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Package Delivery Experiments with a Camera Drone

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***Abstract*— The undergoing efforts for the integration of robotics into logistics systems is affecting the production workflow at all stages, from the transportation and the handling of parts inside storage and production facilities to the final product distribution. In this paper we address the problem of delivering a package by means of a multirotor drone. We describe a fully autonomous package delivery flight demonstration prepared in collaboration with an industrial partner. All computations are performed in real-time on-board the drone. A gimbal camera is utilized to realize the vision-based localization, by means of fiducial markers, of the delivery position and the landing platform on a pickup truck. The demonstration consists of the fully autonomous execution of the following tasks: the drone takes-off from the truck, looks for the delivery position, proceeds to land and drop the package, flies back to the distribution truck and follows it, and the flight is finished by performing the landing on the static vehicle. The experiments focus on the performance of the vision-based truck following.**

I. INTRODUCTION

In this paper we present a fully autonomous drone that using only on-board processing is able to perform coarse navigation using GPS, vision-based precise vehicle following and landing on static platforms (see Figs. 1 & 3). We used our system to perform a fully autonomous package delivery flight demonstration in collaboration with an industrial partner. The main technical challenges related to this work are the navigation control, the real-time vision-based pose estimation of the vehicle and the landing positions and their integration with the navigation control. In order to obtain the required localization precision for the vehicle following and the landing tasks we use visual fiducial markers.

Drones are a hot topic and an ongoing research area. These aerial platforms are suitable for being integrated in logistics systems, for instance, for the transportation of goods. Package delivery by means of an autonomous drone can significantly reduce the costs of distribution. A succinct feasibility analysis by D'Andrea [4] estimated its operating cost at 10 cents for a 2 kg payload and a 10 km range.

The main challenges faced by real-world drone package delivery are highlighted by the following selection of recent research works: an obstacle mapping method that encodes at cell-level the value of occupancy and its variance [1], testing modern deep-learning based object detection algorithms on-board drones [6], trajectory planning intended for navigation in cluttered environments [3] and landing on vehicles that are moving in straight roads at speeds of up to 40 km/h [2].

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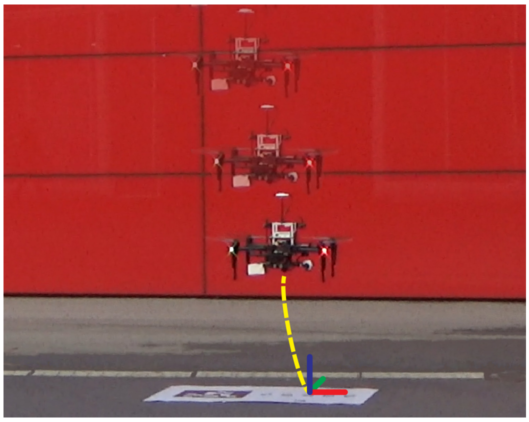

Fig. 1. Illustration of autonomous vision-based controlled drone landing on a marked delivery position in order to deliver a package.

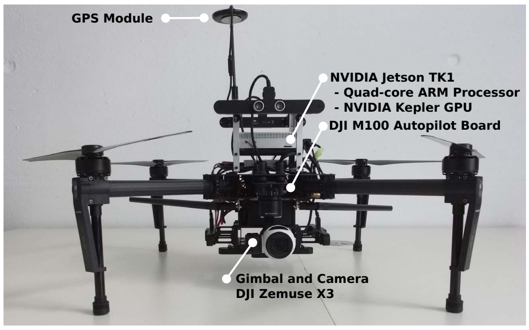

Fig. 2. DJI M100 quadrotor equipped with a Nvidia Jetson TK1 on-board computer (DJI Manifold), autopilot, GPS module, DJI Zenmuse X3 gimbal camera (1280×720 px) and an electro-magnet to carry a package of 100 g.

II. SYSTEM OVERVIEW

a) Hardware Setup
Our drone is equipped as shown in Fig. 2. For the experimental tests, the E-Mobility electric powered pickup truck "ELI" from SFL Technologies [7] was used, see Fig. 3. The delivery position and the landing platform are tagged using a 39×39 cm 36h11-family Apriltag fiducial marker [5]. Using this approach the relative pose of the gimbal camera with respect to the landing-platform at a distance of 3.5 m can be estimated with an accuracy of around 3 cm.

b) Software Setup
The inter-module communication is achieved by means of the Robot Operating System (ROS). Since our experimental results focus on the car following performance, only the main modules related to this task are explained, which are: the gimbal camera landing-platform tracking, the vehicle speed estimation and the control algorithm.

Fig. 3. Drone vision-based vehicle following, marked with a 39×39 cm Apriltag. Experiment: 3 min, mean speed 7.91 km/h and top speed 13.35 km/h.

b.1) Gimbal Camera Landing Platform Tracking
The drone's GPS measurements, the gimbal current orientation and the camera relative pose to the marker are combined to estimate the position of the markers in world coordinates. During specific tasks, these position estimates can be used to command the gimbal to point at the marker that is positioned on top of a landing platform. This approach is used during the vehicle following, package delivery and landing tasks.

b.2) Vehicle Speed Estimation
The marker relative pose estimates are calculated at around 25 fps for a resolution of 1280×720 px. These estimates are stored in a queue with a length of 20 elements. The vehicle speed is estimated for every linear coordinate using linear regression on the elements of the queue, which does not incur significant computation costs.

b.3) Navigation Control Algorithm
The flight behavior of our drone was characterized by performing speed command step-response identification tests. A rough controller parameter tunning was calculated based on the resulting model and it was later experimentally improved.

We utilize a feedback loop controller based on the PID controller architecture for the three linear coordinates and the yaw heading. In order to improve its performance, the controller utilizes both position and speed references. The utilized measurement feedback are the position and velocity provided by the autopilot telemetry, obtained through the fusion of GPS data with the IMU and magnetometer data.

III. EXPERIMENTAL RESULTS

a) Package delivery mission
We succeed in performing a fully autonomous mission where the drone takes-off from the truck, follows a GPS predefined flight trajectory, looks for the delivery position, proceeds to land and drop the package, takes-off again, flies back to the distribution truck, follows it for a while and lands on the static vehicle. This mission is summarized in our video[1].

b) Vehicle following experiment
The task of the drone is to follow the vehicle that is marked with a landing-platform at a constant distance of 2.5 m from behind and above. The vehicle speed estimate, see Sec. b.2, is used as speed reference for the controller.

The vehicle following experiment lasted 3 min during which the drone performed the task successfully all the time. Pictures of this experiment are shown in Fig. 3 and the logged trajectories and speeds of the drone and the vehicle are plotted in Fig. 4. Overall, during this experiment, the mean and top vehicle speed were 7.91 km/h and 13.35 km/h, and the root mean square error (RMSE) of the position and speed control tracking error were 0.37 m and 1.34 km/h.

[1]Package delivery demo: `https://youtu.be/bxM6dls2wuo`

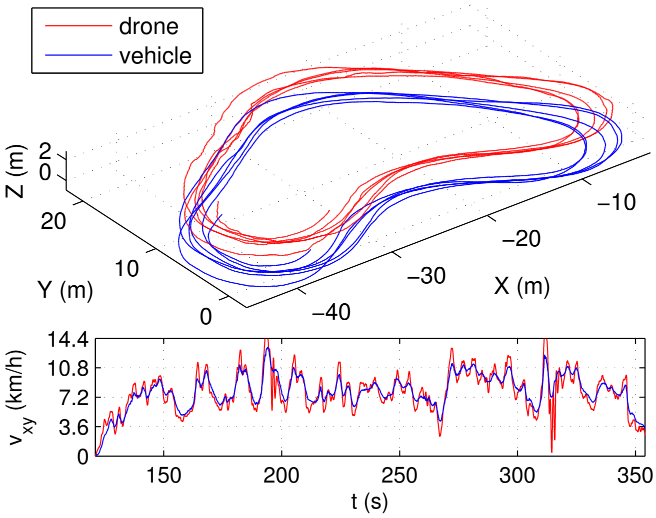

Fig. 4. Vehicle following experiment of 3 min duration. The plot shows the (red) drone and (blue) vehicle 3D positions and speeds over time.

IV. SUMMARY

In this paper we presented a fully autonomous drone that using only on-board processing is able to perform coarse navigation using GPS and vision-based precise vehicle following and landing (see Figs. 1 & 3). Our fully autonomous package delivery flight demonstration, carried out in collaboration with SFL Technologies, was reported by local newspapers[2,3]. In future work we plan to use this system as a first step towards performing autonomous landing on a moving vehicle.

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[3]ELI roll-out demo - Kleine Zeitung - `http://bit.ly/2it6N2P`