Robotic Aerial Stabilization for Rapid Emergency Deployment

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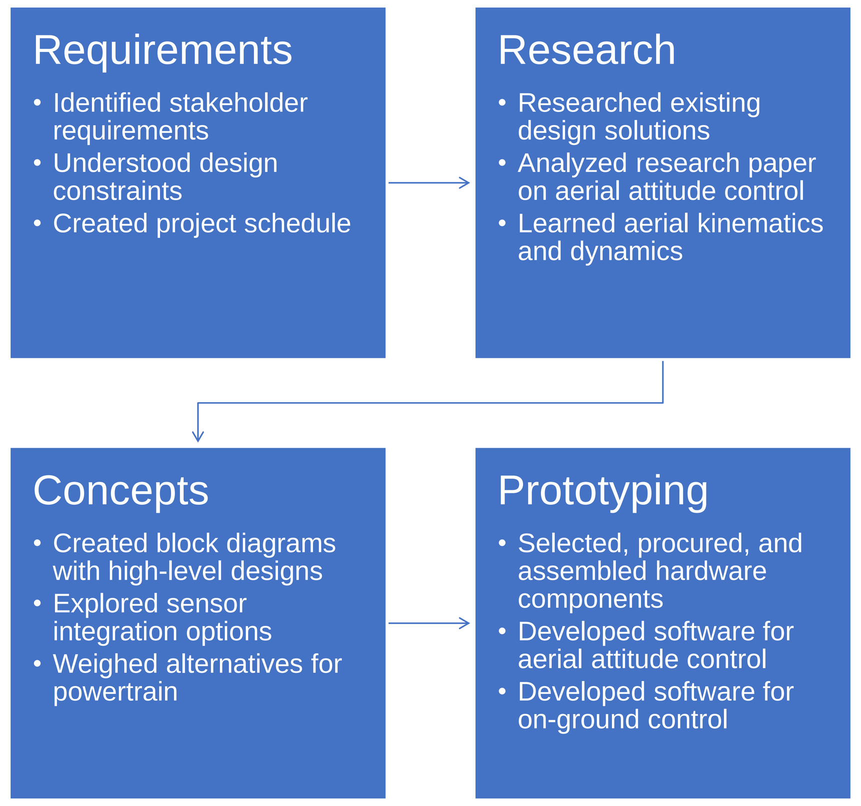
OBJECTIVE

Search and rescue (SAR) missions and other emergency scenarios frequently benefit from the use of highly maneuverable robotics, especially where human entry is limited or unsafe. It is beneficial for these robots to be throwable to overcome obstacles such as high walls. However, these robots often do not land on the ground upright after being thrown, causing them to be immobilized on their side or back.

Our objective is to solve this problem by developing a throwable four-wheel independent drive and steering (4WIDS) rover that stabilizes its aerial orientation before hitting the ground. This project builds upon previous control systems research on aerial attitude control. We also take inspiration from the righting reflex cats, which allows them to reorient in the air by twisting and conserving angular momentum.

As the electrical team on this project, we are responsible for the design and implementation of hardware, software, and avionics.

DESIGN PROCESS & CONSIDERATIONS

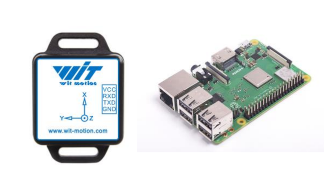


Our design for the rover was justified by its functionality, versatility, and durability. We aimed to create a tool that could handle challenging terrain and obstacles while remaining energy-efficient, using high-quality materials and components. By prioritizing these factors and refining our design through iterative development, we believe that we have created a practical and reliable rover capable of performing a wide range of complex tasks.

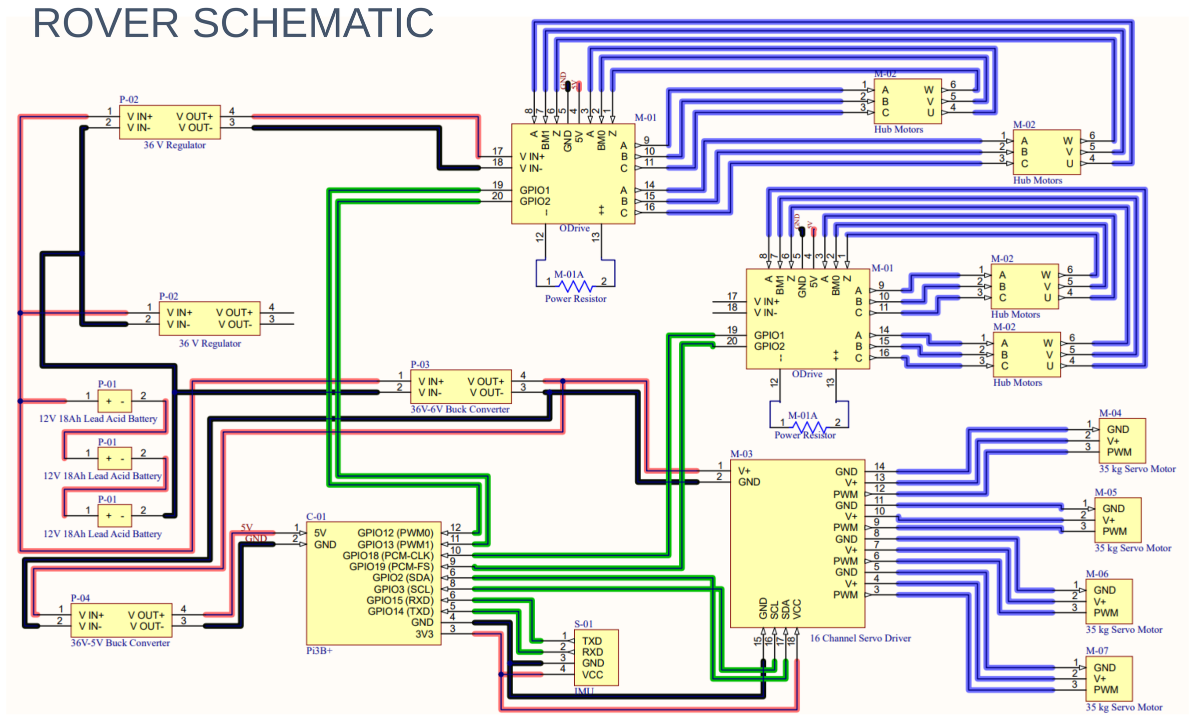
Key considerations in component selection included cost, performance, power consumption, and size. Working under defined constraints enabled us to be creative in identifying design solutions for hardware and software.

HARDWARE DESIGN

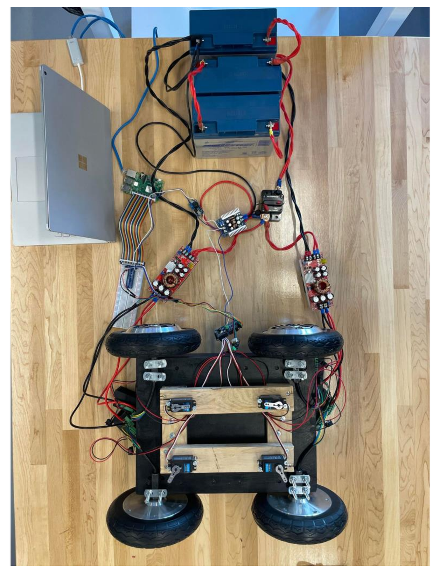
Our hardware design consists of a central single-board computer (SBC), inertial measurement unit (IMU) sensor, motor actuation system, and powertrain. The system architecture allows the rover to be scalable for future applications as selected components can be replaced depending on power or computation requirements.

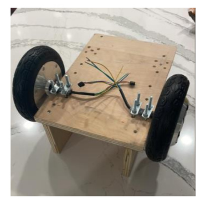
System	Critical Features	Images
Sensors & Computation	The IMU enables real-time measurement of aerial attitude (roll, pitch, and yaw) with a built-in Kalman Filter. The Raspberry Pi 3B+ SBC has high speed processing (1.4GHz) required for the controls.	
Powertrain	Our powertrain accommodates the rover's power consumption of up to 1800W with three 12V lead-acid batteries in series. DC-DC converters are used to create three rails for BLDC motors (36V), servo motors (6V), and SoC (5V).	
Actuation	Brushless DC (BLDC) motors are used for forward/backward motion and servo motors are used to steer the wheels. Motor controllers are used to drive speed and torque. This system allows for the rover to be 4WIDS.	

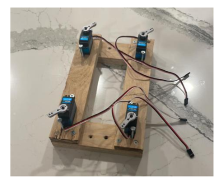
ROVER SCHEMATIC

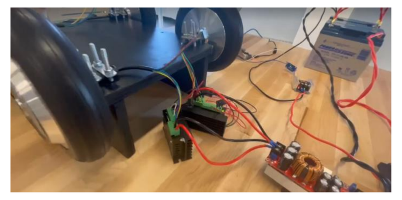


HARDWARE TEST PIPELINE





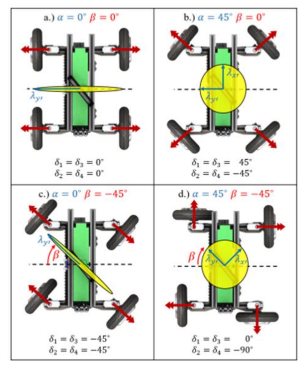


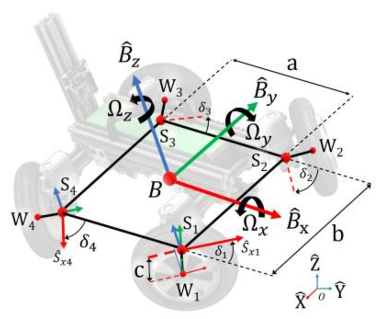


SOFTWARE DESIGN

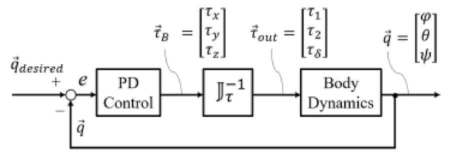
The software architecture of the rover is designed to enable both automatic aerial attitude control and user-controlled on-ground motion. The aerial attitude control mechanism is based on research published by United States Military Academy West Point. The roll, pitch, and yaw of the rover body are controlled with wheel reaction torques. The system involves kinematic parametrization and dynamic body control with a proportional-derivative (PD) controller.

Kinematics: Symmetric movement is commanded of the front-right and rear-left wheels as well as the front-left and rear-right wheels. There are two sub-movements, alpha and beta, used to coordinate the dynamics of the rover while in-air. These sub-movements can be superimposed. The neutral configuration is an alpha of pi/4 and beta of 0. Beta can be adjusted to control the yaw movement.

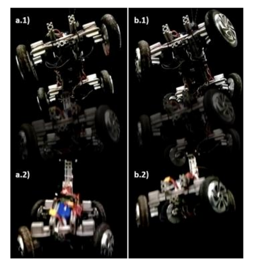


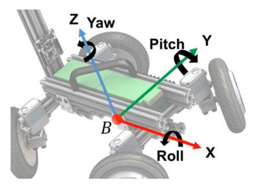


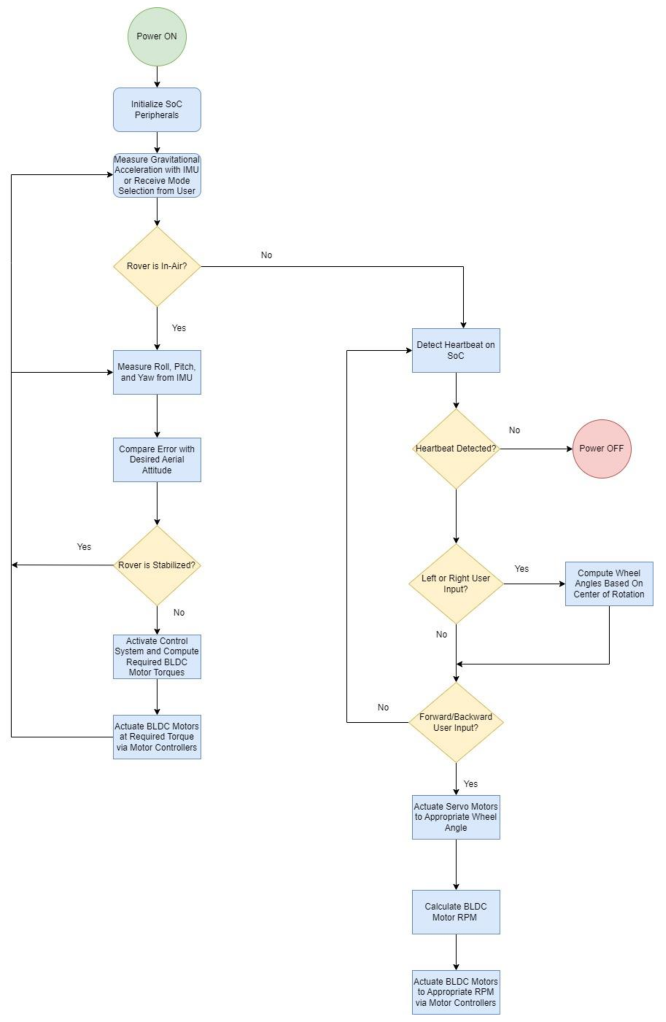
Control System: The IMU measures current aerial attitude and compares them to the desired state. The error is used in a PD controller to compute wheel torques. These torques are computed based on principles of aerial dynamics. These torque values are directly applied to the BLDC hub motors and the system repeats.



$$\vec{\tau}_{out} = \begin{bmatrix}\tau_1\\ \tau_2\\ \tau_3\end{bmatrix} = \mathbb{J}_\tau^{-1} K_P\left(\vec{q}_{desired} - \vec{q}\right) - \mathbb{J}_\tau^{-1} K_D \dot{\vec{q}}$$



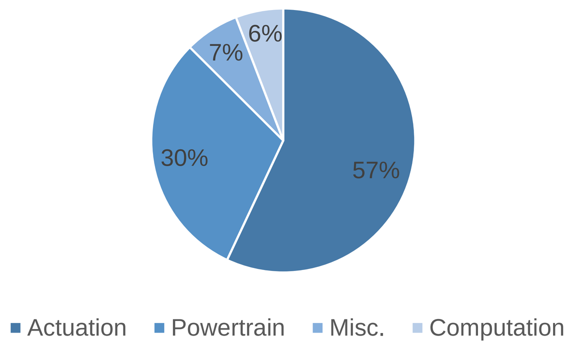




RESULTS & APPLICATIONS

While the rover is still in its early stages, the results of our efforts so far have been promising. We have successfully developed the core hardware and software necessary for an MVP level product, providing a solid foundation for future development. While we cannot yet use the rover for real-world applications, this proof of concept paves the way for a more polished and fully-functional product in the future. By demonstrating the feasibility of this concept and refining our design through iterative development, we hope to create a rover that will be useful in a wide range of applications, from search and rescue missions, to scientific exploration. Ultimately, our goal is to create a tool that will enable greater mobility and flexibility in a variety of contexts, helping to solve complex problems and push the boundaries of what is possible.

COST DISTRIBUTION



This breakdown underscores the importance of prioritizing the core mechanical and electrical components of the rover, which ultimately enable its ability to move and perform complex maneuvers.

FUTURE WORK

For future work on the rover, several exciting possibilities exist. One potential avenue for development is the inclusion of lidar or a camera system to enable greater situational awareness and obstacle avoidance during the descent phase. Additionally, the implementation of computer vision technology could allow for more advanced stabilization algorithms and increased autonomous functionality. Another area for improvement could be the integration of an onboard power supply, which would eliminate the need for an external power source and increase the rover's overall flexibility and maneuverability.

ACKNOWLEDGEMENTS & REFERENCES

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[1] Gonzalez, D. J., Lesak, M. C., Rodriguez, A. H., Cymerman, J. A., & Korpela, C. M. (Year). Dynamics and Aerial Attitude Control for Rapid Emergency Deployment of the Agile Ground Robot AGRO. IEEE Transactions on Robotics, 35(2), 513-526.