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HARDVERSKI RAZVOJ EDUKACIJSKE ROBOTSKE RUKE

HARDWARE DEVELOPMENT OF AN EDUCATIONAL ROBOTIC ARM

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SAŽETAK

Ovaj rad bavi se hardverskim razvojem edukacijske robotske ruke koji se prožima kroz više područja strojarstva i elektrotehnike od same ideje, konstrukcije, 3D ispisa pa sve do sklapanja komponenti sustava. Gotovo svi dijelovi konstruirani su u 3D CAD softveru, ispisani na 3D printeru te sastavljeni od lako dostupnih, jeftinih električnih komponenti u svrhu dobivanja ekonomski što pristupačnijeg konačnog proizvoda uz jednostavnost sklapanja. Upravljanje je moguće izvesti bilo kojom platformom koja sadrži minimalno 10 ulazno izlaznih priključaka opće namjene na 3,3V poput Raspberry PI mini računala, ESP32 ili ESP8266 razvojnih platformi. Korištenjem dodatnih IoT mogućnosti navedenih razvojnih platformi upravljačke mogućnosti edukacijske robotske ruke se šire i na internet. U ovom radu je fokus na mehaničku izvedbu, konstrukciju, 3D ispis i sklapanje komponenata u jednu platformu koja je kompatibilna s većinom DIY platformi za upravljanje i programiranje. Ovisno o platformi moguće je dodavanje raznih osjetnika i izvršnih elemenata uz različite načine komunikacije s drugim uređajima ovisno o željama korisnika i vrsti projekta.

Ključne riječi: *robotika, robotska ruka, aditivna tehnologija, CAD*

ABSTRACT

This article focuses on the hardware development of an educational robotic arm that spans across multiple fields of mechanical and electrical engineering, from the initial idea, design and 3D printing, to assembly of system components. Almost all parts are designed in 3D CAD software, printed on a 3D printer, and assembled from readily available, inexpensive electrical components to achieve an economically accessible final product with ease of assembly. Control can be achieved using any platform that contains a minimum of 10 general-purpose input/output pins at 3.3V, such as Raspberry Pi mini-computers, ESP32, or ESP8266 development platforms. By utilizing additional IoT capabilities of these development platforms, the control capabilities of the educational robotic arm expand to the internet. This work focuses on mechanical performance, design, 3D printing, and assembly of components into a single platform compatible with most DIY control and programming platforms. Depending on the platform, various sensors and actuators can be added with different communication methods with other devices according to user preferences and project requirements.

Keywords: *robotics, robotic arm, additive manufacturing, CAD*

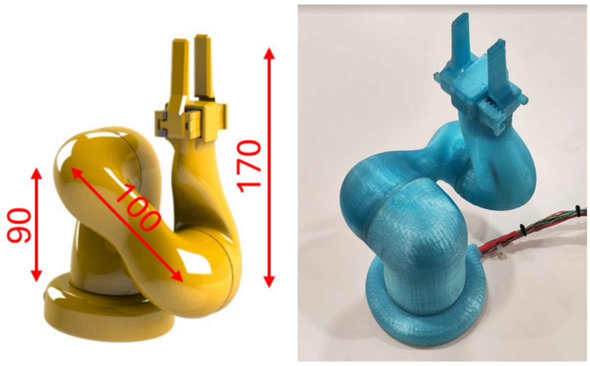
1. UVOD

1. INTRODUCTION

In the contemporary industry, using robotic systems is a norm, which leads to the conclusion that robots become something mundane. Accordingly, the idea of developing a simple robotic arm was born, which has an educational purpose by introducing pupils and students to basic parts of such a system. This connects the fields of mechanical engineering, electrical engineering and computing, or mechatronics. The educational robotic arm serves as a simple and economically acceptable platform with basic capabilities that can be programmed according to the user's wishes, regardless of the choice of system management or the needs of the project. Bearing in mind the educational purpose, it is important that the parts of the robot arm are easy to assemble and disassemble. The robot arm model was constructed in CAD software, and STL files were generated for all parts and transferred to the software that cut the parts into layers and parameterizing the 3D printer. Then the parts were printed on a 3D printer from PETG material which has excellent properties for mechanical parts. The system contains three 28BYJ-48 unipolar stepper motors with a nominal voltage of 5 V for driving the robotic arm joints, which have been converted to bipolar in order to achieve a higher output torque, one SG90 servo motor for the gripper, and three optical sensors for the initial positioning of the robotic arm when it is turned on. Similar papers that dealt with the design and 3D printing of robotic arms. [1]. [2], [3]

2. KONSTRUKCIJA ROBOTSKE RUKE

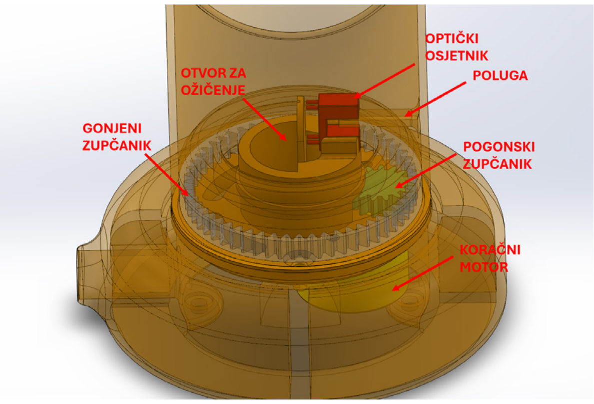
2. ROBOTIC ARM DESIGN



Slika 1 *Renderirani i 3D ispisani model robotske ruke*

Figure 1 *Rendered and 3D printed model of a robotic arm*

The design idea of the robot arm is based on the industrial Kuka LBR iiwa robot arm, where the arms are connected to each other only on one side, where the stepper motors of the joints are located together with the optical position sensor. This robotic arm (Figure 1) of RRR (Revolute-Revolute-Revolute) design contains three degrees of freedom of movement and, by combining them, achieves movements that enable reaching, lifting and lowering objects in different positions and orientations. At the top of the robot arm there is a gripper driven by a mini servomotor with a drive gear that transmits the torque to the toothed gripper bars. All parts of the educational robotic arm were designed in SolidWorks CAD tool and adapted to dimensions for 3D printing with FDM (Fused Deposition Modelling) technology. The total height of the arm with all three segments and the handle is 360 mm. The reach of the arm from the first segment to the tip of the gripper is 270 mm, which is also the maximum working radius of the robotic arm.

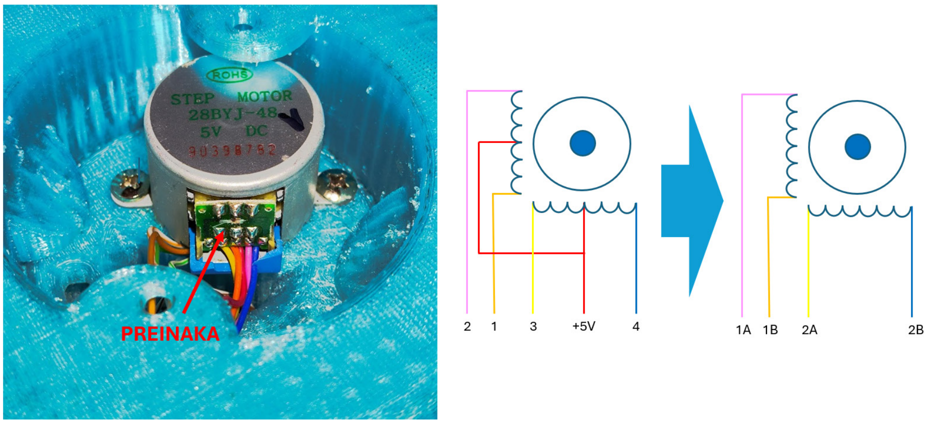


Slika 2 *Rješenje prijenosa momenta u zglobu*

Figure 2 *The solution to transferring torque at the joint*

The joint (Figure 2) consists of a coupling with a ball bearing that connects the arms and executes the circular movement of the joint. The single-row ball bearing used on the coupling is 6086 with an inner diameter of 30 mm, an outer diameter of 42 mm, and a width of 7 mm. In order to increase the carrying capacity of the arm, the weight on the joints can be reduced by using a polypropylene ball bearing. A stepper motor with a drive gear is mounted on the lower side of the coupling, while an internal gear is integrated in the arm itself. Considering the relatively small torque of the stepper motor, the increase is achieved by way of internal and external gears with the ratio of 3.6:1. The greatest load is on the middle joint, and for this reason, the unipolar stepper motor was converted into a bipolar one, which increases the torque and permissible operating voltage of the motor.

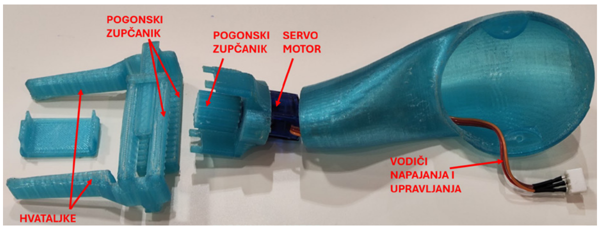
The stepper motor model used to drive the arm is a 28BYJ-48 with a nominal voltage of 5 V, which is a unipolar stepper motor by design. In order to increase the output torque, it is possible to convert



***Slika 3** Prikaz preinake unipolarnog u bipolarni koračni motor [4]*

***Figure 3** Representation of the modification from unipolar to bipolar stepper motor [4]*

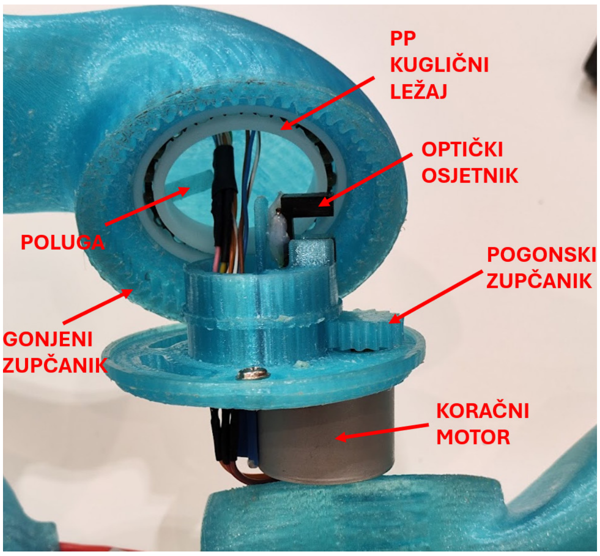
it into a bipolar stepper motor by disconnecting the common power supply of the coils (Figure 3). The modification results in a larger coil through which the current flows, thus generating a larger magnetic field and thereby obtaining a larger torque. In this version of the arm, depending on the desire, it is possible to make changes to all three stepper motors, which results in a reduced number of conductors passing through the centre of the arm. To change the operation from unipolar to bipolar version, it is also necessary to replace the control circuit, and it is no longer possible to use the standard ULN2003 for unipolar stepper motors, but A4988 for bipolar motors. The power supply voltage of the control unit can be up to 35 V and 2 A of current, but in this project, depending on the desired moment on the crucial, most heavily loaded joint, it can be up to 10 V. At the same time, it is necessary to pay attention to the motor overheating. The converted stepper motor from unipolar to bipolar 23BYJ-48 can be connected to a higher voltage than the rated voltage due to the now larger coil. [5]



***Slika 4** Izvedba hvataljke robotske ruke*

***Figure 4** Implementation of the gripper of the robotic arm*

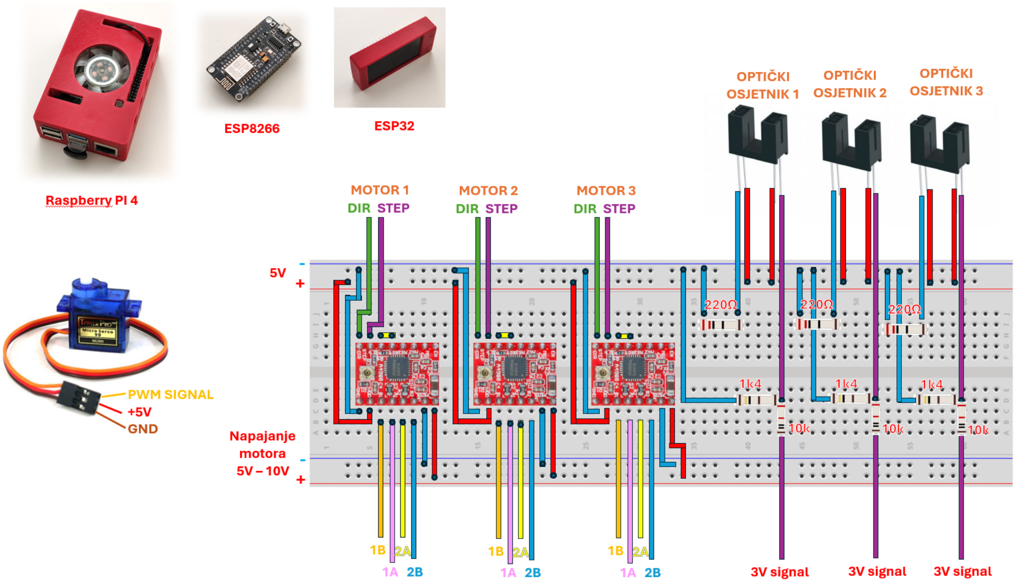
The gripper of the robotic arm (Figure 4) has a range of acceptance from 0 to 50 mm and is driven by an economical SG90 mini-servomotor with a rated voltage of 5 V controlled by pulse-width modulation. The selection of this servomotor results from its low mass and relatively high torque, which enables reliable grasping of objects, while lower repetition accuracy is not crucial. The system is made of one pair of grippers connected to each other by two toothed racks via a drive gear mounted on a servo motor which is connected to the control with three conductors. The red wire indicates +5 V, the brown GND, while the orange indicates the pulse-width modulation control signal obtained from the control.



***Slika 5** Izvedba početnog položaja ruke uz pomoć optičkog osjetnika*

***Figure 5** Implementation of the initial position of the arm using an optical sensor*

Since the robotic arm does not have its position memorized on a power cut, the simplest way is to determine the initial position of the robotic arm by way of sensors. In this version of the robotic arm, an infrared optical sensor of NC logic is used, which outputs a 3 V signal when



Slika 6 *Električna shema [6],[8]*

Figure 6 *Electrical diagram [6],[8]*

the lever is outside the detection area of the optical sensor. The infrared LED is powered with 3-5 V via a protective resistor of 220 Ω. Inside each joint of the robot arm there is a lever that, in a certain position of the joint, passes between the receiver and the transmitter of the optical sensor and thus blocks the infrared light that the transmitter of the sensor sends to the receiver. This activates the sensor, and at the output of the sensor, it signals to the control that the robotic arm in that joint is in the home position. The control then stops the rotation of the stepper motor. The procedure is repeated for each joint of the robot arm until all three sensors detect the blocking of infrared light, that is, until all three initial positions of the joints are detected.

3. ELEKTRIČNA SHEMA

3. ELECTRICAL DIAGRAM

In order to control the robotic arm between the control and the actuators themselves, such as stepper motors, the control circuits of all three joint motors of the robotic arm have to be connected. Also, the power supply of the infrared transmitters of the three optical sensors for the position of the joints, as well as signal acquisition and signal voltage adjustment have to be connected. Any platform that contains at least ten input and output ports (GPIO – General Purpose Input / Output) can be selected for controlling the educational robotic arm. Of the total number of connections, three output connections are signal transmitters for the movement direction of the stepper motors, three output ports are transmitters of the number of pulses for performing the stepper motor movement. To control the servomotor of the gripper, only one output connection is required, which sends a pulse-width modulation signal. For the input signals that we get from the ITR9608 optical sensor of NC logic, three connections are required. With the help of these signals, the control system receives information when a particular joint is in the initial position. During the rotation of the joint of the robotic arm, the lever also moves until it covers the source of infrared light on the transmitter of the optical sensor, and thus the voltage at the output of the sensor drops to 0V. When the sensor is not activated, it continuously outputs a 3V signal. This type of NC logic, where the sensor gives a signal at the output all the time, enables the monitoring of the correct operation of the sensor.

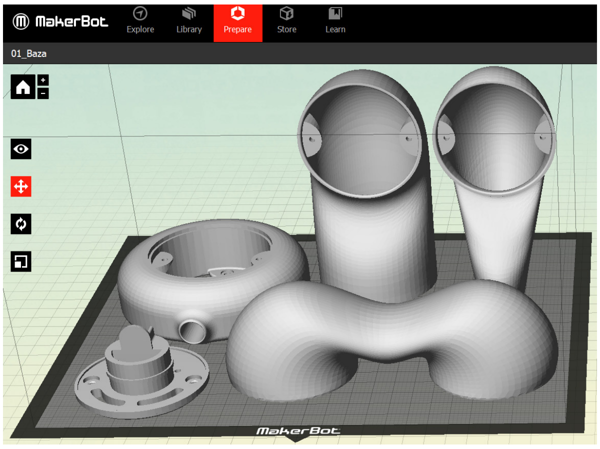
Since the robot arm works with modified unipolar stepper motors, bipolar stepper motor controllers must be used after modification, so A4988 with 28BYJ-48 stepper motors are used in this case. There are two larger coils with connection marks 1A, 1B, 2A, and 2B instead of five connections to the motors, where there were one power supply and four coils. The connections have to be made exactly as indicated on the engine control assembly.

4. 3D ISPIS DIJELOVA ROBOTSKE RUKE

4. 3D PRINTING OF ROBOTIC ARM PARTS

The parts of the robotic arm were manufactured on the Makerbot Replicator 2X 3D printer using the FDM (Fused Deposition Modelling) process. It is a process in which the polymer material in the form of a wire is passed through a nozzle where it softens and is applied in layers to a heated work surface. Owing to the working surface being at a lower temperature, the printed material on the working surface coalesces, thus creating the desired structure.

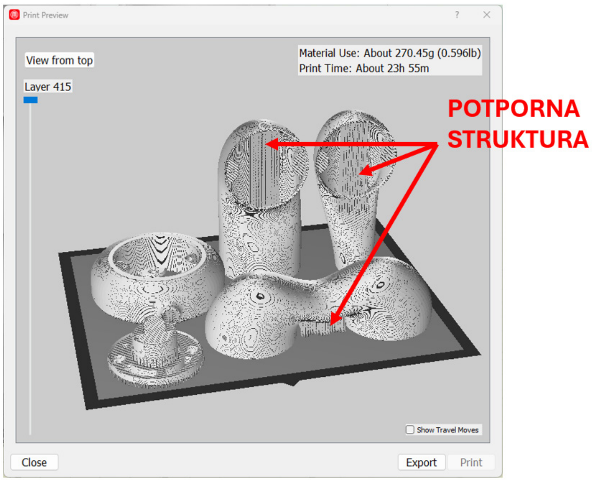
In the process of designing a robotic arm, an STL file has to be generated for each constructed part, which shows the shape of the constructed model through a network of triangles. In order to display the model through a network of triangles as closely as possible to the constructed model, the number of triangles can be increased, and thus their density. [9]



***Slika** 7 Prikaz modela u Makerbot Desktopu*

***Figure** 7 Model in Makerbot Desktop*

The generated STL file (Figure 7) is opened in Slicer software. The software virtually transforms the model into layers of the desired height of 0.05 - 0.3 mm, and a G-code (Geometric code) is generated, which gives the 3D printer a series of commands for the supply of materials, movement of the extruder head through the printer's workspace, the temperatures of the heated bed and materials. Before printing, the software provides basic information about the number of layers, material consumption, and approximate printing time. At the same time, layers can also be inspected one at a time in order to check for faults in the design. The models are constructed and positioned on the desktop so that the support structure is used as little as possible during 3D printing, which makes a greater saving in the material needed for printing (Figure 8).



Material Use: About 270.45g (0.596lb)
Print Time: About 23h 55m

***Slika** 8 Prikaz modela u slojevima*

***Figure** 8 Sliced model visualization*

Today, there is a wide range of materials that can be used in the deposition process such as PLA, ABS, PETG, TPU, NYLON, PC and others. PETG blue transparent material was used for this project. PETG (Polyethylene terephthalate glycol) is the material most often used in the production of PET packaging such as plastic bottles due to its characteristics and properties. The surface of objects made of PETG material is shiny and smooth, the material adheres perfectly to the heated surface of the 3D printer during printing and has an extremely low shrinkage rate during cooling, which is extremely important when printing mechanical parts. The material is resistant to elevated temperatures up to 68˚C and is of high hardness. [7]

Considering the dimensions, the larger parts of the robotic arm are printed with a layer height of 0.3 mm. For printing with PETG material, the extruder temperature of 250˚C and 90˚C for the working surface were selected. The diameter of the nozzle is 0.4 mm, and for the thin walls, it is important that their thickness is a multiple of the thickness of the nozzle.

5. ZAKLJUČAK

5. CONCLUSION

This paper demonstrates the process of developing an educational robotic arm that represents the integration of various disciplines such as mechanical engineering, electrical engineering and computing, or mechatronics. Through the various stages of production, emphasis was placed on practical application, simplicity of production and economy as key aspects that make the project suitable for educational purposes. It is also possible to use different development platforms such as Raspberry Pi, ESP32 or ESP8266, as well as others that meet the minimum requirements of having at least 10 general-purpose input/output ports (3.3V) with at least one output port with pulse-width modulation. By using the additional capabilities of the aforementioned Internet of Things (IoT) platforms, the functionalities of the robotic arm are extended to the Internet, opening up new possibilities for learning, application and control.

Inexpensive stepper motors and their modifications from unipolar to bipolar give positive results in terms of torque, but the negative side is the generation of high motor temperatures, which is might hinder longevity and reliability of work due to faster wear of parts and components. Increasing the transmission gears ratio is also not acceptable because even with the current transmission, the speed is 3.6 times lower due to the attempt to increase the torque. By applying FDM technology and materials for 3D printing, high-quality production of parts with good mechanical properties was achieved. Through this paper, a foundation is created for further research and development with the aim of improving education in the field of robotics and automation.

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6. REFERENCES

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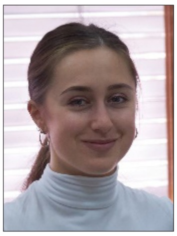

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