SUPERVISOR'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Spanning Tree Coverage Algorithm on Large Spaces for Multi-UAV Systems**
Author's name:	**Jan Chleboun**
Type of thesis :	bachelor
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Cybernetics
Thesis supervisor:	Tiago Pereira do Nascimento
Supervisor's department:	Department of Cybernetics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment — challenging

Evaluation of thesis difficulty of assignment.

The thesis assignment to the student is considered challenging due to several aspects.

1. The first reason is that task was the improvement of a recent published work (W. Dong, S. Liu, Y. Ding, X. Sheng and X. Zhu, "An Artificially Weighted Spanning Tree Coverage Algorithm for Decentralized Flying Robots," in IEEE Transactions on Automation Science and Engineering, vol. 17, no. 4, pp. 1689-1698, Oct. 2020, doi: 10.1109/TASE.2020.2971324.) in a major journal from IEEE.
2. The second big challenge is to implement the contributions on real robot experiments, using real UAVs. The student must use at least three autonomous UAVs and perform a successful experiment. This usually is very time consuming and technically demanding.

Satisfaction of assignment — fulfilled

Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.

My evaluation is that this thesis meets the requested assignment.
None of the required tasks from the final assignment fell short. The student considered fixed obstacles, performed a replanning strategy for moving (unknown) obstacles, created a smoothing approach for the generated trajectories, performed real robot experiments and comparisons with the state-of-the-art approach.

Activity and independence when creating final thesis — A - excellent.

Assess that student had positive approach, time limits were met, conception was regularly consulted and was well prepared for consultations. Assess student's ability to work independently.

My evaluation is that the student performed an excellent job in his thesis.
The student came up by himself with the smoothing strategy during the semester he got the Optimization class which proved to be an excellent suggestion of improvement. The student always came prepared to the biweekly meeting I have with him and other students under my supervision. He was able to work independently and search for answers beyond my orientation. He also participated in a two week experimental campaign the MRS group performed in April at CVUT TEMEŠVÁR.

Technical level — A - excellent.

Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.

My evaluation is that this thesis has an excellent technical level.
This thesis proposes improvements in a recent published coverage algorithms for large ares using UAVs. To understand the difference between the Thesis and the paper, we can state that the published paper presented results in simulation and with real robots in a simplistic environment (which means that the robots did not need to self-localize, the coverage

area was small, and there was no environment noise). The paper also performs a replanning but only when one of the robots breaks-down. In a certain level, the paper also proposes a trajectory smoothing. This thesis, however, performed real robot experiments in a large field (approximately 1600 m2), with three autonomous robots that need to self-localize and process all data locally. The replanning algorithm was used in the thesis case for moving or unknown obstacles, which was not considered in the paper. The experiment was filmed (different from the paper), and a comparison with the paper demonstrates that the smoothing algorithm proposed got better results.

In my opinion, this work is not only excellent, but I am preparing a Q1/Q2 journal paper with the student to publish the result.

Formal and language level, scope of thesis

A - excellent.

Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.

The student has a good written English and learned well how to use notations and formulate a problem. The final thesis produced a material that will make easy to publish a paper afterwords.

Selection of sources, citation correctness

B - very good.

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

The student performed an excellent job on selecting the references. Initially the student struggled a little, which is natural. After presenting the most used data base of journals and using the paper as an example, the student acquired 27 excellent references. I believe he could have got more. For a paper he will need to search more works for a better state-of-the-art discussion. But even though, by taking the example of the paper he compared his work with, I believe that for a bachelor degree, he did a very good job.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

The main objective of the thesis was achieved. The student proposed, developed and implemented an algorithm for the exploration of large environments with known obstacle maps. The student also performed real robot experiments and numerical comparisons with the state-of-the-art approach. The software used is available on Github and can be used in other projects. The results are being formatted to be published in a robotics journal paper. All the work was performed with a rigorous scientific methodology and the date is sufficient, in my opinion, for the graduation as a Bachelor.

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

Summarize thesis aspects that swayed your final evaluation.

I evaluate handed thesis with classification grade A - excellent.

Date: **25.5.2022**   Signature:

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Author's name: Jan Chleboun	**Jan Chleboun**
Type of thesis :	bachelor
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Cybernetics
Thesis reviewer:	Ing. Petr Váňa
Reviewer's department:	Department of Computer Science

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment	**challenging**

How demanding was the assigned project?

The thesis assignment is challenging because the student has to combine methods from several fields. First, he had to implement and extend an existing coverage algorithm. Furthermore, the student was asked to implement an adequate smoothing method, consider obstacles, conduct experiments with real robots, and compare results with the existing algorithm.

Fulfilment of assignment	**fulfilled**

How well does the thesis fulfil the assigned task? Have the primary goals been achieved? Which assigned tasks have been incompletely covered, and which parts of the thesis are overextended? Justify your answer.

Even though the thesis assignment is challenging, the student has fulfilled all the requirements. He has proposed all the required methods and evaluated them in simulated environments and using real robots.

Methodology	**correct**

Comment on the correctness of the approach and/or the solution methods.

The methodology used in the thesis is correct, and most of the definitions are detailed in Section 3.1, which helps the reader to understand the text easily.

Technical level	**A - excellent.**

Is the thesis technically sound? How well did the student employ expertise in the field of his/her field of study? Does the student explain clearly what he/she has done?

The technical level is sound, and all the methods are clearly described.

Formal and language level, scope of thesis	**A - excellent.**

Are formalisms and notations used properly? Is the thesis organized in a logical way? Is the thesis sufficiently extensive? Is the thesis well-presented? Is the language clear and understandable? Is the English satisfactory?

The thesis is well organized, and the text is clear and well understandable. The extent of the bachelor's work is superior. Also, all figures are of high quality.

Selection of sources, citation correctness	**A - excellent.**

Does the thesis make adequate reference to earlier work on the topic? Was the selection of sources adequate? Is the student's original work clearly distinguished from earlier work in the field? Do the bibliographic citations meet the standards?

The student references existing work adequately for any considered method, and the references meet all the standards. Also, the student's contributions are distinguished clearly.

III. OVERALL EVALUATION, QUESTIONS FOR THE PRESENTATION AND DEFENSE OF THE THESIS, SUGGESTED GRADE

Although the thesis assignment is challenging, the resulting bachelor's thesis is of high quality. The thesis contains many different contributions. First, the student implemented the existing AWSTC algorithm and proposed its extension to remove redundancy in the coverage. Secondly, he proposed a new CGWEP algorithm based on cycle growing. Finally, a method TSULSS for trajectory, based on least-squares optimization, has been introduced. These three contributions are all interesting, and they seem to have publication potential. Moreover, the proposed method has been evaluated using real robots.

Qustions:
1. The main criterion for trajectory smoothing is *Turn intensity* in the thesis. It is defined in (3.12) for a discrete trajectory connecting multiple points by straight line segments.

    a) How does the number of points p influence this criterion, and is it necessary to have segments with equal lengths?

    b) How would you compare the smoothness of discrete trajectories provided by the proposed TSULSS method with continuous trajectories provided by existing methods (like Bézier curves, cubic splines, B-splines, …)?

2. Existing smoothing methods (e.g., B-splines) often allow not to visit points of the original trajectory precisely and thus significantly shorten the trajectory in tight corners. Is it possible to extend the proposed TSULSS to behave similarly?

The grade that I award for the thesis is **A - excellent.**

Date: May 31, 2022   Signature: