

## I. IDENTIFICATION DATA

<b>Thesis title:</b>	<b>Global Localization of Mobile Robot Using Randomly Placed Artificial Markers</b>
<b>Author's name:</b>	<b>Can Gundogdu</b>
<b>Type of thesis :</b>	<b>Master</b>
<b>Faculty/Institute:</b>	<b>Faculty of Electrical Engineering</b>
<b>Department:</b>	<b>Department of Cybernetics</b>
<b>Thesis supervisor:</b>	<b>Karel Košnar</b>
<b>Supervisor's department:</b>	<b>CCIIRC/IMR</b>

## II. EVALUATION OF INDIVIDUAL CRITERIA

**Assignment** **Select: ordinarily challenging**

*How demanding was the assigned project?*

The assignment is a standard task in the field of mobile robotics, and there are no extra challenging tasks. The motivation was more to get an integrated solution than solving a task on the edge of research.

**Fulfillment of assignment** **Select: 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.*

The assignment is fulfilled as the student provides a functional method for the localization of the mobile robot in an environment complemented with artificial landmarks. The only diversion from the assignment is the usage of different sensor from the same manufacturer, and this change was discussed with the supervisor.

**Activity and independence when creating a final thesis**

**Grade: B**

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

The student works independently with high enthusiasm. He consults the steps with the supervisor regularly. Unfortunately, there were a few misunderstandings during the work and the student spent some effort on work ending in the "dead end".

**Technical level**

**Grade: D**

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

Even the student spends a lot of effort on the thesis, the results are not presented in a sufficient manner. I am missing a more detailed description of the student's own contribution especially in the chapter dedicated to the localization. There is a reference to the actual code, but it is not described in the text of the thesis. Also, I am missing some important information in the experimental part e.g. how many trials were used for the evaluation of the obstacle avoidance algorithms? The experimental evaluation with the real robot should be also more extensive. Multiple trajectories in the same map should be described and evaluated to get sufficient data for statistics. I would like to see the same type of tables as in the Obstacle avoidance evaluation.

**Formal level and language level, scope of thesis**

**Grade: C**

*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 organized well but I am missing some general classification of the methods in the "State of the Art (SotA)" chapters. The selected methods reflect well the diversity of the available approaches, but I am missing some insight that connects the selected methods with mentioned classes of the approaches. The description of the SotA methods is enough detailed, on the other side, the own contribution of the student should be described in greater detail.

**Selection of sources, citation correctness****Grade: C**

*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 sources are cited well, but some of the mentions should be cited as well e.g. ARToolkit and ARTags on page 2. There is sometimes not clearly visible, where ends the used library and starts the original work of the student.

**Additional commentary and evaluation (optional)**

*Comment on the overall quality of the thesis, its novelty and its impact on the field, its strengths and weaknesses, the utility of the solution that is presented, the theoretical/formal level, the student's skillfulness, etc.*

The work of the student was delayed by a forced stay of the student outside of the Czech Republic due to restrictions connected with COVID19. That generates a rush at the end of the work period mainly during the experimentation, and this rush consequently causes the supervisor doesn't receive a final version of the thesis before the final submission.

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

The student works independently with great effort, nevertheless, the result of the thesis doesn't reach the top quality needed for an excellent marking. There are flaws in the text of the thesis and also the experimental verification could be made more thoroughly.

The grade that I award for the thesis is **D**.

Date: 12. 1. 2022

Name and signature:

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Thesis title:	Global Localization of Mobile Robot Using Randomly Placed Artificial Markers
Author's name:	Can Gundogdu
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of cybernetics
Thesis reviewer:	Ing. Vojtěch Vonásek, Ph.D.
Reviewer's department:	Department of cybernetics

## II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment	ordinarily challenging
<i>How demanding was the assigned project?</i>	
The goal of the thesis is to localize a mobile robot using standard visual landmarks and verify the functionality using the Vicon system as the ground-truth. The task requires knowledge that is covered by major lectures at FEE/KYR.	

Fulfilment of assignment	fulfilled with major objections
<i>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.</i>	
The assignment is too broad to judge if the student fulfilled everything. The student performed some experiments, but they are too simple and not described well. The contribution of the student is not clear. It seems that he only utilized standard methods available in the ROS system and joined them together. It is not clear, what exactly has he to implement or even to design by himself.	

Methodology	partially applicable
<i>Comment on the correctness of the approach and/or the solution methods.</i>	
<p>The overall approach proposed in the thesis (prepare a known map of environment, place landmarks there, detect them using camera, estimate position of the robot using the map and correct the position using Kalman filter) is correct. Author first focused on the obstacle avoidance methods (Section 2.1) and verify them (Section 2.3). <b>I wonder why the first 23 pages of the thesis is devoted to these methods, but they are not used in the subsequent localization experiments?</b> (In the localization experiments, the robot is either following a predefined trajectory or it is driven by a user).</p> <p>The second part of the theses (Chapter 3) is dedicated to the localization. The proposed method is not properly evaluated, the presentation of the results is very bad and the results are not discussed at all.</p> <p>a) Localization is verified only in two real-world scenarios (Section 3.2.5) using "small circular trajectory" and using "larger trajectory". The result of these experiment is the total error 5.34 cm (for small trajectory) and 16.38 cm (for the large one) (the last paragraph of Chapter 3) without discussing if it is satisfactory or not. These number are 'average', but the number of tests is not reported.</p> <p>b) Velocity of the robot is not reported neither, although it has obviously strong influence on the precision of the localization. The author claims that "Apriltag Localization result .. is extremely noisy due to vibrations .. or sudden acceleration ..". The author should evaluate the precision considering the velocity of the robot, e.g., make multiple tests for slow, medium-speed and fast motions. Images of 'blurred Apriltag' would be helpful.</p> <p>c) The problem with noise localization may be also caused by insufficient FPS of the camera, but I didn't find any information about camera's FPS used in the experiment.</p> <p>d) The small environment contained only 9 tags, while the larger one contained 6 tags. <b>While there was only 6 tags in the larger environment and not more?</b> It is not surprising that the localization in the large map was less precise.</p> <p>e) <b>Does the quality of localization depend on the number of tags that the robot actually see? How many tags (out of 6 or 9) was (in average) during the robot motion?</b></p> <p>f) It would be useful to report how sensitive is the localization to the number of actually visible tags and also how sensitive</p>	

it is with respect to the distance of the tags.

**g) The presentation of the results is very poor. Graphs (3.19-3.24, 3.26, 3.29-3.32) are not readable at all (small fonts, thin curves). Axes are not described, units are missing. The reader cannot make any conclusion based on these almost invisible graphs.**

## Technical level

Choose an item

*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 general workflow proposed by the student is standard and correct. However, description of many technical details is missing or is not satisfactory.

The obstacle avoidance methods (Chapter 2) are described chaotically, it is hard to understand how exactly the methods work. There are many mistakes in the description, e.g. Equation 2.5: "if  $d_{\text{obst}_i}(q) < 0$ " should be "if  $d_{\text{obst}_i}(q) < d_0$ ". The DWA method is not described well, the core of the method – the derivation of trajectory ( $v(t)$ ) is not described. Methods Vector Field Histogram and Smooth Nearness Diagram were not used in the theses at all, why are mentioned in the text?

Chapter 3 covers the basic SLAM techniques such as ICP, Orb-SLAM and Graph-SLAM. Again, these methods are described chaotically, the reader cannot understand how exactly they work. Mathematical notation is used without defining it or explaining the meaning. For example, in ICP method, the equation 3.1 is not correct unless it is given where  $p, a_i$  comes from. Similarly, equation 3.10 uses symbols ( $g()$  and  $h()$ ) that are not explained.

The core of the thesis should be "how to estimate localization of the robot based on several landmarks detected in the image knowing their global position in the map". This should be described in Section 3.2.3, which contains only general transformations between two coordinate frames. The author uses several coordinate frames: "base of the robot", "camera frame", "marker frame" and the "global frame". Illustration showing their relationships is missing. Mathematical notation for these frames is also missing. The reader cannot understand how exactly the author utilizes these transformations to localize the robot. Moreover, what if multiple tags are visible in the same frame? How is the information merged?

## Formal and language level, scope of thesis

Choose an item

*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 text is written in English with minimal grammatical errors. The text is divided into four chapters; the names of Chapter 2 and 3 could be chosen better. The author's contribution is in the section 3.2 of Chapter 3 "State of Art Localization in Mobile Robotics". It would be better to have a dedicated chapter for the contribution. Also, experiments are mixed in the Chapter 2 and 3. Instead, experiments should be in a separate chapter.

Despite low number of grammatical errors, the text is hard to read, as author often describes topics not relevant to the thesis. For example, in Chapter 1, the whole paragraph is dedicated for description of T265 camera, which is later not used at all. Similarly, obstacle avoidance methods described in Chapter 2 are not used in the thesis. Moreover, the author often repeats the same information, sometimes even with one sentence. On the other hand, there are numerous sentences that are hard to decode, e.g.:

"The transformation between the base of the robot and the camera frame is used to transform the position of the marker in the base frame of the robot by obtaining the transformation matrix  $T$  and by using the Eq. 3.16 the transformed marker pose is estimated with respect to the robot base frame." (page 43).

Some equations are not typographically correct, e.g. 2.9-2.11. Most of the graphs are not readable, with thin curves, missing description of axes/units and with too small fonts.

### 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?*

References to related work are correct.

### Additional commentary and evaluation (optional)

*Comment on the overall quality of the thesis, its novelty and its impact on the field, its strengths and weaknesses, the utility of the solution that is presented, the theoretical/formal level, the student's skillfulness, etc.*

The text is hard to read and navigate in it, it contains many unnecessary topics (description of 'not used' HW), while it misses the technical details. It is not clear what the student did by himself (except using ROS nodes and connecting them together).

**Which methods did you have to design and implement by yourself? On the other hand, which methods are used from ROS (or from other library)?**

**Describe exactly the algorithm that localizes the robot based on the visual landmark detected in the image. Show all required equations.**

### 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.*

The grade that I award for the thesis is **E - sufficient.**

Date: 01/17/22

Signature: