

A Technical Overview of MAVlab's IMAV2025 participation

Evolved drones, swarming solutions and high endurance flight

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Abstract

This document provides a concise technical overview of our solutions for both the indoors and outdoors challenges at the IMAV2025 Conference and Competitions by Team MAVLab. It aims at providing the key insights in the methods that have been implemented and also at inspiring readers for future research.

1 Introduction

Our team originates at the University of Technology Delft, specifically from the MAVLab at the Aerospace Faculty. We focus our work on small drones and aim at combining the knowledge obtained from nature with our knowledge of the hardware. From this starting point, we approached the challenges that were posed by the Competition Committee, and our solutions will be discussed in the following sections.

2 Indoor Competition

2.1 Mission 1

Mission 1 requires an autonomous drone to fly through five sequential gates of large (1.0 m), medium (1.0 m), and small (0.5 m) sizes to enter the arena. The mission presents two primary challenges: (1) localizing each gate and (2) safely traversing the narrow openings, Fig. 1.

To address these challenges, we used a brushless Crazyflie platform equipped with a Flow Deck for visual odometry and altitude control, and a Multi-ranger Deck for measuring perpendicular distances (front, back, left, right). Using the Flow Deck, the drone first advances toward the gate area, then performs a lateral sweep to align with the horizontal center of a gate.

Gate localization is achieved in two ways. The first method integrates position estimates from the Flow Deck to track the drone's displacement relative to the takeoff platform. The second combines the Flow Deck with the Multi-ranger: the drone approaches the gates, then moves laterally while monitoring for spikes in range measurements caused by the gate's support poles. Detecting one, two, or three spikes corresponds to reaching the first, second, or third gate, respectively. Once a gate is detected, the drone ascends to a height just above the bottom edge of the opening.



Figure 1: Mission 1: The drone takes off, navigates to the gates and starts localizing the entrances and as soon as it detects a spike in the range finders it moves up and then darts forward through the gate

The second challenge, passing through the gates, relies on two factors. First, the Crazyflie's small form factor provides generous clearance within the openings, reducing the effect of lateral drift. Second, a gated Kalman filter is used to prevent false altitude corrections. Flow Deck based navigation is sensitive to terrain changes; flying over a gate can cause the drone to interpret the sudden increase in measured height as a fall and "jump" upward. The gated filter checks for large innovations between expected and measured values and rejects unreliable flow or range updates. This prevents false jumps and allows the drone to pass through the gates with minimal perturbation.

We also prepared the Flapper-Nimble drone as shown in Figure 2, for mission 1 to pass the biggest gates. Since the relative location of gates and the take-off platform is fixed, the odometry flight is implemented. The flapper firstly taking off to 1.25m height with the altitude estimation from the downward time-of-flight sensor. Once the takeoff procedure is completed and the difference between the estimated altitude and the target altitude falls below 0.1 m, the flapper begins to move rightward at 0.5 m/s for 1 second in velocity control mode to align with the biggest gates. The equipped flow deck provides the flapper with accurate velocity estimation. After that, the flapper switched to moving forward with attitude control. The flapper flew forward with a fixed pitch angle for 10 seconds. After passing all gates, the flapper stopped flying forward and landed.

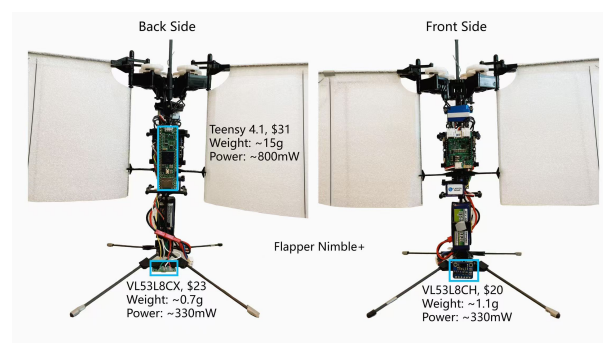


Figure 2: Hardware design of Flapper-Nimble

2.2 Mission 2

Mission 2 requires a drone to draw a line on a whiteboard. Conventional drones, such as the quadrotor, are typically under-actuated, and require changes in attitude to perform lateral motion. However, this limitation results in poor performance in aerial manipulation tasks, where it is crucial to maintain a prescribed attitude while providing lateral forces. In such cases, a fully-actuated (FA) drone that is capable of generating lateral forces at fixed attitude provides an attractive solution to this limitation.

While FA drones provide the necessary actuation required for this task, they are often large as they require a minimum of six rotors. Additionally, tilting rotors for full actuation results in reduced thrust-to-weight ratio. Hence, lateral force, size, and thrust-to-weight ratio present conflicting objectives. For this mission, we used an evolutionary algorithm, more specifically the non-dominated sorting genetic algorithm II (NSGA-II) [1], to design a FA hexarotor drone that is small, yet capable of generating sufficient lateral thrust for the mission [2]. The phenotype parameters evolved in this case are the position of each rotor and the cant angle of the propeller. In this design, radial symmetry is enforced to ensure that the center-of-gravity remains close to the geometric centroid of the drone.

Figure 3 shows the evolved FA hexarotor used in this competition. The FA drone is constructed out of 2mm and 3mm thick carbon fiber plates for the body. The arms are made of carbon fiber tubes with 3D-printed mounts used to fix the arms and motors at prescribed orientations. The drone is equipped with an optic flow sensor for odometry and altitude estimation. The low level control is performed using a modified PX4 autopilot to enable fully-actuated flight mode, and the autonomous missions are carried out by a Raspberry Pi 5 onboard running ROS2.



Figure 3: Fully-actuated hexarotor drone designed using NSGA-II.

2.3 Mission 3

Mission 3 challenges us to find the location of a person in distress, recognized by a person shouting for help. Finding the location of an audio source is already very challenging, but in an unknown environment with the use of drones only, it is even worse. Challenges are posed by reflective properties of the room, noise sources apart from the actual source and most importantly, the ego-noise of the drone's motors. To avoid this we decided to do sound measurements with a drone that is landed

on the ground. This removes the ego-noise problem completely, and gives us options for localizing the source. The next challenge that we face, is finding the location of the audio in the room's reference system. Since we are using Crazyflies for this challenge, our small drones are way too small to do any onboard SLAM or other visual-based localization methods, and thus we chose to use the power of a swarm. We decided to perform localization by using distance measurements obtained by Ultra-Wideband, and since we still limit ourselves to onboard solutions, we use drones as actual beacons. The inter-drone distance measurements are now obtained by a Two-Way Ranging protocol that manages to remove clock differences and allows for calculation of the time-of-flight for a message. Since these messages fly with the speed of light, we can calculate the distance. To make the protocol robust to our swarm, and allow easy and robust addition or removal of drones, we have implemented a protocol where a single drone has the "transmit" token, chooses a random peer to communicate with and afterwards hands over the token. If a drone does not respond within a timeout, another peer is chosen. If no drone overhears a message after a timeout based on their ID, they will take over the token and start the communication again. This way, we have a robust communication scheme. Flying purely on odometry is fairly accurate over shorter distances up to $\pm 15\text{m}$ (as evidenced by Missions 1 and 4), and thus allows us to fly 2 Crazyflies into the room as a beacon and leaving 1 Crazyfly on the takeoff platform as a beacon. A fourth Crazyfly, equipped with a sound system (see Fig fig. 4), is then sent out using this newly created localization system to navigate to a certain number of waypoints where it performs measurements while landed. Two possibilities are considered, one using the sound-pressure level (see Fig fig. 4a) and another using the azimuth angle with relation to a stereo setup (see Fig fig. 4b). Due to time constraints, ultimately only the former is used during the competition.



(a) Crazyflye outfitted with a single microphone for sound-pressure level measurements



(b) Crazyflye outfitted with a stereo microphone setup for azimuth measurements

Figure 4: Drones used for the audio measurements in the indoors challenge.

After enough measurements, an initial estimate of the location can be fitted using a non-linear least-squares fit of the the following equation:

$$\min_{x_s, y_s, L_0} \sum_i \left[L_i - \left(L_0 - 20 \log_{10} \left(\sqrt{(x_i - x_s)^2 + (y_i - y_s)^2} \right) \right) \right]^2 \quad (1)$$

This equation fits an estimated sound level at 1m distance from the target together with its location and follows a inverse-square law. After the first three measurements, we do an initial fit and based on the first estimate, we set a waypoint that is close to the fitted location. We do a couple of these iterations until our confidence level is high enough. In Figure fig. 5, the results of the IMAV2025

challenge can be seen with the performed measurements overlaid on an overview of the flight arena. The colors indicate the level that was measured during the actual attempt and the arrows show the trajectory taken by our measuring Crazyflie.

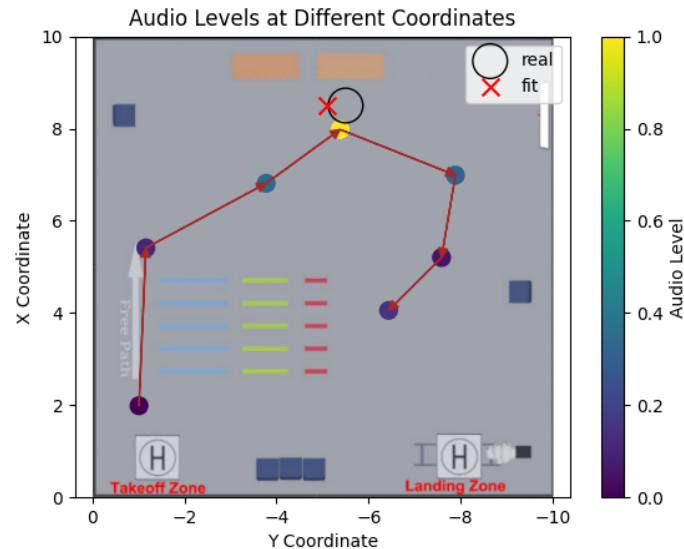


Figure 5: Results of sound localisation.

The dropping of the med-kit is performed by the FA drone shown in Figure 3. The med-kit is attached to the back of the drone with magnets, and a servo motor pushes the med-kit away when the drone arrives at the location of the sound source.

2.4 Mission 4

Mission 4 requires an autonomous drone to navigate to a landing platform and land successfully. As an added challenge, the platform may be moving, and smoke in the environment can partially obscure visual cues.

For this mission, the drone uses the same sensing suite as in Mission 1: a Flow Deck for visual odometry and altitude estimation, and a Multi-ranger Deck for proximity sensing. It also relies on a similar navigation strategy, integrating its position over time using visual odometry. However, instead of using a gated Kalman filter to reject altitude jumps, Mission 4 intentionally exploits them to detect the platform's edge.

When the drone approaches the landing area and enters a proximity threshold, it monitors for a sudden apparent increase in altitude, i.e., a "jump", which indicates that the range finder is now measuring the raised platform rather than the lower ground. Detecting this jump signals that the drone has reached the platform boundary. The drone then creeps forward to align itself with the platform's center, Fig 6.

Next, the drone leverages the Flow Deck's utility for motion tracking. It attempts to maintain zero optic flow for 10 seconds. On a static platform, the ground appears stationary, so the drone simply hovers in place and then descends to land. On a moving platform, the Flow Deck observes motion in the surface below; the drone interprets this as drift and compensates by flying in the

direction of that apparent motion. This allows it to track the moving platform and remain centered above it. Once centered, the drone executes its landing sequence.

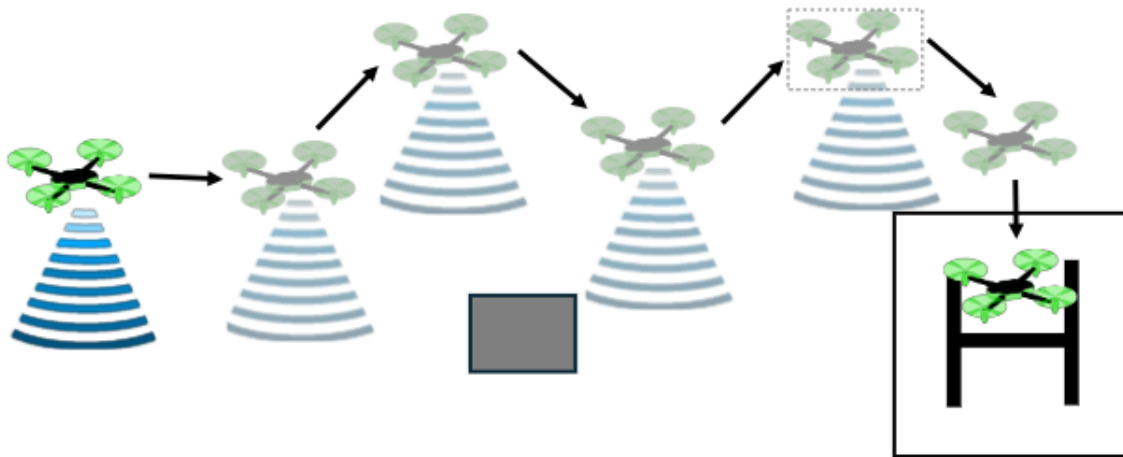


Figure 6: Mission 4: The drone takes off, navigates to the landing pad and as soon as distance sensor measures a spike it creeps forward and initiates it's tracking and landing sequence

2.5 Outdoor Competition

The outdoor competition consists of two parts. First, a task with 4 mission elements was performed. Secondly, an endurance mission called surveillance challenge was performed.



(a) Parrot Disco with onboard computer vision, flown with Paparazzi-UAV software [3] The cover is removed to show the c.h.u.n.c.k. computer-vision enabled autopilot. The autopilot has a front and bottom camera.



(b) 'Baby AR Wing Pro' airframe fitted with a Paparazzi-UAV Lisa-MX autopilot, Ublox GPS, a pitot tube and sensor, an remote magnetometer in the tip, a downward ranger for landing and modems.

Figure 7: Drones used in the outdoor competition.

To perform the mapping required for Mission 1 and locate a missing person for Mission 2, we used the fixed-wing airframe of the Parrot Disco (See fig. 11a and extended its capabilities by integrating the Paparazzi-UAV [3] software for autonomous flight. For the first mission, a map of

the disaster area was required. To achieve this, the bottom camera of the Parrot Disco was used. This camera recorded 320x240 pixel images. Thanks to the *EXIF* module, all images also recorded the GPS location where they were taken. Paparazzi-UAV has advanced flight plan functions like search areas where the planner automatically creates scanlines with smooth half circles, ideal for fixed-wing aircraft, automatically. This is all done based on 2 waypoints that define a rectangle for the simple search mission. Then all 1300 images were merged together with another open-source program called Open-Drone-Map WebODM [4]. The resulting GPS-referenced orthophoto is shown in fig. 9. The reconstructed 3D point cloud is shown in fig. 10.

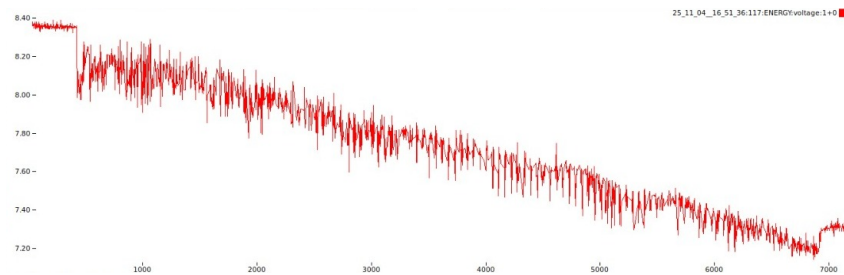


Figure 8: Discharge curve of the Lithium Ion battery during 1h49.

For the surveillance challenge, a 'Baby AR Wing Pro' airframe (See fig. 7b) was equipped with a Paparazzi-UAV Lisa-MX autopilot board and software [3]. In order to extend the endurance of the drone 6 x 5800 mAh 3.6V Lithium Ion battery (INR21700-58E) cells configured in 3P2S configuration for a total of 17.4 Ah at 7.2 volt, was integrated into the airframe. Moreover a toroidal propeller for improved efficiency at lower flight speeds was used, that would lead to a theoretical endurance time of over 2 hours. However, due to the high altitude of the flight at over 2150m AMSL with an air density of less than 780hPa, the propulsion became insufficient after 1h49 minutes of flight. The drone needed full power to stay at altitude and it was therefore landed before the battery was empty. The propulsion was found to be insufficient for the given high altitude conditions. The discharge curve is shown in fig. 8. As the wing-span of the drone was only 68cm, this still results in a score of 2.67 hours per meter. Similar to the Parrot Disco drone for the mapping mission, the Paparazzi autopilot was used to produce a flight plan that the drone could track autonomously over the surveillance area, removing the need for manual flight for the complete flight duration.

3 Conclusion

Several novel systems participated in the 16th International Micro Air Vehicle Competition and Conference. A swarming solution of micro-drones localized sound and landed on moving platforms. A novel genetically optimized hexacopter was presented to drop packages and draw on the whiteboard. Outdoors an open-source solution to mapping with a Disco airframe with Paparazzi-UAV software combined with Open Drone Map was presented. The capability of generating great maps with very low resolution hardware will pave the way to ever smaller and thus cheaper and safer MAVs in the future. The challenge of flying long with small vehicles was addressed with novel battery and propeller technology to achieve over 2.66 hours per meter wingspan in endurance.



Figure 9: Mission 1: GPS-referenced Orthophoto reconstruction of the flight area during the competition slot. The map was generated by merging ~ 1300 downward-looking 320×240 images from the Disco bottom camera using Open Drone Map [4].

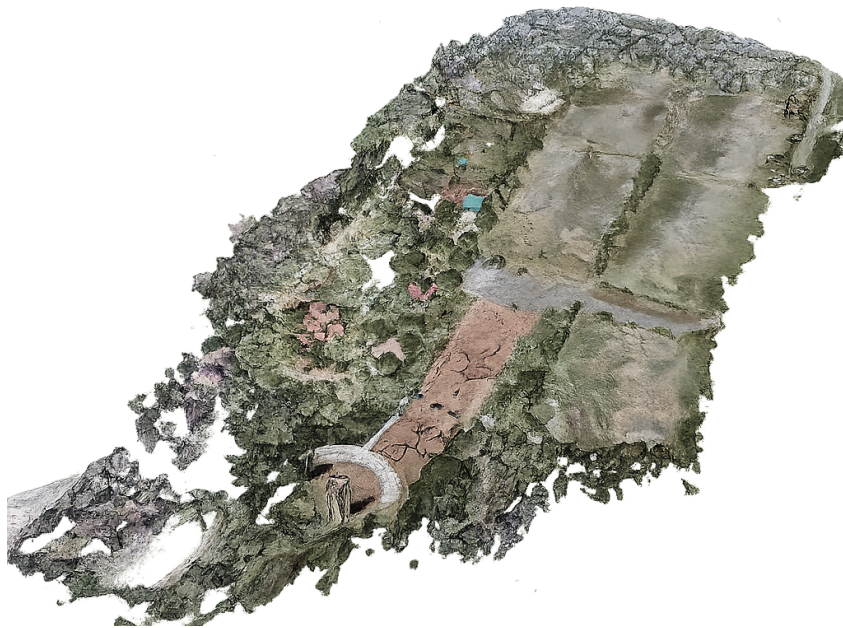


Figure 10: 3D GPS-referenced point cloud created from onboard images of the Disco drone, with the open-source Paparazzi-UAV autopilot that flies a mapping mission and adds GPS data in the EXIF of every image. The merging of images was done with OpenDroneMap. One can clearly see the height of the trees, the deep amphitheater and tall structures at the bottom. The very thin high pole in the middle of the red plaza lacked texture and is not found.



(a) Flight path of the mapping mission.



(b) Flight path of the 1h49 minute 'Baby AR Wing Pro' flight.

Figure 11: Flight path of both missions.

References

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