REVIEW

under the procedure for acquisition of the educational and scientific degree “Doctor”

by candidate: Lyubomira Lachezarova Miteva,

of the PhD Thesis entitled: Modelling and Control of an Anthropomorphic Robot Arm

Scientific field: 4. Natural sciences, mathematics and informatics

Professional field: 4.6. Informatics and Computer Science

Doctoral Program: "Information systems” –Embedded and Autonomous Systems,

Department of Computer Informatics, Faculty of Mathematics and Informatics (FMI),

The review was prepared by: prof. PhD. Vasil Georgiev Tsunizhev, FMI-SU

in my capacity as a member of the scientific jury, according to Order No RD 38-114/06.03.2023 of the Rector of Sofia University.

1. General characteristics of the dissertation and the materials presented

The presented dissertation is entitled "Modeling and Control of an Anthropomorphic Model of a Robot" and has the character of a monograph with expanded reference and self-descriptive material. It consists of a total of 132 pages.

The introduction with the four chapters, supplemented by Conclusion and Prospects for Development as well as the bibliographical reference, occupy 118 pages. The rest of the content is references to the contributions, as well as the publication and project activity of the dissertant. The work is structured correctly, following the requirements and good practices of compiling a detailed research document. The content begins with an Introduction and is followed by four chapters that set out in a logical sequence the doctoral student's research from motivation to the research hypothesis, its modeling and verification through results with an experimental prototype.

In the Introduction, the topicality of the topic of modeling industrial robots of the SCARA type is positioned against the background of an overview of the various types of robots.

In chapter one, an overview of the research area is made, which is a summary of analyses along four lines.

First of all, a functional overview of robotic systems in general is made, three schemes are presented classification by their main functions. Outlined, including with formal definitions, is the narrow subject area of the dissertation – a study of increasing degrees of freedom in manipulation robots.

Next subject of review are approaches to modelling manipulation robots by solving the straight and inverse problem of kinematics, and to the motion patterns of static manipulators.

Since the selected verification approach is through prototype experiments, overviews of the hardware and software layer of the overall control system architecture in this class of manipulators are also presented. The software architecture itself is stratified by examining the parameters and variants of specialized operating systems and also the services of the specialized intermediate layer – incl. implementations with server based and serverless architecture. This exposition raised in me the

question of what is the role of high-level communications (especially in the case of serverless, i.e. p2p systems), which are generally applicable in group service models and more typical in interacting mobile (not fixed) robots. But with fixed manipulators, we can also imagine scenarios of interaction of several robotic arms, and not in the mode of accidental avoidance of dynamic obstacles, but in synchronization of movements in conditions of real-time constraints. Therefore, I find it useful if in this part of the presentation the scalability of the model that addresses the doctoral student was discussed concisely. And I suggest this topic as a complement to her future research plans.

As we can see, such a separation of the overall overview is correct and motivated by the composite or multicomponent subject area, which for its applied purposes requires the attraction of knowledge and information precisely in these main directions.

Also in connection with the overview part, it can be noted that the attracted list of sources – 98 in number, of which only a few are auto citations – is sufficient in scope, depth and structure. It is distributed balanced among the several overview topics. The sources themselves are aptly cited – namely in the overview section. The quality of theoretical sources testifies to a thorough work. Of course, there are also a number of sources with technical and reference information. Also referred are the attracted diagrams and other graphic figures – in the reference List of Figures (they are also in the first chapter). The bibliographical reference describes the individual sources correctly with their full attributes. Only (sorry for the hint) I could not orient myself for the order of their sorting.

In the second chapter «Modelling of a planar anthropomorphic robot» the functional requirements of the studied robot and the methods used to solve the line and inverse problem of kinematics at additional degrees of freedom are presented. A parameter formalization has been developed to solve the relevant problems of the trajectories of the driven joints, which allows to subsequently algorithmize the control process of the manipulator joints.

The third chapter «Control of a planar anthropomorphic robot» treats the questions of the translation of target coordinates to a sequence of commands to bring the actuator components into an appropriate sequence of intermediate states – "transition points". The design of the computer control system of the experimental prototype is also described. The essential part of this algorithmic task is finding a path with minimal cost for the desired trajectory. There is also a time assessment of using approaches to solve this problem.

Chapter 4. "Experimental verification using a 3D printed robot" describes two simulation experiments that differ in implementation environments, as well as experiments with a prototype prepared by the candidate. The scenario chosen by the candidate of the experiments is the overcoming of dynamically occurring obstacles and the corresponding replanning of the manipulator joint trajectories. The choice of the two simulation environments is motivated and graphical proofs for the simulations performed as well as for the experiments carried out with the prototype are given. In the experiments with the prototype were performed in several cases with fixed and dynamic obstacles. The criterion of the experiments carried out is formulated so "avoiding collision with it (i.e. the obstacle) and as quickly as possible returning the robot's gripper to the target trajectory".

The exposition in all parts of the dissertation is careful, laconic and complete, except for the weaknesses I have noted in paragraph 6.

2. Personal data and impressions about the candidate

I know the candidate Lyubomira Miteva on the occasion of her work in the PhD program Embedded Systems. At all exams – accepted, specialized exams, attestations – as well as participating with reports

and publications in the work of the ISGT conference, she has manifested herself as a thorough and diligent young researcher. She has always received the most favorable feedback from her scientific leaders for dealing with the tasks, for the demonstrated ability to integrate into a research team and for her correctness and loyalty in the collegial community.

3. Meaningful analysis of the scientific and applied achievements of the candidate, contained in the submitted dissertation and its publications, included under the procedure

An important advantage of the work is that, in addition to analyzing abstract models, the candidate has implemented a prototype basic model case and studied it experimentally. In addition to experimental verification of the working hypotheses, a more extensive test plan of experiments based on this prototype can produce interesting results for specialists.

Many of the results of the doctoral student belong to field 4.1 physics (mechanics). I will focus mainly on the results of strand 4.6. Informatics and Computer Science.

To this direction I refer part of the objectives of the dissertation, namely:

2) Research and creation of trajectory planning algorithms for the studied robot with additional degrees of freedom in order to overcome static and/or dynamic obstacles and reach a desired target position;

4) Analysis and selection of suitable hardware components and design of a suitable software control system for the created robot with additional degrees of freedom

5) Verification of the proposed hardware and software control system and of the trajectory planning algorithms, by computer simulation and experiment with the designed robotic system. These objectives are scientifically applied and purely applied, which is fully justified from the point of view that the verification program of the study includes prototyping.

The dissertation successfully defends the achievement of the objectives set in this way.

To the scientific and applied contributions of the work in Chapter 3 is proposed an algorithm for planning a planar manipulator trajectory based on graph theory. From the point of view of algorithmic analysis, the algorithm is reasonably decomposed in two phases with 4 steps at each phase. This algorithm is complemented with a module to avoid dynamic obstacles in the real-time workspace. The correctness of the algorithm is protected by the experiments carried out.

The applied contributions of the dissertation refer to the prototyping of the model. A hardware and software control system for the planar manipulator as well as a test plan with the corresponding test cases has been designed. Chapter 4 describes the experiments carried out with a prototype of the modelled manipulator in order to verify the algorithms for trajectory planning in the presence of static or dynamic obstacles in the robot workspace.

4. Approbation of results

The six dissertation publications described by the candidate, as well as the dissertation itself and the prepared autoreferat, are characterized by the following features:

(1) fully, accurately and correctly reflect the dissertation work;

(2) all dissertation publications are indexed in SCOPUS or IEEExplore and it can therefore be calculated that the publication activity requirements are met with redundance:

more precisely, for the general index of the author RNSh by group of indicators D of the ERA, the following most conservative scientific calculations can be made (by the number of co-authors, the points from the attached reference and the [indexes] from the list of publications):

RNSh = 1/3x18 т.[1] + 0.25 x30 т.[2] + 0.5x30 т.[3] + 1/3x18 т.[4] + 0.5x30 т.[5] + 1/3x18 т.[6] = 53 >> 30.

The author has not attached information about a possible citation, but three citations are found in Scopus, if we do not count the self-citations. This indicator is not required by the current procedure, but is evidence of successful research work;

(3) all publications were not reported under a previous procedure;

(4) The publications of the applicant are free from plagiarism in view of the checks carried out in the peer-reviewed and indexed editions as well as the machine verification of the dissertation and the autoreferre.

5. Qualities of the autoreferate

The autoreferate fully, accurately and correctly reflects the dissertation and the results obtained.

6. Critical remarks and recommendations

Despite the numerous merits of the dissertation, some remarks and recommendations can be made.

In general, the selected title does not accurately reflect the content. As I pointed out, the work is dedicated to modeling a robotic device of the manipulator type – a "hand" that, without reproducing the human hand very closely, is designed to perform part of its functions. In the text, this actuator is rightly called a "catcher". The same applies to the number of "arms" and "joints" – the manipulator can be constructed so that, unlike an anthropomorphic hand, it penetrates behind static or even dynamic barriers different in scenario and topology. This is also the focus of the research on degrees of freedom conducted in the dissertation. However, the title, as well as other parts of the dissertation, refers to an "anthropomorphic model of a robot". The correct wording is to replace this expression by "manipulator", even more specifically "plane manipulator" or – as the candidate points out that it explores – "SCARA-type robot". These are an important and widespread class of industrial robots, but if we present them as an "anthropomorphic robot" we make a not quite precise generalization that prevents the direct identification of the research focus in the title.

Another problematic term is "model" (especially given that the title reads "Modeling of ... model ..."). In this case, I find the word "model" parasitic. By model, the dissertation means a prototype through which measurements and verification were conducted. For example, in 4.1 correctly specified "Design a 3D printed prototype of a robot" (not counting as correct generalization "of a robot").

The content-precise title would be [Modeling | Model] ... of planar [robot type SCARA | manipulator | robotic arm] [with [more | additional] degrees of freedom]". I do not see why the term manipulator is ignored in the title, since in the text it is used dozens of times – for example, in 2.4.1 the

robot is called a "plane manipulator". In principle, it is advisable to describe each object or phenomenon in a scientific work in a single term, even if there are equivalent synonyms.

In English, by the way, the author translated the title much more correctly to the content "Modelling and Control of an Anthropomorphic Robot Arm". In this option, only (but much more moderately) questions about the claim to anthropomorphism can be raised. In my opinion, it should read "Modelling and Control of a Planar Robotic Arm", which is closest to the content of the work and is at an appropriate level of generalization.

"With more degrees of freedom than necessary" is the main feature of the manipulator studied. Clearly, therefore, and in a central place in the work (if not directly in the title), the question should be answered by how much "more" than "necessary". Now the answer to this question I found in only one sentence at the end of paragraph in 2.2 as follows "In the dissertation plane motions will be considered, therefore it is necessary for the robot to have more than 3 degrees of freedom". That is, the implicit answer is that "more" (in other paragraphs "additional" is usually used) means >3. How many joints does it get? To answer this question (to which I also found no obvious answer) we can count for example the planar joints of the prototype on fig. 4.14. "Experimental setup to overcome static obstacles with a 3D printed prototype of a planar robot with additional degrees of freedom" – apparently they are four joints; and yes, 4>3. It is worthwhile in some central or at least distinct place in the dissertation to discuss the question of what is the impact of even more additional joints on the functional and nonfunctional traits of the planar manipulator, what are the limitations on the growth of the number of joints, etc. Or at least this problem to be marked in the section Future work – for example, there in place of the purely technical trivial observation that "the internal memory of the Arduino controller is limited. Therefore, it would be good, in the future, to add external memory to the hardware system of the robot." As it stands, the Prospects for Development section I would describe as modest and incomplete against the background of the really substantial open questions.

In Chapter 4. I would recommend a more systematic and comprehensive description of the test cases so as to motivate the completeness of the overall experimental program. This is usually realized by applying a test case plan and accordingly aligning the coefficient of performance of the set criteria for each experiment conducted. In addition, it is useful to introduce a multiplicity of the experiments conducted and respectively a success rate (if it is permissible this percentage should not be 100). In the list of test cases, some comprehensiveness or representativeness should be justified both with regard to the job model (the holder relocation scenarios) and the obstacle pattern – including features such as shape, surfaces, and also for the kinematics of movable obstacles. It is not mandatory to conduct and report all identified cases, but the test program must be clearly motivated and outlined.

It is further worth discussing and perhaps formalizing performance criteria. Does overcoming obstacles affect the precision of the final position, as well as the time limit for execution of the movement? Since the verification program also contains experiments with a prototype (a very important advantage of the work), and such control parameters as memory occupied, deadlines for the implementation of successive control iterations, etc. could also be monitored. Such technical parameters would be very useful in the design of serial manipulators. In general, in the case of real-time service systems, the system of lead times for successive elementary operations must be clearly dimensioned. Conclusions such as "The robot receives the commands sent to it immediately and can return a response immediately" do not give a clear answer about compliance with certain numerically formed criteria.

Stylistic remarks.

I would encourage the author to abandon the use of "bullets" in documents from now on, but to index the relevant text components, which will allow their referencing. For example, now at 2. Chapter on p. 47. The functional requirements for the robot are indicated by bullets and if we count them, it turns out that these are 5 bullets (elsewhere in the dissertation there are significantly more). Now if I want to object that the "resistance of the joints" is a non-functional (technological) parameter, although it is listed in the list of functional parameters, I will have to count which is the specific bullet (in this case the third), but if it was for example the 7th or 10th bullet, a significant potential for wrong reference in counting is already inserted.

"Different types of sensors and “datchiks” are usually attached to the joints." One of the two foreign-language synonyms should be chosen, and not leave options "for every taste". This is true for many doublet terms in the dissertation, the most important cases of which are the already mentioned "robot" – "manipulator" – "robotic arm" and "more" – "extra" joints.

7. Conclusion

Having become acquainted with the dissertation presented in the procedure and the accompanying scientific papers and on the basis of the analysis of their significance and the scientific contributions contained in them, I confirm that the dissertation submitted and the scientific publications to it, as well as the quality and originality of the results and achievements presented therein, meet the requirements of the respective national low ang the related regulations for the acquisition by the candidate of the educational and scientific degree "Doctor" in the scientific field 4. Natural sciences, mathematics and informatics in the professional field 4.6. Informatics and Computer Science. In particular, the candidate meets the minimum national requirements in the professional field and no plagiarism has been established in the scientific papers submitted in the competition.

Based on the above, I recommend to the scientific jury to award Lyubomira Lachezarova Miteva educational and scientific degree "Doctor" in scientific field 4. Natural sciences, mathematics and informatics, professional field 4.6. Informatics and Computer Science, doctoral program "Information systems” –Embedded and Autonomous Systems.

2. 06. 2023. Reviewer: .....

(Prof. PhD. Vasil Tsunizhev)