The MTA SZTAKI micro aerial vehicle and motion capture arena ⋆

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Abstract. In this paper we present the hardware and software components of the SZTAKI MIMO (MIcro aerial vehicle and MOtion capture) arena. An optical motion capture system enables the tracking of retroreflective markers with high precision and data rate. Therefore, it is an ideal tool to record ground truth data in order to evaluate the performance of different computer vision algorithms. Additionally, the arena is equipped with palm-sized micro air vehicles to facilitate the research of machine perception-based state estimation and control. Finally, a demo application is described, where the quadcopter autonomously flies along a racetrack trajectory.

1 Introduction

In order to evaluate the performance of computer vision algorithms that deal with the *tracking of*: objects, humans, and hand gesture [1]; or tackle the problems of *ego-motion estimation*: visual odometry, 3D mapping, and simultaneous localization and mapping[1]; often a marker-based optical motion capture system is used to gather reference ground truth data. Beyond these traditional computer vision tasks, we implemented a system suitable for developing high-speed micro aerial vehicle (MAV) manuvers. Therefore, the MTA SZTAKI MIMO arena is suitable for: high-speed MAV races, ground truth generation tool, and a research testbed for state estimation and control methods. Similar environments were published in [2]–[4]. A joint purpose of the enumerated and our work is to help and accelerate the research in the field of UAV control methods by providing a complete environment for communication and state estimation. Since, for indoor applications of MAVs, where the GPS measurements are completely unreliable, another position feedback method is required.

In this paper we describe the hardware construction of the arena and a demonstration project testing various control, state estimation and trajectory generation methods.

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[1] `https://slam-future.github.io`

Fig. 1. Marker placement

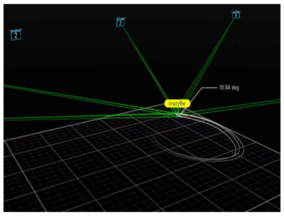

Fig. 2. Motive tracking

Fig. 3. Marker tracking

2 The MIMO arena

In the room we set up an Optitrack[2] system with ten cameras, specially for the fine tracking of flying objects in the available space. The area of the room is about $7 \times 8m^2$ with an internal height of $3,5m$. The cameras are positioned and calibrated in such way, that in every position of the arena the MAVs should fall in minimum 4 cameras field of view for additional redundancy and reaching a sub-millimeter precision. As seen in Figure 2, the position of the markers could be tracked either individually or as a rigid body with extended orientation vectors. The Prime 13 cameras offer onboard image processing implemented in their own FPGA modules, which frees the PC from the computationally expensive task. The processing is done real-time, the Motion Capture (Mocap) supports multi-body capture for a swarm of drones, complex motion tracking and flight recordings for offline data processing. All cameras are connected with Ethernet cables for the sufficient data transfer to a unifying switch, then uplinked to a Windows-based host computer, running the official product of the Optitrack system, the Motive.

As seen in Figure 1, for tracking the body retroreflective markers are attached to the MAV's airframe, and their relative position are stored. Asymmetry of the attached markers is a key for body identification, but a challenge for unbalanced hover stabilization.

The core of the communication and peripheral hardware management is based on the host computer running ROS Kinetic, an open-source middleware, widely used in robotic research fields. The project for communication between ROS and the MAVs was originally presented by [5], but was extended to support Optitrack external mocap measurements.

The arena furthermore includes the MAVs as well. For development and testing we chose the Crazyflie 2.0, an open-source, open-hardware solution, shown in Figures 1,3. The Crazyflie is a dual microcontroller (MCU) system, developed specifically for research and academic purposes, to test control algorithms on real hardware. An *nRF51* microcontroller is responsible for battery management and the custom CRTP (Crazy Real-Time Protocol) communication. The other MCU, a more powerful *STM32*, is responsible for the control algorithms and sensor management. It has a sufficient $168MHz$ CPU, $196kb$ RAM and even

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[2] `https://optitrack.com`

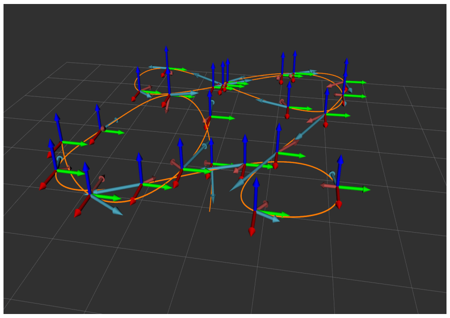

Fig. 4. Optimized trajectory for racetrack

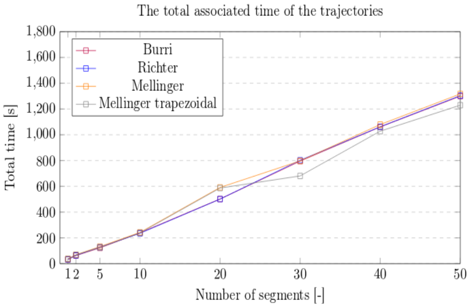

Fig. 5. Trajectory optimization testing

an additional $1Mb$ of flash, to implement any kind of custom, self-developed control and estimation method for testing. Additionally, a 6DoF Euler-angle IMU sensor and an embedded barometer sensor is responsible for the internal state estimation. The implemented onboard firmware is based on FreeRTOS operating system, enabling developers to run parallel tasks simultaneously, with specified priority and easy expandability for additional modules.

3 Autonomous flight of MAVs

We had a dual purpose during the project development. While creating a testbed for researchers, we also wanted to create a MAV arena for simultaneous races between piloted quadcopters and autonomously flown vehicles. The system was suitable for the implementation of an alpha version linear PID control method for off-board controlling. Here we used a cascade control method, with the inner loop running onboard, and the outer loop on the host PC. As this method was only suitable for small angle excursions from the hover state, we later implemented different nonlinear control methods for more aggressive flights.

For autonomous flights, the control published by Mellinger et al. [6] was used and incorporated into the STM32 firmware. Here the desired trajectory is uploaded to the Crazyflie with CRTP packets in the form of $7th$ order polynomial segments among the waypoints, but for optimized trajectory generation, there is the computational opportunity to incorporate the generation into the firmware. For 3D space trajectory optimization we implemented several different approaches, as it can be seen in Figure 5, tested them on simulation, as in Figure 4, and on real hardware as well in the arena. For an aided piloted control, a nonlinear full-state control method was implemented into the firmware originally published by Brescianini et al. [7]. Both methods are based on a 3D rotation matrix representation of the state, and the state estimation of an Extended Kalman filter, with high-frequency IMU sensor measurements and updates from the lower frequency external position mocap system.

4 Conclusion

To summarize, the goal of the work was reached with a working MAV racetrack for high-speed navigation of either autonomously flown MAVs, following an optimized trajectory, or with pilot commanded position controlling. Here the use of the MIMO arena is dual. On the one hand, we are able to maintain a robust and precise state estimation for the MAVs in real time, and on the other hand we are also able to evaluate the performances with detailed and trustworthy flight data.

Furthermore, a working real hardware testbed was created, that enables rapid implementation of any kind of developed control and estimation method. The system can be used by researchers in the field of control, state estimation or 6DoF trajectory generation, and also for educational purposes for visualizing the theories. By leveraging the here presented communication and state estimation tools, we have lowered the required knowledge and time to open experimentation for users with various degrees of expertise. The algorithms to test should be simply implemented in C code, and be included into the firmware as an additional header. The motion capture system meanwhile provides either a ground truth data for benchmarking, or position updates for the estimation.

Our current research interest includes onboard camera based autonomous navigation and visual localization in a cluttered indoor environment, where the MIMO arena provides state estimation, communication and a safety backup for crash prevention.

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