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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Grigoriy Yashin

PhD Program: Engineering Systems

Title of Thesis: Development of group of flying robots with multifunctional robotic limbs aimed at operations in cluttered environments

Supervisor: Associate Professor Dzmitry Tsetserukou

Name of the Reviewer:

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:**  **Date: 15-11-2020**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

Review of PhD thesis "Development of Group of Flying Robots with Multifunctional Robotic Limbs aimed at Operations in Cluttered Environments." by Grigoriy Yashin.

The PhD dissertation of Gigoriy Yashin is devoted to designing and developing an automatic control method for remote aerial manipulation of multi-functional flying robots for exploitation in cluttered environments or even terrain. The main motivation of the thesis are potential applications of unmanned aerial vehicles (UAVs), which can be used not only e.g., for parcel delivery in logistic business, but are also to perform exploration of underground space, rescue operations, assistance in emergency situations, industrial inspection and maintenance. The several potential applications of this work include design of flexible robots to accomplishing difficult tasks such as monitoring and exploration of various types of terrain (including underground tunnels and mines), sensor installation in dangerous conditions, searching for survivors in an changed and unpredictable environment (e.g., rescue operation after an earthquake).

Grigoriy formulated the main research and technical/engineering questions as a research task: How to improve the functional efficiency and control algorithm of the UAVs equipped with robotic limbs. He analyzed the kinematic and dynamic models using Maple and MATLAB/SIMULINK to design two different multi-functional flying robots (AeroVR robot and DroneGear) equipped with robotic limbs. The GUIs in MATLAB were designed for each robot to estimate and adjust the parameters of servomotors and provide algorithm for movements. To better characterize the problem, he attempted to address the following technical problem: How an operator can remotely control the aerial manipulator in a most efficient and convenient way. To solve these problems Grigoriy Yashin developed and tested several types of wearable interfaces for tracking the orientation of the operator's hand. To provide the operator with a perception of the robot's current state, he developed a VR application that displays a robot's digital twin and a video stream from the robot's camera in real-time. Furthermore, he proposed and tested algorithms for motion planning for walking robots. Moreover, he developed a locomotion algorithm (LocoGear) for the landing platform of multi-rotors using a heuristic approach, Lagrangian approach, and kinetostatic methods.

These topics of research is not completely new, but the author of the thesis proposed his own solutions and implementations. In fact a quite large number of the works were proposed the autonomous performance of individual specific tasks, such as the insertion tasks, grabbing objects in flight, surface inspection, object grasping by two aerial manipulators, while only very few papers were devoted to the tele-operation of the flying robots and semi-autonomous manipulation. Therefore, an efficient controlling of flying robots still remains challenging problem, especially when it is necessary to control it manually or in semi-autonomous mode. To address these problems Grigoriy developed the LocoGear algorithm for a landing platform with four legs and a VR-based tele-operation algorithm. Moreover, he designed, simulated, and tested the algorithms to control two robots (AeroVR robot and DroneGear). The kinematic models of robots were calculated using methods of forward and inverse kinematics. The dynamic model of the AeroVR robot was designed in Simulink, the dynamic model of the DroneGear robot was calculated in Maple and MATLAB. Finally, the performance of both robots was extensively tested in laboratory conditions with a ground-truth VICON Mocap. In the framework of the LocoGear project, Grogory used a heuristic approach to select the parameters of the locomotion algorithm for a stable robot movement using data from angle encoders and tracking the robot movement along a specified path using the Motion Capture (Mocap). Based on the experimental results, he has

chosen a simple parabolas as a trajectory for the legs motion and robot inclination, and curtate cycloid as CoR path during the CoM transfer. Furthermore he estimated the servomotor torques during the motion cycle (the sequence of the actions for the robot motion on one step) using Lagrangian dynamic model and kinetostatic methods.

The software for both robots was developed in Arduino IDE using C/C++. The GUIs in MATLAB were designed for each robot to estimate and adjust the parameters of servomotors and movement algorithms. The code in Unity for communication between a real robot, wearable interface, and its digital twin is written using C#. The code for exchanging information between the UAV's autopilot, the robot's on board computer, and Unity was written using Python. At this time, all developments are not available in Github. So software was not written using unified environment, for example Python, but it looks rather fragmented and seems to be not very user friendly. ?

Grigoriy Yashin is leading author of two journal papers (IEEE RAL and IEEE JMASS journals) and one conference paper published in proceedings of prestigious IEEE ICAR conference. He is also author of patent and he submitted one additional journal paper which is currently under review. In my opinion, the most reputable publication was published in the IEEE RAL journal, while the most significant contribution was presented in the paper dedicated to the locomotion algorithm (published in IEEE JMASS journal) and also work devoted to developed VR-based tele-operation system (presented IEEE ICAR conference). Research results about remote control of aerial manipulation submitted to the Journal of Intelligent & Robotic Systems (currently is under review) is also quite interesting and perspective.

Critical minor remarks

Some limitations of the proposed approach appeared at the validation experiments. Both robots were tested only in laboratory conditions. It would be quite important and interesting to test developed method in real-life outdoor conditions. Moreover, the movements of the robotic limbs were performed at a relatively low speed of servomotors to avoid the sudden movements of the robots, which can potentially lead to unstable behavior.

The author of the thesis should double check English, grammar, spelling and punctuation marks. In many places are missing dots and commas. For example, each figure and table caption should be finished by full stop (dot). Each sentence should be finished by full stop even it contains equations.

Summarizing, in my opinion the most important achievements of the thesis are as follows:

Development of control algorithm of flying robots consisting of AeroVR and DroneGear equipped with multi-functional robotic limbs which can be controlled remotely through a teleoperation system.

Designing a novel VR-based teleoperation system using the IMU-based interface which allows the operator to perform manipulation more naturally. The extensive experimental results showed a quite stable behavior of the flying robot while grasping target objects in laboratory environment.

Development of locomotion algorithm which allows landing gear for multi-rotors to move along the straight line in a stable way with the speed of 0.75 cm/sec.

Provisional Recommendation

x☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*