Review of the doctoral thesis

AERIAL ENVIRONMENTAL MAPPING IN RECONNAISSANCE ROBOTICS

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Overview

This doctoral thesis deals with the set of problems from the aerial photogrammetry performed with small unmanned aircraft system/s, exploited in several practical applications focused on innovative approaches in the mapping methodology and information sharing for the cooperative robotic teams.

The presented doctoral thesis takes the format of the thesis by a set of publications (five), the thesis is divided into three main chapters containing over 200 pages (217), including the publication record of the Ph.D. candidate.

Relevance to current need of the scientific community

Even though much work has been done in the field of aerial photogrammetry in the past, there is still a wide area for optimization, improvement and particular innovations, which could satisfy needs in specific industrial or other (security, military) applications. Flexible aerial photogrammetry is as an important feature in the context of outdoor operations were the terrain data are unavailable or an application and dynamics of the environment prevent usage of non-actual terrain/elevation data. The presented thesis touches the set of topical areas which were seriously incorporated in the theory of military ISR (Intelligence, Surveillance, and Reconnaissance) domain for a long time and prefer of prerequisite (for effective decision making) the latest operational picture of the desired area in real-time. Thus, the selected topic of the thesis could be considered as highly relevant and fully aligned with the latest trends in many domains, especially in operational applications of autonomous systems.

Fulfillment of the main objectives

The author within the doctoral thesis introduced a relatively complex series of innovative proposals, improvements, and solutions touching the area of direct georeferencing and robotic systems (UAV/UGV) in operational applications. In particular, the author proved its scientific and engineering the effort by development and evaluation of a sensor system for aerial photogrammetry performed via small unmanned aircraft and demonstrate its performance in various cases which were covered by separate papers published in scientifically recognized journals. Particularly, the author select following aims:

- Developing a multi-sensor system to facilitate direct georeferencing in aerial photogrammetry performed via small UASs; the adopted approach integrates state-of-the-art technologies in the given segment.
- Designing a calibration procedure for the system and determining its performance.
- Verifying the system's usability and usefulness in real-world conditions and scenarios related to mobile robotics and environmental mapping, above all, missions where the common GCP-based UAS photogrammetry is inapplicable.

The author presents a set of development activities and achievements addressing the thesis topic, including the problem analyses, solution and SW/HW development, system

configuration, calibration, experiment organization, and its evaluation up to the operational application, implementing new features and concepts. Generally, the author's steps were logically sorted and apply the appropriate methodology, following the latest technology trends and bringing pragmatic aspects for the scientific, industrial, and security/military domains. Some details, roadmap, and background of his achievements are discussed in the part – Research Summary. The author referenced over 200 (in total) publications within his published papers featuring appropriate, state of the art in the topical context of the thesis and particular paper. He followed an extensive approach for experimental evaluation of the developed system and proof of selected concept. The author undoubtedly performed a huge engineering effort and reached valuable achievements. Considering the mentioned facts and level of solution complexity, it could be clearly stated, that the **main objectives** of the thesis **have been fulfilled** and concrete results were summarized in the **"Publications"** section.

Publication effort

An excellent research effort supporting the thesis is apparent from the publication record of the Ph.D. candidate. Publications prove the origin of solutions and concepts and indicate the significant amount of time and energy spent in the development and experimentation activities within the study period.

Scientific methods application

The work follows the standard scientific approaches, including the application of research methodology, system and concept development, experimentation, and validation. The author proves his ability for wide "multi-disciplinary" knowledge application and depth of problem understanding. The state of the art analyses was properly described in a separate chapter and "dispersed" within published scientific papers. In the context of what was said, the scientific and methodological approach was logical, convenient, and led to valuable results.

Main results and contributions of the work

As it was mentioned above, the main contribution of this thesis lies in its "proof of concept" of UAS mapping function supporting a wide scale of operational applications. We could expect, that this feature will become a natural component of any operation and all systems in the operational swarm will possess this capability. There exist clear proofs that information sharing and centralized operational picture in real-time creates a fundamental basement for the effective decision support and automation of any "tactical" activities.

The chosen approach continuously evolved in several incrementally complex applications with specific goals and fairly good/professional achievements. For instance:

- The fully operational multi-sensor UAS system (published within a paper: Precise Multi-Sensor Georeferencing System for Micro UAVs, 2016)
- An in-flight calibration method employing aerial triangulation-based reference data to support the least-square estimation of the aforementioned calibration parameters and overall verification of the system's performance via comprehensive experiments confirming the reachability of a centimeter-level object accuracy during a common UAS photogrammetry mission (published within a paper: Calibration and Accuracy Assessment in a Direct Georeferencing System for UAS Photogrammetry, 2018)

- New opportunities for remote sensing in environmental mapping and operational tasks applied in robotic cooperation during radiation search missions (published within a paper: Cooperation Between an Unmanned Aerial Vehicle and an Unmanned Ground Vehicle in Highly Accurate Localization of Gamma Radiation Hotspots, 2018)
- An estimation of the snowfield depth in a mountainous area (published within a paper: Towards Automatic UAS-Based Snow-Field Monitoring for Microclimate Research, 2019)
- Comprehensive experiment to demonstrate the benefits of combining diverse robotic platforms to accomplish CBRNE tasks (published within a paper: Using an Automated Heterogeneous Robotic System for Radiation Surveys, 2020)

The author of the doctoral thesis proved to have an excellent ability to apply a scientific methodology, perform research, and achieve valuable practical results. I recommend the thesis to be accepted for defense and upon its successful completion to assign Petr Gábrlík the Ph.D. degree.

I propose the following questions for the debate:

- What are the options to run the 3D mapping process in real-time (onboard on the UAS) to share the updated terrain data concurrently within the operation?
- What is more appropriate, centralized or distributed reasoning of UAS systems and a possible approach in “tactical” mission/s adaptive planning (benefits, disadvantages)?

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