Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Ivan Kalinov

PhD Program: Engineering Systems

Title of Thesis: Development of a heterogeneous robotic system for automated inventory stocktaking of industrial warehouse

Supervisor: Associate Professor Dzmitry Tsetserukou

Name of the Reviewer: Prof. Ighor K. Uzhinsky

I confirm the absence of any conflict of interest I do confirm the absence of any conflict (Alternatively, Reviewer can formulate a possible conflict)	**Signature:**  **Date: 18-11-2020**

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

The thesis is focused on the development of the heterogeneous robotic system for automated stocktaking of industrial warehouses.

In the begging of this thesis, Ivan describes motivation and stocktaking problem.

The second chapter of the thesis is devoted to background of the problem. Ivan provides logistics industry analysis and emphasizes the importance of formulated problem from the industry side. The chapter also provides a broad patent analysis of the relevant field of knowledge, as well as an overview of scientific papers on selected topics.

In the third chapter, Ivan presents his research question and gap, which he wants overcome using developed system, as well as reference and impact model of proposed research with key factors.

In the fourth chapter, the author describes a developed experimental prototype consisting of two main subsystems i.e. the unmanned aerial vehicle (UAV) and the unmanned ground robot (URG). This chapter

also provides a full description of the component base, as well as the BP system for the possibility of supervising the system in the warehouse, which is caused by the requirements of the industry described in the second chapter.

In the fifth chapter, Ivan presents a control system and novel high-precision localization system for the autonomous heterogeneous robotic system and a method of getting global position in xyz coordinates with 2 cm precision in a large indoor environment. UAV localization is based on the developed adaptive active infrared (IR) marker system to achieve reliable flight on different altitudes and light conditions. Ivan achieves this by using the URG as an intermediate station that provides precise global coordinates in two-dimensional (2D) space and gives the information about its vertical coordinate 3 to the UAV.

In the sixth chapter, Ivan presents a novel approach for real-time barcode detection and scanning using convolutional neural network (CNN). According to the experiments, the proposed approach improves the UAV localization using scanned barcodes as landmarks in a real warehouse with low-light conditions. Instead of using the standard UAV trajectory, Ivan implements flight-path optimization based on barcode locations. This approach reduces the time of warehouse stocktaking and decreases the number of mistakes in barcode scanning.

Finally, author provides the set of successful experiments for system evaluation that proves system efficiency and emphasizes thesis contribution.

The whole work is done well and, generally, it meets requirements for an industrially oriented, engineering Ph.D. thesis. Its structure is pertinent to the topic researched and to the content covered. The methods employed for the topic's analysis and for the delivery of scientific results are relevant to the subject researched and reflect both the state-of-the art and the research topic's significance for practical applications.

The provided publications are satisfactory with a patent approved on the proposed and developed system. Particularly impressive is the realized prototype of the system that is ready for testing and the concept verification in real-life environment.

The author has fixed his previously presented thesis text, including incorporation of an in-depth analysis of key reference factors and impact models and, particularly, information on industrial experiments carried out at the warehouse of the Leroy Merlin company.

The whole text is written much better than it was done in the previous its version.

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

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*