THESIS REVIEWER'S REPORT

I. IDENTIFICATION DATA

Thesis title:	**Multi-UAV Trajectory Planning in Unknown Environments with Limited Information Sharing**
Author's name:	**Afzal Ahmad**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Computer Science
Thesis reviewer:	Ing. Tomáš Petříček, Ph.D.
Reviewer's department:	Department of Cybernetics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **challenging**

How demanding was the assigned project?

The aim was to review literature on safe multi-UAV trajectory planning and, based on the review, to design or possibly extend a method of safe trajectory planning for multiple UAVs navigating toward their respective goals. The method should be decentralized and depend only on limited sharing of information. I consider that a rather challenging goal, especially due to the nature of experiments that have to be performed to verify the proposed method.

Fulfilment of assignment **fulfilled with minor objections**

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.

The author presents a trajectory planning method for UAVs with cooperative collision avoidance, where participating UAVs share with others only the goal position and an ad hoc preference token used in collision avoidance. Each UAV optimizes its own criterion (shortest path to goal) given inferred constraints from other UAVs which have higher priority. The cooperation is limited to collision avoidance; whether there is a shared criterion optimized in planning is not discussed in the thesis. The experimental section does not quantify the level of safety achieved by the proposed method. Also, the comparison to other methods is only qualitative and is not supported by experiments.

Methodology **correct**

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

Definitions related to collision avoidance are rather difficult to understand. E.g., there is a strict notion of "path being in collision" (4.3) defined in terms of reachability sets around neighbor UAVs, which seems to be very conservative and define possible "worst-case" collisions. Besides that, there is a volumetric occupancy model which reflects the currently known environment and anticipated motion of neighbors. Would the latter be sufficient for safe planning using a selected algorithm (A*)?

Safety guarantees are questionable as it is unclear how the system would behave in the situations where the goal direction opposes the current motion estimate. The weak point of the proposed method seems to be the fact that in these situations the information shared does not provide any hint for anticipating immediate actions of other UAVs and therefore reliably avoid collisions.

Another objection is related to the usage of the motion estimate of neighbor UAVs, as these seem to be only used to validate the motion model which favors the direction toward the goal. It seems that it may be beneficial to use these directly to anticipate the motion of neighbor UAVs.

Technical level **C - good**

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?

Giving some overview description of the method and an algorithm outline for the planning and collision avoidance would be helpful in understanding the method and its usage within the whole system.

Experimental sections do not provide any quantitative evaluation of the method in terms of safety or other metrics which would capture the overall performance of the multi-robot system. The author states in chapter 6 that "[...] the motion

planner can often fail to find a path in real-time. In such cases, it is often better to stop and re-plan to a modified goal position." which raises questions about efficacy of the presented method.
The experimental setup, where all goals can be reached by following an almost straight path (not considering possible collisions), seems to favor the selected motion model (preferring the direction toward the goal) and seem not to be enough to evaluate the level of safety achieved by the method; it would be interesting to see the system in test in more realistic conditions.

Formal and language level, scope of thesis	**B - very good**
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 written in English. The text is well written overall and easy to read. As already stated, the structure of the thesis could be improved by adding an overview description of the method and an algorithm outline for planning and collision avoidance, which would help understand how the individual parts relate to each other in the system.	

Selection of sources, citation correctness	**B - very good**
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 author cites relevant references and clearly distinguishes his work from the work of others. Bibliographic entries are not complete (e.g., journal articles are consistently missing volume and number, and pages are not listed anywhere), nevertheless, the data would be sufficient to find the cited sources.	

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

Summarize your opinion on the thesis and explain your final grading. Pose questions that should be answered during the presentation and defense of the student's work.

Questions:

What are the benefits of sharing the goal, which may be far apart and which may tell little about immediate actions, instead of a more immediate waypoint?

Assuming that UVDAR provides only relative localization, how are the goal positions interpreted without a common reference frame?

For a single random encounter of UAVs, what advantage do the ad hoc preference tokens generated on-the-fly provide to pre-assigned ones? What are the limitations and possible failure cases of the presented coordinated collision avoidance procedure?

Wouldn't a policy following (3.1) and (3.2) drive the UAV from the goal instead of toward it, considering (3.2) increases with distance from the goal?

Could (3.1) be modified such that it can be skewed in other directions than toward the goal? Could the current motion estimate provide extra cues for planning and collision avoidance besides validating the "toward-the-goal" motion model?

Occupancy from neighbor UAVs depends on time. Is this fact used in planning or is occupancy fixed during planning?

The grade that I award for the thesis is **C - good**.

Date: **31. 5. 2022** Signature: