Master Thesis Proposal

Coordinated control of ground and aerial vehicle during takeoff and landing

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1 Motivation & Problem Statement

Unmanned aerial vehicles (UAVs) have recently been used more and more frequently to perform various tasks such as remote monitoring, mapping and search and rescue. [11, 3]

As versatile as their application is, there are a number of shortcomings that have to be overcome, like limited flight duration and payloads.

A possible approach to tackle these difficulties is to combine a ground vehicle with an aerial vehicle, thus compensating the respective disadvantages. This way, a UAV can move as part of the ground vehicle and only deploy in the immediate vicinity of the operation site. In addition, it can be ensured that there is always a proper landing platform within range where the UAV can recharge. Furthermore, the fact that the ground vehicle is always within range means that the ground vehicle can perform the more complex computational work and even take over the control of the aerial vehicle, thus reducing its computing hardware requirements.

Not only the aerial vehicle benefits from the ground vehicle, but also the other way around. If the path is obstructed or a reorientation is necessary, the aerial vehicle can be used to get a better overview by providing a bird's eye view of the current situation. The aerial vehicle can be used to search for alternate paths or to reach locations that are inaccessible to the ground vehicle. [9] It also allows the aerial vehicle to be used as a radio relay and thus extend the range of an existing radio network. [4]

The main purpose of this work is to develop a system for a quadrotor UAV to autonomously take off and land on a moving ground vehicle.

2 Aim of the Work

The goal of this master thesis is to design a controller that allows an UAV to take off and land autonomously on a moving vehicle. The controller can interface with both the vehicle and the UAV to determine their respective best actions.

To determine the absolute and relative position of the involved vehicles one or more localization systems are needed. Due to the hardware constrains, different localization systems of the ground and the areal vehicle have to be used, and therefore the respective uncertainties of the different systems have to be taken into account. In addition, both systems are too inaccurate to land reliably, so additional relative localization (most likely in form of a camera) might be used to improve the positioning of the UAV relative to the ground vehicle once they are close to each other. These systems need to be properly fused to achieve accurate and reliable localization.

To the best of our knowledge, all relevant previous vision based implementations use cameras that are attached to the UAV itself (see Section 4). However, since lightweight UAVs are used in this work, this is not feasible. Therefore we investigate alternative approaches to solve this problem.

3 Methodological Approach

The methodological approach consists of the following steps:

1. **Literature Review**
   An extensive literature review is the starting point of this work. Since different concepts are combined, it is important to get a comprehensive picture in order to tie in with the respective state of the art.

2. **Modelling and formulation of different approaches**
   The problem is modeled as two objects with their relative physical properties. Thereafter various implementation and realization methods are developed and examined. The objective is to find the most efficient, but at the same time the least complicated solution to the problem. Furthermore relevant performance metrics are defined that can be used to evaluate the implementation.

3. **Implementation and evaluation using a simulated environment**
   An appropriate software framework (e.g. *Robotic Operating System (ROS)* [17]) shall be selected and used to implement the most promising controller approach. A simulation environment is used to evaluate this implementation. The advantage of this is that it is possible to estimate whether and how well the actual implementation can work without adapting the hardware. In addition, physical damage to the hardware can be avoided with simulation. One of the available environments is *CrazyS* [15], which is is based on the physics and visualization engine *Gazebo* [7] and is aimed to model, develop and integrate the *Crazyflie 2.0* [6] nano-quadcopter.

4. **Laboratory Experiments**
After simulation, the approach used is implemented with hardware and validated in a laboratory experiment. For this the *F1/10* racing car is used as ground vehicle and a *Crazyflie 2.0* nano-quadcopter is used as aerial vehicle. This helps to determine whether there is a potential sim-to-real transfer gap and to what extent the implementation needs to be adapted. The overall performance is then evaluated based on several scenarios.

4 State of the Art

As take-off is trivial compared to landing, the literature is mainly concerned with the latter. Most of the time the landing platform is assumed stationary [12, 16, 8], but there is also research dedicated to moving platforms. [14, 13, 1]

Rucco et al. [14] used a trajectory-tracking approach with known positions to find optimal rendezvous trajectories for ground vehicle and fixed-wing UAVs. A similar approach for quadrotor UAVs is pursued by Guatam et al. [5] where the authors define 3D guidance laws based on pure pursuit, line-of-sight and pure proportional navigation.

Given that vision sensors are frequently part of the hardware configuration of a UAV, they are often used as part of the landing system. Most approaches use markers on the landing platform which are detected by image feature detectors (like SIFT [10] and SURF [2]). Using the known dimensions of the marker and the intrinsic camera parameters it is then possible to estimates the position of the UAV relative to the landing pad, see [16, 1, 8].

Rodriguez-Ramos et al. [13] as well as Polvara et al. [12] combine vision-based landing with deep reinforcement learning to train the landing maneuver by means of simulation. This has the advantage that no high-resolution images are required, so it can be easily implemented with cheap hardware. They archived good results in simulation, however the evaluation on real hardware showed degraded performance, most likely because of the sim-to-real transfer gap.

5 Relevance to the Curricula of Computer Engineering

The aim of this thesis is to design a controller that interfaces cyber-physical systems of different domains (ground and aerial vehicle). For this purpose, theoretical as well as practical knowledge, especially from the fields of *Automation* and *Cyber-Physical Systems* of the master's program *066 938 Computer Engineering*, is used and built upon.

The following courses are relevant to the topics discussed in this thesis:

- 182.753 Internet of Things
- 182.763 Stochastic Foundations of Cyber-Physical Systems
- 183.660 Mobile Robotik
- 191.119 Autonomous Racing Cars
- 376.054 Machine Vision and Cognitive Robotics

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