Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

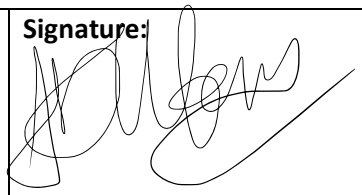
Name of Candidate: Evgeny Tsykunov

PhD Program: Engineering Systems

Title of Thesis: Human-swarm interaction for the guidance and deployment of drones using impedance control and tactile feedback

Supervisor: Associate Professor Dzmitry Tsetserukou

Name of the Reviewer: Anton Ivanov

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:**  Tue Jan 19 17:57:24 MSK 2021

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:

This thesis is well written with a clear structure. It consists of 8 Chapters on 158 pages. The structure of the thesis is explained in detail. In general, the language is very good an understandable, even to people not from the field.

The content of the thesis is consistent with the topic of presentation. It describes in sequence three topics: control of swarm of microdrones, implementation of haptic feedback to control the swarm and detailed description of experiments that were setup to check the hypothesis.

The work contains a collection of different techniques approaches. It is important to highlight, that not only the mathematics of the drone flying was carefully evaluated and presented, but it was also

implemented to demonstrate feasibility of the methods. Thesis contains a mix of mathematical derivation and excellent description of the engineering work performed.

This dissertation describes two novel concepts: control of swarm of drones using impedance methods and using haptic feedback to improve control of the swarm. The state of the art is also clearly explained and contribution to the field is sizeable. The author explores the area of haptic control, which very new and advances significantly this field. It is clear that the field is novel and is practically created from scratch (e.g. SwarmGlove experiment).

Impedance control laws can be adapted to control drone formations already. Concepts are very well presented in this work and can be applied, for example, surveying with multiple drones, where management of obstacles is required.

Relevance of the results to real-world applications for the haptic feedback can be used in controlling survey drones in unfamiliar or uncharted environments, where human judgement of a trained can be used to evaluate conditions and take decision rapidly.

However, all experiments were performed in a highly controlled environment of 5 x 5 m, which is not very representative of a real-world application. In reality one would have to rely on mid-sized drone capable of flying with GNSS positioning and long range communications. This fact is noted in the summary section, but I would like to see a reflection on how the performance of the algorithms mentioned will deteriorate when large positioning errors and communications delays will be introduced. Also, this technique requires more evaluation to prove benefits provided by the haptic feedback system. While it can definitely be interesting in an entertainment industry, simple visual feedback may be sufficient for complexity and cost reasons. Of course, while operating in environments where visual feedback is not possible or limited, haptics can provide yet another dimension. It is clearly technology in development and has to be studied further, but immediately I don't see any reasonable applications (i.e. more study needed before creating a startup).

Another point to reflect upon is obstacles map. My understanding is that all obstacles in these experiments are known ahead of time. The reason for using haptic / visual feedback is to avoid unknown obstacles in real time while controlling the drone.

Quality of publications is sufficient. We can see from authors' Scopus record that some publications are already being cited by authors outside Skoltech. Given that this field of Robotics, where most communication happens at conferences, the publication quality is very high.

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

There are some minor comments to be corrected in the thesis

Pg 45 (Figure 2.11) explain picture 2.11 in more detail. What are we looking for in the picture?

Pg 46 (sect 2.7) may be this summary can be improved a bit to show reasoning for selecting tech for this particular research. simple table might do it.

Pg. 70 Figure 4.9 **Subscript** "h" is stands for Human.

Pg. 112 (sect 6.5) how the obstacle information is transmitted back to user? I'm sure it is written somewhere, but I didn't manage to find it.

Pg. 139 It is mentioned above, but I will repeat it here as well. In this work, the experiments are performed in an outdoors environment not described and some reflection should be done on how quality of outdoors signals will affect control. Impedance based control methods can be used outdoors (although not with microdrones), rapid feedback using tactile sensation can improve precision of maneuvering, given sufficient training of the operator.

Provisional Recommendation

☒ *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*