R E V I E W

of a PhD Thesis

PhD student: Ivaylo Robertov Georgiev

Title of the PhD thesis: "Design and Control of a 3D Printed Humanoid Hand"

Professional area: 5.1 "Mechanical Engineering"

Scientific specialty: "Robots and Manipulators"

Reviewer: prof. Tanio Tanev, Institute of Robotics - BAS

1. General description of the dissertation

The dissertation consists of a total of 115 pages and is structured into 5 chapters, with a bibliography of 65 referenced literary sources, contributions, and a list of publications related to the dissertation (5 publications on the topic of the dissertation). Links to 5 appendices are provided. The dissertation includes: a title page; table of contents; introduction; main body; conclusion – a summary of the obtained results with a declaration of originality; bibliography, all of which comply with the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria. The documents also include a protocol and a printout from specialized software confirming the absence of plagiarism.

2. Relevance of the developed problem to the up-to-date scientific developments

The dissertation is dedicated to a current scientific and applied problem related to the development of humanoid hands. These hands are used in robotics for grasping and manipulating objects of various shapes, in prosthetics, rehabilitation, and human-robot interaction. They enable robots to perform complex tasks in real-world environments and support assistive technologies for people with disabilities. Research in the field of humanoid hand development aims to bridge the gap between robotic capabilities and human dexterity. This topic is of global interest, with ongoing efforts to design and study humanoid hands capable of grasping and manipulating a wide range of objects—

essentially achieving dexterity comparable to that of the human hand. They are also being developed for use in prosthetics and rehabilitation processes, with the goal of improving the quality of life for individuals with injuries.

In this context, it should be noted that the objective of the dissertation—to design and create a 3D-printed humanoid robotic hand based on a modular principle, and to investigate its functional capabilities, with each finger driven by an independently controlled motor—is relevant both scientifically and in terms of practical application.

3. Degree of knowledge of the state of the problem

The dissertation cites 65 literary sources, the majority of which have been published in the past 10 years. These sources are directly related to the topic of the dissertation.

In the "Overview of the Subject Area" (Chapter 1), the anatomy of the human hand is presented, various types of humanoid hands and their applications are reviewed, and a classification of grasp types is provided. Components of the humanoid hand such as actuators, sensors, control systems, and rapid prototyping technologies are analysed.

The presented overview and bibliography demonstrate that the doctoral candidate has a solid understanding of the problem, as well as the methods and techniques used in the field, and correctly interprets the achievements in this area.

4. Correspondence of the chosen research methodology and the set goal and tasks with the achieved contributions

The chosen research methodology is logical and successfully achieves the main goal and objectives of the dissertation. The development and design of an innovative modular humanoid hand, along with the hardware and software for its control, and the experimental studies conducted using a 3D-printed model, are presented in a coherent sequence. This leads to a comprehensive study of the dissertation topic and demonstrates that the author has selected and applied an appropriate research methodology in accordance with the stated aims and objectives of the dissertation.

5. General characteristics of the thesis

In Chapter 1 ("Overview of the Subject Area"), the literature sources are analysed, the anatomy of the human hand is discussed, various types of humanoid hands and their main applications are reviewed, and a classification of grasp types is provided. Key components for the development of a humanoid hand are analysed. A comparative table of humanoid hands is presented, based on application, degrees of freedom, actuation methods, sensors, and the technologies used for fabrication or control. Technologies for rapid prototyping of robotic hands are also analysed. Various methods of object grasping by the human hand are examined, along with a general classification of grasp types.

In Chapter 2 ("Design and Mechanics of a 3D-Printed Robotic Humanoid Hand"), an innovative design of a humanoid robotic hand is presented. The novelty lies in the modularity of the 3D-printed fingers and the ability to print fully assembled fingers, as well as the integration of all control and actuation components within the palm of the hand. A method is introduced for creating assembled fingers that are directly fabricated using 3D printing technology. Fundamental principles for successful 3D printing of assembled rotational joints are outlined, and a comprehensive algorithm for designing a 3D-printed assembled mechanism is proposed. The finger design is based on a modular principle—the fingers are identical, differing only in phalange lengths and joint constraints. The chapter concludes with a description and schematic of the complete hand structure. The hand was designed using AutoCAD Mechanical and consists of five modular fingers, a base, and a front cover, with each component manufactured using 3D printing.

Chapter 3 ("Hardware Description") is dedicated to the design of the hardware for controlling the hand, including the selection of motors, sensors, and electronic components. A block diagram and an electronic schematic of the hardware connections for a modular finger are presented. The electronic components, their connections, and their functionality are described in detail. A complete wiring diagram for a finger of the robotic hand is proposed. The chapter also discusses the selected micro DC motors, position-sensing sensors, and the I2C communication protocol used for data transmission between the individual modules in the control of the hand's fingers.

Chapter 4 ("Software for Hand Control") provides a detailed description of the developed software for controlling finger movements and processing sensor data. A finger control application is presented, developed using the LabView software package, along with a graphical user interface. A second application for hand control was created using the Python programming language, also featuring a graphical interface built with a standard built-in library. This program allows control of an individual finger, a group of fingers, or all fingers simultaneously. A separate version of this program was developed for gesture recognition, enabling the formation of signs from the American Sign Language (ASL) alphabet. A fourth program was created for grasping spherical and cylindrical objects. For the purpose of hand control, software support for the I2C communication protocol was developed. This protocol ensures efficient and standardized communication between the various system components, with each individual finger of the robotic hand functioning as an I2C slave device.

Chapter 5 ("Experimental Verification Using a 3D-Printed Model") is dedicated to describing the testing process of the 3D-printed humanoid hand. At the beginning of the chapter, the workspace and reachable points of the humanoid hand's finger are analytically examined, with graphs generated using custom programs written in Visual Lisp for AutoCAD. Experiments were conducted with the fabricated hand prototype to verify the functionality of the 3D-printed hand in grasping everyday objects, as well as 3D-printed items in basic geometric shapes such as spheres and cylinders.

The experiments revealed that the hand is capable of successfully grasping spheres with diameters ranging from 10 to 60 mm and cylinders with diameters from 10 to 40 mm. The robotic hand struggles to grasp spheres with a diameter of 70 mm and cylinders with a diameter of 50 mm. Gesture experiments were also conducted, demonstrating the ability to perform 20 out of the 26 gestures from the American Sign Language (ASL) alphabet. The reasons why 6 gestures could not be executed by the developed hand were analysed.

6. Scientific and/or scientific-applied contributions of the thesis

Two scientific-applied contributions and four applied contributions have been formulated. I accept these contributions as genuinely achieved in the dissertation work. In summary, the scientific-applied contributions are: A method has been developed for creating assembled 3D-printed fingers of a humanoid hand, and an innovative design has been proposed that allows the fingers to be printed as a single object with movable joints using 3D printing technology. The geometric and kinematic characteristics of the fingers of a humanoid hand have been studied.

The applied contributions are summarized as follows: A prototype of a humanoid hand with modular fingers has been created. Hardware and software have been developed for the control and configuration of the 3D-printed modular humanoid hand. Software has been created for reproducing sign language gestures using the 3D-printed humanoid hand. Experiments have been conducted that confirm the functionality of the 3D-printed hand.

The stated scientific-applied and applied contributions can be defined as the creation of new designs and technologies, the acquisition of confirmatory facts, and the enrichment of existing knowledge with practical application. The achieved scientific-applied and applied contributions are useful and have practical relevance. They demonstrate that the doctoral candidate is capable of conducting research activities and applying the results in specific practical developments.

7. Evaluation of the publications on the thesis

The results of the dissertation work are reflected in five co-authored publications, with one article listing the doctoral candidate, Ivaylo Georgiev, as the first author. The publications are indexed in globally recognized scientific databases such as SCOPUS and/or Web of Science. One of the publications appears in a journal with an Impact Factor (IF) of 0.7.

These publications demonstrate that the results of the dissertation have been presented to a broad scientific audience and meet the requirements for the defence of a doctoral dissertation.

8. Abstract (Autoreferat)

The extended abstract is 40 pages long, with each chapter of the dissertation briefly and accurately presented. The main contributions of the dissertation are clearly outlined. The abstract is provided in both Bulgarian and English.

9. Critical remarks and recommendations

No significant errors were found in the dissertation, and I have no major critical remarks. Nevertheless, the following suggestions and critical notes can be pointed out:

- The chapters lack concluding sections, with only a general conclusion presented at the end of the dissertation. The work would benefit from including brief conclusions at the end of each chapter. This is particularly important for Chapter 1 (Overview of the Subject Area), where conclusions could be drawn regarding the current state of research in the field, the advantages and limitations of existing results from other studies, as well as an analysis of opportunities for future developments and existing challenges. Such additions would support the overall aim of the dissertation.
- In Chapter 5 (Experimental Verification Using a 3D-Printed Model), the manipulability index is analysed for a simplified finger model. Since the finger is actuated by a single motor, the joint velocities are dependent and cannot be controlled independently. In this case, the concept of the manipulability index, which is a function of the Jacobian, should be refined in light of this fact.

The remarks made do not diminish the quality of the results obtained, but rather serve as recommendations for the doctoral candidate's future publications.

10. Conclusion

The topic of the dissertation is current and relevant. The doctoral candidate demonstrates a deep understanding of the subject matter and the achievements of leading companies and research teams worldwide, as evidenced by the presented literature review. Scientific-applied and applied contributions have been achieved in the course of the dissertation work.

In conclusion, I believe that the requirements of the Law on the Development of Academic Staff in the Republic of Bulgaria, its implementing regulations, and the regulations of the Bulgarian Academy of Sciences have been fulfilled. I positively evaluate this dissertation, which gives me grounds to propose that M.Sc. Ivaylo Robertov Georgiev be awarded the educational and scientific degree "Doctor" in the scientific specialty "Robots and Manipulators," within the scientific field 5.1 "Mechanical Engineering."

18.11.2025

Reviewer:

/ prof. Tanio Tanev/