Simulation of Robot Arm for Diabetes Mellitus Patients

Subekti\textsuperscript{1}, Aan Budi Setiawan\textsuperscript{2}, and Abdul Hammid\textsuperscript{1}
\textsuperscript{1}Mechanical Engineering Vibration Laboratory, Universitas Mercu Buana, Meruya Selatan, Kembangan, Jakarta Barat, 11650, Indonesia
\textsuperscript{2}Student of Mechanical Engineering Vibration Laboratory, Universitas Mercu Buana, Meruya Selatan, Kembangan, Jakarta Barat, 11650, Indonesia

Abstract. Diabetes is caused by metabolic disorders. The treatment is to control blood sugar levels which can be done with non-pharmacological therapy, namely reflexology. The intensity of therapy continuously carried out will speed up the healing process of diabetes. On this basis, we simulated a robotic arm for reflexology treatment for diabetics. The robotic arm system used was five degree of freedom, which used 5 servo motors in the design. The simulation results show that $\sigma_{\text{material}} \geq \sigma_{\text{structure}}$, so it can be concluded that the material used is rigid and strong to withstand the loads acting on the robot arm structure. While the magnitude of M1 servo motor torque is 2502 Nmm, M2 is 7492 Nmm, M3 is 7492 Nmm, M4 is 6934 Nmm and M5 is 4351 Nmm. In designing the robot arm, 1,2,3,4 servo motors used 8000 Nmm of torque, and 5 servo motors used 4500 Nmm of torque, so the servo motor used was safe to hold the torque on the robot arm.

1. Introduction
Diabetes mellitus (DM) is a chronic metabolic disorder caused by the pancreas not producing enough insulin or the body cannot use the insulin produced effectively, and in Indonesia, this disease is more commonly called sugar disease \cite{1}. Efforts to handle diabetes mellitus must be done properly, one of the treatments for this disease is to regulate blood sugar levels within normal limits. According to Apriyanti \cite{2}, controlling blood sugar levels is the best way that can be done to avoid complications in people with diabetes mellitus. Blood sugar level control can be done in various ways, including pharmacological therapy and non-pharmacological therapy \cite{3}. Pharmacological therapy is done by giving medicines to patients with diabetes mellitus. It could be by insulin therapy or oral hypoglycaemic drug therapy, or a combination of both. While non-pharmacological therapy is with treatment without drugs. One of them is reflexology, according to Kamaluddin (2010), non-pharmacological therapy is considered to have fewer side effects and more economical \cite{4}.

According to a study conducted by Robiul (2014), there were significant differences between blood sugar levels before and after reflection \cite{5}. His results showed the median blood sugar after reflection was 150.50 mg/dl and before reflection was 181 mg/dl. While the average blood glucose level of patients with DM before reflexology was 199.76 mg/dl while in the control group was 183.18 mg/dl \cite{6}. The average blood glucose level of patients with DM after reflexology is 159.14 mg/dl while in the control group was 170.43 mg/dl. In addition to lowering blood sugar levels, according to McRitchie (2013), reflexology can improve respiratory function, improve blood circulation, reduce tingling, and reduce stress in diabetes mellitus \cite{7}.
The key success of reflexology is the intensity of therapy carried out continuously [8]. But the limited time and a limited number of therapists who are able to do foot therapy cause the routine exercise of the patient becoming hampered. To allow people with diabetes to do foot therapy without a therapist, it is necessary to provide tools so that people with diabetes can still practice wherever and whenever without dependence on the therapist’s schedule. This can increase the recovery ratio for diabetics. Based on the above considerations, technology foot reflection is needed. One of the technologies used in the treatment of diabetes is robotic technology. Interactive, high-intensity and repetitive foot therapy robots can perform foot therapy without a therapist. The existence of this robot makes the budget for therapists trimmed. Robot therapy will overcome the problem of lack of therapists for people with diabetes.

A robot is a multi-function manipulator that can be programmed to do certain tasks. In general, there are only two types of robots, namely robots that move, and robots that do not move (robot arm). Their use depends on the needs. The robot arm has a working principle adopted from the human arm. The components in the robot arm consist of three parts, namely, mechanical construction, actuator, and control system. The mechanical structure of the robot is very important in building a robot arm. According to Buchori (2019), designing a robot not only illustrates it but also calculates the mechanical strength of the robot arm structure [9]. To obtain quality and balanced mechanical structure, the calculation of each component must be accurate. Based on the movement of robots, Adriansyah (2013) implements communication on multi-robot systems using Bluetooth technology [10].

In this study, we will do a dynamic simulation that produces the material stress and torque of the servo motor needed by the robot arm. The results of the calculation of this robot arm can be used as a reference for selecting the material needed by the robot arm. In order to obtain high-accuracy analysis, we use Solid works 2018 software, considering that this software has been equipped with a finite element analysis program that allows users to analyse their design results. The author will conduct material simulations and servo motors used on robotic arms to carry out reflexology treatment for diabetics.

2. LITERATURE REVIEW
Manipulators are a mechanical structure consisting of several rigid bodies (links) see in Figure 1, which are connected with joints. To determine the thickness of the robot arm material structure and the servo motor used, it is very important to do the calculation at the beginning. This calculation is done to find the minimum value needed by the material structure and servo motor, which aims to enable the robot arm to withstand the loads acting on the robot arm [11]. The specifications of motor 1 and motor 2 can be calculated using the equation as below [12]:

\[ T_1 = W_1L_1 + W_2L_2 + W_3L_3 + W_4L_4 \] (1)
\[ T_2 = W_3L_5 + W_4L_6 \] (2)

Information:
- \( T \): Torque (Nmm)
- \( W \): Weight (N)
- \( L \): Length (mm)

The selection of motor specifications is determined by the amount of torque that occurs in the mechanical structure of the robot arm [13].

\[ T_{motor} \geq T_{structure} \] (3)

The required robotic arm structure thickness can be calculated using the equation below:

\[ \sigma_{mat} = \frac{M}{Z} \] (4)

Information:
- \( \sigma_{mat} \): Material permit voltage \( (N/mm^2) \)
- \( M \): Bending moment \( (Nmm) \)
- \( Z \): Cross section modulus \( (mm^3) \)

In the case of calculating the robot arm structure, bending moments that occur in the robot arm structure is equal to the rate of torque that occurs in the robot arm. So that it can also be written as:

\[ T = M \] (5)

Material is declared safe with conditions [14].

\[ \sigma_{material} \geq \sigma_{struktur} \] (6)
3. MATERIALS AND METHOD

In designing robot arms, we need to use materials that are cheap and have good strength. This also applies to the servo motor that was used. S45C material is medium carbon steel which has a carbon content of 0.3% - 0.5%, so it has excellent workmanship and strength properties [15]. The thickness of the material used in this study was 3 mm and the safety factor were 1.2. To find out the properties of S45C material see Table 1.

Table 1. Material Properties S45C

| Index          | Unit  |
|----------------|-------|
| Yields strength| $3.43 \times 10^8$ N/m² |
| Tensile strength| $5.69 \times 10^8$ N/m² |
| Allowable stress| $2.86 \times 10^8$ N/m² |
| Thickness      | 3 mm  |

Source: (Aida, 2017)

In this paper, the author used a servo motor as the most important component in the robot arm. The servo motor has a function to move the joint and base arm of the robot arm. The selection of servo motors was strongly influenced by the torque that occurred in the robot arm structure caused by the weight of the robot arm components as well as the forces acting on the robot arm. Servo motor specifications used in the study can be seen in Tables 2 and 3. The robot arm is designed with the same function as the human arm. The end effector is designed to resemble a pressure device commonly used by therapists to perform reflexology on the feet, which is commonly used for the treatment of diabetics.

Table 2. Specifications for servo motors 1-4

| Description | Unit   |
|-------------|--------|
| Torque      | 8000 Nmm |
| Power       | 6.5V~13V |

Source: (Feetech, 2019)

In terms of the robot arm structure, the arm length has been adjusted to the area of the foot. Thus, all the reflection points on the soles of the feet can be reached using this robot arm. In addition, this robot is designed with attention to its aesthetics and beauty. The parts on the robot arm can be seen in Figure 2. The robotic arm components can be seen in Table 4. In general, the element method was used to run the simulation, so that the material voltage could be obtained. The robot arm design that had been completed was then simulated. First, the robot arm components were given gravitational force. Giving gravity was intended so that each component of the robot arm had gravity. Then, second, we added a motor to each robot arm connection. This motor drove all robot arm components during the simulation. The servo motor movement on the robot arm was limited to 180°. Next, we added a normal force that
was perpendicular to the pressure component, which was 25N. This style resulted from the action-reaction that arose between the suppressor component and the sole of the foot.

Table 3. Specifications for servo motors 5

| Description | Unit          |
|-------------|---------------|
| Torque      | 4500 Nmm      |
| Power       | 6.0–7.4 V     |

Source: (Hsservo, 2019)

The third step, we selected the components to be simulated by selecting the von Mises or deformation results. This step was to determine the value of the voltage that occurred in the robot arm component. Finally, we displayed the simulation results of the torque that occurred in each servo motor, resulting from the loads that had been added to the previous steps. For more details, the simulation of the robot arm can be seen in Figure 3.

Table 4. Description of robot arm components

| NO | Description                  | Remark                  |
|----|------------------------------|-------------------------|
| 4a | Shoulder-arm 1a              | Shouldering-2a          |
| 1b | Shoulder-arm 2b              | Arm 2b                  |
| 2a | Arm 2a                       | Arm 3a                  |
| 2b | Arm 2b                       | Arm 3b                  |
| 3a | Arm 3a                       | Arm support end effector|
| 3b | Arm 3b                       |                         |
| 4  | Arm support end effector     |                         |
| M1 | Servo motor 1               |                         |
| M2 | Servo motor 2               |                         |
| M3 | Servo motor 3               |                         |
| M4 | Servo motor 4               |                         |
| M5 | Servo motor 5               |                         |

4. RESULTS AND DISCUSSION

Motion Analysis Results

The simulation results of motion analysis on structures 1a and 1b based on Von Mises showed in Figure 5 (a) show that the maximum stress that occurred in the structure was $2.777 \times 10^7$ N/m$^2$ & $1.698 \times 10^7$ N/m$^2$. The lowest voltage was $8.156 \times 10^3$ N / m$^2$. The simulation results of motion analysis on structures 2a and 2b based on Von Mises showed in Figure 5(b) show that the maximum stress that occurred in structures 2a and 2b was $2.568 \times 10^4$ N/m$^2$ & $2.342 \times 10^4$ N/m$^2$. The lowest voltage was $1.464 \times 10^4$ N/m$^2$. The simulation result of motion analysis on structures 3a and 3b based on Von Mises
showed in Figure 6 (a) indicate that the maximum stress that occurred in structures 3a and 3b was 5.38 \times 10^7 \text{ N/m}^2 and 3.698 \times 10^7 \text{ N/m}^2. The lowest voltage was 2.023 \times 10^3 \text{ N/m}^2.

The motion analysis simulation on structure 4 based on the Von Mises shown in Figure 6 (b) shows that the maximum stress that occurred in structure 4 was 1.033 \times 10^6 \text{ N/m}^2. The lowest voltage was 6.7 \times 10^3 \text{ N/m}^2. Referring to equation (5), a structure is declared safe if the \( \sigma_{\text{material}} \geq \sigma_{\text{structure}} \). The simulation results above show that the highest stress occurred in structure 2b was 2.342 \times 10^4 \text{ N/m}^2. The material used in this design was S45C with a thickness of 3mm, and the permitted voltage was 2.86 \text{ N/m}^2. Based on the above equation, we can conclude that the S45C material with a thickness of 3 mm is safe to withstand the loads acting on the robot arm structure.

**Motor Torque Analysis**

Figure 7 (a) shows a graph showing the need for an M1 servo motor. The graph shows that the torque value was 2504 Nmm. Figure 7 (b) shows a graph showing the need for M2 & M3 servo motors. From the graph, we can know that the torque value was 14983 Nmm, because the servo motors used were 2, the torque could be divided by 2, each M2 servo motor and M3 receive a 7492 Nmm torque load.

Figure 8 (a) shows a graph indicating the need for an M4 servo motor. From the graph, we identify that the torque value was 6934 Nmm. From the calculation of the torque as presented above, the highest torque was found on 2 & 3 servo motors, which was 7492 Nmm. Referring to equation (2), the servo motor is declared safe if the \( \sigma_{\text{material}} \geq \sigma_{\text{structure}} \). The torque of the servo motor used was 8000 Nmm, while the 5 servo motor had a torque of 4351 Nmm, the servo motor capacity used was 4500 Nmm, it can be concluded that the two motors servo used could withstand the loads acting on the robot arm structure. Figure 8 (b) shows a graph showing the need for an M5 servo motor. The graph shows a torque value of 4351 Nmm.
CONCLUSION

From the above analysis, we could obtain the following results:

1. The material voltage of each robot arm structure was Table 5.

| No | Component | The highest voltage N/m² | The lowest voltage N/m² |
|----|------------|--------------------------|-------------------------|
| 1  | Structure 1a | 2.777 x 10⁷            | 8.156 x 10³              |
| 2  | Structure 1b | 1.698 x 10⁷            | 8.156 x 10³              |
| 3  | Structure 2a | 2.568 x 10⁴            | 1.464 x 10⁴              |
| 4  | Structure 2b | 2.342 x 10⁶            | 1.464 x 10⁴              |
| 5  | Structure 3a | 5.38 x 10⁷             | 2.023 x 10⁴              |
| 6  | Structure 3b | 3.698 x 10⁷            | 2.023 x 10⁴              |
| 7  | Structure 4  | 1.033 x 10⁸            | 6.7 x 10³                |

From the simulation, we identify that the highest voltage was in the 2b structure with material stress of 2.342 x 10⁶ N/m², the material used was S45C with Allowable stress of 2.86 x 10⁸ N/m². By referring to equation (6) we can conclude that the material used by the robot arm was safe to accept the load on the robot arm.

Figure 6. Motor torque requirement
The torque that occurred in each servo motor was Table 6.

Table 6. Simulation results of Torque

| No | Component | The Highest torque (Nmm) |
|----|-----------|--------------------------|
| 1  | Motor 1   | 2502                     |
| 2  | Motor 2   | 7492                     |
| 3  | Motor 3   | 7492                     |
| 4  | Motor 4   | 6934                     |
| 5  | Motor 5   | 4351                     |

From the simulation results from 1 servo motor to 4 servo motor, it was found that the highest torque occurred in 2 & 3 servo motors with the torque of 7492 Nmm. The specification of the servo motor used was 8000 Nmm. While the 5 servo motor has a torque of 4351 Nmm, the servo motor used has 4500 Nmm of torque. Referring to equation (2) the 1, 2, 3, 4, 5 servo motor is declared safe to hold the load and move the robot arm.

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