the Flying UGV project marks a critical juncture in the development lifecycle, offering an exhaustive evaluation against the stringent demands of the NASA MINDS competition. This initiative, aimed at university-level innovation, compels Team Gliese-514 to engineer prototype technologies that align with the broader objectives of NASA's Artemis mission, envisioning applications beyond Earth's confines. While the immediate efforts of the team remain terrestrial, they embody aspirations of celestial applicability, anticipating the rigors of space exploration.

Team Gliese-514's journey through the iterative design process of the Flying UGV has combined innovation, practicality, and strategic foresight, all within the resource-limited yet intellectually rich environment of academic research. The team's decisions have consistently focused on pioneering a functional and innovative prototype while adhering to the pragmatic constraints of budget, resources, and time.

The CDR serves as a platform for Team Gliese-514 to elaborate on the meticulous considerations and decisions at each developmental phase, highlighting the collaborative synergy within the team. Comprising a diverse group of engineers, Team Gliese-514 has navigated complex design challenges, integrating mechanical, electronic, and computational elements to forge a system that embodies their vision. From the dynamics of terrestrial and aerial mobility to the complexities of sensor integration and data processing, every design element has been scrutinized and optimized.

The narrative in this CDR chronicles the technical evolution of the project and reflects Team Gliese-514's adaptive strategy in addressing unforeseen challenges and leveraging emerging technologies. The team aims to demonstrate not just the technical viability of the Flying UGV but also its potential as a scalable model for future innovations in unmanned exploration systems, both on Earth and beyond.

The design of the Flying UGV stands as a testament to Team Gliese-514's relentless pursuit of excellence and innovation in the demanding and evolving landscape of space technology. Through this CDR, Team Gliese-514 presents a detailed exposition of their design journey, showcasing a prototype that, while currently earthbound, holds the potential to contribute to the next generation of lunar and Martian exploration technologies.

A. *Using Treads Over Mecanum Wheels*

Team Gliese-514's decision to use treads instead of mecanum wheels for the Flying UGV project stemmed from a comprehensive analysis of the vehicle's operational demands and environmental challenges. Mecanum wheels, while offering significant maneuverability on flat surfaces due to their omnidirectional capabilities, falter on uneven or rugged terrain where weight distribution and traction are crucial. Treads, conversely, ensure consistent traction and stability, excelling in diverse and challenging landscapes.

Table 1 presents a detailed comparison between tread wheels and mecanum wheels, illustrating their respective advantages and limitations across various operational criteria. This comparison guided the team in choosing the wheel type best suited for the UGV's requirements in diverse terrains.

Characteristic	Mecanum Wheel	Tread Wheel
Terrain Adaptability	Good on flat, struggles on uneven	Excellent on all terrains
Maneuverability	High (omnidirectional)	Moderate (linear)
Speed	High	Moderate to low
Durability	Moderate	High
Weight Impact (per wheel)	Lighter (approx. 48.5g)	Heavier but stable (approx. 70.7g)
Energy Efficiency	75% on smooth terrain, 50% on rough terrain	65% on smooth terrain, 80% on rough terrain
Estimated Load Capacity	Up to 5 kg	Up to 8 kg

TABLE I
NUMERICAL AND QUALITATIVE COMPARISON OF MECANUM AND TREAD WHEELS

Treads provide robust traction and a more forgiving operational profile on uneven ground, slopes, and obstacles. Their design, featuring a broader surface contact area, leads to improved weight distribution and enhanced stability, crucial for the UGV's mission requiring reliable ground handling and stability Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) have long been used to do specific tasks to each respective technology. The proposed Flying UGV aims to leverage the advantages of both UAVs and UGVs to improve lunar exploration for the NASA Artemis program. By combining the benefits of aerial and ground-based exploration, the Flying UGV will provide unparalleled versatility in mapping and assessing potential landing sites on the moon. This advanced exploration capability will significantly enhance mission planning, safety, and overall success of the Artemis program. bionics-docs-drivetrains.

Figure 1 shows the tread system implemented on the Flying UGV, illustrating the physical configuration and how it integrates into the overall design of the vehicle. This visual representation highlights the practical application of treads in the UGV, reinforcing the decision based on their suitability for challenging terrains and heavy-load operations.

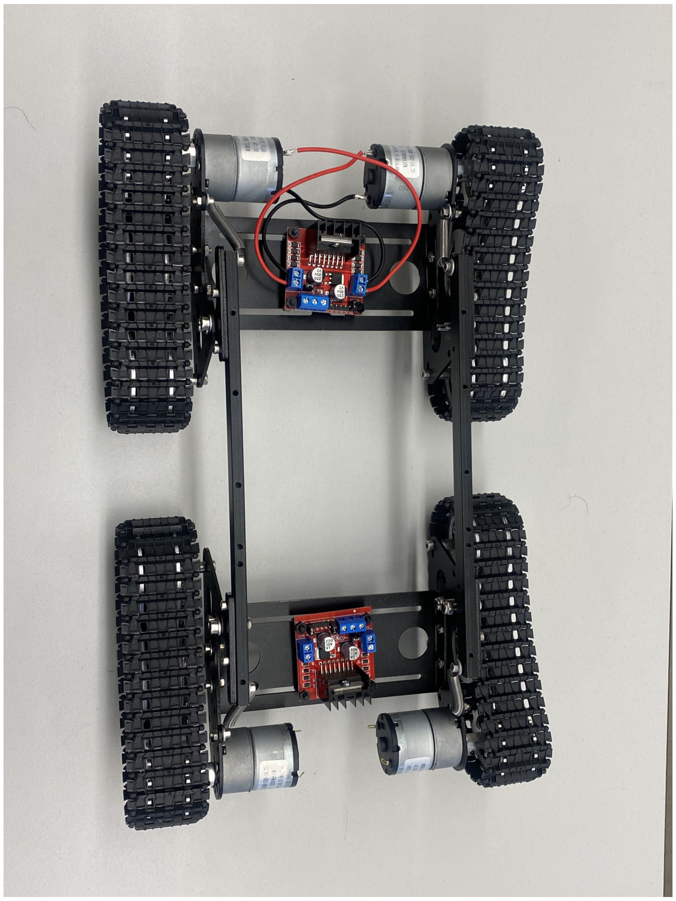

Fig. 1. Tread system on Flying UGV

Moreover, the tread-based system reduces the mechanical complexity of the vehicle compared to mecanum wheels, which require individual control for directional movement. Operating treads with fewer motors reduces mechanical complexity and potential failure points, enhancing the UGV's reliability and simplifying maintenance and repair processes, essential for long-term operational sustainability.

In conclusion, Team Gliese-514 strategically chose treads over mecanum wheels based on operational, environmental, and logistical considerations for the Flying UGV project, emphasizing the team's dedication to developing a robust, efficient, and high-performing vehicle capable of excelling in diverse and challenging conditions. This choice aligns with the goals of the NASA MINDS challenge and the broader mission of advancing unmanned ground vehicle technology.

B. *Using a Raspberry Pi Over the Jetson Nano*

Team Gliese-514's selection of the appropriate single-board computer (SBC) for the Flying UGV project required a detailed comparison between the Raspberry Pi 4 and the Jetson Nano. These platforms, each powerful and versatile, serve different operational needs, presenting distinct advantages and limitations.

Table 2 presents a detailed comparison between the Raspberry Pi 4 and the Jetson Nano, outlining key specifications like CPU, GPU, memory, storage, I/O ports, power consumption, software ecosystem, price, and ROS compatibility. This comparison was critical in guiding Team Gliese-514's decision, emphasizing the Raspberry Pi 4's advantages in terms of software support, power efficiency, and cost-effectiveness, which are essential for the project's requirements [2].

Feature	Raspberry Pi 4	Jetson Nano
CPU	Quad-core Cortex-A72	Quad-core ARM Cortex-A57
GPU	Broadcom VideoCore VI	128-core Maxwell
Memory	Up to 8GB LPDDR4	4GB LPDDR4
Storage	microSD	microSD/16GB eMMC
I/O Ports	Multiple GPIO, USB, HDMI	GPIO, USB, HDMI
Power Consumption	Low	Moderate
Software Ecosystem	Extensive	Specialized
Price	Lower	Higher
ROS Compatibility	High	Moderate

TABLE II
COMPARISON OF SPECIFICATIONS: RASPBERRY PI 4 VS JETSON NANO

Figure 2 depicts the benchmark graph comparing the Raspberry Pi 4B 8GB and Jetson Nano 4GB across a series of performance tests. The graph illustrates how the Raspberry Pi 4 offers better value for money for general computing tasks and embedded projects, with the Jetson Nano being considered only for GPU-intensive tasks that can benefit from CUDA cores [2]. The Raspberry Pi 4 B emerges as a more cost-effective Linux PC, especially in configurations with 8GB and 4GB RAM, establishing it as the better choice for the Flying UGV project.

The extensive software support and compatibility of the Raspberry Pi 4 were crucial in Team

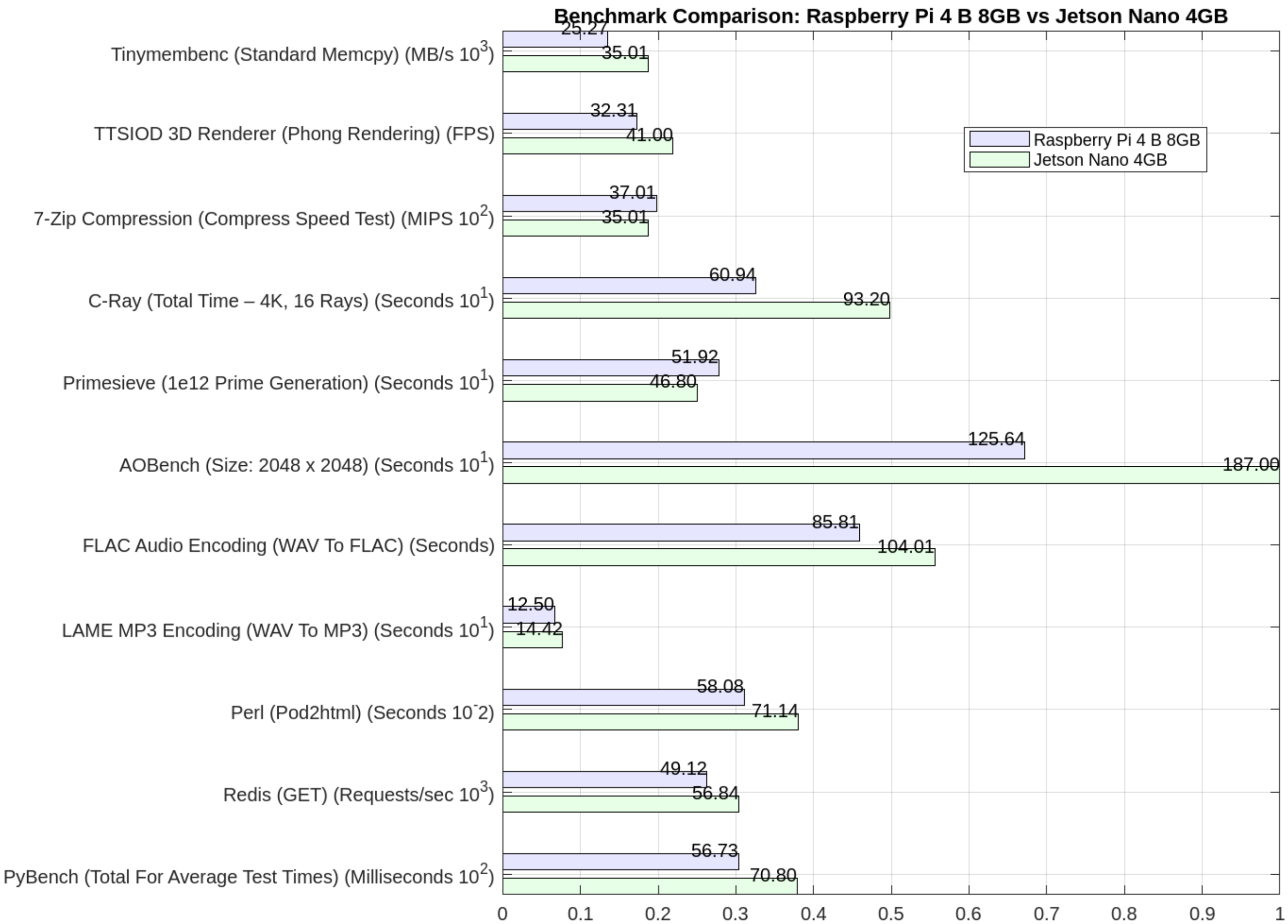

Fig. 2. Benchmark Comparison: Raspberry Pi 4 B 8GB vs Jetson Nano 4GB

Gliese-514's selection process. The well-established ecosystem of the Raspberry Pi 4, offering broad support for various libraries and tools, facilitated seamless integration with existing codebases, accelerating development and testing phases.

The adaptability of the Raspberry Pi 4 with the Robot Operating System (ROS) significantly influenced the team's choice, ensuring a straightforward integration path for developing complex control systems required by the UGV. The balance between performance, cost, and ecosystem flexibility made the Raspberry Pi 4 the clear choice for the project, aligning perfectly with the team's long-term goals and the broader mission of advancing unmanned ground vehicle technology.

C. Using a Pixhawk Over the Navio 2

Team Gliese-514's selection of Pixhawk over Navio 2 as the flight controller for the Flying UGV project was driven by a comprehensive evaluation of their features, performance, and compatibility with the system requirements.

Fig. 3. Pixhawk flight controller.

Figure 3 illustrates the Pixhawk flight controller, which was selected due to its superior technical specifications and compatibility with the complex requirements of the UGV project. This decision was critical to ensure the autonomous vehicle's reliability, functionality, and scalability. The team explored the factors influencing this choice and the distinct advantages of Pixhawk in the project context, which are further delineated in **Table III**.

- **Advanced Capabilities of Pixhawk:** Pixhawk offers an array of advanced features essential for the complex operations of autonomous vehicles. Its robust architecture supports integrated multithreading, real-time processing, and a Unix/Linux-like programming environment, facilitating the implementation of sophisticated autopilot functionalities such as autonomous navigation, mission planning, and real-time control and monitoring of various vehicle parameters[3].
- **Ease of Transition and Support:** Transitioning to Pixhawk was seamless for Team Gliese-514, thanks to its user-friendly interface and widespread adoption in the drone and autonomous vehicle communities. The availability of extensive documentation, active online forums, and technical support significantly reduced the project's developmental timeline and technical risks.
- **Personal Experience and Reliability:** Team Gliese-514's hands-on experience with Pixhawk confirmed its superior stability and reliability compared to Navio 2. Pixhawk demonstrated consistent performance under varying operational conditions, showcasing its robustness and dependability for critical mission tasks.
- **Integration Simplicity with Pixhawk:** The design philosophy of Pixhawk emphasizes simplicity and efficiency, allowing it to operate independently without a full Linux stack, thus streamlining the system integration process. This standalone functionality, coupled with the option for enhanced capabilities through additional modules, offers a flexible and scalable solution for the UGV's evolving needs. Although Navio 2 shows higher CPU speed and RAM, it significantly relies on an attached Raspberry Pi 3 for its functionality. This dependency not only increases the system's overall weight and power consumption but also complicates the integration process due to the additional components required for operation. In contrast, the Pixhawk operates independently, offering a more streamlined and efficient solution for the UGV's flight control system.

  The Pixhawk's standalone capability, as illustrated in **Figure 4**, ensures a higher level of reliability and compatibility with the UGV's hardware, making it a safer and more efficient choice for the project. Its design philosophy, emphasizing simplicity and efficiency, aligns perfectly with Team Gliese-514's objectives to develop a sophisticated, reliable, and scalable unmanned vehicle system.
- **Autopilot Software Flexibility:** While both Pixhawk and Navio 2 are compatible with standard autopilot software like APM, Pixhawk's broader software compatibility and capacity for advanced functionalities without extensive modifications made it the preferred choice for the project[4].

Feature	Pixhawk	Navio 2
CPU Processing	High performance	Moderate performance
Software Compatibility	Extensive (with Unix/Linux-like environment)	Limited by Linux stack
Autopilot Software	Supports multiple including APM, PX4	Supports APM, limited to Raspberry Pi compatibility
Integration	Standalone operation, easy integration with peripherals	Requires Raspberry Pi for full functionality
Reliability	Highly reliable with stable performance	Less reliable, issues in software compatibility
Community Support	Wide community support, extensive resources	Smaller community, limited resources

TABLE III
COMPARATIVE ANALYSIS OF PIXHAWK AND NAVIO 2 FLIGHT CONTROLLERS

The selection process was greatly informed by the side-by-side comparison shown in **Table III**, where the Pixhawk's higher performance and reliability scores stood out against the Navio 2. Its extensive software compatibility and strong community support underscored its suitability for the sophisticated systems of the UGV.

Team Gliese-514's strategic decision to adopt Pixhawk was underpinned by its advanced technological capabilities, ease of integration, and proven

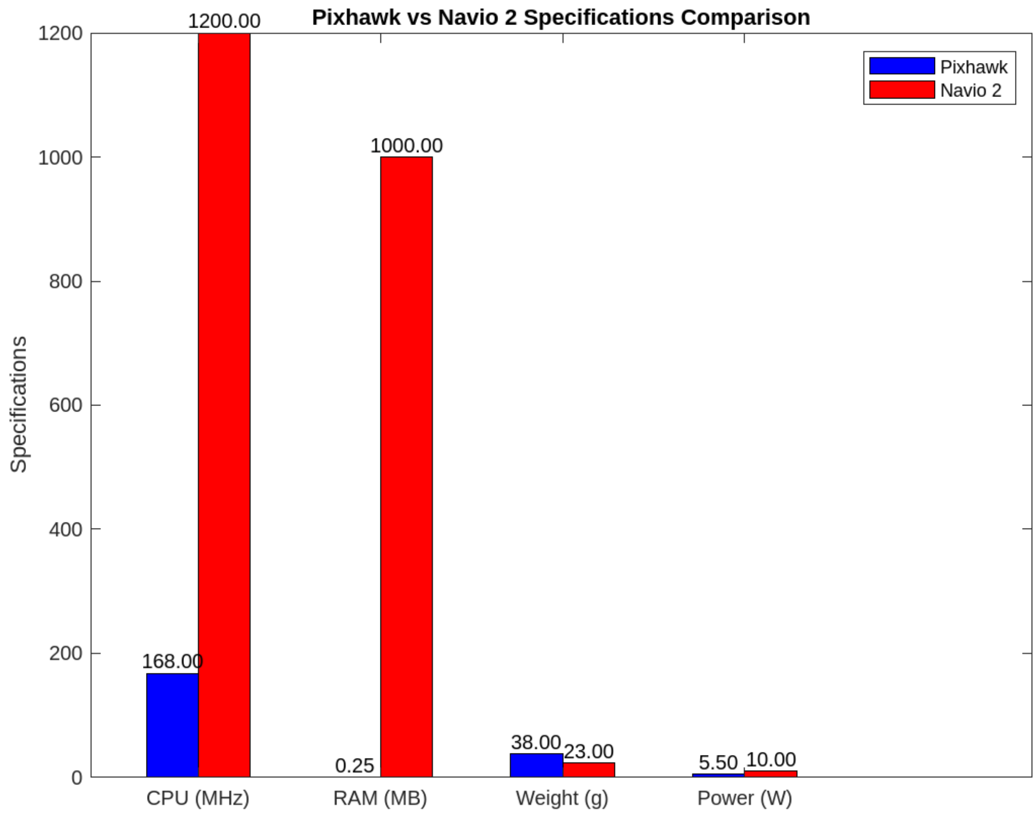

Fig. 4. Comparative Analysis of Pixhawk and Navio 2 Specifications

track record in reliability and performance, affirming the team's commitment to excellence and innovation in developing a state-of-the-art unmanned vehicle system.

D. Controller System Integration

In the area of remote control and communication for Team Gliese-514's hybrid UGV, selecting the appropriate controller was crucial to ensure precise and responsive maneuvering. To aid in this selection, the team conducted a detailed comparison between the RadioMaster Pocket and the FrSky Taranis X9D Plus, well-known alternatives in the remote-control segment. This comparative analysis is detailed in **Table IV**, highlighting the key features and specifications that influenced the decision-making process.

RadioMaster Pocket features include compact and lightweight design, extended battery life, broad firmware and protocol compatibility, and cost-effectiveness, making it suitable for field operations and budget-conscious projects[5]. In contrast, the FrSky Taranis X9D Plus is noted for its durability, ergonomic design, and advanced feature set, though at a higher cost and increased weight[6].

RadioMaster Pocket:

- **Portability:** Compact and lightweight design with detachable stick ends and a foldable antenna, ideal for field operations.
- **Power Source:** Utilizes 18650 batteries for extended field use.
- **Firmware and Compatibility:** Comes with preloaded EdgeTX firmware; supports ExpressLRS and MPM CC2500 variants for broad protocol compatibility.
- **User Interface:** Features a backlit LCD screen and built-in LED lights for ease of use in various lighting conditions.
- **Customization:** Offers optional colored cases for personalization.
- **Cost-Effectiveness:** Provides a balance of performance and affordability, making it a versatile choice for budget-conscious projects.

FrSky Taranis X9D Plus:

- **Durability and Ergonomics:** Known for its robust build and comfortable grip, suitable for extensive and rigorous use.

- **Power Source:** Typically powered by a larger, rechargeable battery, offering long usage times but with increased weight.
- **Firmware and Compatibility:** Runs on OpenTX firmware and is compatible with a wide range of receivers, known for its reliable performance.
- **User Interface:** Equipped with a larger, full-color LCD screen, providing detailed telemetry data and easier navigation through menus.
- **Customization:** Limited to standard cases, focusing more on functionality than aesthetic customization.
- **Cost:** Generally higher priced due to advanced features and build quality.

Feature	RadioMaster Pocket	FrSky Taranis X9D Plus
Design	Compact and portable	Larger, traditional design
Stick Ends	Detachable	Fixed
Antenna	Foldable	Fixed
Battery Type	18650	NiMH or LiPo
Firmware	EdgeTX	OpenTX
Weight	288 grams	900 grams (approx.)
Display	Backlit LCD	Full-color LCD screen

TABLE IV
COMPARISON OF RADIOMASTER POCKET AND FRSKY TARANIS X9D PLUS CONTROLLERS

Fig. 5. RadioMaster Pocket

Figure 5 showcases the RadioMaster Pocket controller, which Team Gliese-514 selected for its balanced performance, portability, and cost-effectiveness, demonstrating how it integrates within the control scheme of the hybrid UGV.

The decision factors leading to the selection of the RadioMaster Pocket over the FrSky Taranis X9D Plus were its superior portability, user-friendly battery management, efficient interface and display capabilities, and overall value. These aspects were deemed more suitable for the mobility requirements and operational efficiency needed in Team Gliese-514's hybrid UGV project, making the RadioMaster Pocket the preferred choice for the team's remote control and communication needs.

E. Battery Selection for Optimal Performance

Team Gliese-514's journey to selecting the optimal battery for the Flying UGV project was marked by a meticulous evaluation of various candidates, each assessed for their ability to provide a balance between power delivery, weight, and stability, which are crucial for the seamless operation of a hybrid vehicle.

a) Understanding Battery Specifications:

- **S (Number of Cells in Series)**: The 'S' in the battery specification signifies 'Series' and represents the number of cells connected in series within the battery pack. A 4S battery comprises four cells in series, affecting the total voltage. Typically, each LiPo cell has a nominal voltage of 3.7 volts; thus, a 4S battery would have a total nominal voltage of 14.8 volts (3.7V $\times$ 4). The series count increment escalates the voltage, providing more power to the motors [7].
- **C (Discharge Rate)**: The 'C' rating denotes the battery's discharge rate, indicating the speed at which the battery can expend its stored energy. A 50C battery can discharge 50 times its capacity. For instance, a 5000mAh battery with a 50C rating can theoretically deliver 250A (50 $\times$ 5Ah). A higher C rating facilitates greater power delivery to the motors, enhancing the vehicle's performance during intensive operations [7].
- **mAh (Milliamp Hours)**: This measures the battery's energy storage capacity. A greater mAh value signifies a larger energy reserve, enabling longer operation on a single charge. A 5000mAh battery, for example, can provide

5000 milliamps (or 5 amps) for one hour under optimal conditions.

- **Voltage (V)**: Voltage measures the electrical potential difference the battery offers. It influences the power delivered to the motors and electronics, affecting the vehicle's speed, torque, and overall performance.

b) Relevance to Battery Choice: The battery selection is vital for balancing the UGV's power requirements against its weight and space constraints. A higher voltage (4S or more) is preferable for power-intensive tasks but increases weight and size. The discharge rate (C rating) must meet the peak power demands without causing overheating or reducing battery lifespa

Initially, the HobbyKing Rhino 5000mAh 4S 50C Lipo Battery Pack was chosen to balance weight and power output. However, real-world tests revealed its limitations in delivering sustained power for stable, extended flight, which necessitated reevaluating battery requirements.

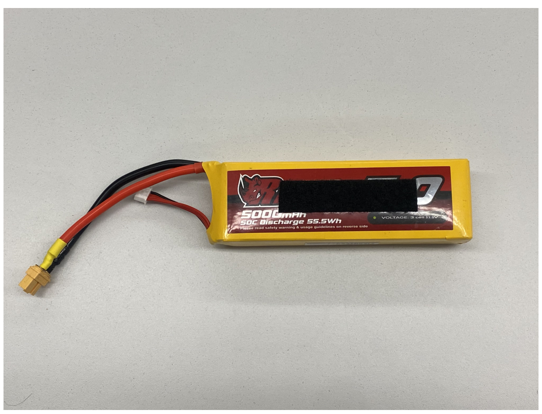

Fig. 6. Rhino 5000mAh 4S 50C Lipo Battery

Figure 6 shows the initial battery choice, the Rhino 5000mAh, which underperformed in sustaining the required power, leading to the consideration of alternative options.

The HRB 6S 5000mAh Lipo Battery, known for its robust power output, was the next candidate. It initially showed promise in improving the drone's flight capabilities but its heavier weight negatively impacted the vehicle's center of gravity and stability.

Figure 7 illustrates the HRB 6S battery, which, despite its high power output, was disadvantaged by its weight, affecting the UGV's performance and efficiency.

The HOOVO 4S Lipo Battery 14.8V 100C 5200mAh emerged as the optimal choice, offering

Fig. 7. HRB 6S 5000mAh Lipo Battery

high-capacity storage and efficient power delivery while maintaining a lower weight.

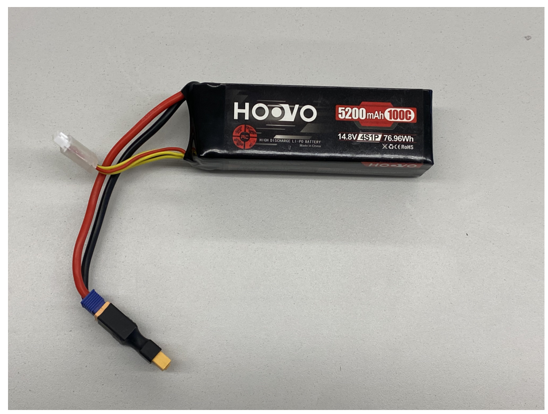

Fig. 8. HOOVO 4S Lipo Battery

Figure 8 depicts the HOOVO 4S Lipo Battery, which combined efficiency, capacity, and stability to meet the project's demanding requirements.

Through rigorous testing and comparative analysis, detailed in **Table V**, the HOOVO 4S Lipo Battery was identified as providing the best amalgamation of power, weight efficiency, and operational capacity for Team Gliese-514's hybrid UGV.

Table V presents the comparative test results of the batteries, demonstrating the superior performance of the HOOVO 4S 5200mAh Battery as it presents the best compromise between power capabilities, weight, and form factor. These tests were crucial for evaluating how each battery would perform under the specific demands of the hybrid UGV, assessing not only the raw power output but also how efficiently each unit managed its energy over time, directly impacting the operational efficacy and reliability of the UGV [8].

Battery and Specifications	Weight (g)	Used Capacity (mAh)	Current (A)	Voltage (V)	MN5008 Motor efficiency acquired
HobbyKing Rhino 4S 5000mAh 11.1V 50C 55.5Wh	463	3600	10.88	9.92	78.3%
HRB 6S 5000mAh 22.2V 100C 111Wh	733	4850	11.68	10.94	92.7%
HOOVO 4S 5200mAh 14.8V 100C 76.96Wh	414	4900	11.49	10.73	88.6%

TABLE V
BATTERY TEST RESULTS

In the Flying UGV project, these elements were meticulously assessed to guarantee optimal performance. The testing process, guided by standardized methods detailed by Battery University, helped in understanding the batteries' behavior under load, their discharge rates, and capacity retention over time, ensuring the selected battery could sustain prolonged operations without significant performance degradation [8]. The chosen battery had to provide sufficient power for sustained aerial and terrestrial operations while keeping the weight manageable to maintain agility and extend operational time. The HOOVO 4S 5200mAh battery emerged as the optimal selection, offering a balanced combination of power, discharge rate, capacity, and weight, thus meeting the project's performance and design standards.

This careful selection process underscores Team Gliese-514's commitment to integrating reliable and efficient components, ensuring that the Flying UGV can achieve its intended functionality while maintaining a high standard of performance and safety.

F. Motor Selection for Enhanced Performance and Reliability

The motor selection process for the Flying UGV project was a nuanced and iterative journey, emphasizing the need for a balance between power, efficiency, and thermal management. Initially, the iFlight XING 2306 motors were chosen for their proven track record in drone racing, offering a blend of robustness and efficiency with their durable construction and optimized windings. However, as the project's scope evolved and the demands on the propulsion system increased, it became clear that these motors, while effective in standard applications, needed to be fully suited to the expanded requirements of our hybrid UGV.

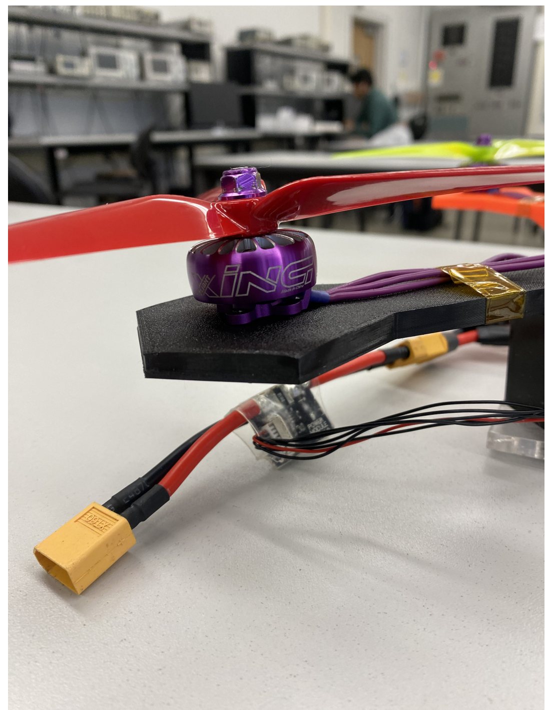

Fig. 9. XING 2306 motor

Figure 9 displays the initially chosen XING 2306 motor, whose limitations became apparent when tested with larger propellers, leading to thermal management issues.

The transition to larger propellers for enhanced lift capacity revealed limitations in the XING motors, particularly in terms of thermal management. The overheating issues signaled a critical need to reassess our motor strategy, prompting a detailed analysis of alternative options that could meet the dual demands of aerial and ground mobility without compromising on performance or reliability [10], [11].

a) Relevance of Motor Testing: During the development phase, Team Gliese-514 conducted thorough motor performance tests to ensure that the chosen motors would meet the demanding requirements of the hybrid UGV. **Figure 10** illustrates the comprehensive testing data obtained from eCalc, a renowned motor performance simulation tool[9]. These tests are critical in understanding the motor's behavior under various loads, which is pivotal for the design and operation of the UGV.

The electrical power usage, plotted against the current in Amperes, allowed the team to determine the motor's power consumption profile, which directly impacts battery life and efficiency. The efficiency curve provided insights into the motor's optimal operating point, where the power to thrust ratio is maximized, indicating the most effective use of energy.

Moreover, the revolutions per minute (RPM) data showed how the motor's speed varied with power input, an important factor for controlling the UGV's speed and agility. The waste power graph highlighted the power lost due to inefficiency, predominantly as heat, which informed the team about the cooling requirements for sustained operations.

The temperature curve was particularly relevant, as excessive heat generation can lead to motor failure. Understanding the thermal characteristics ensured that the selected motors would operate within safe temperature ranges, thus avoiding overheating and ensuring longevity. Annotations such as 'Motor @ Hover' provided a quick reference to key operational conditions, like the current needed for the UGV to maintain a stable hover, which is a common requirement for aerial vehicles.

Overall, these performance metrics were instrumental in validating the motor selection, guaranteeing that the motors would not only deliver the necessary power but also maintain efficiency and reliability in line with the ongoing development and optimization of the hybrid UGV system.

Figure 10 illustrates the performance characteristics of the XING 2306 motors, which, while robust, fell short in maintaining consistent thermal efficiency under the hybrid UGV's operating conditions.

The exploration led to the selection of TMotor Antigravity MN5008 KV170 motors, specifically engineered for high-performance and demanding applications. These motors stood out for maintaining lower operating temperatures, a feature crucial for sustained performance and long-term reliability.

Figure 11 showcases the MN5008 motor, demonstrating its compatibility with larger propellers and its improved thermal management capabilities.

In our tests, the TMotor MN5008 demonstrated a marked improvement in thrust production without overheating, thus solving the limitations we faced with the previous motors.

Figure 12 depicts the comprehensive performance capabilities of the MN5008 motors, highlighting their superior thermal efficiency and thrust production.

Motor Model	Weight (g)	Full Throttle Voltage (V)	Thrust per motor (kg)	Thrust at full throttle (kg)	Operating Temperature (°C)
XING 2306	33.4	44.57	0.6-0.7	3.5	89
MN5008	135	47.03	1-1.2	4.2	63

TABLE VI
MOTOR TEST RESULTS

Table VI summarizes the test results for both motor types, justifying the selection of the TMotor MN5008 for its superior performance, particularly in thermal management and thrust capability, which are crucial for the hybrid UGV's operations.

In addition to the aerial propulsion needs, the selection process for the ground component's motors was equally meticulous. The 33GB-520 motors were identified as the optimal choice for the ground module, offering a balance of power, efficiency, and weight that complemented the overall design of the UGV. These motors provided the necessary traction and speed for ground maneuverability while integrating seamlessly with the vehicle's power and control systems. At 100 grams, their weight contributes positively to the overall mass distribution of the vehicle, ensuring that the ground component remains maneuverable and effective.

The motor selection process underscored the importance of a holistic approach to system design, where each component is chosen not only for its individual performance but also for its contribution to the system's overall functionality and performance. The final motor configurations, combining the TMotor MN5008 for aerial operations and the 33GB-520 for ground mobility, illustrate the project's commitment to creating a hybrid UGV that excels in both domains.

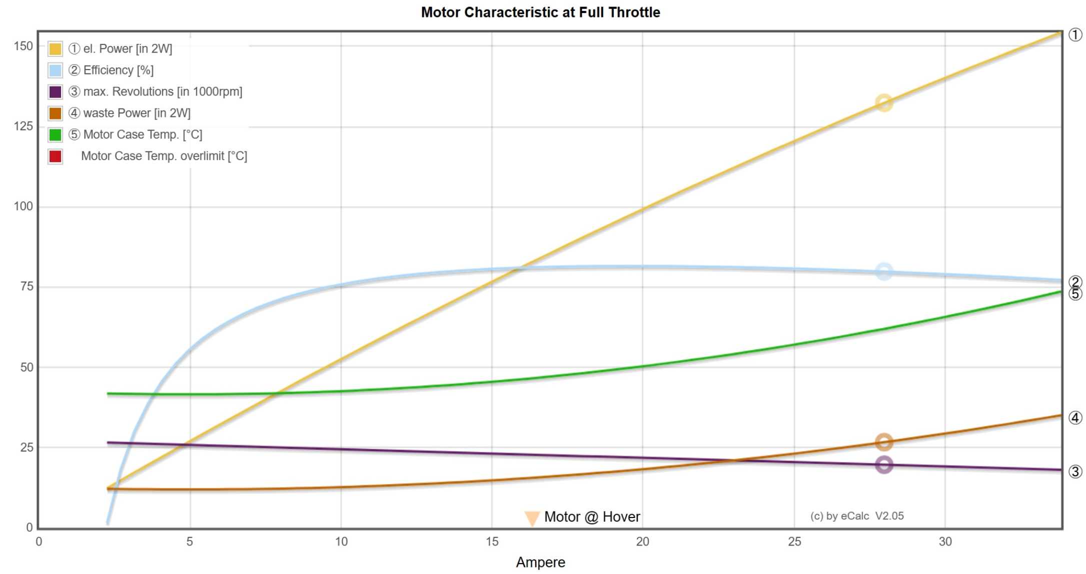

Fig. 10. XING 2306 characteristics at full throttle

Fig. 11. MN5008 motor attached to the propeller

In summary, the detailed evaluation and selection of motors for the Flying UGV project were driven by a comprehensive understanding of the vehicle's operational needs and the performance characteristics of potential motor candidates. This approach ensured the selection of motors that not only met but exceeded the project's requirements for power, thermal management, and reliability, setting a solid foundation for the ongoing development and optimization of the hybrid UGV system.

G. ESC Selection for Efficient Power Delivery

Team Gliese-514 undertook a detailed analysis to identify an ESC capable of efficiently powering the motors of the Flying UGV. Given the significant weight of the combined ground module and drone, a high-power delivery with efficient energy use was essential to maximize flight duration. Additionally, a small footprint and lightweight design were crucial to minimize space and added weight. These considerations led the team to opt for a 4-in-1 ESC, streamlining power management for all four motors, reducing size and weight, and simplifying wiring [12], [13].

Despite the benefits of 4-in-1 ESCs, such as reduced size and centralized control, they pose challenges like increased heat generation, heightening the risk of overheating and potential intermittent power loss. Furthermore, these ESCs present a single point of failure; damage from excess current in one motor could necessitate replacing the entire unit, increasing repair costs.

The selection process culminated in choosing the TMotor F55A Pro II, a 4-in-1 ESC capable of delivering up to 55 amps continuously per motor, with a peak current of 75 amps. Weighing just 17.5 grams and occupying less than 20 square centimeters, it met the project's requirements for compactness and

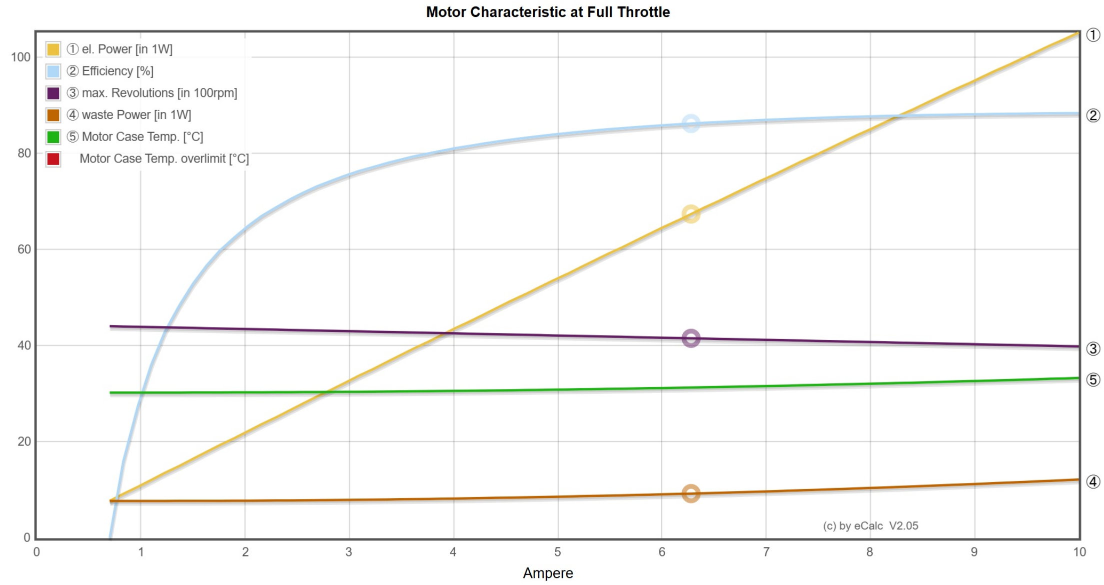

Fig. 12. MN5008 characteristics at full throttle

efficiency. Its integrated large heat sink addressed thermal concerns, supporting 3-6S batteries, suitable for various motor and battery configurations, with cost-effectiveness as an additional advantage.

Initial tests with the Xing 2306 motors validated the ESC's performance; it managed power delivery efficiently, maintaining temperatures below 60°C. Subsequent trials with lighter drone designs and larger 170 KV motors with 14-inch propellers confirmed the F55A Pro II's low thermal output and sustained performance, affirming its suitability for the project's needs.

Table VII compares various ESC models based on their continuous and peak current ratings, weight, and supported battery configurations. This comparison is critical for ensuring that the selected ESC can handle the power requirements of the motors while also contributing to the overall efficiency and weight management of the UGV.

Figure 13 shows the TMotor F55A Pro II 4-in-1 ESC, the selected electronic speed controller for the project. This image is relevant as it visualizes the compact and integrated design of the ESC, illustrating how its form factor and build contribute to the overall efficiency and space optimization in the UGV design. The integrated large heat sink visible in the image is a key feature for thermal management, ensuring that the ESC can handle the power delivery without overheating, which is crucial for maintaining reliable and sustained performance in the field.

ESC Model	Continuous Current (A)	Peak Current (A)	Weight (g)	Supported Battery	Notes
TMotor F55A Pro II	55	75	17.5	3-6S	High efficiency, integrated heat sink
Hobbywing Xrotor Micro	60	80	15	3-6S	Low latency, supports DShot1200
Racerstar REV35 4in1	35	50	12	3-6S	Budget-friendly, good for beginners

TABLE VII
COMPARISON OF ESC MODELS FOR THE FLYING UGV PROJECT

H. Propeller Selection for Enhanced Thrust and Stability

Team Gliese-514's propeller selection process for the hybrid Unmanned Ground and Aerial Vehicle (UGV/UAV) was a detailed endeavor aimed at balancing aerodynamic efficiency, lift capacity, and system stability. Initially, 5-inch propellers were chosen, aligning with standard drone designs. However, the added weight from the UGV elements

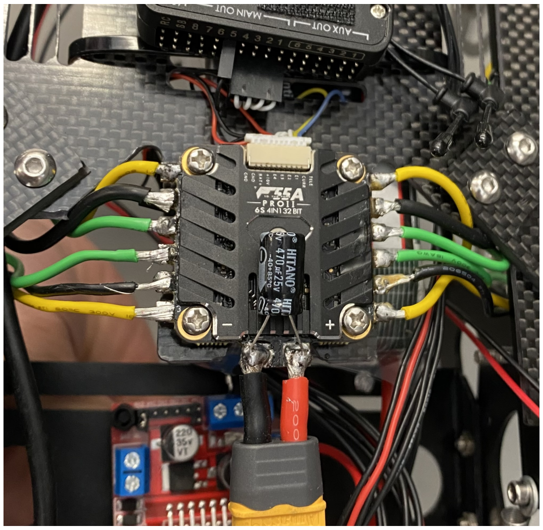

Fig. 13. The TMotor F55A Pro II 4-in-1 ESC

like the heavier chassis, wheel motors, Raspberry Pi, motor drivers, battery, and Pixhawk controller necessitated a reassessment.

Fig. 14. 7 inch propeller

The team moved to 7-inch propellers to improve thrust capacity, which, despite better performance, were still insufficient for the hybrid UGV/UAV's requirements. This led to the decision to adopt 14-inch diameter propellers, following a comprehensive evaluation of the trade-offs between size, thrust, and impact on the vehicle's design.

Fig. 15. 14 inch propeller

Figure 14 and **Figure 15** illustrate the different propeller sizes considered by Team Gliese-514. The larger propellers provided the necessary thrust for sustaining the combined weight of the vehicle, ensuring stable and efficient lift-off and flight [**?**]. The transition to 14-inch propellers required design adaptations to accommodate the increased size while maintaining structural integrity and meeting propulsion demands.

Propeller Size (inches)	Lift Capacity (kg)	Efficiency (%)	RPM (rev/min)	Power Consumption (W)
5	0.50	80	10000	100
7	0.75	85	8000	150
14	1.50	90	6000	250

TABLE VIII
COMPARISON OF PROPELLER SIZES AND THEIR PERFORMANCE

Table VIII shows the performance metrics for different propeller sizes. The larger propellers improved flight stability and control, which is vital for the vehicle's operation in both aerial and ground modes. The enhanced thrust and stability from these propellers enabled smoother transitions between modes, meeting the project's objectives of a versatile and efficient hybrid UGV/UAV.

The propeller selection journey for Team Gliese-514 was a strategic process that significantly improved the operational capabilities of their hybrid vehicle. The shift from 5-inch to 14-inch propellers was a calculated enhancement, reflecting the importance of iterative testing and adaptation in developing a system that fulfills the sophisticated demands of a hybrid UGV/UAV, ensuring effective and reliable performance across its various operational roles [14].

I. Evaluation of Chassis Materials

In the developmental journey of the Flying UGV, Team Gliese-514 identified the choice of materials for the chassis as pivotal. Initially, acrylic was used for the aerial components due to its availability and proven track record in 3D printing applications, providing a sturdy and cost-effective solution for prototyping and initial aerial tests.

However, the integration phase of aerial and ground components presented a challenge, especially with the cumulative weight impacting the hybrid system. This led to the consideration of carbon fiber, known for its excellent strength-to-weight ratio, commonly used in aerospace and high-performance automotive industries.

The incorporation of carbon fiber into the vehicle's design marked a transformative decision that enhanced operational efficiency. By adopting carbon fiber, the team achieved a reduction in overall weight, maintaining structural integrity and optimizing the propulsion system, thus improving maneuverability.

Characteristic	Acrylic	Aluminum	Carbon Fiber
Density (g/cm^3)	1.18	2.70	1.75
Tensile Strength (MPa)	70	300	4130
Flexural Strength (MPa)	90	150	230
Impact Strength (kJ/m^2)	0.16	0.35	1.20
Thermal Conductivity (W/mK)	0.20	205	8
Cost (Relative)	1	1.5	2.5

TABLE IX
MATERIAL CHARACTERISTICS COMPARISON

Table IX provides a comparison of different materials' characteristics, highlighting why carbon fiber is an optimal choice for the UGV's chassis. The table details properties like density, strength, and cost, underscoring carbon fiber's superior performance attributes that are essential for the aerial and ground operations of the UGV.

Carbon fiber's lower thermal conductivity compared to aluminum is beneficial for the structural stability and performance under varying thermal conditions, essential for maintaining mechanical precision and reliability[17].

Specification	Value	Notes
Material Composition	100% Carbon Fiber	Pure carbon fiber, no fillers
Surface Type	Plain Weave Glossy	High strength, lightweight
Size Options (mm)	240x240, 300x300, 400x400	Multiple sizes available
Thickness Options (mm)	0.5, 1, 1.5, 2, 2.5, 3, 4	Variety of thickness choices
Filament Type	3K Carbon Fiber	3000 filaments, strong yet lightweight
Workability	Easy to Cut	Can be precisely shaped and cut
Applications	Multifunctional	RC, drones, automotive, electronics, etc.

TABLE X
SPECIFICATIONS OF THE CARBON FIBER SHEETS USED

Table X details the specifications of the carbon fiber sheets utilized in constructing the chassis of the UGV. This high-quality material was selected for its superior strength-to-weight ratio and ease of handling, which are crucial for the vehicle's structural integrity and performance efficiency. The table showcases the versatility of the carbon fiber sheets, highlighting their adaptability to various application needs, including those of the Flying UGV.

Despite the higher cost of carbon fiber compared to acrylic and aluminum, the benefits it brings to the project justify the investment. Its use in the UGV chassis aligns with the team's goal of engineering a vehicle capable of enduring complex missions while remaining agile and efficient.

Figure 16 showcases the assembled carbon fiber chassis, exemplifying its integration into the UGV design. This visual representation emphasizes the material's adaptability and compatibility with the vehicle's design requirements, illustrating the prac-

Fig. 16. Carbon Fiber Chassis Assembly

tical implementation of carbon fiber to achieve a lightweight yet robust structure.

The strategic material choice evolution from acrylic to aluminum, and ultimately to carbon fiber, signifies Team Gliese-514's approach to optimizing the Flying UGV's design for improved performance. The integration of carbon fiber into the chassis has been a significant advancement, providing a balance of lightweight, strength, and durability, propelling the project towards its goal of creating a versatile and robust hybrid vehicle. This strategy not only meets the project's current needs but also establishes a foundation for future enhancements, with potential for increased use of carbon fiber to achieve greater performance efficiency and operational effectiveness.

J. UGV Body Dimensions: Impact of Length Variation

Dimensional considerations for Team Gliese-514's hybrid UGV played a critical role in achieving a functional design, particularly when integrating the aerial (UAV) and ground (UGV) components. Initially, the project inherited a compact UAV design optimized for aerial operation, which was not suitable for integration with the larger UGV component. The UGV dimensions were measured at 14.8 x 9.4 x 4.1 inches (37.5 x 24 x 10.5 cm) in length, width, and height, respectively.

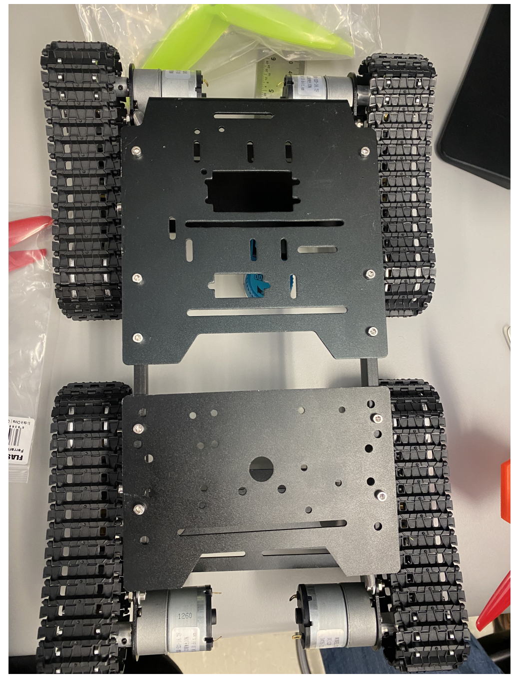

Fig. 17. Chassis with original dimensions

Figure 17 shows the original UGV chassis dimensions. The compact size was initially perceived as a benefit but later identified as a constraint for integrating larger UAV components.

To address the integration challenges, extending the UAV's arm length was a strategic decision driven by the need for increased lift capacity and accommodating larger propellers. This modification transitioned the vehicle from a purely aerial to a hybrid system capable of effective ground and aerial operations. The adoption of 14-inch diameter propellers, facilitated by the extended arms, was pivotal in providing the necessary thrust and stability for the system's combined weight.

Figure 18 illustrates the updated arm assembly, highlighting the lengthened arms that allow for larger propeller installation and thus improved lift and stability for the hybrid vehicle.

The integration of the UGV and UAV components into a cohesive system posed complex engineering challenges. The larger body of the UGV had to merge seamlessly with the aerial component without compromising functionality. This required a holistic approach to design, considering each dimension and material choice for its impact on the overall performance.

Fig. 18. Updated Arm Design

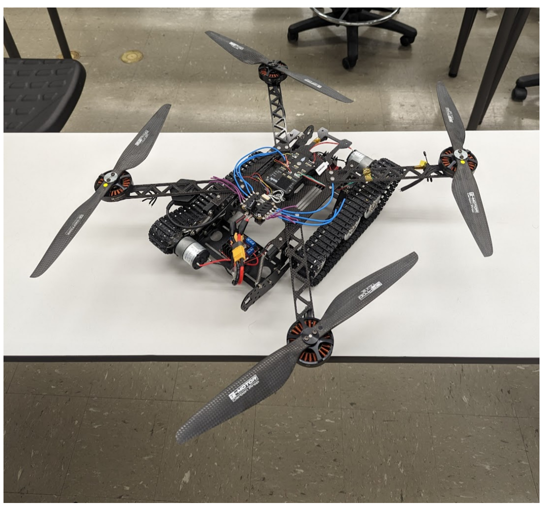

Fig. 19. Updated UHV Assembly

Figure 19 displays the integrated hybrid UGV/UAV assembly, showcasing the outcome of extensive design revisions and integration efforts.

The updated UGV assembly demonstrated improvements in maneuverability, weight reduction, and integration of the aerial and ground components. The implementation of carbon fiber in various parts significantly reduced the weight, enhancing the vehicle's operational efficiency and stability. The strategic modifications of the UGV body dimensions were central to achieving a functional and efficient hybrid system, underscoring the importance of adaptable design strategies in developing complex multi-functional vehicles.

The comprehensive analysis of UGV performance in reconnaissance roles, as outlined in the referenced study, provides a foundational understanding of how dimensional attributes affect operational capabilities. This insight is crucial for Team Gliese-514, aligning with their design considerations for the hybrid UGV. The study underscores the significance of chassis dimensions in enhancing maneuverability, payload capacity, and overall mission effectiveness [16]. By integrating these design principles, Team Gliese-514 aims to optimize the UGV's functionality, ensuring it meets the stringent requirements of both ground and aerial operations. This approach to design and performance analysis exemplifies the project's commitment to developing a versatile and robust hybrid UGV, capable of navigating complex environments and executing diverse mission profiles efficiently.

K. Sensor Integration and Data Processing

For Team Gliese-514's hybrid UGV, sensor integration was a critical process, guided by strategic decisions to enhance the vehicle's capabilities in exploration, navigation, and mapping. The addition of cameras and a LiDAR sensor was a tactical choice to provide the UGV with comprehensive environmental awareness.

Camera Sensor Integration: Integrating multiple camera sensors addressed the need for extensive visual monitoring and mapping. Faced with the Raspberry Pi's limitation of supporting only one camera, the team chose a camera port multiplexer to expand visual data acquisition capabilities, allowing the UGV to capture diverse visual information from multiple perspectives. This integration facilitates detailed environmental analysis and supports complex navigation tasks, providing a comprehensive visual understanding of the UGV's surroundings.

Figure 20 illustrates the UGV equipped with the integrated camera and sensor systems. This visualization is pivotal in demonstrating how multiple sensors are cohesively assembled on the vehicle to enhance its data gathering and processing capabilities, essential for real-time navigation and environmental monitoring.

LiDAR Sensor for Precision Mapping: Incorporating a LiDAR sensor significantly enhanced the UGV's mapping and navigation precision. The LiDAR sensor produces high-resolution 3D maps, crucial for accurate terrain modeling, advanced navigation strategies, and effective obstacle detection

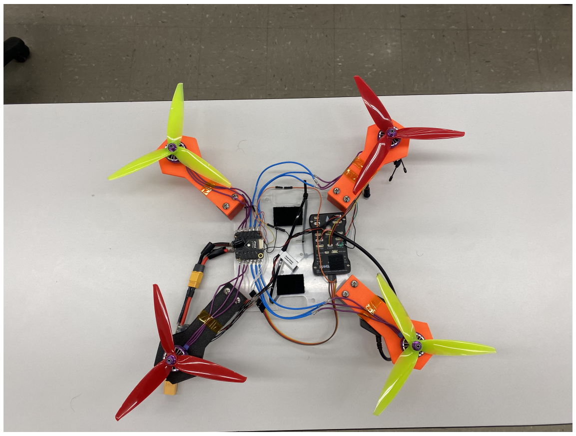

Fig. 20. Drone with sensors installed

and maneuvering. The capabilities of LiDAR in detecting and mapping the environment make it a vital component for the UGV's operation, as detailed in the study by M. A. Kovalev et al., which explores the potential of LiDAR sensors in UAV detection and mapping [18].

Figure 21 shows the LiDAR sensor installed on the UGV. The inclusion of this figure underscores the practical application of LiDAR technology in the UGV, highlighting its role in enhancing the vehicle's three-dimensional environmental perception and navigation accuracy.

Fig. 21. LiDAR Sensor

The integration of sensor technology in the UGV was a methodical process aimed at optimizing its exploration, navigation, and mapping functions. The strategic selection and integration of camera and LiDAR sensors have significantly improved the vehicle's environmental perception and operational capabilities, demonstrating Team Gliese-514's commitment to developing a highly functional and efficient hybrid UGV system.

L. Software Integration for Sensor Communication and Control

Team Gliese-514 enriched the software landscape of their hybrid UGV project through the integration of ROS Noetic on the Buster version of Debian Raspbian OS, chosen for its compatibility and stable software environment.

Figure 22, ROScore Initialization is depicted. This initial step is crucial as ROScore acts as the central node that other ROS processes communicate with, ensuring coordinated operation across the UGV's software system.

- **ROS Integration and Challenges:** The team faced compatibility issues during initial integration efforts, notably with older libraries like QT4. Despite these challenges, Team Gliese-514 successfully established the ROS master, incorporating essential packages and libraries. This setup enabled the use of the rplidar package for direct communication with the RPLIDAR-A1, facilitating preliminary mapping and environmental border delineation.
  Figure 23 illustrates the process of launching MAVROS with PX4 on ROS, a critical step in establishing a communication bridge between the UGV's flight controller and ROS for enhanced data exchange and system control.
- **Enhancing SLAM Capabilities:** To improve SLAM capabilities, the Hector SLAM package was integrated, requiring modifications for user-friendliness and operational efficiency. Adjustments to launch files were made to enable real-time processing and effective odometry, supporting detailed environmental mapping and trajectory visualization in RViz.
- **MAVROS for Advanced Data Integration:** MAVROS was integrated to link the Raspberry Pi 4 with the Pixhawk 4, enabling the publication of sensor data as ROS topics. This integration demanded further configuration to resolve compatibility and communication issues with the Flight Control Unit (FCU), underscoring the necessity for firmware compatibility and extensive library support.
  Figure 24, the Sensor Data Communication via MAVROS is shown. This integration is vital for transmitting real-time data between the UGV's sensors and the flight controller, facilitating sophisticated data-driven operations

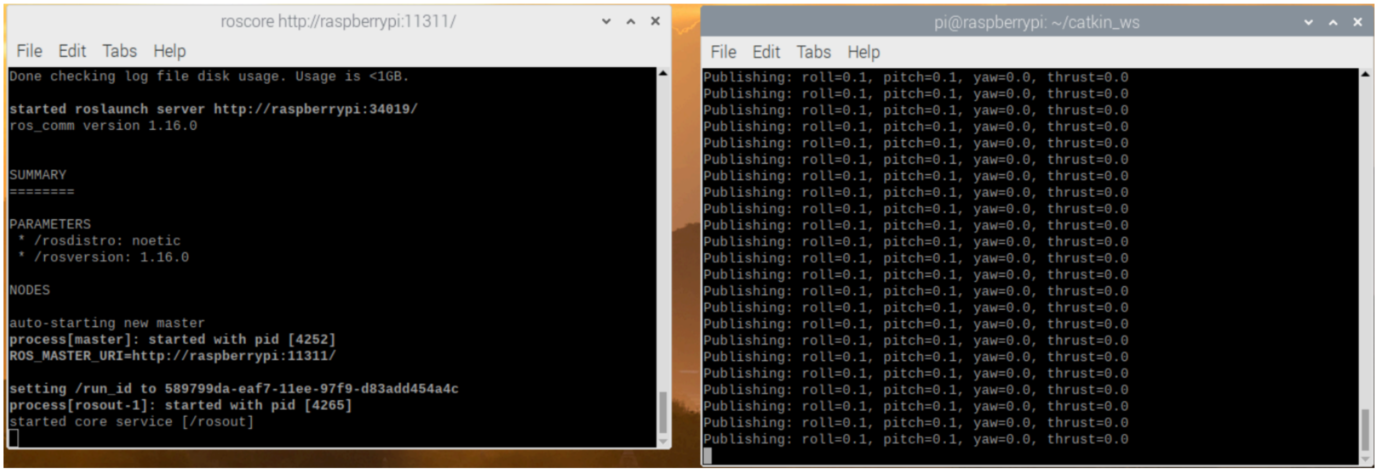

Fig. 22. ROScore Initialization

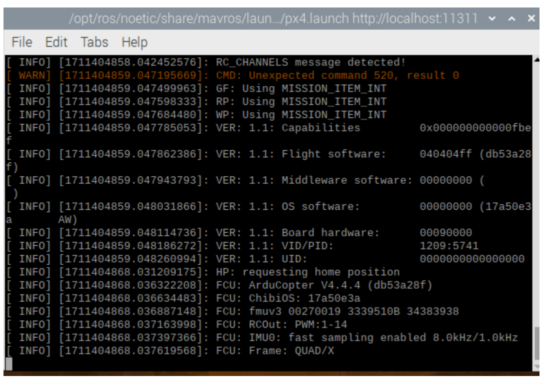

Fig. 23. Launching MAVROS with PX4 in ROS

and decision-making.

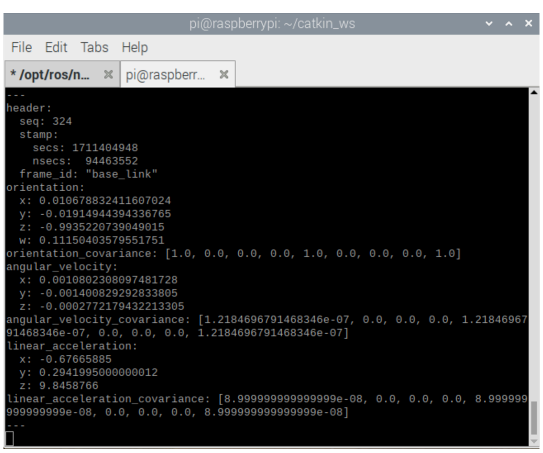

Fig. 24. Sensor Data Communication via MAVROS

To facilitate the ground mode operation of the UGV, PWM signals generated by the Raspberry Pi are employed to control the speed and direction of the ground mode motors. This method is crucial for navigating different terrains effectively and showcases the adaptability of the UGV's control system. **Figure 25** presents the PWM Generation on Raspberry Pi for Motor Control, illustrating how the Raspberry Pi is configured to manage the UGV's motor activities, enabling precise control over its movements in ground mode.

Fig. 25. PWM Generation on Raspberry Pi for Motor Control

The software integration for sensor communication and control in the UGV project was a meticulous process, essential for establishing a robust and efficient system. The strategic implementation of ROS Noetic, along with critical package integrations and configurations, has significantly enhanced the vehicle's sensor communication capabilities and operational control, reflecting Team Gliese-514's dedication to creating a sophisticated and reliable hybrid UGV system.

M. Control with ArduPilot

Team Gliese-514 integrated ArduPilot, a leading open-source autopilot software system known for its versatility and reliability, for the operation and testing of their hybrid UGV. ArduPilot's ability to interface with various unmanned vehicles makes it an exemplary choice for their project, which encompasses both aerial and ground navigation.

Figure 26 showcases the ArduPilot Mission Planner interface, illustrating the user-friendly environment that Team Gliese-514 utilizes for configuring and controlling their hybrid UGV. This interface is pivotal in the team's ability to program flight paths, monitor real-time data, and adjust operational parameters, directly influencing the UGV's performance and mission success.

- **ArduPilot's Comprehensive Functionality:** ArduPilot provides a full-featured suite compatible with multirotors, ground vehicles, and hybrid systems, facilitating seamless transitions and control between terrestrial and aerial functionalities of the UGV.
- **Community and Development Support:** The strength of ArduPilot lies in its robust community and development ecosystem, offering continuous improvements and access to advanced features, which is crucial for addressing the challenges of a hybrid unmanned vehicle system.
- **Compatibility and Flexibility:** ArduPilot's compatibility with diverse hardware platforms and its open-source nature allow for customized software tailoring, enhancing sensor and communication system integration, and improving the UGV's operational efficiency.
- **Advanced Communication and Real-time Data Processing:** The software enables sophisticated mission planning, navigation, and sensor integration, crucial for the autonomous operation of the vehicle, providing a comprehensive control system for the UGV's diverse components.
- **Reliability and Industry Adoption:** The widespread adoption of ArduPilot in over a million vehicles globally and its use by major institutions affirm its reliability and suitability for various operational conditions faced by the hybrid UGV.

Table XI provides a comparative analysis between ArduPilot and alternative software solutions, highlighting the attributes and capabilities that make ArduPilot the preferred choice for Team Gliese-514's hybrid UGV. The table elucidates ArduPilot's

Criteria	ArduPilot	Alternative Software
Functionality	Full-featured, supports UAV, UGV, and hybrid	Limited to specific vehicle types
Community Support	Large global community, extensive resources	Smaller community, fewer resources
Compatibility	High, with various hardware platforms	Moderate to low
Flexibility	Highly customizable and adaptable	Less flexible, may have proprietary constraints
Real-time Data Processing	Advanced, with low latency	Basic to moderate, potentially higher latency
Reliability	Proven in over a million vehicles	Less documented
Industry Adoption	Extensive, used by major institutions	Limited or specific to certain sectors
Autonomous Capabilities	Sophisticated mission planning and execution	Basic autonomous functions
Update Frequency	Regular updates and enhancements	Less frequent or static
Development Ecosystem	Open-source, continuous improvement	Closed-source or limited development

TABLE XI
COMPARISON OF SOFTWARE INTEGRATION WITH ARDUPILOT

advantages in terms of functionality, community support, compatibility, and flexibility, which are essential for the effective control and operation of the hybrid vehicle.

The integration of ArduPilot in Team Gliese-514's hybrid UGV marks a significant step forward in the vehicle's design and functionality, enhancing its operational capabilities and laying a foundation for future innovation. This strategic choice in software and sensor integration ensures efficient performance and versatility in various applications, making the UGV a robust tool for exploration and navigation.

N. Data Acquisition and Processing in Hybrid UGV/UAV Operations

The integration of data acquisition and processing systems forms the core of Team Gliese-514's hybrid Unmanned Ground and Aerial Vehicle (UGV/UAV) operations, crucial for the project's functionality. This section details the methods and technologies employed to efficiently capture, process, and utilize data in real-time, bolstering the vehicle's autonomous decision-making capabilities.

Fig. 26. Ardupilot Mission Planner

a) Data Acquisition Strategy: The hybrid UGV/UAV adopts a multi-sensor approach for data acquisition, equipped with high-resolution cameras, LiDAR sensors, and various environmental sensors. These instruments capture diverse data sets, including visual imagery, topographical maps, thermal readings, etc. The acquisition strategy is designed to ensure seamless sensor integration, maximizing coverage and minimizing blind spots across both aerial and ground modes.

b) Real-time Processing and Analysis: At the heart of the system is a powerful processing unit capable of swiftly handling extensive datasets using advanced algorithms and computing hardware. By applying Edge Computing principles, the vehicle processes data on-the-fly, reducing latency and enhancing responsiveness, allowing for real-time environmental data analysis and immediate navigation adjustments.

Figure 28 demonstrates the 3D visualization of LiDAR mapping in RViz, illustrating how the UGV/UAV utilizes LiDAR data for detailed topographical mapping and autonomous navigation, highlighting the system's capability to process and visualize complex environmental data effectively.

c) Integration with Control Systems: Processed data are seamlessly integrated into the vehicle's control systems, facilitating a closed-loop operation where sensory inputs directly influence navigation and operational tactics. Frameworks like ROS (Robot Operating System) and ArduPilot provide a high degree of autonomy, enabling complex task execution with minimal human intervention.

Figure 27 shows the data obtained from the Pixhawk 4, emphasizing the integration of real-time data into the UGV's control system, which is critical for dynamic and responsive vehicle operations.

d) Future Directions in Data Handling: Team Gliese-514 plans to incorporate cloud computing and IoT technologies to advance data processing capabilities, supporting enhanced analytics, remote control, and collaborative operations with other robotic systems. Implementing stronger data encryption and cybersecurity measures is also a priority to safeguard against unauthorized access and maintain mission-critical information integrity.

In conclusion, the data acquisition and processing framework within Team Gliese-514's hybrid UGV/UAV is robust, efficient, and poised for future technological advancements, supporting the vehicle's present and future operational requirements.

O. Future Enhancements

Looking ahead, Team Gliese-514 envisions a series of enhancements and refinements to advance the performance, versatility, and operational efficiency of their hybrid Unmanned Ground and Aerial Vehicle (UGV/UAV). The development roadmap, anchored in optimizing functionality and broadening application scope, underscores a commitment to continuous improvement and innovation.

- **Lightweight Chassis Development:** A key focus is transitioning to a chassis made predominantly from carbon fiber or other lightweight materials to reduce the vehicle's overall weight.

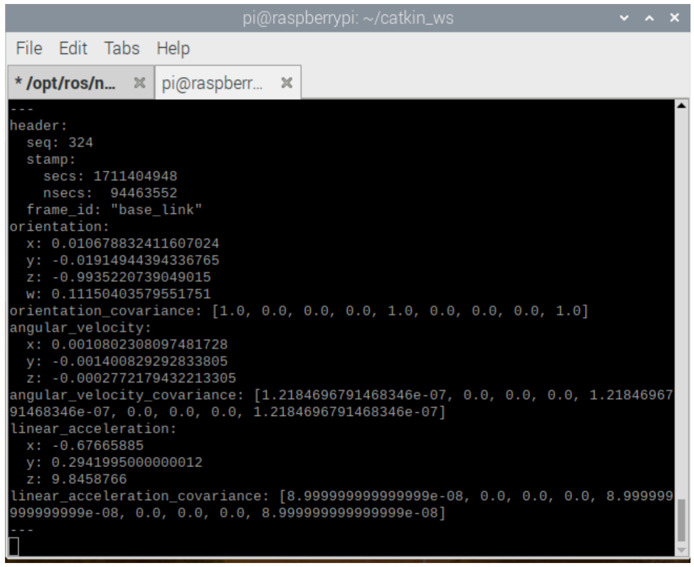

Fig. 27. Data obtained from the Pixhawk 4

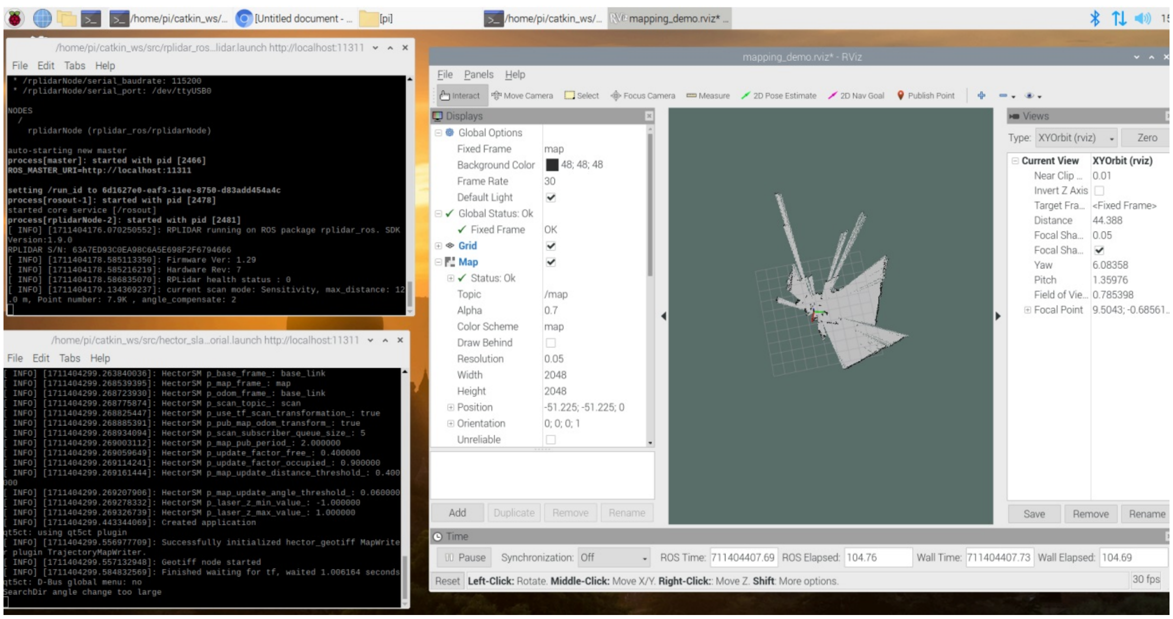

Fig. 28. 3D visualization of Lidar mapping in RViz

This change aims to enhance propulsion efficiency, increase payload capacity, extend flight durations, and improve maneuverability. Thorough testing will ensure these lighter materials maintain necessary structural integrity and durability for both aerial and terrestrial operations.

- **Drivetrain Modifications for Enhanced Maneuverability:** Future iterations will consider drivetrain modifications to improve steering capabilities, possibly incorporating mecanum wheel technology for omnidirectional movement. This approach seeks to balance the durability of treads with the flexibility of mecanum wheels, merging the advantages of both systems.
- **Advanced Sensor Integration and Data Management:** Further development will focus on integrating additional sensors to boost the vehicle's environmental awareness and data gathering capabilities. Plans include adding local storage to enhance data collection and analysis, supporting more autonomous and precise task execution.

- **Power Management and Secondary Energy Sources:** Addressing the dual-mode energy demands involves integrating a secondary power source to extend mission durations and provide stable power. Exploring solar panels, energy harvesting systems, or advanced battery technologies will aim to complement the existing power system and increase the hybrid vehicle's endurance and versatility.
- **Unified Control and Data Acquisition System:** Development of a unified control system will streamline vehicle maneuvering and data acquisition, featuring intuitive controls and integrated operational commands. Enhancements in remote operation capabilities and data access, including advanced camera system integration, will enrich environmental data collection and operational interaction.
- **Detachable Components for Independent Operation:** Innovations may include mechanisms for the aerial and ground components to detach and operate independently, expanding operational capabilities and allowing concurrent aerial and ground tasks. This feature would necessitate sophisticated docking and release mechanisms for seamless transitions between combined and independent operations.

These enhancements aim to make the hybrid UGV more versatile, efficient, and capable, addressing existing limitations and expanding the vehicle's functionalities. Team Gliese-514's efforts will push the boundaries of hybrid unmanned vehicle technology, setting the stage for future innovative applications.

III. Conclusion

The development of the hybrid Unmanned Ground and Aerial Vehicle (UGV/UAV) by Team Gliese-514b represents a significant stride toward innovative, multifunctional robotic systems. Throughout the project, we navigated complex design challenges, integrating advanced technologies to create a vehicle capable of versatile, efficient operation in diverse environments. The successful integration of aerial and ground capabilities, supported by sophisticated sensor systems and robust control mechanisms, underscores our commitment to pushing the boundaries of unmanned vehicle technology.

Our critical design review process illuminated the project's strengths, such as the adaptable propulsion system and the strategic material choices for the chassis, which collectively enhance the vehicle's performance and reliability.

Looking forward, the planned enhancements, including the transition to lighter chassis materials like carbon fiber and the potential for modular, detachable components, promise to further elevate the operational capabilities of our hybrid vehicle. These future developments, coupled with ongoing testing and optimization, will ensure that our UGV/UAV system remains at the forefront of unmanned vehicle innovation.

This project not only exemplifies the potential of hybrid unmanned vehicles in supporting a range of missions but also sets a foundation for future explorations in the realm of autonomous systems. The experiences and insights gained through this endeavor contribute valuable knowledge to the field, paving the way for further advancements and applications in unmanned vehicle technology.

Appendix A
Appendix A: Design and Material Specifications of the Hybrid UGV/UAV

This appendix details the design and material choices for Team Gliese-514's hybrid Unmanned Ground Vehicle (UGV) and Unmanned Aerial Vehicle (UAV). The development process focused on optimizing the structural and functional aspects of the vehicle to achieve a balance between performance, durability, and weight.

A. CAD Design Overview

The Computer-Aided Design (CAD) models provided a comprehensive view of the hybrid UGV/UAV, illustrating the integration of various components and subsystems. **Figure 29** represents the detailed CAD design of the hybrid system.

B. Assembled Prototype

Figure 30 displays the assembled prototype, showcasing the practical implementation of the CAD design and the effectiveness of the material choices in the real-world model.

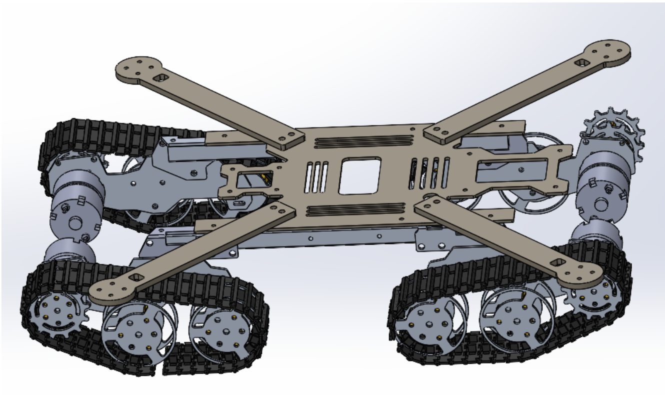

Fig. 29. CAD Design of the Hybrid UGV/UAV

Fig. 30. Assembled Prototype of the Hybrid UGV/UAV

C. Separate UAV and UGV Designs

The UAV and UGV components were designed to function seamlessly both as independent units and as an integrated system. **Figures 31** and **32** show the individual designs of the UAV and UGV, respectively.

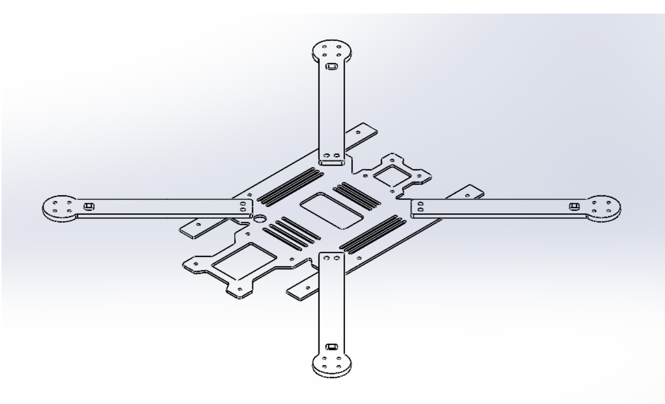

Fig. 31. Design of the UAV Component

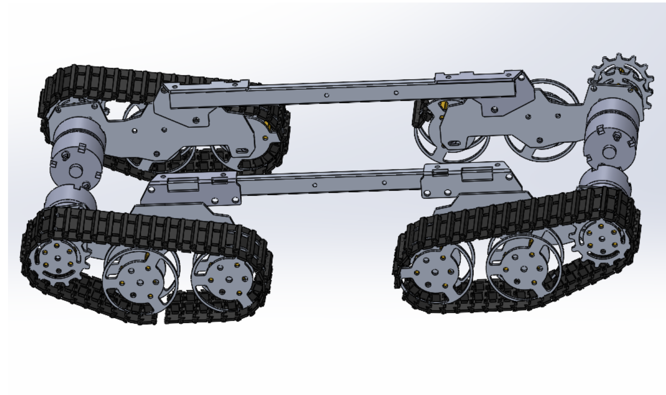

Fig. 32. Design of the UGV Component

D. Materials Used

The selection of materials was crucial for achieving the desired balance between strength, weight, and durability. The main chassis of the UGV/UAV hybrid utilized carbon fiber due to its high strength-to-weight ratio and corrosion resistance. **Figure 33** illustrates the carbon fiber material used in the construction of the hybrid vehicle.

Fig. 33. Carbon Fiber Material Used in the Hybrid UGV/UAV

E. Chassis Dimensions

The chassis of the hybrid UGV/UAV underwent several design iterations to accommodate the integration of aerial and ground functionalities. The final dimensions were settled at 14.8 x 9.4 x 4.1 inches (37.5 x 24 x 10.5 cm), optimizing the space for component fit and operational efficiency while maintaining structural integrity.

- Length: 14.8 inches (37.5 cm)
- Width: 9.45 inches (24 cm)
- Height: 4.1 inches (10.5 cm)

The design and material specifications of the hybrid UGV/UAV were meticulously planned and executed to meet the operational requirements and objectives of Team Gliese-514, ensuring a robust, efficient, and versatile unmanned vehicle system.

Appendix B
Cost Breakdown

Name	Cost ($)	Amount	Total Cost ($)
Carbon Fiber Sheets	24.99	6	149.94
RadioMaster Pocket	79.99	1	79.99
Navio2 Flight Controller	199.00	1	199.00
RadioMaster ELRS Reciever	19.99	2	39.98
T-Motor F55A Pro II	94.06	2	188.12
Raspberry Pi 4	35.00	1	35.00
4s Battery	41.50	2	83.00
6S Batter	59.50	2	119.00
Camera	25.00	1	25
T-Motor MN5008 Motors	89.99	4	359.96
Xing 2306 2450KV Motors	23.99	4	95.96
UGV Chassis	118.99	1	118.99
PixHawk Flight Controller	125.00	1	125.00
Power Module	13.69	1	13.69
Motor Drivers	11.49	1	11.49
Telemetry Module	64.99	1	64.99
14” Propeller Pair	49.98	2	99.96
7” Propeller Set	3.99	1	3.99
5” Propeller Set	3.99	1	3.99
Lidar Sensor	99.00	1	99.00
Misc. Wire	15.00	1	15.00
Radiolink GPS Module	39.00	1	39.00
Keyboard & Mouse for RPi	19.00	1	19.00
Mis. Hardware	24.00	1	24.00
Total			**$2022.53**

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