AeroTerraBot: The Ultimate Transforming Vehicle

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ABSTRACT

The purpose of this project is to demonstrate the innovation and technical challenge of creating a remote-controlled vehicle that can seamlessly transform between two fundamentally different forms, a ground-based tank and an aerial quadcopter. The core problem addressed is the design and fabrication of reliable mechanical linkages and actuation systems that enable smooth transformation between driving and flying modes. The expected results of the project include delivering a fully functional prototype that transforms seamlessly between tank and quadcopter modes at the press of a button.

Keywords— Innovation, remote-controlled vehicle, ground-based, mechanical linkages, tank and quadcopter.

INTRODUCTION

The development of robots is advancing rapidly in engineering today. This has driven a demand for robots capable of versatile movement across various environments. Usually, robots are designed for a singular environment. For example, robots that move on the ground are effective at traversing terrain and can carry significant payloads. On the other hand, flying drones are highly agile and rapid but they often cannot handle obstacles on the ground.

There are situations in real-world scenarios, such as when searching for individuals or monitoring distant areas or delivering things to remote areas, where we need a vehicle that can move on both land and in the air seamlessly. Robotic systems require this capability to be truly versatile.

Hybrid robotic vehicles are still new. These are primarily observed in academic research environments. When you buy something like this, it usually only does one thing. Moreover, there is a lack of accessible, user-buildable robots capable of readily transforming between different machine types.

The primary challenge in designing a shape-shifting robot, akin to a transformer, lies in achieving seamless integration of its components. It is crucial to ensure that the mechanical linkages and actuation systems are sufficiently robust to prevent structural failure or excessive weight gain during transformation. These hybrid robotic vehicles must be capable of seamless transformation.

The AeroTerra Bot is a remote-controlled vehicle. It is designed to bridge the capabilities of ground-based and aerial robotic systems. The project demonstrates a method for fabricating a functional transforming robot. The AeroTerra Bot integrates the advantages of a ground-based tank with the beneficial attributes of an aerial quadcopter. The developers of the AeroTerra Bot employed computer-aided design and advanced materials, such as carbon fiber, to ensure its structural integrity and light weight. This is crucial for the AeroTerra Bot's optimal performance in both modes.

This involves the development of a dependable mechanical transformation system using high-torque servos and linear actuators; the integration of a high-performance control system featuring a Teensy 4.0 microcontroller and custom PCB; and the implementation of the Dream Flight firmware to coordinate mode-switching and flight stabilization.

The project aims to deliver a robust prototype capable of switching between tank and quadcopter modes at the press of a single button.

The AeroTerra Bot excels at facilitating access to challenging environments. This capability stems from its ability to navigate areas inaccessible to conventional robotic systems. Furthermore, the AeroTerra Bot can access hazardous or extremely difficult-to-reach locations.

The AeroTerra Bot project also aligns effectively with several Sustainable Development Goals (SDGs). Specifically, these include Quality Education and Industry, Innovation, and Infrastructure. The AeroTerra Bot project helps with Quality Education and Industry, Innovation and Infrastructure. The AeroTerra Bot does this by helping people learn about science and technology. It also helps us learn about ways to move around.

Theoretical contributions focus on overcoming kinematic constraints, optimal linkage systems for smooth transformation, and control algorithms for multi-mode function. Section II surveys existing literature on hybrid robots; Section III. details the methodology, including material selection and mechanical assembly; Section IV discusses the software and control logic; and Section V presents the testing results and potential applications.

Field applications are experimentally demonstrated in areas such as search-and-rescue, surveillance, and complex obstacle negotiation, but commercial viability is not yet established.

LITERATURE SURVEY

The creation of robotic systems is a significant area in robotics research (Ryalat et al., 2025). These systems are distinctive due to their ability to operate in both terrestrial and aerial environments (Hu et al., 2023). Researchers in robotics recognize the need for robots capable of agile terrestrial locomotion and flight (Sugihara et al., 2023). This capability allows hybrid robotic systems to access environments inaccessible to conventional robots (Fan et al., 2019). Hybrid robotic systems excel at navigating terrains and can utilize flight for rapid deployment (Zhang et al., 2023).

Evolution of Hybrid Terrestrial–Aerial Systems

Early research explored hybrid systems to assess the feasibility of combining flight and ground movement simultaneously (Sreevishnu et al., 2018). The objective was to ascertain the possibility of integrating flight and ground locomotion into a single platform (Kosvch et al., 2018). The AQT-HR is an example of this. It is a machine that operates both terrestrially and aerially (Zhang et al., 2023). There are also robots that are attached to something with a kind of string. These are known as tethered robots, designed for specific aerial and terrestrial tasks (Bartoletti et al., 2024). Additionally, the Air Crab is a machine capable of flight and ground-based manipulation (Cao et al., 2024). Hybrid systems, like the AQT-HR and the Air Crab, are noteworthy for their versatile capabilities (Cao et al., 2024; Zhang et al., 2023).

Mechanical Design and Transformation Challenges

The primary challenge in designing reconfigurable robots lies in circumventing kinematic limitations and ensuring reliable morphological transformation (Moreno et al., 2018). Researchers have explored various approaches to robot articulation and actuation to facilitate seamless shape transitions (Matheou et al., 2023). The robots that can change shape are hard to make because they must be able to change shape in a way that is reliable. Researchers are working on the linkage systems and the control strategies that enable this (Matheou et al., 2020). The objective is to develop robots capable of flawless morphological transformation (Sun et al., 2023).

When considering weight reduction, it is crucial to address the trade-off between increased strength and added mass, a significant design challenge (Ramezani et al., 2021). Therefore, to mitigate this issue, materials such as carbon fiber and high-temperature-resistant nylon are employed for weight reduction (Opalach et al., 2021). This approach ensures reliability and optimal performance while achieving weight reduction (Ramezani et al., 2021).

Mechatronic integration is crucial in modern designs, which emphasize holistic system integration (Chhabra & Emami, 2010). They leverage control systems to streamline multi-mode actuation (Raduev et al., 2022). This integration facilitates the management of multi-mode actuation, thereby enabling the smooth operation of modern designs (Deaconu et al., 2019).

Control Systems and Software Architectures

Control strategies for robots have evolved significantly. Previously, they involved simple remote operation. Currently, robotic control strategies are complex, employing advanced mathematical techniques to maintain hybrid robot stability (Brogliato et al., 1997). This is a critical aspect for hybrid robots (Brogliato et al., 1997). Localization is crucial for robots.

Various methods are employed to enable robots to determine their position (Slaaczek, 2017). This includes using wave-based technologies, such as ultrasonics, to enhance the autonomous capabilities of reconfigurable robots (Semhoski & Idzkowski, 2024). These advanced techniques will foster greater robotic independence, as localization is critical for enhancing the intelligence and self-sufficiency of reconfigurable robots (Slaaczek, 2017).

Firmware and Logic

When we use firmware like dRehmFlight for our flight controller, it helps our high-torque servos and brushless motors work well together when we switch modes (Koch et al., 2019). This firmware is essential for the flight controller's proper operation with servos and motors (Martin-Sumell et al., 2023). Moreover, the dRehmFlight firmware enables mode switching, which is highly beneficial for our flight controller (Tomić et al., 2012).

Computational Intelligence

Computational intelligence is a field of growing interest. Research focuses on how to use special computer models and neural networks to make agricultural and neuro-robotic systems more effective in decision-making and task execution. These systems can be used in different ways. Computational intelligence is the key to making these systems more intelligent. Researchers are investigating how to utilize Computational Intelligence to improve the way these systems work. This approach is significant as it can facilitate making better decisions and get better results from these systems.

Field Applications and Commercial Viability

While many hybrid robots are currently limited to experimental demonstrations in university research, their potential utility in search-and-rescue, surveillance, and obstacle negotiation is well documented (Oliveira & Ramezani, 2024; Sato et al., 2021). The primary goal of current DIY and academic prototypes is to move toward a robust, seamless mechanical transformation that can eventually achieve commercial viability.

SYSTEM ARCHITECTURE OVERVIEW

The architecture is designed to manage the complexity of a transforming vehicle by decoupling high-level user commands from low-level stabilization and actuation.

Command and Control Layer: The remote controller acts as the primary interface, sending user-defined signals for movement (pitch, roll, yaw, throttle) and the mode-switching command.

Microcontroller: Serves as the central "brain" of the system, selected for its high processing speed and compatibility with complex flight algorithms.

Flight Controller Firmware: A specialized VTOL-capable software layer handles real-time stabilization and coordinates the transition logic between modes.

Actuation and Drive Layer: The system routes signals through a custom PCB to manage the specific power and data requirements of the hybrid hardware.

Aerial Mode Actuators: Four brushless DC motors, regulated by Electronic Speed Controllers (ESCs), provide the necessary lift and thrust for quadcopter flight.

Terrestrial Mode Actuators: Two brushless motors are specifically geared to drive the tank treads for ground locomotion.

Transformation Mechanism: A combination of two high-torque servos and two linear actuators physically reconfigure the vehicle's frame to transition between its driving and flying states.

Power and Physical Layer: The chassis utilizes high strength-to-weight materials, including 3D-printed Carbon Fiber-Reinforced Nylon (PAHT-CF) and CNC-machined 3 mm carbon fiber sheets, to ensure the architecture remains light enough for flight while rigid enough for ground impact.

Hybrid Wheel/Track System: The mechanical design integrates a Hybrid Wheel concept that allows the same structural footprint to support both tread-based ground movement and propeller-based flight.

Hardware Connections: The hardware is built around a fast Teensy 4.0 microcontroller. This microcontroller communicates with three parts of the system: the Power System, the Actuation System, and the Communication System. All three systems connect to the Teensy 4.0 microcontroller.

Central Processing Unit (Microcontroller) Connections: The Teensy 4.0 is the central controller to which every subsystem connects. It features numerous pins, and each pin is used for a specific type of signal. The Teensy 4.0 uses these pins to perform its tasks.

PWM/Digital Pins: Connected to the signal wires of the 4× Electronic Speed Controllers (ESCs) for flight motors and the Motor Drivers for the tank treads.

Fig. 1. 3-D diagram of aero terra bot

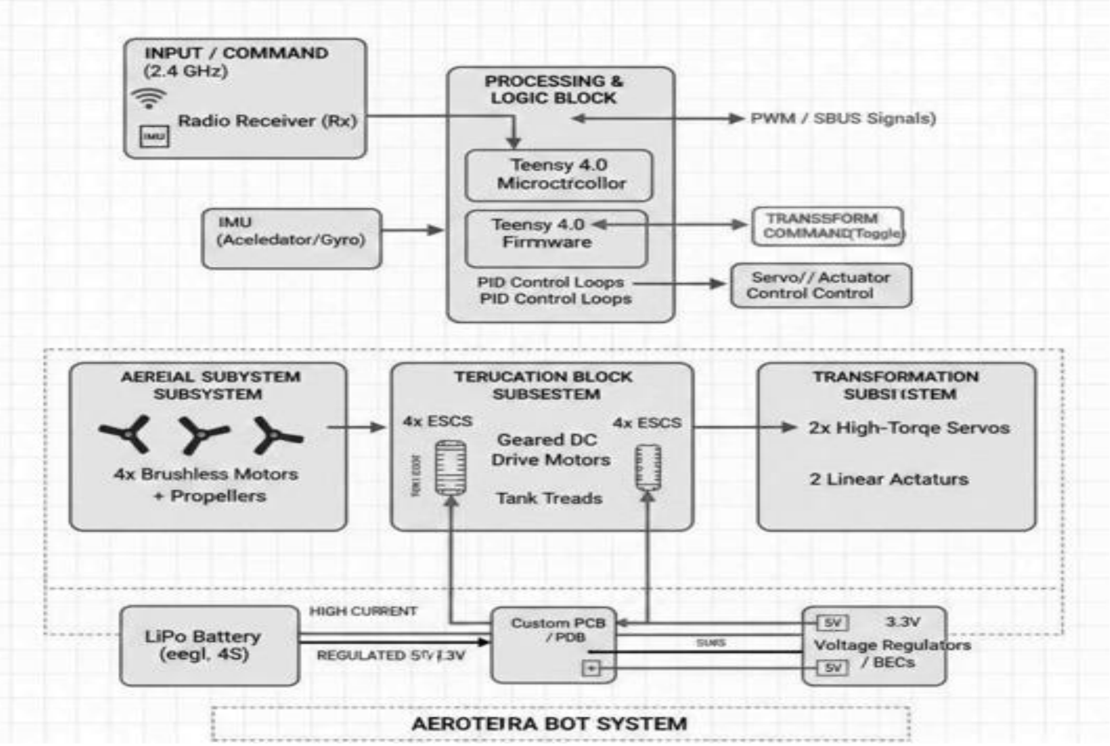

Fig. 2. Block diagram of aero terra bot

Servo Outputs (High-Speed PWM): The high-speed PWM pins of the servo outputs connect to the 2× High-Torque Servos and 2× Linear Actuators, which help trigger the transformation by sending appropriate control signals.

I²C Bus (SDA/SCL): Interfaces with the MPU6050 IMU (Inertial Measurement Unit) to receive real-time orientation data for flight stabilization.

UART/SBUS Port: Connects to the Radio Receiver, which decodes commands from the transmitter and forwards them to the controller.

Power Distribution Network

The brushless motors require a substantial amount of power, while the logic circuits require a stable and precise voltage supply. Therefore, a custom Power Distribution Board (PDB) is utilized, specifically designed to meet the voltage requirements of both the brushless motors and the logic circuits.

The Primary Power Loop handles voltage distribution by connecting the 3S or 4S LiPo Battery directly to the PDB, which then routes power to the four flight ESCs. This configuration supports either a 3S or 4S LiPo battery, ensuring compatibility with both the Primary Power Loop and the Power Distribution Board (PDB).

Power Regulation and Actuation

The regulated power loop incorporates a 5 V/3 A Battery Eliminator Circuit (BEC) that steps down the battery voltage to safely power the Teensy 4.0 microcontroller and the radio receiver. The transformation power loop provides a dedicated 5 V to 7.4 V supply for the linear actuators and high-torque servos. This arrangement ensures that the microcontroller remains unaffected when the actuators and servos draw significant current during torque-intensive mechanical transformations, allowing the transformation mechanism to operate smoothly.

Actuation Interfacing

The flight system utilizes four brushless motors connected to Electronic Speed Controllers (ESCs) through three-phase bullet connectors. The ESCs receive PWM control signals from the Teensy 4.0, enabling rapid speed control of the flight motors for stable aerial operation.

The ground drive system uses geared DC motors connected to an H-bridge motor driver, allowing bidirectional movement of the tank treads. The ground vehicle employs tank-style differential steering, coordinated by the software running on the Teensy 4.0.

During transformation, the Teensy simultaneously controls the linear actuators and high-torque servos, rotating the mechanical arms while extending or retracting the frame to switch between ground and aerial configurations.

Grounding and Signal Integrity

To ensure stable operation and minimize electrical noise generated by the high-power motors, a common grounding strategy is implemented for all electronic components, including the ESCs, Teensy 4.0, and sensors (Jiang et al., 2024). This shared ground is essential for reliable communication among system components.

Shielded or twisted-pair wiring is used for the Inertial Measurement Unit (IMU) and radio receiver signals to reduce electromagnetic interference (EMI). This minimizes noise induced by high-current power cables and ensures accurate sensor measurements and reliable control signals (Zhou et al., 2020).

HARDWARE CONNECTION

Component	Connection Purpose
Teensy 4.0 Pin Type	MPU6050 (IMU), I²C (SDA/SCL)
Flight Stabilization	Feedback
Radio Receiver	UART/Serial
Flight ESCs (4×)	PWM Outputs
Drive Motors	Digital/PWM
Linear Actuators	PWM/Digital
High-Torque Servos	PWM

OUTCOME

The Functional Hybrid Prototype is an advanced machine. It is a fully functional vehicle. The Functional Hybrid Prototype integrates features of a ground-based tank with the capabilities of a flying quadcopter. This enables it to perform functions typical of a tank while also possessing flight capabilities. This prototype is notable for its ability to combine these functionalities as a working machine.

Easy Mode Change: The robot has a way to switch from driving on the ground to flying in the air with just one button. This makes the transformation of the robot, from driving mode to flying mode, easy. The robot can change from driving to flying with the press of a button.

Mechanical Reliability: We want to make sure the mechanical systems work well every time. This means designing and building reliable mechanical linkages and actuation systems that enable smooth transformation between modes.

The robot's structure prioritizes a high strength-to-weight ratio, ensuring that it is robust enough for ground operations while remaining lightweight enough for flight. Materials such as carbon fiber-reinforced nylon and CNC-machined carbon fiber sheets are utilized to achieve this balance, which is crucial for the robot's operational effectiveness.

Integrated Control System: A stable and responsive control architecture utilizing a Teensy 4.0 microcontroller and custom flight firmware coordinates high-torque servos, linear actuators, and brushless motors. Practical field applications demonstrate the vehicle's potential for search-and-rescue, surveillance, and remote delivery. In addition, the AeroTerra Bot serves as a valuable STEM educational platform, supporting robotics education, innovation, and sustainable development goals through quality education and industry innovation.

CONCLUSION

This paper presents the AeroTerra Bot. The AT BOT is a type of robot capable of easily transitioning between ground locomotion and aerial flight. The development of the AT BOT involved a multi-linkage system, powerful motors, and a Teensy 4.0 microcontroller. This capability allows it to dynamically transform its operational mode.

The AT BOT project was successful, performing as intended. The carbon fiber-reinforced materials used in the structure were essential for achieving both strength and low weight, enabling reliable operation on the ground while remaining light enough for flight. The dRehmFlight firmware enabled seamless switching between driving and flying modes while maintaining flight stability.

Beyond its technical achievements, the AeroTerra Bot contributes to broader objectives, including the United Nations Sustainable Development Goals (SDGs), particularly Quality Education and Industry, Innovation, and

Infrastructure. The robot demonstrates significant potential for applications such as search-and-rescue missions, remote delivery, surveillance, and STEM education.

The AT BOT can traverse difficult ground terrain using its specialized tank treads and can fly over obstacles using its quadcopter configuration. These capabilities make the AeroTerra Bot a promising solution for accessing hard-to-reach areas, assisting in disaster response, delivering supplies to remote locations, and monitoring regions that are otherwise inaccessible.

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