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Designing a Robot-Manipulator of the Structure of a Human Upper Limb

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Abstract. Today, robotics is one of the key areas of creating new "smart" technology. The peculiarity of such robotic devices is a wide variety of movements of their executive bodies, including the ability to construct so-called "anthropomorphic" movements that imitate to some extent the movements of a person and his limbs. One of the important qualities of any anthropomorphic device is the kinematic similarity of its working movements to similar human movements. However, the movements of most existing robots are formed according to traditional machine control schemes, which leads to the "machine" kinematics of these movements, which is sharply different from the "living" kinematics of a person, although the intended purpose of the movements is almost the same. Therefore, when developing anthropomorphic manipulators, it is extremely important to ensure not only the kinematic similarity of their movements to the movements of human arms and legs, but also to give them smoothness. The issue of creating a natural-looking human hand is of great relevance for modern science and technology. This is primarily dictated by the need to create universal manipulators for flexible production, solving the problem of prosthetics of the upper limbs and developing anthropomorphic robots to assist a person in various areas of his activity. The article discusses the possibilities of creating a robot manipulator in the form of a human upper limb, in the sense that the robot will be able to repeat the basic movements of the hand: shoulder, elbow and hand. Available low-cost means were used in the design, which helps to reduce the cost of the final product in order to make it accessible to all segments of society. The goal is achieved using 3D modeling and additive printing technology. The work of the hand gripper, that is, bending and unbending the fingers, is not considered in the work. As a result, we will receive a ready-to-use prototype of the hand for the operator, who will remotely move his hand “transfer” the movement to the robot manipulator.

Keywords: robot, manipulator, human upper limb, prototype, movement, 3D modeling.

Introduction

One of the main areas of modern science and technology is robotics, which is a mechatronic system that combines fundamental and applied research in the field of mechanics (including machine mechanics), electronics and information technology [1, 2, 3, 4].

A striking illustration of the mutual penetration of information technology and industry is robotics, which is a classic example of a mechatronic system that combines the principles of mechanics and electronics (control).

Currently, more and more attention is being paid to the creation of humanoid robots, both those that are similar in appearance and those that imitate all human movements [5, 6, 7].

Possession of skills in computer-aided design systems [8, 9] is a prerequisite in the engineering profession, thanks to which productivity and quality of work achieves better results, and the drawing board and pencil are a thing of the past.

Due to the presence of multi-link kinematic chains, mostly open during movement, a person has a large number of degrees of freedom.

Thus, the mobility of the fingertips relative to the chest is determined by 12 degrees of freedom; the wrist relative to the shoulder blade - 7; and the total number of degrees of freedom of the entire body is a three-digit number.

The kinematic diagram of the arm skeleton shows the movable links of the skeleton and the types of hinge joints (two ball joints and one cylindrical joint).

The skeleton model has seven degrees of freedom: three degrees of freedom in the shoulder girdle, one degree of freedom in the elbow joint and three degrees of freedom in the hand [10, 11, 12].

The basic movements (Fig. 1) are illustrated using a rotational pair, so it can be said that the shoulder movements are characterized by a spherical kinematic pair. In this work, a prototype with 3 degrees of freedom is designed: 1 degree at the elbow, and 2 degrees at the hand.

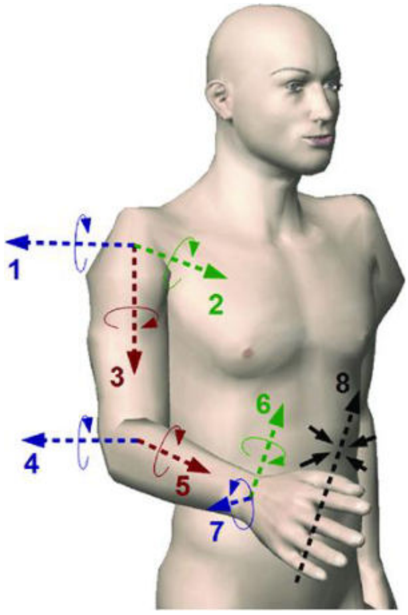

Fig. 1 - Basic movements (degrees of freedom) of the human upper limb: 1 - flexion and extension at the shoulder joint; 2 - adduction and abduction at the shoulder joint; 3 - internal and external rotation at the shoulder joint; 4 - flexion and extension at the elbow joint; 5 - pronation and supination at the radioulnar joint; 6 - flexion and extension at the wrist joint; 7 - abduction and adduction at the wrist joint; 8: grasping and releasing with the hand

1. Materials and methods

1.1 Materials

The development of modern electrical engineering and microelectronics has made it possible to simultaneously reduce the weight and dimensions of mechanical systems through the use of electronic components and increase the efficiency and durability of operation.

Selecting the Basic Hardware for a Structural Prototype:

- The hardware part of the system is the Arduino UNO microcontroller (Fig. 2). Arduino boards are a line of electronic devices equipped with a microcontroller, their own memory, a set of digital and analog contacts, an ADC module, and a port for connecting to a computer. Arduino Uno is a controller based on the ATmega328P-AU processor. In addition to the processor, it includes: 16 digital contacts, 6 analog contacts, a 16 MHz quartz resonator, a USB connector, a power connector, an ICSP connector for in-circuit programming, and a reset button. The ATmega16U2 microcontroller is used as a USB-UART converter [13].

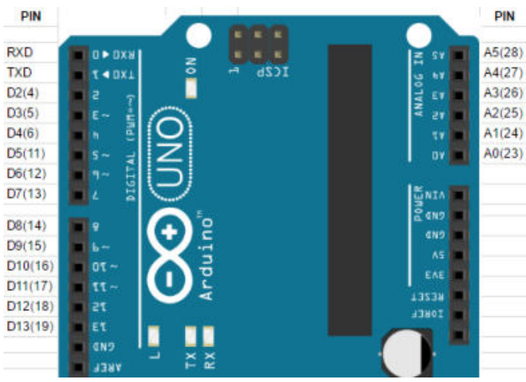

Fig. 2 – Digital and analog controller contacts

- **Electromechanical actuators for robotic arm**: In our work, we used the MG996R servo drive to rotate the links. MG996R (Fig. 3) high torque digital servo drive features a metal gear train that delivers a very high torque of 10 kg in a tiny package.

Fig. 3 – MG996R Servo Motor Kit

MG90S (Fig. 4) – This is a micro servo motor with metal gear. This small and lightweight servo has a high output power, so it is ideal for radio controlled airplanes, quadcopters or robotic arms.

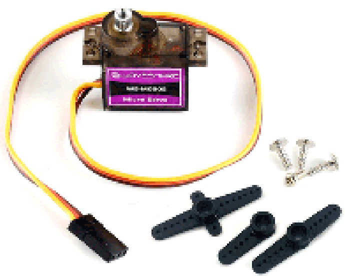

Fig. 4 – Servo motor kit MG90S

The module (HCMODU0097) is a breakout board for the NXP PCA9685 16-channel pulse width modulator controller (Fig. 5). It has 16 fully programmable pulse width modulator outputs with 12-bit resolution, giving a total of 4096 programmable steps with an adjustable duty cycle from 0% to 100%. In addition, the output frequency of all 16 channels can be programmed.

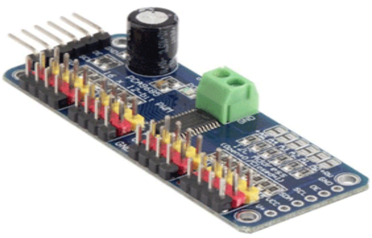

Fig. 5 – Pulse width modulator - servo controller

LSM303DLHC (Fig. 6) is a digital 3-axis accelerometer and 3-axis magnetometer with I2C interface.

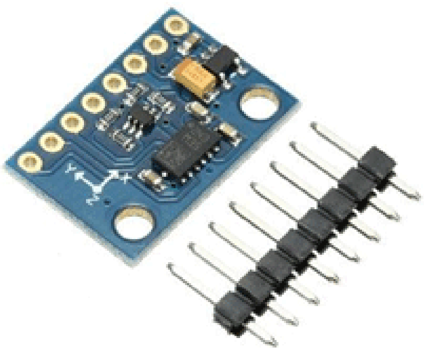

Fig. 6 – Gyroscope GY-511

1.2 Methods

Design of a structural prototype:

Design of prototype blocks: The design of the structural prototype was based on an open-source project by user Bitluni on the “electromaker.io” platform [14]. The design of the structural prototype of the robot-manipulator was performed in the SolidWorks solid modeling software tool.

Fig. 7, 8, 9, 10, 11, 12, 13 show the structural elements of the prototype in sequential order.

Servos are extremely useful in robotics and automation. Robots use servo motors because of their smooth switching and precise positioning. Servo Motors are DC motors equipped with a servo mechanism for precise angular position control.

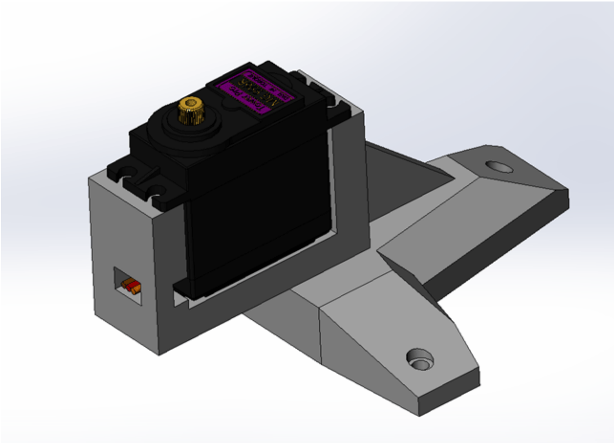

Fig. 7 – Structural element of the prototype

Fig. 8 - Structural element of the prototype

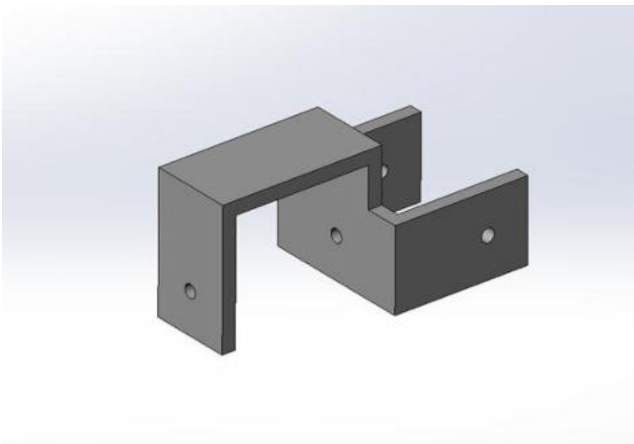

Fig. 9 - Structural element of the prototype

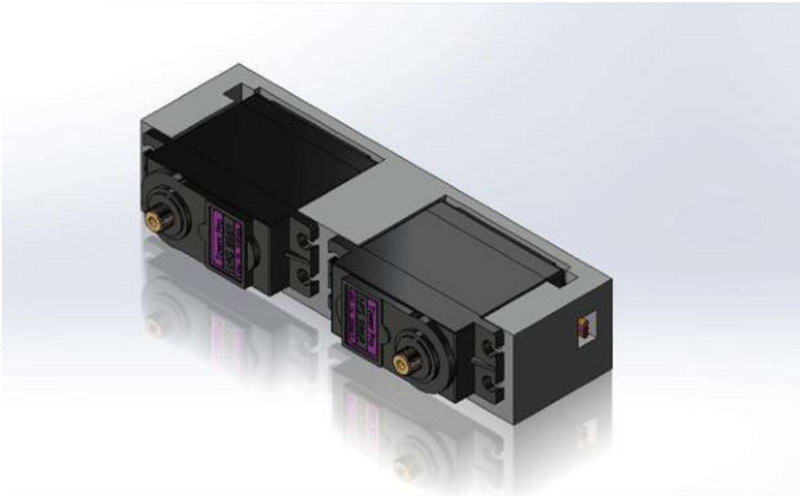

Fig. 10 - Structural element of the prototype

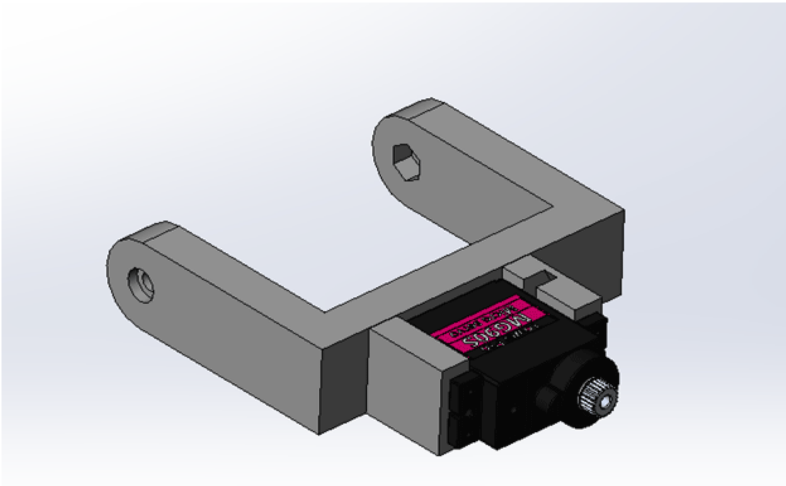

Fig. 11 - Link for pronation and supination in the radioulnar joint

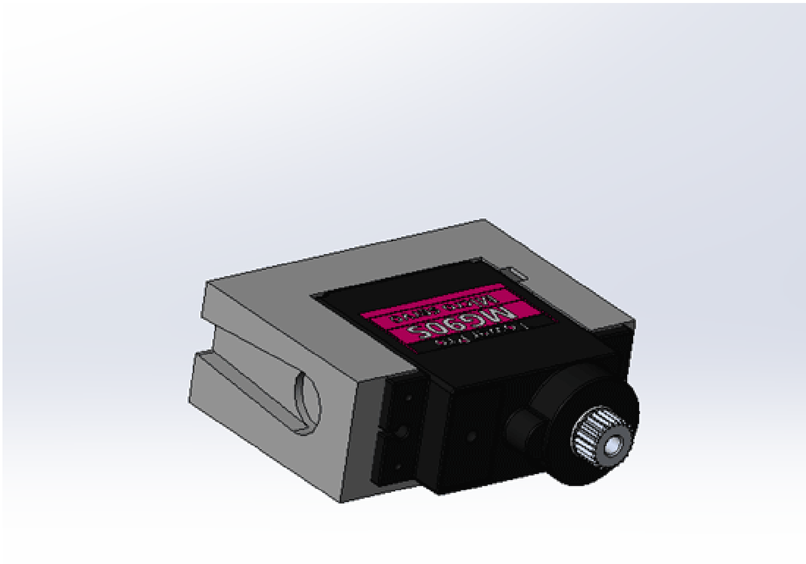

Fig. 12 - Wrist flexion and extension link

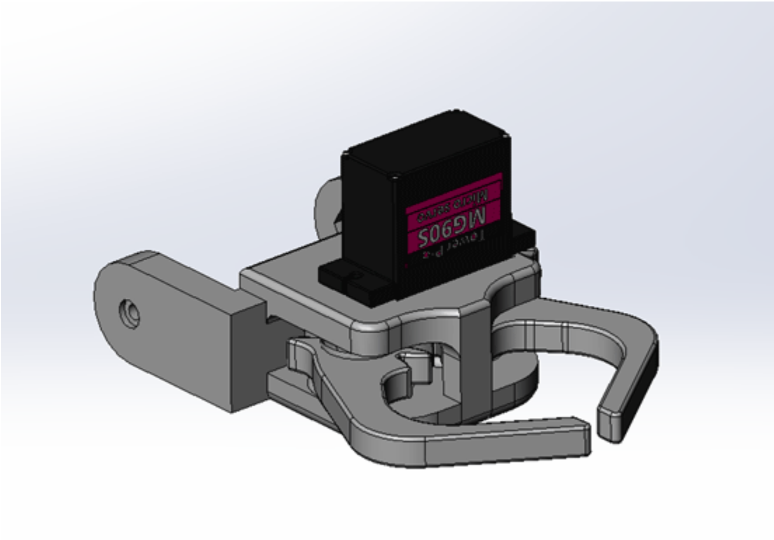

Fig. 13 - Gripper device

The complete assembly (Fig. 14) represents a structural prototype of a robotic manipulator for simulating human upper limb movement.

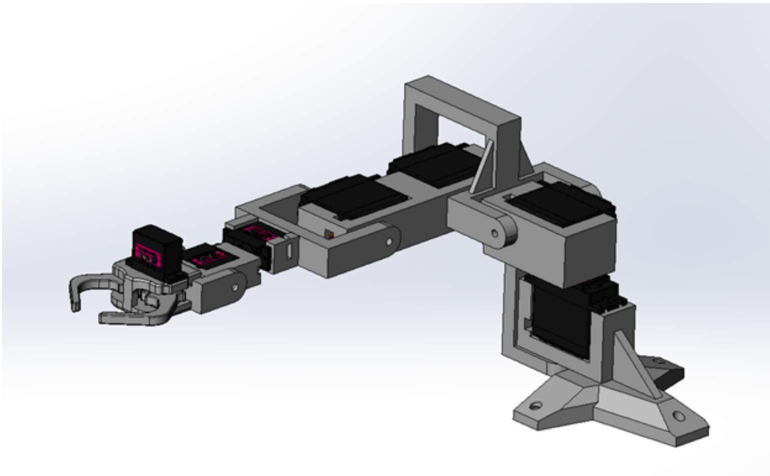

Fig. 14 - Structural prototype of a robotic manipulator for simulating the movement of the human upper limb

2. Results

Assembly of all structural elements of the prototype

During the process of 3D printing and assembly of the prototype itself, there were some mismatches and the elements of the parts were improved.

Fig. 15 - 3D Printing Process

Fig. 16 - Fasteners and bearings

Fig. 17 - Bearing location

Bearings are used to better rotate kinematic pairs to ensure frictionless movement, which affects the final moment of force in the link.

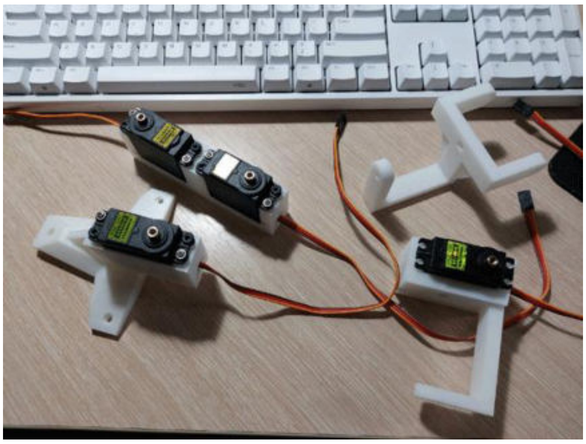

Fig. 18 – Installing bearings to the manipulator links

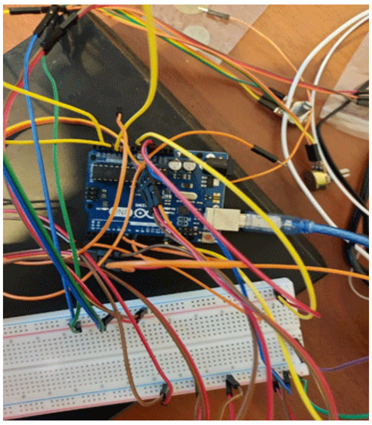

Fig. 19 – The process of connecting to Arduino and testing

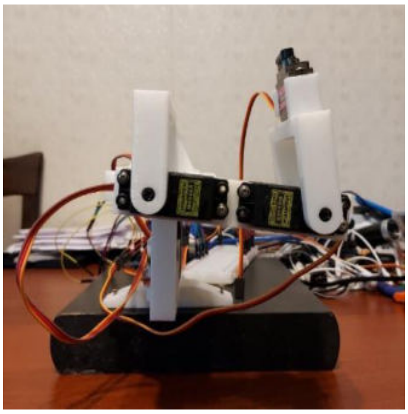

Fig. 20 – Assembling the manipulator links

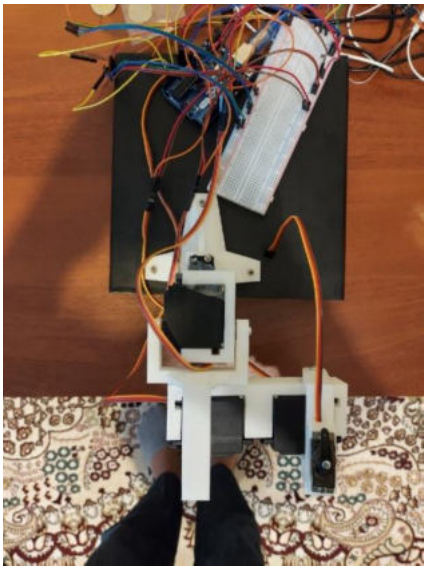

Fig. 21 – Assembling the manipulator

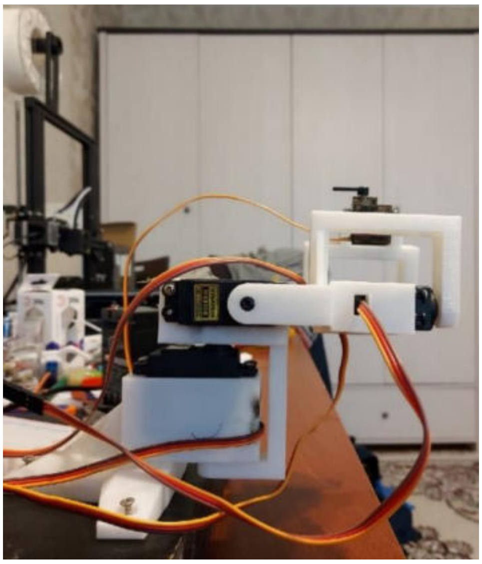

Fig. 22 – Designed prototype of a robotic manipulator

Conclusion

The digitalization process today affects almost all countries in the world. Currently, robotics is becoming one of the key areas of development of science, technology and engineering, which in the 21st century will determine the scientific, technical, industrial and defense potential of the state.

In recent years, various robotic devices have been increasingly introduced into the medical field [15, 16, 17]. One of the promising areas of medical robotics is the development of hardware and software for prosthetics of limbs and their individual parts. This allows to a significant extent to restore the quality of life of a person, his physical (movement, taking, carrying objects, etc.) and sociological needs, reduce the social burden on his relatives, nursing services, etc. As a result, practical skills were obtained during the process of performing the work. The human upper limb, its mobility and features were considered. The hardware and technical component was selected for designing a prototype of a robot-manipulator. A prototype of a robot-manipulator was designed that replicates the structure of the joints and the movement of the human upper limb. The article shows the general assembly and various elements involved in the layout. The scheme and methods of connecting electronics to the entire hardware platform are considered.

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