MTMS: Multi-Terrain Mobility Systems

Project proposal

`High tech systems`

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Abstract

The MTMS (Multi-Terrain Mobility Systems) project proposal outlines the potential development of a multi-terrain robot capable of transitioning between ground, aerial and water based modes. Existing research, combining 2 out of 3 of the previously mentioned modes, showcases that creating such a system would be possible, however combining all 3 has yet to be done. The primary objective for the coming year of the project is to build a functional prototype running on Robot Operating System 2 with integrated wheels and rotors, enabling manual control and basic navigation for ground and aerial based modes. Over the course of the year, the focus will be on hardware assembly, system integration, and testing of the robot's hybrid mobility capabilities. In the following years, further development will focus on integrating the water based mode, creating a fully autonomous navigation functionality, obstacle avoidance, and terrain mapping. The overall budget for this initial phase is approximately **two thousand six hundred** euros.

Description

For our project, we want to build a Multi-terrain mobility system, where we will start with ground and aerial mobility for this current year. Water based movement and autonomous control will follow in future years. The ground based movement will take the form of a remote control car, then it will be able to fold its wheels below its body to morph into a type of drone, allowing for aerial movement. We are going to depict how we will design such a system, what software and hardware we will need, what the timeline for building said system will be and how we can extend upon it in future years.

Design

We plan to take most of our inspiration from the M4 robot built by CalTech [1] and the Flying STAR built by Nir Meiri and David Zarrouk [2]. Both these robots have propellors and wheels on the end of their arms and rely on moving these arms down to move between mode of transportation. We want to implement a similar approach, and challenge ourselves to include a joint in the arms for extra ground and air mobility with morphing capabilities. We can build upon research for wheeled quadrupedal such as Bjelonic, M. et al's research [3].

Software

We chose to use ROS2 (Robot operating System 2) software as it provides a robust, widely adopted framework for robotic development, with extensive community support. Additionally, we opted for ROS2 instead of ROS1, due to improved architecture and speed of the framework. Hence, compatibility with ROS2 was a main factor taken into account when choosing our hardware components.

Hardware

Because we are designing a robot with non-standard functionality, obtaining parts off the shelf can be difficult, particularly for connecting all the electronics together. This is why we plan to 3D print many parts ourselves, which provides the flexibility needed for our design specifications. Within the team, we are currently discussing the use of Fusion 360 or Onshape for designing these parts, as both programs offer similar tools suited to our requirements.

However, this approach presents challenges for future multi-mobility in water. While 3D printing offers quick prototyping, the materials (PLA) are not reliably waterproof. Additionally, isolating electronics from water effectively and ensuring buoyancy requires specific materials and design adjustments. While we are not focusing on this aspect in the current project phase, our long-term goal includes research in waterproofing, buoyancy, and electronics protection. This foundational research aims to eventually make the system rainproof and eventually submersible.

Flight Controller and Power Electronics

For the flight controller, we plan to use the Pixhawk 6C, due to its many capabilities and native ROS2 compatibility. The PX4 provides us with a well-supported platform for handling aerial navigation, allowing integration with the robot's multiple sensors and actuators. We can use tools like Ardupilot which enables us to test and fine-tune our system across different flight modes.

On the power electronics side, we're assembling a power distribution system internally inside the system. This includes a 4S 4000Mah battery with step-down buck converters to maintain specific voltage requirements across the system. To keep the mechanical design of the system adaptable, we'll incorporate a basic PCB with inputs and outputs for wire connections (a basic power distribution board with outsourced components). This will centralizes wiring but also simplifies adjustments to the setup.

To track power usage, we will integrate a current and voltage sensor within the power electronics system. This will allow us to monitor consumption in real-time.

While autonomy is limited, this initial phase of the project is focused primarily on predefined movement sequences in ROS2. We aim to research the potential for greater autonomy by using sensor data for future, including obstacle avoidance via infrared sensors. Currently, the system will be controlled manually, with specific automatic reactions.

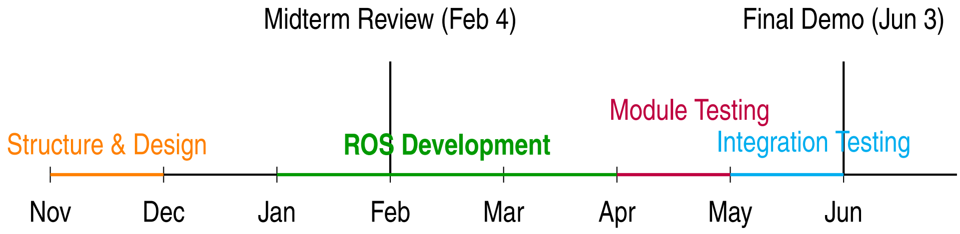
Component	Quantity	Voltage (V)	Current (A)	Power (W)
Hip Servos	8	7.4	3.0	177.6
Wheel Motors	4	12	1.5	72.0
Propeller ESCs	4	12	4.0	192.0
Main Controller	1	5	0.5	2.5
Flight Controller	1	5	0.4	2.0
Total				**446.1**

Table 1: Estimated Power Consumption of Key Components

Future Development

As mentioned the focus for this year will be on ground and aerial control, however, eventually we wish to create an all-terrain vehicle that can survive any circumstances. So one clear future development would be implementing mobility in the water. After that, we want to slowly progress to autonomy within the robot, such that even without human control it can reach its destination. This would obviously require advanced navigation, obstacle avoidance, and autonomous mission planning, but also terrain detection and knowing when to morph, all powered by ROS2 algorithms. We will discuss how the current sensor data and manual control operations serve as the foundation for the future autonomous capabilities of the robot.

Workpackages and timeline



This timeline outlines the planned phases and milestones for the MTMS project. After receiving approval for our plan on November 15, we plan to order all necessary components, which according to their checked lead times should arrive by the end of November. Having acquired all components we can dedicate December to assembling the robot, including designing and 3D printing custom parts as needed. From January to April, we'll work on ROS2 development and control implementation. Where January the focus will be on ground based control, February the focus will be on morphing and in March the focus will be on Aerial control. In April and May, individual modules will undergo testing, followed by full integration testing by mid-May. Key milestones include the midterm review on February 4 and the final demonstration on June 3.

Impact

Our MTMS is set to redefine exploration of unknown or hazardous terrains. Unlike current solutions that are limited to only one or two specific terrain types, such as ground and aerial or aerial and water, the end goal for our MTMS is that it can navigate and adapt to three terrain types: ground, aerial and water. This versatility could revolutionize exploration in locations where traditional methods are ineffective or unsafe, such as disaster sites, alien landscapes, or varied terrains that demand adaptability.
The impact of our system lies in its accessibility and efficiency, especially compared to high-budget, long-term projects like Caltech's M4 [1]. By prioritizing a leaner budget and a short development timeline, MTMS could make advanced terrain mobility more achievable for a wider range of applications. We will also focus on a smaller scale testing environment by developing the system in ROS2, which enhances the research value. While water traversal is outside this year's scope, we'll start researching the possibilities for future development. Ultimately, our project could open up the road to more versatile multi-terrain traversal which is more financial accessible and contributes to further research in this field.

Demo Day package

On the final presentation day, we will demonstrate the multi-terrain robot prototype that we developed over the course of the year. The goal of this demo is to showcase the robot's dual mobility capabilities, transitioning smoothly between ground and aerial modes, and moving in each mode, while being manually controlled via a ROS2 interface.

Key Objectives for Demo day

- **Manual Control via ROS2 Interface:** We will demonstrate the robot's ability to be controlled manually through a ROS2-based interface. Attendees will be able to see how we utilize ROS2 to operate both the wheeled and rotor-based mobility systems, highlighting the integration between hardware and software.
- **Ground Mobility:** The robot's wheeled mobility system will be showcased by navigating through an obstacle course, demonstrating its ability to handle different types of terrain, such as uneven surfaces and ramps.
- **Aerial Mobility:** Following the ground demonstration, we will showcase how the robot switches to its aerial mode. However as it is not feasible to fly the robot during the demo day itself this skill will be presented in a pre-recorded video. Here we will showcase stable flight control.

Midterm Demo Day

On the midterm demo day we wish to showcase the hardware design of the robot and its ability to move on the ground. We aim to showcase our progress in both the hardware and software component by presenting our moving vehicle. The complex movements such as morphing and flying will not be showcased here as we do not aim to have these implemented by the midterm presentation.

Equipment and Budget

The costs of all necessary hardware components for this project will come to a total of €2594.65. The breakdown of these costs is depicted in the table below. Alongside these hardware costs there are theoretical labor costs that come along with creating such a project. To realize this project we will need a team of 5 people, who will work on this project approximately 6 hours a week for the next 33 weeks. Assuming a pay of €15 an hour this will bring in an additional cost of €14850 in labor. However, due to the nature of our project we will not count labor costs towards the final budget.

Component	**Description**	**Price**	**Supplier**	**Del**
Main Computer	UP Xtreme i14	€967	Up squared/Mouser	Em
Flight controller	Pixhawk 6C	€220	Holybro	
Secondary Computer	Raspberry Pi 5	€94.90	reichelt	
Microcontroller	Raspberry Pi pico	€8.5	Tinytronics	
Lidar sensor	For scanning area	€124	Generation robots	
GPS Module	M10	€80	Holybro	
Telemetry Radio	433MHz	€100	Holybro	
3x Batteries	To power the system	€290.37	Racedayquads	
4x wheel	To enable driving	€28	Amazon	
4x 3MR Series - 3-Blade 8x4.1 Propeller	To enable flight	€20	masterairscrew	
4x DC motor	To move the wheels	€74,04	Mouser Electronics	
2x motor driver board	to control the motors	€33	Tiny tronics	
4x EMAX Bullet Series 35A 3-6S ESC	To control and adjust power for the brushless motors	€80	Emax	
4x Pro Series 2812 Brushless Motor	To move the propellors	€120	Emax	
8x Servo (180°)	To enable the 2 joints per leg	€176	TinyTronics	
2x Mini 12V 4”Stroke Electric Linear Actuator	To enable shifting between flight and driving	€60	Amazon	
3x Camera’s (120°)	To enable the person in control to see around vehicle	€91,28	Adafruit	
2 kg PLA filament	For 3D prining custom parts for assembly and frame	€59,80	TinyTronics	
Miscellaneous	Additional wiring, connectors and assembly parts	€90	TinyTronics, etc	Depend
Total	-	**€2720.00**	-	

Table 2: Component and Budget List for Multi-Terrain Robot

References

[1] Sihite, E., Kalantari, A., Nemovi, R. et al. *Multi-Modal Mobility Morphobot (M4) with appendage repurposing for locomotion plasticity enhancement.* Nat Commun 14, 3323 (2023). https://doi.org/10.1038/s41467-023-39018-y

[2] N. Meiri and D. Zarrouk, *Flying STAR, a Hybrid Crawling and Flying Sprawl Tuned Robot*, 2019 International Conference on Robotics and Automation (ICRA), Montreal, QC, Canada, 2019, pp. 5302-5308, doi: 10.1109/ICRA.2019.8794260.

[3] M. Bjelonic et al., *Keep rollin’—whole-body motion control and planning for wheeled quadrupedal robots,* IEEE Robotics and Automation Letters, vol. 4, no. 2, pp. 2116–2123, Apr. 2019. Available: https://arxiv.org/pdf/1809.03557