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INTRODUCTION TO ROBOT TECHNOLOGY

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1 Introduction

Robotics develops machines that can substitute for humans and replicate human actions. Robotics is an interdisciplinary branch of computer science and engineering. Robotics involves design, construction, operation, and use of robots. The goal of robotics is to design machines that can help and assist humans.Robots can take any form, but some are made to resemble humans in appearance.

1.1 Objective

The human body has an extraordinary capacity for movement. These movements occur thanks to various muscles in the body. Thanks to the movement provided by the muscles and joint points of the human body, the ability to access its surroundings increases. Generally, the same movements can be performed with less effort, but the movement will be limited and the movement may be interrupted when it encounters an obstacle. In order to prevent this interruption, extra muscles that we can move are needed.

By nature, people are in contact with objects throughout their lives and have limbs that provide grasping function thanks to their contact with objects. Fingers, made up of human limbs, allow humans to interact with their environment throughout their daily lives. From a scientific point of view, a single finger consists of four short bones, and a finger exhibits four independent movements, different from each other.

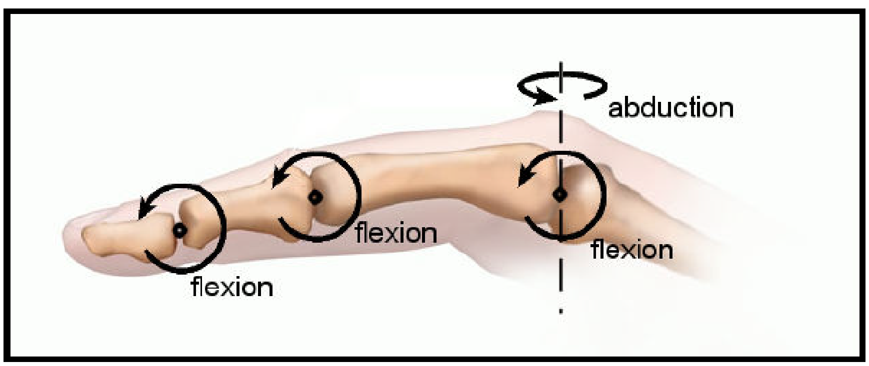

Figure 1: Motions of the finger bones. (Source: RelayHealth, 2010)

There are 4 different joint points that enable the movement of the human finger as shown in the figure. The project undertaken; It was carried out in reference to the article of ["BIOKINEMATIC ANALYSIS OF HUMAN BODY"][3] of associate professor Erkin Gezgin, who has done studies on biomechanical analyzes of the human body. Within the scope of the project, it was decided to design a prosthetic finger. In this report, the design and analysis of the prosthetic finger are given in detail.

2 Methodology

2.1 Denavit–Hartenberg parameters

In mechanical engineering, the Denavit–Hartenberg parameters(also called DH parameters) are the four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator. A commonly used convention for selecting frames of reference in robotics applications is the Denavit and Hartenberg (DH) convention which was introduced by Jacques Denavit and Richard S. Hartenberg. In this convention, coordinate frames are attached to the joints between two links such that one transformation is associated with the joint, $[Z]$, and the second is associated with the link $[X]$.

The following four transformation parameters are known as D–H parameters:

- d: offset along previous z to the common normal
- θ: angle about previous z, from old x to new x
- a: length of the common normal. Assuming a revolute joint, this is the radius about previous z.
- α: angle about common normal, from old z axis to new z axis

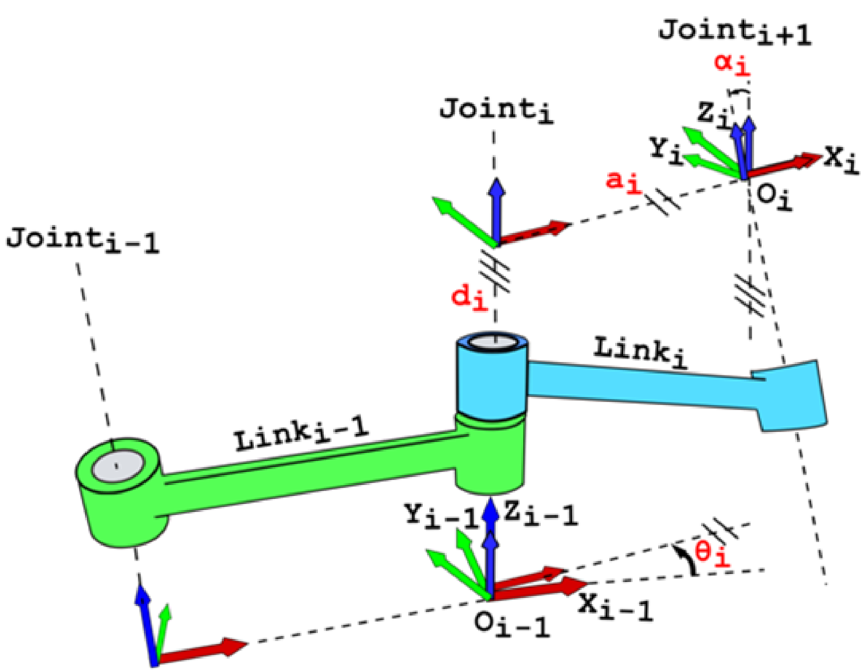

Figure 2: Four DH Parameter

Denavit–Hartenberg convention was used to model finger movement. This method is widely used in robot designs. Also, it is not a difficult method to apply. Transform matrices, which are combinations of rotation and translation matrices, are expressed. In the kinematic analysis section below, the analysis was made by applying this method.

3 Results

3.1 Kinematic Analysis

3.1.1 Direct Task

In order to make the DH Convention of the finger robot, first of all, all [Z] and [X] axes were placed on our robot. In this way, the necessary parameters for the DH table were found.

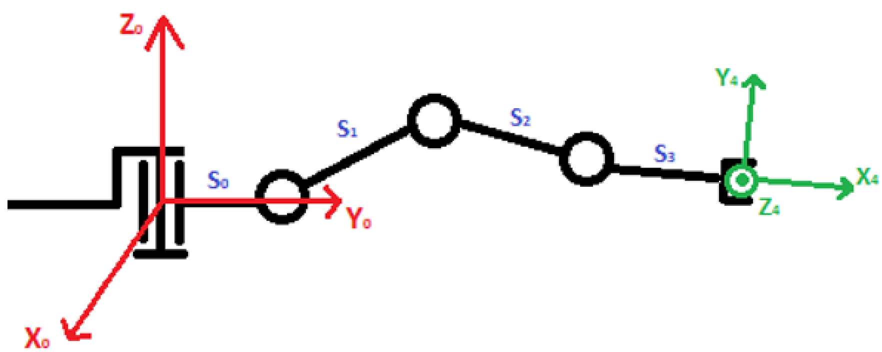

Figure 3: First and Final Catessian cordinate on Finger

Based on the links and joints in the figure 3 shown above, the following DH parameters were found.

Table 1: Denavit–Hartenberg Table

n	$a_{i-1,i}$	$\alpha_{i-1,i}$	S_i	θ_i
1	0	0	0	$^*\theta_1$
2	s_0	$\pi/2$	0	$^*\theta_1$
3	s_1	0	0	$^*\theta_1$
4	s_2	0	0	$^*\theta_1$
5	s_3	0	0	0

When the analysis method is applied, the table is formed as above table 1. After that, we create the transformation matrices, respectively.

Calculated transformation matrices for each row of DH Table

$$
{}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}
$$

$$
{}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & s_0 \\ 0 & 0 & -1 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}
$$

$$
{}^{2}_{3}T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & s_1 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}
$$

$$
{}^{3}_{4}T = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & s_2 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}
$$

$$
{}^{4}_{5}T = \begin{bmatrix} 1 & 0 & 0 & s_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}
$$

$$
{}^{0}_{5}T = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & P_x \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & P_y \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}
$$

Multiplying each tranformation matrix in order for overall tranformation matrix

$$\begin{aligned}\gamma_{11} = &-\cos\theta_4 * (\cos\theta_1 * \sin\theta_2 * \sin\theta_3 - \cos\theta_1 * \cos\theta_2 * \cos\theta_3) \\ &- \sin\theta_4 * (\cos\theta_1 * \cos\theta_2 * \sin\theta_3 + \cos\theta_1 * \cos\theta_3 * \sin\theta_2)\end{aligned} \tag{7}$$

$$\begin{aligned}\gamma_{12} = &\sin\theta_4 * (\cos\theta_1 * \sin\theta_2 * \sin\theta_3 - \cos\theta_1 * \cos\theta_2 * \cos\theta_3) \\ &- \cos\theta_4 * (\cos\theta_1 * \cos\theta_2 * \sin\theta_3 + \cos\theta_1 * \cos\theta_3 * \sin\theta_2)\end{aligned} \tag{8}$$

$$\gamma_{13} = \sin\theta_1 \tag{9}$$

$$\begin{aligned}\gamma_{21} = &-\cos\theta_4 * (\sin\theta_1 * \sin\theta_2 * \sin\theta_3 - \cos\theta_2 \cos\theta_3 * \sin\theta_1) \\ &- \sin\theta_4 * (\cos\theta_2 * \sin\theta_1 * \sin\theta_3 + \cos\theta_3 * \sin\theta_1 * \sin\theta_2)\end{aligned} \tag{10}$$

$$\begin{aligned}\gamma_{22} = &\sin\theta_4 * (\sin\theta_1 * \sin\theta_2 * \sin\theta_3 - \cos\theta_2 * \cos\theta_3 * \sin\theta_1) \\ &- \cos\theta_4 * (\cos\theta_2 * \sin\theta_1 * \sin\theta_3 + \cos\theta_3 * \sin\theta_1 * \sin\theta_2)\end{aligned} \tag{11}$$

$$\gamma_{23} = -\cos\theta_1 \tag{12}$$

$$\begin{aligned}\gamma_{31} = &\cos\theta_4 * (\cos\theta_2 * \sin\theta_3 + \cos\theta_3 * \sin\theta_2) \\ &+ \sin\theta_4 * (\cos\theta_2 * \cos\theta_3 - \sin\theta_2 * \sin\theta_3)\end{aligned} \tag{13}$$

$$\begin{aligned}\gamma_{32} = &\cos\theta_4 * (\cos\theta_2 * \cos\theta_3 - \sin\theta_2 * \sin\theta_3) \\ &- \sin\theta_4 * (\cos\theta_2 * \sin\theta_3 + \cos\theta_3 * \sin\theta_2)\end{aligned} \tag{14}$$

$$\gamma 33 = 0 \tag{15}$$

$$\begin{aligned}P_x = &s_0 * \cos\theta_1 + s_1 * \cos\theta_1 * \cos\theta_2 \\ &+ s_2 * \cos\theta_1 * \cos(\theta_2 + \theta_3) \\ &+ s_3 * \cos\theta_1 * \cos(\theta_2 + \theta_3 + \theta_4)\end{aligned} \tag{16}$$

$$\begin{aligned}P_y = &s_0 * \sin\theta_1 + s_1 * \sin\theta_1 * \cos\theta_2 \\ &+ s_2 * \sin\theta_1 * \cos(\theta_2 + \theta_3) \\ &+ s_3 * \sin\theta_1 * \cos(\theta_2 + \theta_3 + \theta_4)\end{aligned} \tag{17}$$

$$P_z = s_1 * \sin\theta_2 + s_2 * \sin(\theta_2 + \theta_3) + s_3 * \sin(\theta_2 + \theta_3 + \theta_4) \tag{18}$$

The direct task part of the analysis ends here. the inverse task will follow.

3.1.2 Inverse Task

The position of the tip of the robotic finger was found by using the angles in the direct task part. Now the opposite will be done in this section. Angle values will be found for the location of the end effector.

$$\theta_1 = Atan2(\gamma_{13}, -\gamma_{23}) \tag{19}$$

θ_1 have one solution.

$$ {}_1^0T^{-1}\ {}_5^0T = \begin{bmatrix} \gamma_{11}^{(1)} & \gamma_{12}^{(1)} & \gamma_{13}^{(1)} & P_x^{(1)} \\ \gamma_{21}^{(1)} & \gamma_{22}^{(1)} & \gamma_{23}^{(1)} & P_y^{(1)} \\ \gamma_{31}^{(1)} & \gamma_{32}^{(1)} & \gamma_{33}^{(1)} & P_z^{(1)} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{20}$$

$$\gamma_{11}^{(1)} = \cos(\theta_2 + \theta_3 + \theta_4) \tag{21}$$

$$\gamma_{12}^{(1)} = -\sin(\theta_2 + \theta_3 + \theta_4) \tag{22}$$

$$\theta_2 + \theta_3 + \theta_4 = Atan2(-\gamma_{12}^{(1)}, \gamma_{11}^{(1)}) \tag{23}$$

$$s_2 * \cos(\theta_2 + \theta_3) = P_x^{(1)} - s_0 - s_1 * \cos\theta_2 + s_3 * \gamma_{31}^{(1)} = A \tag{24}$$

$$s_2 * \sin(\theta_2 + \theta_3) = P_z^{(1)} + s_1 * \sin\theta_2 + s_3 * \gamma_{32}^{(1)} = B \tag{25}$$

Taking square of equation (24) and (25), then adding them together;

$$\begin{aligned} s_2^2 &= A^2 + 2As_1 * \sin\theta_2 + s_1^2 * \sin(\theta_2)^2 \\ &+ B^2 + 2Bs_1 * \cos\theta_2 + s_1^2 * \cos(\theta_2)^2 \end{aligned} \tag{26}$$

$$C = \frac{s_2^2 - A^2 - B^2 - s_1^2}{2s_1} = A\sqrt{1 - \cos\theta_2} + B * \cos\theta_2 \tag{27}$$

$$A\sqrt{1 - \cos\theta_2} = C - B\cos\theta_2 \tag{28}$$

Taking square of equation (28);

$$0 = (A^2 + 1) * \cos{\theta_2}^2 - 2BC * \cos\theta_2 + \cos(\theta_2)^2 + C^2 - A^2 \tag{29}$$

$$\theta_2 = \arccos\left(\frac{2BC \pm \sqrt{(2BC)^2 - 4(A^2+1)(+C^2 - A^2)}}{2(A^2+1)}\right), \theta_2 \text{ has four answer.} \tag{30}$$

$$
{}^{1}_{2}T^{-1}\,{}^{0}_{1}T^{-1}\,{}^{0}_{5}T = \begin{bmatrix} \gamma_{11}^{(2)} & \gamma_{12}^{(2)} & \gamma_{13}^{(2)} & P_x^{(2)} \\ \gamma_{21}^{(2)} & \gamma_{22}^{(2)} & \gamma_{23}^{(2)} & P_y^{(2)} \\ \gamma_{31}^{(2)} & \gamma_{32}^{(2)} & \gamma_{33}^{(2)} & P_z^{(2)} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{31}
$$

$$
\gamma_{21}^{(2)} = \sin(\theta_3 + \theta_4) \tag{32}
$$

$$
\gamma_{22}^{(2)} = \cos(\theta_3 + \theta_4) \tag{33}
$$

$$
s_2 * \cos\theta_3 = P_x^{(2)} - s_1 - s_3 * \gamma_{21}^{(2)} \tag{34}
$$

$$
s_2 * \sin\theta_3 = P_y^{(2)} - s_3 * \gamma_{22}^{(2)} \tag{35}
$$

$$
\theta_3 = Atan2\left(\frac{P_y^{(2)} - s_3 * \gamma_{22}^{(2)}}{s_2}, \frac{P_x^{(2)} - s_1 - s_3 * \gamma_{21}^{(2)}}{s_2}\right) \tag{36}
$$

for each θ_2 value, θ_3 has one solution.

Use equation (23) to find θ_4.

$$
\theta_4 = Atan2(-\gamma_{12}^{(1)}, \gamma_{11}^{(1)}) - \theta_2 - \theta_3 \tag{37}
$$

for each θ_2 and θ_3 pair, θ_4 has one solution.

3.2 Design

At the stage of micro-size robot design, which is the main purpose of the project, the design of the prosthetic finger was decided. The kinematic joints of the finger are RRRR. During the finger design stage, all the studies designed and produced were examined. The finger consists of 4 interconnected limbs. These limbs move in 4 degrees of freedom and the design has been developed accordingly. During the design phase, the limb lengths were taken from a real finger length. These lengths were accepted as link lengths at the analysis stage. In the design, 1 ground, 3 links and 1 en effector were used. The designs are shown in the figure 4.

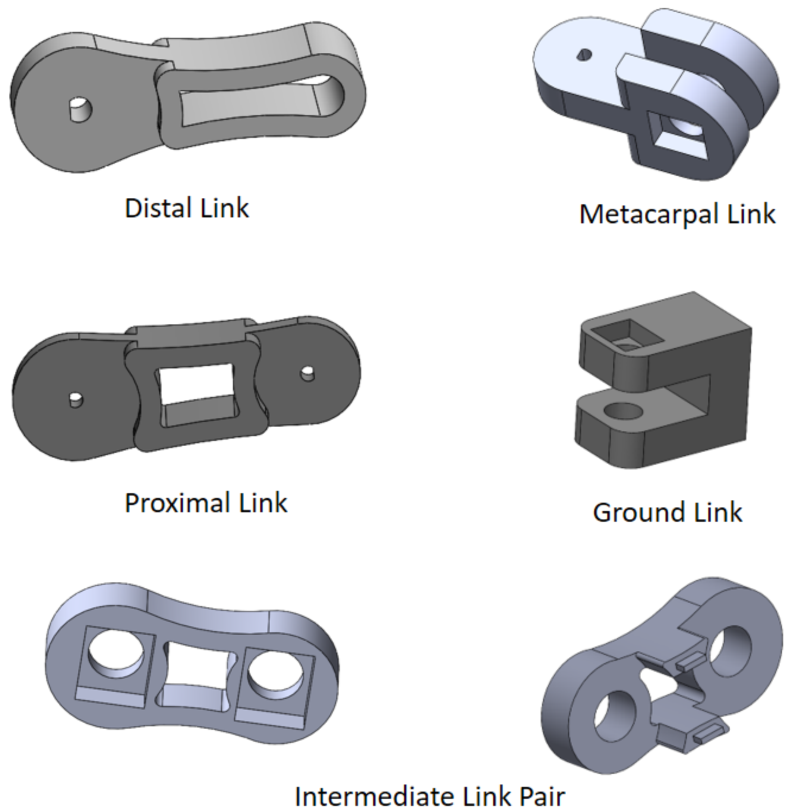

Figure 4: Parts of Links

The figure in which the parts in the top figure 4 are combined is as follows. All connections are made as seen in the bottom figure 5. all connections on the parts are designed to match motor shafts.

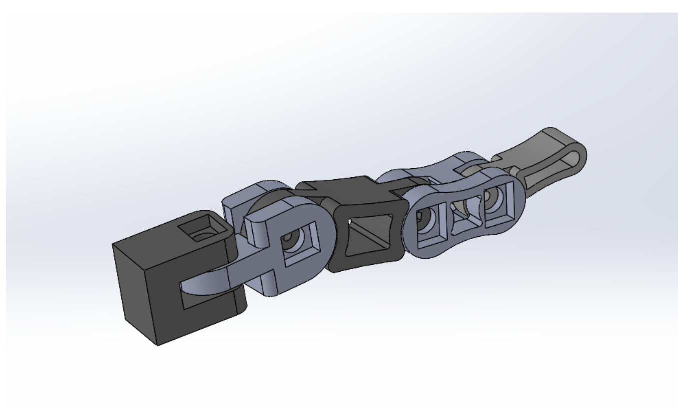

Figure 5: Assembled Prosthetic Finger

3.3 Production

In the design of the prosthetic finger, first of all, motor selection should be given importance. Because the finger is a short human limb. If it is not carefully selected and designed, it may not perform the required task. In the selection, primarily the motor size and torque were examined. Therefore, the motor to be purchased should provide the required torque and should not take up much space.

After the engine selection was completed, the parts drawn using the CAD program were printed with a 3D printer. The fill rates of the parts were printed with a certain fill rate based on strength and lightness. The dimensions required for the perfect fit of the motor shaft were calculated and a certain tolerance was given.

After the printing was finished, the supports on the parts were carefully removed. Then the lengths of the pieces were then measured. Checked for any incompatibility that may occur in the joints. After these processes were verified, the assembly phase was started.

3.3.1 List Of Materials

1. Reducted DC Motor x 4
2. DC Motor Driver x 2
3. Arduino
4. Breadboard
5. Jumper
6. Soldiring Iron
7. Solder
8. Power supply

3.4 Programing

Within the scope of the project, the control was made in the form of on-off. Coding has been made on 4 motors so that each limb of the prosthetic finger can be opened and closed. Considering the human limb and project boundaries, this control style is most appropriate. The required operating ranges for each motor were found and a pwm control was made to operate within those ranges.

3.4.1 Code

```
int motor1pin1 = 10;
int motor1pin2 = 11;

int motor2pin1 = 12;
int motor2pin2 = 13;

int motor3pin1 = 6;
int motor3pin2 = 7;

int motor4pin1 = 4;
int motor4pin2 = 5;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(motor1pin1, OUTPUT);
  pinMode(motor1pin2, OUTPUT);
  pinMode(motor2pin1, OUTPUT);
  pinMode(motor2pin2, OUTPUT);
}

void loop() {
  // put your main code here, to run repeatedly:
  if(Serial.available()){
    char incomingByte = Serial.read();
    if(incomingByte == 'e'){//1
      digitalWrite(motor1pin1, HIGH);
      digitalWrite(motor1pin2, LOW);
      delay(25);
```

```
    } else if (incomingByte == 'd'){
      digitalWrite(motor1pin1, LOW);
      digitalWrite(motor1pin2, HIGH);
      delay(25);
    } else if (incomingByte == 'r'){//2
      digitalWrite(motor2pin1, HIGH);
      digitalWrite(motor2pin2, LOW);
      delay(25);
    } else if (incomingByte == 'f'){
      digitalWrite(motor2pin1, LOW);
      digitalWrite(motor2pin2, HIGH);
      delay(25);
    } else if (incomingByte == 't'){//3
      digitalWrite(motor3pin1, HIGH);
      digitalWrite(motor3pin2, LOW);
      delay(25);
    } else if (incomingByte == 'g'){
      digitalWrite(motor3pin1, LOW);
      digitalWrite(motor3pin2, HIGH);
      delay(25);
    } else if (incomingByte == 'y'){//4
      digitalWrite(motor4pin1, HIGH);
      digitalWrite(motor4pin2, LOW);
      delay(25);
    } else if (incomingByte == 'h'){
      digitalWrite(motor4pin1, LOW);
      digitalWrite(motor4pin2, HIGH);
      delay(25);
    }
  } else {
    digitalWrite(motor1pin1, LOW);
    digitalWrite(motor1pin2, LOW);
    digitalWrite(motor2pin1, LOW);
    digitalWrite(motor2pin2, LOW);
    digitalWrite(motor3pin1, LOW);
    digitalWrite(motor3pin2, LOW);
    digitalWrite(motor4pin1, LOW);
    digitalWrite(motor4pin2, LOW);
  }
  delay(100);
}
```

4 Discussion

The human body has a wonderful structure. designing a robot to fit this structure can naturally be seen as a challenge. Although designing a small robot increases the difficulty, it does not mean that it is impossible. After the analysis, the most problematic part of our design was the design. because designing a robot compared to a real human finger limited us in terms of equipment. Choosing the connecting parts of the robotic finger and the motor that can move this finger was one of the points we focused on finding a place to place it. In general, we carried out our design within the scope of the project without any problems.

References

[1] J. Denavit and R. S. Hartenberg, “A kinematic notation for lower-pair mechanisms based on matrices,” 1955.

[2] R. Hartenburg, J. Denavit, and F. Freudenstein, “Kinematic synthesis of linkages,” *Journal of Applied Mechanics*, vol. 32, no. 2, p. 477, 1965.

[3] E. Gezgin, *Biokinematic analysis of human body.* Izmir Institute of Technology (Turkey), 2011.

[4] J. J. Craig, *Introduction to robotics: mechanics and control.* Pearson Educacion, 2005.

[5] wikipedia, “Denavit–hartenberg parameters,” last edited on 24 October 2022, at 23:21 (UTC), last accessed 21 December 2022. [Online]. Available: https://en.wikipedia.org/wiki/DenavitHartenberg_parameters