Supervisor Report on the Ph.D. Thesis of Ing. Tomáš Báča

Czech Technical University in Prague (CTU), Faculty of Electrical Engineering (FEE)
121 35 Prague 2, Karlovo náměstí 13, Czech Republic

Dr. rer. nat. Ing. Martin Saska - Dept. of Cybernetics, martin.saska@fel.cvut.cz, phone: +420 22435 7634

The presented thesis entitled *Cooperative Sensing by a Group of Unmanned Aerial Vehicles* (UAVs) contributes to the field of systems of autonomous multi-rotor aerial vehicles. T. Báča, together with his advisor, have in fact established the research of groups of multi-rotor UAVs at the Multi-Robot Systems (MRS) group, FEE, CTU in Prague. His preliminary results of UAV control became a foundation of the MRS system being used by hundreds of researchers and students at CTU and well-established robotic groups world-wide. This thesis summarizes the journey from the first steps of UAV control in our group towards successful participation in MBZIRC 2017 and 2020 competitions, and numerous other research projects. Without any exaggeration, I have to say that none of these success stories would be possible without T. Báča. His knowledge, extreme work commitment, and teamwork were the key components that got MRS group at CTU on the map of respected UAV labs worldwide.

The introductory work of the thesis motivates the proposed research well and contextualizes it for the current state-of-the-art. The thesis summarizes numerous scientific contributions in the field of control and state estimation, but also reflects industrial requirements and applications for which UAVs and teams of UAVs are intended. The practical aspects of mobile robotics are important to follow as robotics in general is an application-motivated research discipline. This is included in the student's research stream on ionizing radiation mapping which is a very promising problem of society where teams of UAVs could contribute. In addition, the MBZIRC 2017 and 2020 competitions, where T. Báča was the most important team member and the main author of winning systems in both of the competitions, represented the most challenging and up-to-date problems proposed by industrial end-users. In the introductory part, let me also highlight Figure 2.1 that provides an amazing diagram of the proposed research created as a connected graph of most of the student's publications. The scheme describes comprehensive research towards a complete robotic system for controlling a team of cooperating UAVs with all crucial scientific problems solved.

In chapters 3-5, the student summarizes his contribution in selected core publications of his research. The first chapter deals with his basic research in the field of model predictive control (MPC) of UAVs and UAV state estimation, both having presented significant contributions at the time of their publication. The first fast onboard MPC designed for microprocessors on small UAVs was an important achievement forwarding research of cooperating micro-scale aerial platforms. The second chapter focuses on scientific challenges of remote sensing and manipulation with a team of UAVs. As examples of successful deployment of the system, 3 MBZIRC challenges are presented. The MBZIRC challenges provided strong evidence of the quality of the student's research results, as his system and approaches succeeded in a competition against most of the top robotic laboratories worldwide and gained 13 million CZK in total prize money. In chapter 5, the student's multidisciplinary research going from robotics through space technology into radiation measurement is combined together, forming another unique achievement of a team of cooperating micro-scale UAVs solving distributed localization of ionizing radiation sources. It is worth mentioning that a byproduct of this research was the student's significant contribution in a Czech cube satellite and suborbital rocket missions, where he injected robotic technology into a sensor management system.

To sum up my review, I must reiterate that T. Báča's work has had significant impact on the work of all members of the MRS group and numerous laboratories worldwide. The system he developed has been used by 100+ CTU students and researchers for experimental verification of their scientific work. His publications gained around 1,000 citations with h-index 16 according to Google scholar. The impressive set of his publications (16 impact journals - 12 Q1 and 13 conference papers) satisfies requirements on PhD thesis at FEE, CTU in Prague. The thesis content is original, novel, and brings significant contribution in the discussed research fields. Through the presented collection of the articles accompanied by the introductory and explanatory text, T. Báča shows that he is familiarized with the related state-of-the-art methods and the methodology of the scientific work. The text of the thesis itself is readable and easy to follow. T. Báča is well prepared for the postdoc phase of his scientific career that I am convinced will be very successful. Therefore, I can

recommended the presented dissertation for the defense.

In Prague, January 21, 2021

Dr. rer. nat. Ing. Martin Saska
Supervisor