# Modeling and Control of Humanoid Arm for Assisting Humans with Tremor

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***Abstract*—Various diseases and ageing problems cause humans to tremor. This can make day-to-day life more tedious for those affected by tremors. This article proposes a customised Poppy humanoid right arm with a gripper that can help the elderly by pouring them water, fetching them objects, and helping them grasp fragile items in a safer manner. The design is created in SOLIDWORKS, and a circuit diagram is designed in Fritzing for control of the arm. Subsequently, the kinematics are derived, both forward and inverse, and joint-space trajectory planning is performed for trajectory creation. Lastly, simulations are carried out in MATLAB's Simscape, and the results show the effectiveness of the proposed arm.**

***Index Terms*—Service robot, humanoid arm, gripper**

## I. Introduction

In the recent years, applications of robotics had a great impact on rehabilitation engineering. Prosthetic limbs changed the lives of many individuals affected by wars, diseases and accidents. Researchers introduced different robotic technologies to achieve agents that assist humans. The rehabilitative and assistive technologies contributed in increasing the quality lives of many disabled and elderly individuals. To accomplish this, robotic limbs are designed, modelled, built and controlled using different approaches. The process of implementing a robotic limb goes through defining the type of robot, the number of degrees of freedom required, the type of end-effector, the trajectory needed, and the kinematics and dynamics studies of the limb.

In this work, a 4-DOF humanoid right arm for assisting humans with tremor is proposed. The end-effector of this robotics arm is a custom gripper embedded with a sensor to hold any object without breaking it, as shown in Figure 1.

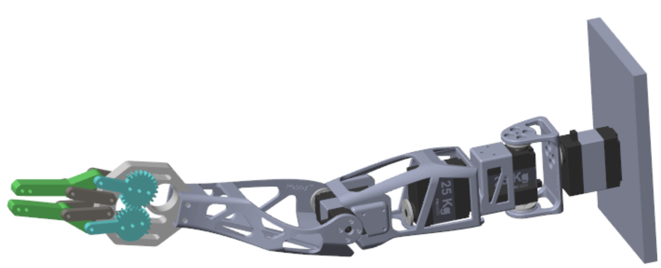

Fig. 1: Modified Poppy Humanoid right arm

It is safe to say that robots play an important role in improving human life. Thus, a modified Poppy humanoid right arm is proposed to help people with tremors by handling objects for them, easing their everyday life as well as making it safer for them by handling fragile objects in a stable manner. The modified design is imported into Simscape Multibody for simulation and analysis before manufacturing. The design is then 3D printed, and the needed components are acquired for assembly. The gripper works with widely available servo motors such as the MG995. Due to its lightweight and compact structure, the end effector allows the arm to carry up to 750 grams.

The rest of this paper is divided as follows: In Section II, we discuss previous work in the field of service robotic agents. Section III will highlight our proposal, its goal, and the workflow required to achieve that goal. Section IV will contain the hardware components required as well as a circuit diagram for the control of the robot. Section V will dive into the assignment of the robot arm's frames as well as derive the arm's forward kinematics using the DH convention as well as the inverse kinematics using the Newton-Raphson method. Subsequently, Section VI talks about trajectory planning and displays the simulation as well as the hardware results. Lastly, Section VII briefly summarises our work, discusses its limitations, and suggests recommended future work.

## II. Literature Review

Robot-assisted therapy is widely applied for patients suffering from old age, detrimental diseases, or stroke.

In [1], Borboni et al. proposed a robotic approach to the rehabilitation of the hands of patients that suffer from residual injuries resulting from a stroke. A stroke can cause a partial destruction of tissues in the brain, with consequential inhibition and degradation of neural and sensorimotor functions. A glove, a flexible transmission on a flexible bar, and an actuation system comprise a device. The actuation system is designed to move five fingers separately. The system was created to allow patients to continue rehabilitation even in the absence of a therapist.

Agoggeri et al. [2] made a comparison between the end-effector robots and exoskeletons in terms of mechanical design, usability, which includes setup, lightness, and more factors, and the training paradigms for hand rehabilitation of patients suffering from the aftermath of a stroke. The end-effector robots proved superior to exoskeletons in terms of flexibility. However, they suffer from the lack of control of distal joints and aspects of object manipulation, unlike exoskeletons.

Wang et al. [3] designed and fabricated the Eagle Shoal, a tactile-sensing dexterous hand for domestic service robot applications. This hand consists of a palm and three actuated fingers equipped with tactile sensors, motors, and control boards. The palm and each finger have 2-DOF. The hand was mainly designed to aid research in the field of rehabilitation, but it will be used in the future for robotic manipulation research.

Portugal et al. [4] addressed the implementation and application of a service robot platform for interaction with elderly people. The aim was to provide motivation for the elderly to remain active and boost their psychological well-being. These mobile robots are equipped with sensors, a touch screen, a full HD camera, and speakers for communication. Face detection and recognition were implemented to reduce the elderly's fear of speaking to a robot in order for the robot to perform live.

Nadas et al. [5] designed and implemented a dual-axis exoskeleton for upper-limb rehabilitation. The main goal is to allow stroke patients to regain postural and motion control of the upper limb. The exoskeleton is attached to the upper limbs and allows the rehabilitation of the damaged side using the healthy side by mirroring the motion of the healthy one. Forward kinematics were derived, and passive-mirror physiotherapy was utilized.

## III. Proposed Agent

The proposed service agent is a humanoid right arm with a gripper end effector embedded with a sensor that allows it to hold different objects without breaking them. The purpose of the arm is to pour water into a cup and then proceed to water the person of interest, as shown in Figure 2. This is mainly to help elderly people where tremors and shaky hands are common, to help them with their day-to-day life and keep them safe from fragile glasses that may fall out of their hands.

Fig. 2: A robotic arm holding a bottle of water [6]

The proposed robotic arm consists of 5 main parts which are shoulder, upper arm, arm connector, forearm, and the gripper as an end effector. In addition, we will use 4 servo motors (10Kg.cm), one motor for each joint, and an additional servo motor (MG90) for the gripper. We will use Arduino Uno as our microcontroller, and a power supply of 5V-10A to provide the suitable current for each motor.

The workflow for achieving this goal is as follows:

- Create/source a design in SOLIDWORKS for a humanoid arm and a gripper.
- Simulate the humanoid arm in Simscape Multibody to test that it works properly.
- Purchase the required components and manufacture the humanoid arm.
- Assemble the components.
- Write code to control the arm as required.

## IV. Hardware Design and Implementation

In order to build the hardware, certain components are required, as well as a circuit diagram for the control of the system.

### A. Hardware Components

Table I shows the required components.

TABLE I: Hardware Components Table

| Name | Location | Number | Price |
|---|---|---|---|
| Servo Motor (10Kg.cm) | Future Electronics | 4 | 550 |
| Servo Motor (MG90S) | Free Electronics | 1 | 90 |
| Power Supply (5V, 10A) | Free Electronics | 1 | 100 |
| Arduino Uno | Free Electronics | 1 | 360 |
| FSR | Future Electronics | 1 | 160 |

Figure 3 shows the designed gripper for the humanoid right arm end effector. The gripper is an essential component of the arm, as this is the end effector that will be responsible for holding the objects. The gripper can be cut out of acrylic sheets or 3D printed. Both options will provide a lightweight yet sturdy gripper that can carry a recognisable amount of weight without failing.

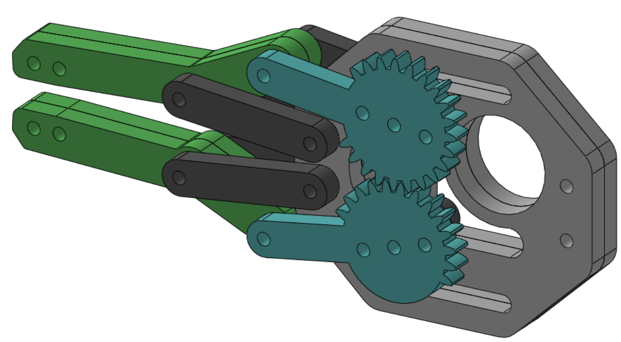

Fig. 3: Gripper Design

### B. Circuit Diagram

Figure 4 shows the required circuit for control of the humanoid right arm, including the five servos, power supply, and Arduino microcontroller.

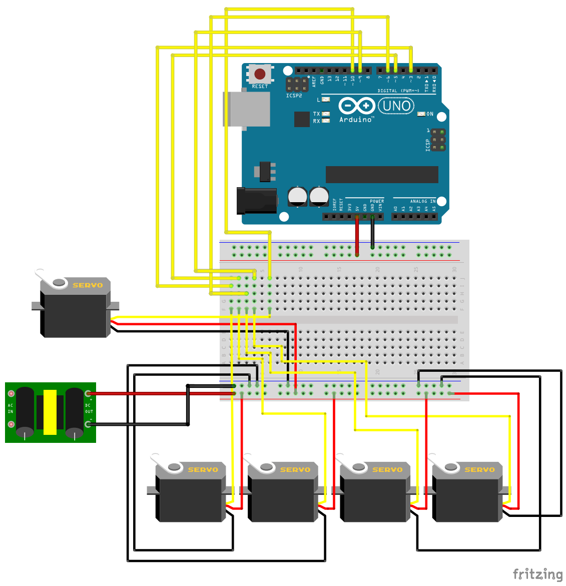


Fig. 4: Humanoid Arm Circuit

### C. Hardware

Figure 5 and Figure 6 show the manufactured arm, fixed to a base, with the circuitry required to operate it.

## V. Robot Kinematics

### A. Robot's Frame Assignment

In order to facilitate the analysis of the robot, several frames of reference are established on the robot's arm, as shown in Figure 7. The frames employ a reference from which

Fig. 5: Finalized Hardware

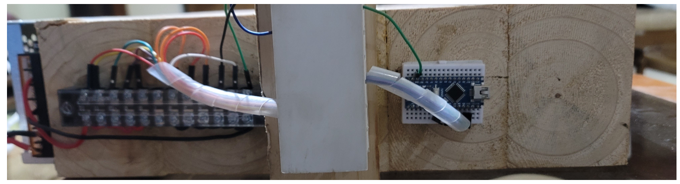

Fig. 6: System Circuitry

TABLE II: DH-Parameters Table

| $i$ | $\theta_i$ | $d$ | $a_i$ | $\alpha_i$ |
|---|---|---|---|---|
| 1 | $q_1 + \pi/2$ | $l_1$ | 0 | $\pi/2$ |
| 2 | $q_2$ | 0 | 0 | $-\pi/2$ |
| 3 | $q_3 + \pi/2$ | $l_2 + l_3$ | 0 | $\pi/2$ |
| 4 | $q_4 + \pi/2$ | 0 | $l_4$ | 0 |

dimensions and angles can be taken consistently. The frames are assigned in a way such that the DH convention can be used to derive the forward kinematics.

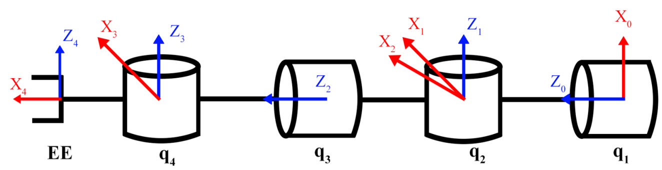


Fig. 7: Frame assignment

### B. DH Convention

The forward kinematics problem states that given the actuated joint angles/lengths, calculate the resulting Cartesian position of the end effector's point of action. The DH convention was used to get the transformation matrix from the base frame to the end effector frame. The kinematics of the forward position can then be determined. The DH table is filled as shown in Table II.

The transformation matrix can then be represented as:

$$T_f =^0 T_1.^1T_2.^2T_3.^3T_4 \tag{1}$$

where

$$^0T_1 = \begin{bmatrix} C(q_1) & -S(q_1)C(\alpha_1) & S(q_1)S(\alpha_1) & a_1C(q_1) \\ S(q_1) & C(q_1)C(\alpha_1) & -C(q_1)S(\alpha_1)) & a_1S(q_1) \\ 0 & S(\alpha_1) & C(\alpha_1) & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$^1T_2 = \begin{bmatrix} C(q_2) & -S(q_2)C(\alpha_2) & S(q_2)S(\alpha_2) & a_2C(q_2) \\ S(q_2) & C(q_2)C(\alpha_2) & -C(q_2)S(\alpha_2)) & a_2S(q_2) \\ 0 & S(\alpha_2) & C(\alpha_2) & d2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$^2T_3 = \begin{bmatrix} C(q_3) & -S(q_3)C(\alpha_3) & S(q_3)S(\alpha_3) & a_3C(q_3) \\ S(q_3) & C(q_3)C(\alpha_3) & -C(q_3)S(\alpha_3)) & a_3S(q_3) \\ 0 & S(\alpha_3) & C(\alpha_3) & d3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$
{}^{3}T_4 = \begin{bmatrix} C(q_4) & -S(q_4)C(\alpha_4) & S(q_4)S(\alpha_4) & a_4C(q_4) \\ S(q_4) & C(q_4)C(\alpha_4) & -C(q_4)S(\alpha_4)) & a_4S(q_4) \\ 0 & S(\alpha_4) & C(\alpha_4) & d4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}
$$

where $S$ and $C$ represent the sine and cosine functions, respectively.

### C. Inverse Kinematics

The inverse kinematics problem states that, given the Cartesian position of the end effector's point of action, calculate the actuated joint angles/lengths. In order to compute the inverse kinematics of the arm, the Newton-Raphson numerical method is utilized, which is given as:

$$
q_{n+1} = q_n - \frac{\partial F}{\partial q}^{-1} .F(q_n) \tag{6}
$$

where $q_{n+1}$ is a matrix containing the calculated joint angles, $q_n$ is a matrix containing the angles from the previous iteration, $\frac{\partial F}{\partial q}^{-1}$ is the inverse Jacobian matrix, calculated using the forward kinematics, and $F(q_n)$ are the functions for X, Y, and Z from the DH convention evaluated at each iteration. This numerical method works by iteratively evaluating the function and its derivative (slope) to get a new solution to re-evaluate the function. For accuracy, the method was iterated as many times as required such that the error between the desired and actual end effector positions is less than $10^{-3}$ meters.

The Jacobian was calculated inside of MATLAB symbolically by taking the partial derivative of the end effector's X, Y, and Z equations with each joint angle, resulting in a $3 \times 4$ matrix.

## VI. Simulation

### A. Trajectory Planning

The following cubic polynomial was developed for the robot's trajectory and is represented as:

$$
q = C_0 + C_1t + C_2t^2 + C_3t^3 \tag{7}
$$

where $q$ is the joint angles, $t$ is the time, and $C_0$, $C_1$, $C_2$, and $C_3$ are the polynomial coefficients that are calculated using the initial conditions for position and velocity.

In order to better visualise the trajectory, Figure 8 displays on of the planned trajectories for the arm from the initial position that should pick up a water bottle and then pour it into a cup.

### B. Results

The robotic arm was simulated in Simscape Multibody and given several joint-space-based trajectories to follow All trajectories were tested both on Simscape and the hardware.

Figure 9, Figure 10, and Figure 11 show the position of the end effector in the X, Y, and Z axes. The system near-perfectly tracks the desired joint angles. Because there are no modelled dynamics, this behaviour is to be expected. The deviation between the signals can be attributed to the model

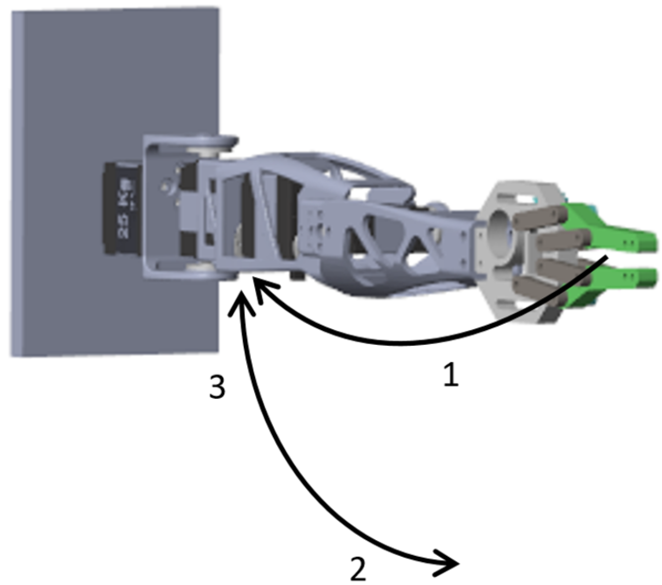


Fig. 8: Planned trajectory for pouring water into a cup

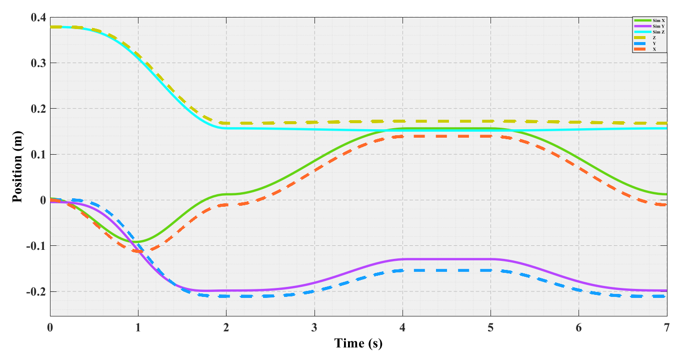


Fig. 9: Comparison between Simscape and the derived model for end effector position for the water pouring trajectory

developed. The model does not account for any part thickness and assumes that all links and joints lie on the same plane. However, this is not true for actual hardware. Additionally, the joint angles are a crucial limiting factor, as these are limited by the hardware. A collision between the arm components would be catastrophic and result in failure.

## VII. Conclusions and Future Recommendations

In this report, a 4-DOF customised Poppy humanoid arm is proposed to aid humans with tremors. The components required are highlighted, and a circuit diagram displays the wiring for the system. The designed gripper is introduced and briefly discussed for its advantages. The forward and inverse kinematics are derived using the DH convention and the Newton-Raphson numerical method. The arm is simulated in MATLAB's Simscape Multibody, and trajectories are created using cubic polynomials. Lastly, simulation and hardware

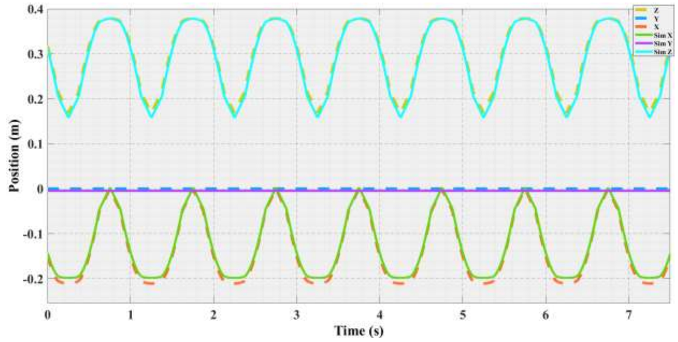


Fig. 10: Comparison between Simscape and the derived model for end effector position for a sinusoidal trajectory

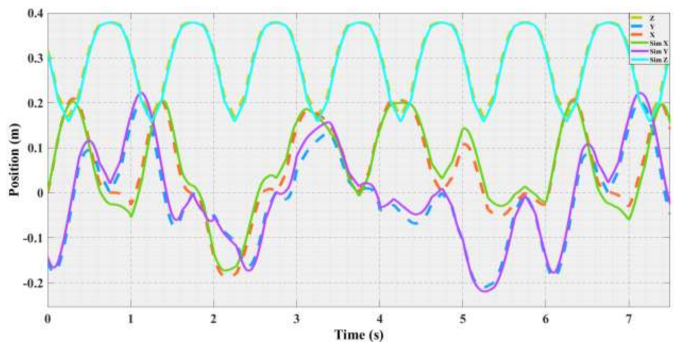


Fig. 11: Comparison between Simscape and the derived model for end effector position for a random trajectory

testing show that the proposed arm is fully functional and can perform several trajectories to accomplish its task.

There were several limitations to this work. The motors used were servo motors, which can only rotate about 180 degrees. This severely limited the workspace of the arm, as some joints should be able to rotate freely. Additionally, this work was only concerned with the kinematics of the arm. This may be sufficient, but in order to improve the system's performance and safety, dynamics must be considered. This can also help reduce the cost of the motors, as appropriate torque motors can be purchased for each joint. For future work, it is recommended to use different motors, such as continuous servos or stepper motors. Additionally, manufacturing the arm using sturdier material is advised, as it can improve the rigidity of the arm and allow it to carry larger and heavier objects.

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## VIII. Appendix

Watch a video of the robot arm hardware performing the water pouring trajectory by scanning this QR code: