Energy-Sensitive Vision-Based Autonomous Tracking and Landing of a Quadrocopter on a Moving Platform

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***Abstract*—abstract abstract abstract abstract abstract abstract abstract abstract abstract abstract abstract abstract abstract abstract**

I. Introduction

In the last years Unmanned Aerial Vehicles (UAVs), especially multicopter drones, are used for various applications such as monitoring, surveillance, transportation of small payloads and agricultural applications [1] [2].

One of the major constraints of such applications is their limited level of autonomy due to battery limitations. It is therefore seen that to further extend the autonomy, the UAV will have to land in order to charge the battery.

The flight extension can be also achieved by implementing energy-efficient computational components, such as efficient computer vision algorithms, by selecting the desired quality of service (QoS) of the computational components [3]. With such an approach, combined with an autonomous landing strategy, we aim to reduce the energy consumption of the UAV during flight and therefore increase the level of autonomy.

Apart from presenting an increased energy efficiency concerning the computations, our approach further elaborates on the landing of the UAV on a moving platform. It can be easily shown that it is not generally energy- or time-efficient for the UAV to fly back to its base, once the battery reaches a critical level. Instead it is proposed that the UAV should land on the moving vehicle that is inherently in the proximity of the UAV during normal operation.

The solely use of GPS signal for autonomous precision landing is not considered as a safe option. The noise and errors of the GPS signal are not predictable and instead a vision-based autonomous landing system is considered a more optimal option.

In this project an agricultural case of a quadrocopter UAV, tracking and landing on a moving tractor will be studied.

II. State of the Art

TODO: Georgios: Autonomous landing

Vision-based autonomous landing on a marker has been extensively studied by many researchers. Key distinctions include whether the marker is on a moving platform, the type of the marker, the algorithms used to detect it, as well as the mounted sensors on-board of the UAV.

For stationary platforms, one of the first experiments with vision-based autonomous landing was conducted by Saripalli et al. [4]. Here, a helicopter with a color camera facing vertically towards the ground would land on an H-shape pattern (similar to ones found on a helipad) using a hierarchical behavior-based control architecture. In physical tests a marker of 122cm X 122cm size was detected for a maximum altitude of 10m. A landing marker inspired by a QR code but consisting of three artificial markers is demonstrated by Yuan et al. [16], and was shown to provide a 6-DOF pose over an altitude range of 0-20m. Our work is however focused on the ability to land on moving platforms.

Saripalli et al. [5] extended their prior work and used a Kalman Filter to track a moving platform. However all the computations were performed offline. An ArUco marker was used as a landing marker by Lee et al. [6] to detect a moving platform. The control of the UAV is performed based on the error provided by the vision algorithm but all the computations were performed off-board. In 2017, Arrar, et al. [7] focused on extending the detection range by using an AprilTag [8] as a landing marker. However all the computer vision algorithms were also executed off-board. A crucial aspect of our application is to perform all the computations on-board, in order to evaluate them according to their energy efficiency and QoS.

A contribution by Chen at al. [9] utilized a marker consisting of a circle and rectangles of different colors along with a LiDAR scanning range finder for height estimation. The marker was detected by performing color segmentation on the incoming image frame. By fusing the height measurement from the LiDAR into the vision measurement, a relative pose of the UAV from the moving platform was obtained. A color segmentation approach was also implemented by Lee et al [10]. A red rectangle was used as a landing marker and a vertically facing camera with a fish-eye lense was used to detect it. The team has demonstrated a successful landing from an altitude of 70m. Both teams have used an on-board companion computer to perform all the computation on the UAV. However a color segmentation approach is not considered as a safe option for a real case since it is difficult, if not impossible, to assure that the landing marker will be the only object of a specific color in the scene.

A hybrid camera system consisting of a fish-eye IR camera and a stereo camera was demonstrated by Yang et al. [11]. An ArUco marker was used to mark the moving platform and a convolutional neural network (CNN) Yolov3 was trained specifically for marker detection. A similar approach concerning the detection of a landing marker was demonstrated by Nguyen et al [12]. The team has used it's own landing marker and trained a CNN named lightDenseYOLO to detect it. A sucessful detection of a 1m X 1m marker size was demonstrated from a distance of 50m. An AprilTag marker was used as a landing marker by Kyritsis et al. [13] for the purpose of "2016 DJI Developer Challenge". The identification of the AprilTag marker was performed through Graphics Processing Unit (GPU) parallelized processing. The three teams have utilized the companion's computer GPU to detect the landing marker, however for our agricultural case, the GPU should be used by a CNN to detect objects around the moving platform and the CPU should be used for detecting the landing marker. By doing so, a different QoS could be chosen for each algorithm.

An AprilTag marker was also used by Feng et al. [14] in which a constant wind speed of 5 m/s was used as an external disturbance in simulation environment. Nevertheless, a fluctuation in the wind's magnitude and direction is more likely to happen in a real case.

Concerning the robust estimation of the moving platform's position and velocity, certain researchers have used a Kalman Filter or Extended Kalman Filter [7], [14], [15] while Yang et al. [11] constructed a velocity observer algorithm by calculating the actual moving distance of the moving platform over a period of time.

III. Energy-Sensitive Control of Tracking and Landing

Idea: fairly short section painting the overall picture of our concept for making the UAV control be energy sensive. First describe energy sensitivity as a concept, based on powprofiler (QoS-¿energy prediction) and the other IEEE RC paper as an example. Then describe the overall tracking and landing algorithm abstractly (pseudo code outline of what it does) and what the relevant QoS levels are (i.e., rate at which the marker detector runs). Include also a "black-box" workload representing whatever other work is being done as whatever QoS, this will be the CNN.

IV. Vision-Based Autonomous Tracking and Landing

TODO: Georgios: your key contribution here

V. Evaluation

A. Use case: agricultural safety

Briefly describe the use case and simulation, including the use of CNN to detect

B. Experimental setup

How the experiment will be done concretely, i.e., time to land as a function of QoS and wind or whatever.

C. Results

Results of the experiments

D. Discussion

Discussion of the results

VI. Conclusion and Future Work

What we did, why it was exciting, and what we want to do.

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