

Atena Team (Brazil), Indoors Category

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ABSTRACT

The Atena Team from the University of São Paulo, São Carlos School of Engineering (EESC-USP), presents *Harpia*, a 3D-printed, open-source quadrotor MAV developed for the IMAV 2025 indoor "Search and Rescue" competition. The platform is designed for full autonomy in a cluttered, GPS-denied environment, where it must perform complex tasks including navigating narrow gates, physically interacting with a whiteboard, localizing an acoustic source, delivering a payload, and landing on a moving target. To meet these demanding requirements, *Harpia* integrates a robust perception and control architecture centered on a modular, FDM-manufactured airframe. The core of the autonomous system relies on a LiDAR-inertial odometry framework, utilizing a Livox Mid-360 sensor and Fast-LIO2, to ensure reliable state estimation where visual methods may fail. Global localization and mapping are managed by the RTAB-Map framework for drift correction, while a Finite State Machine (FSM) orchestrates the high-level mission logic. This paper provides a comprehensive technical description of the *Harpia* platform, detailing the design and integration of its mechanical, electrical, and software systems, presenting structural simulation results, and outlining the complete software stack that enables a resilient solution for autonomous indoor navigation.

1 INTRODUCTION

The Atena Team from the University of São Paulo, São Carlos School of Engineering (EESC-USP), presents *Harpia*, a custom-built quadrotor Micro Air Vehicle (MAV) designed to compete in the IMAV 2025 indoor competition. Developed since 2023, *Harpia* serves as an open-source research platform with a focus on modularity and rapid prototyping. Its airframe is manufactured entirely using Fused Deposition Modeling (FDM) 3D printing, allowing for swift design iterations and easy maintenance, which are critical in a competi-

tive environment.

The design of *Harpia* is directly driven by the complex challenges of the competition's "Search and Rescue" theme. The indoor mission requires MAVs to operate with full autonomy in a cluttered, GPS-denied 10 × 10 meter arena. The series of tasks—which include navigating through narrow gates with a minimum clearance of 0.5 meters, physically interacting with a whiteboard to draw a line, locating an acoustic "cry for help" to deliver a med-kit, and landing on a moving platform with obscured visibility—imposes stringent requirements on the platform's perception, control, and mechanical resilience.

To meet these demands, *Harpia*'s architecture is centered around robust state estimation and mission execution. We employ a LiDAR-inertial odometry system, using a Livox Mid-360 sensor, to ensure reliable navigation in low-texture environments where visual methods may degrade. Localization and mapping are handled by the RTAB-Map framework, which provides the global consistency needed for completing long-duration missions. The entire mission logic is orchestrated by a Finite State Machine (FSM), which manages transitions between tasks and ensures a structured and reliable execution of the complex operational sequence.

This paper provides a comprehensive technical overview of the *Harpia* platform. Section 2 details the mechanical development, including frame design and structural analysis. Section 3 outlines the electrical configuration and power distribution. Section 4 describes the flight control systems and the onboard computing hardware. Finally, Section 5 presents the software architecture, covering odometry, mapping, and the mission execution logic.

2 MECHANICAL DEVELOPMENT

2.1 Frame development

For the indoor modality, the UAV used is a custom-built quadcopter of the X500 type, whose configuration ensures symmetric mass distribution and contributes to flight stability. The 3D model was developed in CAD software (Computer Aided Design), based on the studies carried out by the team, using SolidWorks® and Autodesk Fusion 360™ as design tools. In the project development, the following criteria were prioritized:

- Alignment of the center of mass with the geometric center;
- Minimization of stress concentration zones;
- Modularity, in order to facilitate maintenance and component replacement.

The main structure is subdivided into the following mechanical parts: upper and lower plates, support beams (responsible for supporting the bases), arms, struts, landing feet, as well as the mount for the onboard computer along with the support structure for the LiDAR.

It should be noted that the adoption of arms reinforced by struts, connected to landing feet, increases local torsional stiffness, which contributes to absorbing the loads generated by the motors, especially during sudden variations in rotation.



Figure 1: The previous version of *Harpia* at IMAV 2024.

2.2 Manufacturing Process

2.2.1 Printing Materials

The frame was entirely manufactured using additive manufacturing, with 3D printed FDM (Fused Deposition Modeling), due to their capability for rapid prototyping and low operational cost. The material used for printing most of the parts was ABS, a thermoplastic polymer with a higher elastic modulus than PLA and greater impact resistance. The exception was the landing feet, which were printed in TPU, in order to reduce impact during the drone's landing. A 3D rendering of *Harpia* is presented in Figure 2.

2.3 Structural Analysis

A structural simulation was conducted to validate the integrity and safety of the UAV's design. The analysis evaluated three key metrics: von Mises stress distribution to identify potential failure points (Figure 4), the factor of safety to quantify structural robustness (Figure 3), and total displacement to assess frame rigidity (Figure 5).



Figure 2: 3D rendering of *Harpia*.

Furthermore, the design was validated under a worst-case load condition, which simulated the maximum possible static forces by modeling all motors operating at full thrust while the landing gear was fully constrained. The successful outcome of this demanding simulation confirms the robustness of the frame against extreme operational loads.

A summary of the key quantitative results is presented in Table 1.

Table 1: Summary of the structural analysis results.

Metric	Value
Factor of Safety (min)	7.267
Max Von Mises Stress	2.752 MPa
Max Displacement	0.324 mm

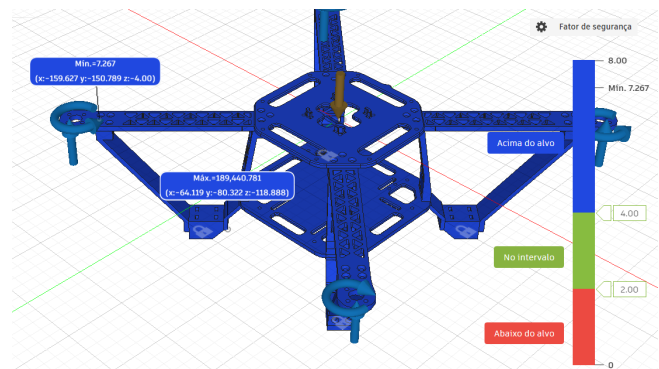


Figure 3: Factor of Safety distribution across the frame.

2.4 Propulsion System

The propulsion system employs T-motor MN3508 KV580 motors (Figure 6) paired with the APC 10x4.5MR propellers. This configuration ensures sufficient lift for stable flight and confirms the UAV's capability to successfully complete all competition missions. To enhance both safety and maneuverability, a minimum thrust-to-weight ratio of 2:1 was

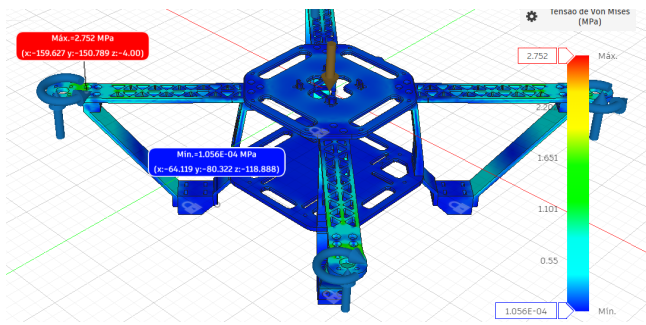


Figure 4: Von Mises stress distribution, measured in MPa.

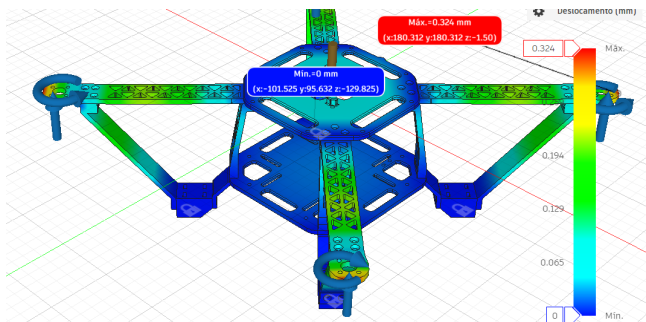


Figure 5: Total displacement of the frame, measured in mm.

defined. This criterion guarantees sufficient margin for take-off and allows the UAV to execute abrupt maneuvers without overloading the propulsion system, even under conditions of reduced propeller efficiency or variations in air density.



Figure 6: T-motor MN3508 KV580

2.5 Adaptations for tasks

For the whiteboard task, we are developing a pen activation mechanism. In this system, the pen itself will be firmly attached, likely with glue, to a mobile part. A compressed spring, held back by a locking pin, is set up to drive this part. When the pin is pulled, it releases the spring, which then pushes the mobile part and the attached pen forward to make contact with the board for writing. On Figure 7 is possible to check the idea of the mechanism.

For the med-kit task, a detachable base mechanism will be developed for a delivery system. A fixed support will be

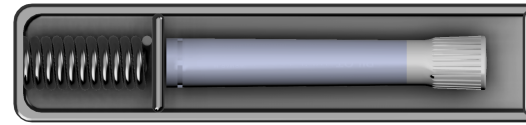


Figure 7: Mechanism for whiteboard task

attached to the UAV's airframe, designed to securely hold a removable platform. This platform will carry the 30g Med-Kit. Upon remote activation, a servo-controlled actuator will release the removable base from the fixed support, allowing the Med-Kit to be dropped at the target location.

3 ELECTRICAL CONFIGURATION

3.1 Power Supply Circuit

The power supply circuit is responsible for distributing adequate electrical energy to all components, ensuring both flight autonomy and component safety. For this purpose, the Gaoneng Li-Ion 6S 4000mAh battery (Figure 8) was selected. Its capacity, voltage, and discharge rate provide adequate energy for the drone's systems.



Figure 8: Gaoneng 6S 4000 mAh Li-ion

The battery output is distributed into three main modules. The first is the propulsion system, where each motor is powered through an Electronic Speed Controller (ESC) integrated with a BEC (Battery Eliminator Circuit). The selected ESC, the T-Motor Pacer P50A 6S 4IN1 (Figure 9), integrates four controllers into a single compact unit. Compared to using four separate devices, this configuration reduces weight and volume, while offering compatibility with the BLHeli32 firmware along with the DShot1200 protocol, providing low-latency and reliable communication between the flight controller and the propulsion system.

The second module consists of a flight controller and a Single Board Computer (SBC), each supplied by its own BEC. The flight controller receives power through a PM02



Figure 9: T-Motor Pacer P50A 6S 4IN1

power module, while the SBC is supplied via a 40-watt step-down voltage regulator. These BECs were selected due to their effectiveness in previous tests conducted by the team. The third module comprises all onboard sensors, most of which operate at a nominal voltage of 3 to 5 volts. The only exception is the Livox Mid-360 LiDAR, which operates in input voltages up to 27 volts and is, therefore, supplied directly from the battery. All other sensors are directly connected to the flight controller and the onboard computer, being powered through them at the appropriate voltage.

It should be noted that the project is subject to future revisions, as adjustments may be required to optimize the drone's performance up to the competition date. Consequently, the selection of components presented above may be revised, since the power supply and distribution are directly influenced by potential design modifications.

3.2 Radio-controller

The radio control system employed is the RadioMaster Boxer, operating with the ELRS protocol and a 2.4 GHz HappyModel EP1 receiver. This setup, which supports up to 12 communication channels, was chosen as the manual control system for the drone due to its prior availability to the team and its proven reliability in previous missions. Although the drone is designed for fully autonomous operation, manual control was incorporated primarily as a safety measure, ensuring an additional layer of operational security during flights.



Figure 10: RadioMaster Boxer controller

3.2.1 SiK Telemetry Radio V3

For bi-directional data exchange, the system utilizes a SiK Telemetry Radio V3 (Figure 11) operating at 915MHz. This

link allows the ground station to receive real-time flight data from the drone, such as airspeed and battery status, while also enabling the transmission of new flight commands or mission updates. The radio was selected for its proven compatibility with PX4 [1], open-source firmware, and strong industry reputation. It offers significant advantages over older versions, including superior noise filtering, greater range, and enhanced reliability for long-duration missions with PX4.



Figure 11: SiK Telemetry Radio V3

3.3 Sensors

The Pixhawk IMU (Inertial Measurement Unit) calculates several inertial parameters that are used to estimate the drone state along with different sensors. Besides, the Terabee range finder will be used to measure the relative distance of the drone to the ground and give the vertical position.

Furthermore, the ReSpeaker XMOS XVF3800 microphone will be employed in the mission to detect the box emitting the "cry for help" signal. In addition, a camera will be integrated for the computer vision tasks of the drone. Both devices will be connected to the onboard computer, where the processing and decision-making will take place.

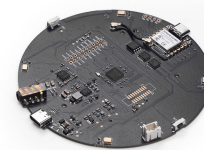


Figure 12: ReSpeaker XMOS XVF3800

To enhance the drone's autonomous navigation in complex environments, the project integrates a Livox Mid-360 model LiDAR sensor. This sensor provides a dense point cloud that can be processed and interpreted as odometry, with the resulting odometry data being sent to the flight controller for improved state estimation and navigation. Furthermore, the Livox Mid-360 offers seamless portability with ROS, enabling efficient integration into the system's perception and control architecture.

The odometry computed by Fast-LIO2 on the companion computer is sent to the flight controller and fused within



Figure 13: Livox Mid-360 LiDAR

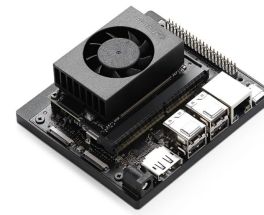


Figure 15: Nvidia Jetson Orin Nano

the Pixhawk's onboard Extended Kalman Filter (EKF) along with internal IMU and rangefinder data to produce the final state estimate for the vehicle.

4 AVIONICS AND ONBOARD COMPUTING

4.1 Flight Control and Firmware

The flight controller used is the Pixhawk 6C Mini. Operating autonomously, it regulates the motor speeds based on the target position of the drone and communicates with the ground station. It integrates an IMU and supports a wide range of peripherals, ensuring flexibility for system integration. In summary, the Pixhawk receives the desired position from the onboard computer while simultaneously estimating the current position and running the motor control algorithms required to reach the target. Furthermore, communication with QGroundControl will be established via TCP, ensuring a reliable and flexible link between the drone and the ground station. Communication with the companion computer is achieved through MAVROS [2], enabling seamless data exchange between the Pixhawk and higher-level modules.



Figure 14: Pixhawk 6C Mini

Additionally, we employ the NVIDIATM Jetson Orin Nano as the onboard Single Board Computer (SBC), dedicated to image processing and sensor data handling. The Jetson Orin Nano is responsible for base recognition, mission phase algorithms, and overall trajectory planning. Its high processing capability, combined with the Linux operating system, allows seamless use of ROS (Robot Operating System) [3] for communication between control, navigation, and vision modules.

5 SOFTWARE

The development of the software architecture was guided by the specific requirements of the IMAV indoor competition, where aerial vehicles must operate reliably in GPS-

denied, cluttered, and dynamically changing environments. Such conditions demand a perception and control stack that is resilient to sensor degradation, adaptable to diverse mission objectives, and computationally efficient to run on embedded hardware. To address these challenges, the proposed system integrates established open-source frameworks within the *Robot Operating System* (ROS) [3], allowing modular design, reproducibility, and seamless integration of perception, state estimation, planning, and mission logic. An overview of the complete architecture is presented in Figure 16.

5.1 Adoption of the Clover Framework

The low-level control system for the proposed aerial platform is based on the Clover framework [4] developed by CopterExpress. Clover is an open-source software stack designed specifically for educational and research purposes, offering seamless integration with popular flight controllers, including Pixhawk and PX4. The system provides pre-configured ROS packages that support quadrotor flight control, onboard sensing, and mission-specific task automation. The framework also offers compatibility with simulation environments such as Gazebo [5], facilitating both hardware-in-the-loop (HIL) testing and real-world operation.

Key motivations for adopting Clover include its mature and well-documented ecosystem, active community support, and the flexibility it provides for customizing flight behaviors. The integration with PX4 ensures robust flight performance, while the open-source nature of Clover allows for continuous refinement and adaptation to IMAV's specific mission requirements. Clover's architecture supports real-time control, efficient onboard computation, and an easy-to-extend mission stack, which is particularly valuable in competition settings where system reliability and speed are critical.

5.2 Odometry Estimation

Accurate odometry is a cornerstone for autonomous navigation in indoor competitions, where GPS is unavailable and drift-prone estimators can compromise mission success. While Visual-Inertial Odometry (VIO) has been widely adopted in UAV research, our preliminary experiments revealed severe degradation of performance in environments with low texture and non-uniform lighting, both of which are frequent in the IMAV arena. For this reason, we prioritized LiDAR-inertial odometry, which offers greater robust-

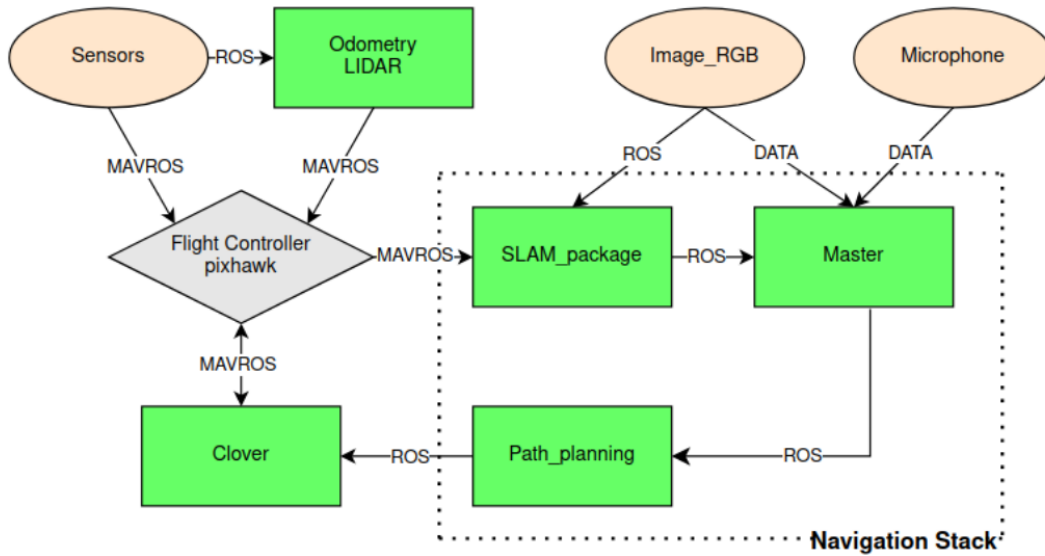


Figure 16: High-level software architecture of the UAV, highlighting the interaction between low-level control (Pixhawk), high-level perception and planning (Jetson Orin Nano), and ROS-based mission packages.

ness against environmental variability.

The Livox Mid-360 LiDAR was selected due to its dense 3D point cloud and full 360-degree horizontal field of view, providing a richer spatial perception than stereo or monocular cameras alone. Odometry estimation is performed using the *Fast-LIO2* framework [6], which fuses LiDAR features with IMU data in an Extended Kalman Filter [7]. This design achieves high-frequency state estimation with low drift, enabling stable navigation through narrow gates and cluttered indoor passages. Complementarily, a Terabee range finder provides precise altitude measurements, reinforcing vertical stability in tasks such as gate traversal and precision landings.

5.3 SLAM and Mapping

To perform both localization and mapping of unknown indoor arenas, we employ the *Real-Time Appearance-Based Mapping* (RTAB-Map) framework [8]. Unlike filter-based approaches, which scale poorly over long trajectories, or particle methods, which are computationally expensive, RTAB-Map leverages a graph-based formulation, separating the perception front-end from the global optimization back-end [9]. This provides accurate loop closure detection and drift correction, which are essential to maintain global consistency during long IMAV missions.

RTAB-Map supports multi-sensor integration, combining inputs from LiDAR and vision sensors. The system dynamically manages data using a hierarchical memory model (Short-Term, Working, and Long-Term Memory), allowing scalability without sacrificing real-time performance. The outputs include 2D occupancy grid maps, used for online nav-

igation, and 3D reconstructions (OctoMap/point clouds) [10], which are valuable for diagnostics and offline evaluation of mission performance.

5.4 Finite State Machine for Mission Execution

The execution of IMAV missions demands not only precise perception but also structured decision-making. To orchestrate the sequence of tasks, we implement a Finite State Machine (FSM) within the master node. Each mission is decomposed into a finite sequence of states, and transitions between them are triggered by sensor feedback and mission-specific conditions. This formalism enhances modularity and reduces the probability of cascading failures during competition.

The FSM covers four mission phases, each addressing distinct IMAV challenges. In Phase 1, the UAV traverses gates of varying diameters, relying on LiDAR odometry for spatial localization and the range finder for altitude control. The compactness of the airframe is exploited to maximize success in passing through the narrowest gate. In Phase 2, the front-facing camera detects an *ArUco* marker [11] on the board. By coupling RTAB-Map's localization with LiDAR distance regulation, the UAV is able to maintain stability and maximize the length of the continuous line drawn. In Phase 3, the stereo microphone detects the acoustic signal of the "cry for help," estimating the direction of the sound source. Once localized, the downward camera centralizes the target, and a servo mechanism releases the medical kit. In Phase 4, the UAV identifies the base using computer vision algorithms implemented in *OpenCV* [12], aligns with the oscillating plat-

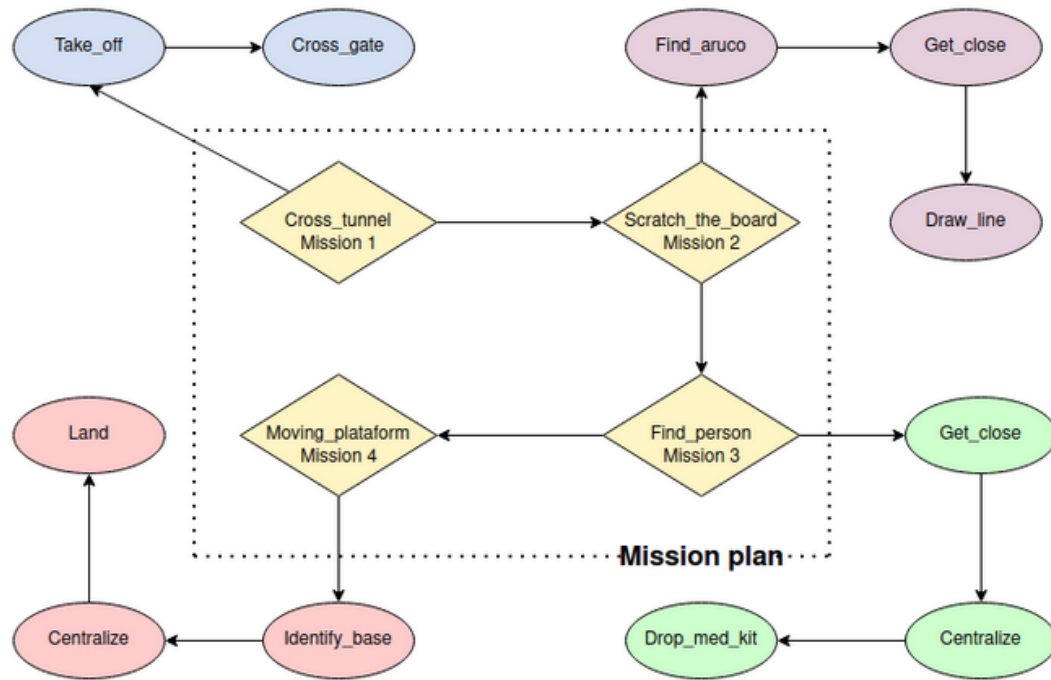


Figure 17: Finite State Machine (FSM) representing the four mission phases, sensor dependencies, and transitions designed for IMAV indoor tasks.

form, and executes a controlled landing synchronized with the platform's motion.

6 CONCLUSION

This paper has presented a comprehensive technical overview of the *Harpia* MAV, an open-source, 3D-printed quadrotor developed by the Atena Team for the IMAV 2025 indoor competition. The design was guided by the competition's demanding "Search and Rescue" theme, resulting in a modular and resilient platform capable of full autonomy in cluttered, GPS-denied environments. We have detailed the key subsystems, from the structurally validated airframe to the integrated electrical and software architectures.

The core of our approach lies in the fusion of robust hardware with a sophisticated software stack. By prioritizing LiDAR-inertial odometry and a graph-based SLAM framework, we have engineered a state estimation system that is resilient to the challenging visual conditions expected in the arena. The implementation of a Finite State Machine provides a structured and reliable method for orchestrating the complex sequence of mission tasks, from gate navigation to precision landing.

Future work will focus on extensive flight testing to validate the integrated system's performance in real-world scenarios that replicate the competition's challenges. Key development efforts will be directed towards refining the mission-

specific algorithms, including the whiteboard drawing mechanism, acoustic source localization, and the vision-based final approach for landing on the moving platform. Through continued development and rigorous testing, we are confident that the *Harpia* platform represents a capable and competitive entry for the IMAV 2025 competition and serves as a valuable open-source platform for autonomous aerial robotics research.

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