# REVIEW

By Assoc. Prof. Dr. Denis Safidinov Chikurtev – IICT-BAS

On a dissertation for the acquisition of the educational and scientific degree **"Doctor"**

Professional field: **5.1. Mechanical Engineering**

Scientific specialty: **" Robots and manipulators "**

Author of the dissertation: **Ivaylo Robertov Georgiev**

Thesis topic: **Design and Control of a 3D Printed Humanoid Hand**

## 1. Relevance of the problem and purpose of the research

Humanoid robots are the subject of much research and are in the process of entering use in a number of countries. Various companies and scientific organizations are developing their own humanoid robots, with the aim of application as service robots in people's daily activities or supporting activities in production processes and industry in general. Despite increased research and progress in development, there is still a lack of universal solutions that can be offered to the mass market. There are a number of challenges such as designing sustainable mechanical structures and platforms, reducing weight, improving mobility, optimizing the number of degrees of freedom, developing control approaches, interacting with the environment and people.

The problem considered in the dissertation refers to an innovation in the production of a humanoid hand using three-dimensional printing technology. A hardware system for driving the hand and a software control system are presented. The kinematic characteristics and movements of each finger of the hand are analyzed. The presented research can be used for the production, driving and control of other robotic mechanisms or prostheses. The developed prototype of a humanoid hand can be integrated into a manipulator and used as an end effector for picking up and placing objects.

I believe that the topic of the dissertation research is relevant due to the increasing demand for solutions for improving humanoid and collaborative robots. In addition, 3D printing technologies have developed significantly over the years, and in the research the doctoral student has presented precisely their wide application in the field of robotics.

The aim of the dissertation is: The goal of this dissertation is to design and create a 3D printed humanoid robotic hand built on a modular principle, and to investigate its functional capabilities. Each of the hand's fingers is to be driven by an independently controlled motor. The modularity refers to the fingers, including their control hardware and software..

To achieve the goal, the doctoral student has defined the following tasks:

1. To conduct a literature review and analysis in the field of robotics and medicine concerning the creation of humanoid robotic hands, with particular attention paid to the application of additive technologies in this area.

2. To develop an approach for creating assembled 3D printed fingers for a humanoid hand. Using this approach, to design a model of a humanoid hand.

3. To investigate the basic geometric and kinematic characteristics of human hand fingers.

4. To create a prototype of a humanoid hand with modular fingers, which includes the mechanical and hardware elements of the 3D printed hand.

5. To develop the hardware and software for the control and configuration of the 3D printed modular humanoid hand.

6. To develop software for reproducing signs from sign language (specifically, a sign language alphabet), applicable to the created prototype.

7. To conduct experiments confirming the functionality of the 3D printed humanoid hand..

## 2. Degree of knowledge of the state of the problem and general characteristics of the work

The candidate demonstrates in-depth knowledge of the subject and in particular the design of various models of humanoid hands and the principle of operation of actuators, servo motors and principles of designing mechanical models, using CAD application software. In addition, the doctoral student demonstrates knowledge of the problems in these systems, methods and approaches to solving these problems and analytical thinking. The innovative technology used for three-dimensional printing is well mastered by the doctoral student. He demonstrates in-depth knowledge and skills in preparing and modeling the constituent components of the robotic hand.

The dissertation is structured in 5 chapters, in a volume of 115 pages. It contains 53 figures, 9 tables, mathematical equations, 65 literary sources and 5 appendices.

Chapter 1 presents an overview of the subject area. The anatomy of the human hand and more specifically the wrist and fingers is examined in depth, which includes an overview of the characteristics of bones and joints. Standard limits of the size of the bones of the hand and joint limitations are presented. The doctorate has presented current trends and research in the field of humanoid robotic hands. A systematization of the types of mechanical structures and kinematic models of hands developed by various researchers and companies worldwide, including the Bulgarian Academy of Sciences, is presented. Hardware components used in robotic hands such as actuators, sensors and microcontrollers are described. Tactile sensors, electromyography sensors and visual sensors are mentioned. Different approaches to classifying grippers are analyzed, such as the Kutkoski method and "GRASP". The

information in Chapter 1 is entirely overview and informative, lacking elements of criticality and definition of research problems in the relevant scientific field.

Chapter 2 presents an approach for creating assembled fingers through 3D printing without the need for an assembly process. For successful implementation of the approach, a list of functional requirements is presented, which includes the number of degrees of freedom, grip, material selection, joint mechanisms, actuator selection, fingertip design, and minimization. The approach presents a design of fingers consisting of 4 elements. The elements are printed assembled after the printing process. In order to improve the printing process, approaches such as "The axis of the cylindrical and conical sections should be located perpendicular to the build surface", "45-degree principle", "Two-support principle", "Minimal clearances in the bearing sections" are described. An algorithm for creating a 3D printed assembled mechanism is presented, which consists of 6 steps. The algorithm covers the entire process of designing a three-dimensional assembled mechanism using fused deposition modeling (FDM) technology. At the end of Chapter 2, the PhD candidate proposes a modular design of the fingers and a complete design of the humanoid hand. Detailed drawings of the constituent elements of the fingers are presented and the assembly principle is described.

Chapter 3 describes the process of needs analysis and hardware selection. Hardware components such as DC motors, potentiometer and integrated circuit are presented. A complete assembly drawing of all component mechanical and electronic elements is presented and described. Then, a block diagram and a connection diagram of the electronic components for one finger are presented. Technical specifications of the electric motors and potentiometers used are presented. Communication between the individual microcontrollers and the control computer is implemented via the I2C protocol. The doctoral student has described in detail the essence of the I2C protocol and the principle of operation of the USB-ISS communication module.

Chapter 4 describes the developed software for controlling the robotic arm. The control levels are divided into two parts: controlling each finger separately and controlling the entire hand for grasping and displaying gestures, through different application programs. The finger control is implemented through a graphical interface that provides buttons and fields for data entry. This interface is composed of 5 menus: manual movement, automatic movement, setting position, changing communication address and reading current position.

The software for controlling the entire hand is at a higher level. It is implemented again as an application with a graphical interface. The application is written using the Python programming language and provides functions for folding and unfolding all fingers. The gesture control is implemented as a separate program, where the letters of the English alphabet can be selected through a graphical interface. The last described software is for grasping spherical and cylindrical objects. It offers multiple buttons with predefined sizes of the objects it will grasp. At the end of the chapter, the software support of the hand is presented, where the addresses and registers used to perform the various movements of the hand are described.

Chapter 5 describes experimental verification of the proposed gateway, hardware and software. The following characteristics are verified:

• Precision of movement: Can the hand reach a desired position with high accuracy and repeatability?

• Grip strength and endurance: Can he grasp and hold various objects without damaging or dropping them?

• Reproduction of signs from sign languages: Can the signs be correctly reproduced by hand?

• Workspace: Defining the working area of the fingers of the hand in which various objects can be manipulated.

The PhD candidate presented an analysis of the workspace through kinematic characteristics. The experiments conducted are: 1 - gripping household objects, 2 - gripping printed objects, 3 - forming gestures. The results achieved from experiment 1 show that the designed robotic hand can grip various medium-sized objects, but cannot grip small objects such as USB flash drives. It can also hold objects weighing up to 85 grams.

The results achieved in experiment 2 show that the robotic arm can grasp cylinders and spheres of different diameters. It is mentioned that there are difficulties in grasping small objects. The results of experiment 1 and 2 are not presented as a measurable indicator and there is no information on the success rate.

The results of experiment 3 show whether the hand is compatible and capable of showing gestures from the English alphabet in American language. The result shows that 20 out of 26 gestures are possible. An idea is presented to solve the problem of the lack of combinations for the missing gestures.

## 3. Compliance of the proposed research methodology with the set goals and objectives of the dissertation work

A standard methodology for solving scientific and applied problems is applied. The structure of the dissertation is arranged semantically, starting with defining the problems in the topic and the need for research in this area. Then it moves on to a detailed description of the characteristics and methods for solving these problems. A solution is proposed for designing a humanoid robotic hand using three-dimensional printing technology, and finally, research and tests for verification of a robotic hand are conducted.

## 4. Contributions

The doctoral student has presented 6 contributions to the dissertation work, categorized into two categories: scientific and applied and applied contributions.

Scientific and applied contributions:

1. A novel approach for creating assembled 3D printed fingers for a humanoid hand was developed. An innovative design was proposed that allows the fingers to

be printed as a single object with movable joints using FDM (Fused Deposition Modeling) printing technology. This was achieved through a combination of factors such as: the position and orientation of the finger on the 3D printer's build platform; the shape of the joints; the clearance between the finger links; and the printing processes. The approach enables the creation of fully functional fingers that can be printed in an assembled state.

2. The geometric and kinematic characteristics of humanoid hand fingers were investigated. This includes the reachability zones of the fingertip of a humanoid hand with dependent movements, as well as the distribution of the manipulability coefficient within those zones.

Applied contributions:

3. A prototype of a humanoid hand with modular fingers was created. The modular fingers are printed fully assembled on an FDM 3D printer, and the modularity is evident not only in the mechanical components but also in the hardware elements and the developed software. This applied contribution simplifies the assembly of the finger and the overall assembly of the hand. Modular fingers allow for easy replacement in case of damage, uniformity in control and setup, and other advantages.

4. Hardware and software for the control and setup of the 3D printed modular humanoid hand were developed.

5. Software for reproducing signs from the sign language alphabet was created and applied to the 3D printed humanoid hand.

6. Experiments were performed that confirm the functionality of the 3D printed hand. The experiments include object gripping and sign language reproduction.

I accept contributions 1 to 5, which are correctly formulated and valid. Contribution 6 covers experimental and testing activities, therefore I do not accept it.

## 5. Dissertation publications

The candidate has presented 5 scientific publications in the dissertation. All of the publications are referenced in Scopus. The doctoral student is a co-author with his scientific supervisor in all publications and has not presented an independent publication. All submitted publications are cited in the text of the dissertation. The points received from the publications significantly exceed the minimum for the Institute of Robotics - BAS and show that the scientometric indicators are met.

## 6. Opinions, recommendations and notes

It is impressive that the candidate's work and the systems and technologies presented find direct and real-world application in the fields of robotics, 3D printing, and mechanical engineering. The results achieved can directly have a positive impact on the humanoid robot sector, mechanical design modeling technologies, and approaches to building assembled mechanical structures.

I recommend publishing independent research. I recommend supplementing the bibliography with more sources.

**Conclusion**

The presented dissertation meets the set of criteria and indicators for the acquisition of the educational and scientific degree "doctor", according to the Law on the Development of the Academic Staff in the Republic of Bulgaria (ZRASRB), the Rules of the Bulgarian Academy of Sciences for the Implementation of the ZRASRB, the Rules of the Specific Conditions for Acquiring scientific degrees and for holding academic positions at Institute of Robotics - BAS. In conclusion, I give **a positive assessment** of dissertation work.

It is strongly recommended to the scientific jury to award **Ivaylo Robertov Georgiev** the educational and scientific degree **"Doctor"** in the professional field **5.1. Mechanical Engineering.**

Date: 20.11.2025

Jury member:

( Assoc. Dr. Denis Chikurtev)