Autonomous low-altitude flight with a multi-rotor and experimental results

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I. Introduction

Data acquisition for surveying and mapping from Unmanned Aerial Vehicles (UAVs) is an increasingly common procedure because UAVs offer the possibility to cover wide areas, with the advantage of being able to fly over inaccessible and/or dangerous zones. This happens in those scenarios that are modified by a catastrophic event (e.g. earthquakes, landslides, volcanic eruptions, etc.), where it is not easy and safe to collect data from the ground [1], [2]. In most of these cases, it is important to perform several missions at several low altitudes to collect data close to the terrain, e.g. for the detection of post-earthquake survivors [3], for the landslide and mudslide monitoring [4], for the ground deformation analysis [5], [6].

II. Related work

The typical workflow of aerial image acquisition through an on-board camera of a UAV is divided into two phases. The first phase is dedicated to the collection of information on the scenario by flying over the area of interest at high altitude, manually operated by an operator. In the second phase, the acquired data are processed and a Region of Interest (ROI) and the Points of Interest (POIs) are located in order to run a second, more detailed, low-altitude mission.

Several works present innovative solutions to reconstruct and to navigate within an unknown scenario, based on either simultaneous localization and mapping (SLAM) [7] or through real-time dense 3D mapping [8]. However, they do not deal with the problem of low-altitude flight, following the morphology of the terrain. A control strategy presented in [9] allows a fixed-wing UAV to fly autonomously, following the morphology of the terrain at an altitude of about 9 m *Above Ground Level* (AGL) and reactively avoiding static obstacles, by means of custom designed optic flow detectors. However, this approach needs dedicated hardware, and its 'porting' to mass-market UAVs and autopilots could be difficult. Moreover, such an optical-flow based strategy may be ineffective in the case of uniform surfaces, such as a snow field after an avalanche, or a mud or lava field. Other solutions for low-altitude navigation of UAVs propose expensive sensing setups, such as laser scanners [10], or multi-modal sensing systems including lasers, stereo cameras, and ultrasonic distance sensors [11], all of them requiring high-payload vehicles and computationally intense processing.

III. Proposed Solution

The methodology that we have developed exploits the current state of the art in the field of UAV-based photogrammetry software to create a georeferenced Digital Elevation Model (DEM) of the scene. The developed tool uses the reconstructed DEM and a set of points of interest, introduced by the operator on a map, to generate the low-altitude trajectory. The trajectory is generated taking into account the morphology of the area of interest, while still ensuring a safe distance from any obstacle. In contrast to the previously described strategies, our method has been developed with the aim of being suitable even for low-cost UAVs and with limited computing resources on-board. To this end, the computed trajectory is exported as a list of waypoints that can be imported in commercial or open-source software autopilots, thus allowing the execution of the mission by several low-cost UAVs. The overall workflow of our method is as follows:

- the high altitude survey of Phase 1 is executed (manually or autonomously) with the aim of collecting aerial images of the area;
- the acquired images are processed by using photogrammetry software to obtain an accurate, georeferenced elevation model of the scenario;
- the DEM is imported into our tool allowing us to select the desired Points of Interest and to compute the 3D trajectory on a dilated version of the DEM, to keep a safety distance.
- the trajectory is exported in a comma-separated values (CSV) file that can be uploaded to commercial on-board autopilots by means of mission-planning applications on a ground station, for the autonomous execution of the mission
- the images acquired during the low-altitude mission are processed to obtain a high-resolution georeferenced elevation model of the area.

IV. Tests and Results

After a preliminary testing phase with the help of a software-in-the-loop simulation architecture, the developed solution has been tested in the field by using a quadrotor, a