Low cost MAV platform AR-drone in experimental verifications of methods for vision based autonomous navigation

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***Abstract*— Several navigation tasks utilizing a low-cost Micro Aerial Vehicle (MAV) platform AR-drone are presented in this paper to show how it can be used in an experimental verification of scientific theories and developed methodologies. An important part of this paper is an attached video showing a set of such experiments. The presented methods rely on visual navigation and localization using on-board cameras of the AR-drone employed in the control feedback. The aim of this paper is to demonstrate flight performance of this platform in real world scenarios of mobile robotics.**

I. INTRODUCTION

The motivation of this contribution is to share our experience with using the AR-Drone [1] in various MAV research projects, where the drone is used as a proof of concept tool for real robotic applications. The aim is to show flight and sensory performances of the platform in real-world scenarios of autonomous MAV navigation/surveillance/reconnaissance. The paper provides an overview of the drone's abilities and possible applications that can be realized with such a low-cost MAV. The motivation is to expend the community for research and educational activities in the field of autonomous aerial robotics using this low cost MAV platform.

In addition, we would like to point out advantages of this low cost platform, which consist in ready-to-use control/sensory equipment. The drone represents a robust solution necessary for exhausting experimental test flights guided by algorithms being under development, which usually goes with a higher number of crashes. Finally, one should highlight that this MAV platform comes with a simple, straightforward, and open-access control system and a software development kit for custom applications, which is also very important for utilization of the drone in small teams of researchers and for learning the basic principles.

An important part of this paper is the attached video created as a sequence of various MAV applications and research experiments with AR-Drone playing the main role (download: *http://imr.felk.cvut.cz/demos/videos/drone/*). In this paper, each experiment is introduced with a practical motivation of the research, which is followed by a brief description of the experimental setup.

II. SYSTEM OVERVIEW

A. AR-Drone quadcopter

The AR-Drone is a small quadcopter [1] consisting of a carbon fibre frame, polystyrene body, four turbines propelled by brushless motors, removable battery, sensors, control electronics, and a polystyrene hull preventing of damages. Drone sensors comprise of 3-DOF accelerometer, 3-DOF gyroscope, sonar based altimeter, and two cameras - one forward (640×480 pixels) and one bottom (176×144 pixels). Designers of control algorithms may use WiFi, or on-board ARM9 processor running at 468MHz with 128 MB of DDR RAM running at 200MHz. The drone can achieve speed of 5 m.s^{-1} and its battery provides enough energy up to 13 minutes of continuous flight with maximum payload of 100g. The pitch and roll precision is app. 0.2° and the observed yaw drift is about 12° per minute when flying and about 4° per minute when in standby.

In order to perform our experiments, we have created an application, which uses the wireless interface to acquire data and performs a simple image analysis. This software is freely available [2] and can be used as a core for more complex applications. The software uses the IMU-based position controller that computes drone pitch, roll, yaw, and vertical speed in order to reach a required position of the drone in the 3D space.

In the presented experiments, the cameras of the drone are employed for its localization and navigation based on computer vision techniques. The bottom camera is utilized to detect patterns on the ground (possibly on cooperating UGVs) and to determine the position of the drone relative to the detected patterns. Once the position of MAV is established, the required position is sent to the aforementioned position controller. The front camera is used in a monocular-based navigation, which was originally intended for ground robots [3]. In this method, the drone is first guided through an environment to create a landmark map, which is later used by the drone to autonomously fly the taught path repeatedly.

III. EXPERIMENT DESCRIPTION

In the presented experiments, four different robotic platforms have been employed: the AR-Drone, the Pioneer 3-AT (P3AT) platform equipped with a monocular camera, compass and gyro, MMP-5 UGV platform moving blindly[1] based only on a feedback from the MAV, and the G2Bot platform with a precise odometric system.

A. Autonomous flight based on the visual navigation in an outdoor environment with human-MAV interaction.

Motivation: The experiment shows performance of the AR-Drone using the visual based navigation [3]. A navigation along a pre-learnt path is necessary for MAV being

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[1]Without on-board sensors used for navigation and odometry

able of autonomous operation in real world environments, where *return-to-base* or *repeat-the-flight* tasks are crucial.

Experiment description: The AR-Drone is remotely teleoperated through the outdoor environment to desired locations. During the flight, the environment is mapped using the front camera. In the second part of the experiment, which is presented in the attached video, the AR-Drone is run fully autonomously. To show the robustness of the system, accidental pedestrians have been allowed to enter the working space during both, the learning and autonomous traversing phases which makes such an utilization of MAV realistic according to real-world scenarios of surveillance.

B. AR-Drone - P3AT coordination towards cooperative autonomous inspection of inaccessible areas.

Motivation: In real-world environments, many places of interest may be inaccessible to ground mobile robots and an intervention of a flying robot is necessary. Contrariwise, the applicability of MAVs is limited due to their low battery capacity and payload. Therefore a heterogeneous team of well equipped UGVs carrying mobile heliports with MAVs (providing information from hardly accessible locations) increases the overall accessibility and operational time.

Experiment description: The target of this verification experiment is to visit all areas of interest (AoIs) pre-selected by a security expert during a preliminary inspection round. In the experiment, the UGV is autonomously navigated using the visual navigation [3] to places of MAV taking off, which is followed by autonomous flights of MAV to locations inaccessible with the mobile robot. In the video, one can see an image from the UGV front camera with highlighted information utilized for the navigation and an image from the AR-Drone bottom camera employed for relative localization and for AoIs inspection. Besides, one can see performance of an active mobile heliport developed within our team to correct position of the AR-Drone after each landing. The experiments show ability of the AR-Drone to repeatedly land and take off fully autonomously.

C. AR-Drone employed as an ad-hoc external localization unit for multi-robot applications

Motivation: A precise relative position determination of members of autonomous formations is one of the most critical aspects of their real deployment. For example in search and rescue (S&R) missions, it is not always possible to set up an external positioning system in searched buildings, GPS available in outdoor applications is not accurate enough for precise formation driving and obstacles may interrupt the direct visibility between the robots, which is required for relative localization using on-board sensors.

Experiment description: We have emulated an S&R scenario, where a formation of three robots has to search victims in an environment with obstacles. The scenario is aimed to verify the ability of the AR-Drone to provide relative localization for the formation control (see [4] for description of utilized formation driving method). In the video, one can see a view from the bottom MAV camera with results of the image processing used for the relative localization, views from UGVs searching victims, and also charts showing the precision of the localization together with the performance of the formation driving approach. In the second experiment, a formation with a dynamic shape is presented to verify the ability of the formation stabilization in a case of break-in of the direct visibility. In the third experiment, a sequence of undetectable slippages of wheels of a follower has been emulated to show robustness of this formation driving.

D. AR-Drone used for verification of localization uncertainty decrease in an autonomous inspection

Motivation: The last part of the video shows possibility of AR-Drone utilization for evaluation reliability of a novel research theory dealing with localization uncertainty during autonomous navigation between different areas of interest. The idea of the proposed method is based on the self-organizing map (SOM) in which a model of the localization uncertainty evolution is integrated and used in path planning by adding auxiliary locations supporting the navigation.

Experiment description: A path for visiting four goals (white markers) has been found through the auxiliary locations (red markers) to experimentally verify feasibility and real applicability of the proposed planning approach. The AR.Drone has been requested to autonomously traverse the path several times and to take snapshots of the goals' area using the bottom camera. The reliability of the autonomous inspection has been measured as percentage of successful goals' visits (markers detected in the snapshots). By utilization of AR-Drone, it was possible to experimentally verify the research achievements and to numerically show that the new approach increases the overall reliability.

IV. CONCLUSIONS AND FUTURE WORKS

In this paper, a performance of low-cost MAV platform AR-drone in research activities has been presented via a video showing several robotic applications. Recently, our endeavor leads to verify possibility of using AR-drone in swarms of MAV working under a relative localization.

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