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Dynamic Model Of Anthropomorphic Robotics Finger Mechanisms

Abdul Haseeb Zaidy,[1] Mohd. Rehan,[2] Abdul Quadir,[3] Mohd. Parvez[4]
[1234]*Mechanical Engg. Department,AFSET Dhauj Faridabad, India*

Abstract: *Research on Dynamic Model of Anthropomorphic Robotics Finger Mechanisms (ARFM) is being carried out to accommodate a variety of tasks such as grasping and manipulation of objects in the field of industrial applications, service robots, and rehabilitation robots. The first step after kinematic modeling in realizing a fully functional of anthropomorphic robotics Finger mechanisms is dynamic modeling. In this paper, a dynamic Model of Anthropomorphic robotics Finger mechanism is proposed based on the biological equivalent of human hand where each links interconnect at the metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints respectively. The Lagrangian method was used to derive the dynamics for the proposed of Mathematical Model of Anthropomorphic robotics Finger mechanisms.*

Keywords: *Anthropomorphic robot Finger, Modeling, Robotics, Simulation.*

I. Introduction

Among the vast applications of robotics, robotic assistance in human daily life and has been the major factor that contributes to its development. The focus on the anthropomorphism robotic limbs is currently undergoing a very rapid development. The creation of a multifingered anthropomorphic robotic hand is a challenge that demands innovative integration of mechanical, electronics, control and embedded software designs.

II. Literature Review

The normal human hand has a set of hand which includes palm and fingers. There are five fingers in each hand, where each finger has three different phalanxes: Proximal, Middle and Distal Phalanxes. These three phalanxes are separated by two joints, called the Interphalangeal joints (IP joints). The IP joints function like hinges for bending and straightening the fingers and the thumb. The IP joint closest to the palm is called the Metacarpals joint (MCP). Next to the MCP joint is the Proximal IP joint (PIP) which is in between the Proximal and Middle Phalanx of a finger. The joint at the end of the finger is called the Distal IP joint (DIP). Both PIP and DIP joints have one Degree of Freedom (DOF) owing to rotational movement [1]. The thumb is a complex physical structure among the fingers and only has one IP joint between the two thumb phalanxes. Except for the thumb, the other four fingers (index, middle, ring and pinky) have similar structures in terms of kinematics and dynamics features. Average range of motion among the four fingers for flexion-extension movement is 650 at the DIP joint, 1000 at the PIP joint and 800 at the MCP joint while the abduction-adduction angles for the index finger has been measured as 200 at the MCP joint[1,2]. Figure 1 illustrates the structure of a human finger.

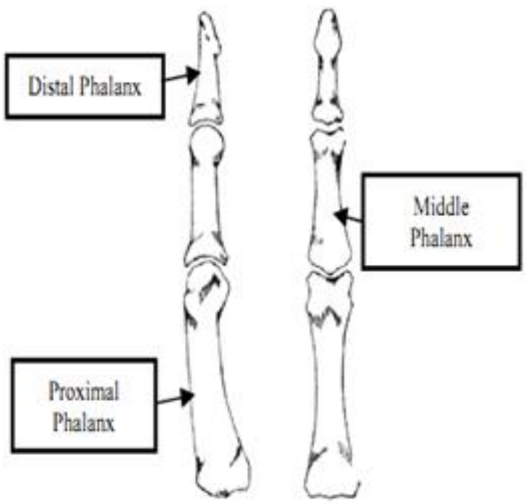

Fig.1: Structure of Human Finger

III. Dynamic Model Of Finger Mechanism

Based on the Fig. 2, the Lagrangian method was used to derive the dynamics. In dynamic part, the equations have been derived to find out the torque of ARFM. Referring to the derived forward kinematics,

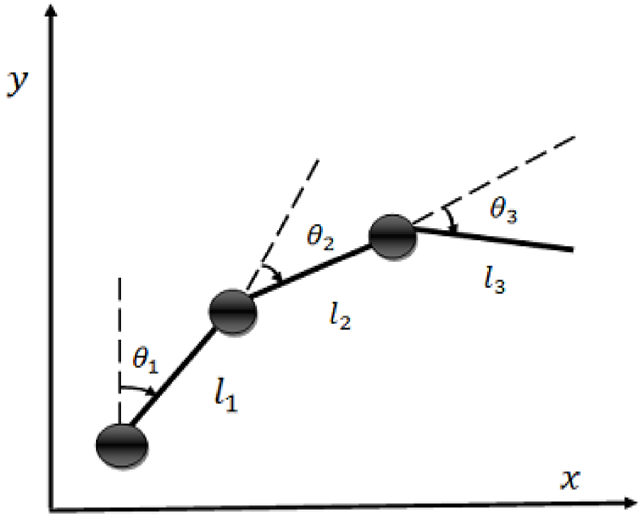

Fig. 2. Flexion of angles of one finger

$$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2) + l_3 \cos(\theta_1 + \theta_2 + \theta_3)$$
$$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2) + l_3 \sin(\theta_1 + \theta_2 + \theta_3)$$

Referring equation forward kinematic above, the angular velocity is computed using Euler langrange formula [3]

$$\omega_i = \frac{d\theta_i}{dt}$$

The angular velocity

$$\omega_1 = \dot{\theta}_1$$
$$\omega_2 = \dot{\theta}_1 + \dot{\theta}_2$$
$$\omega_3 = \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3$$

Then, the linear velocity of mass centre each link of the finger was found using Euler langrage formula [3].

$$\dot{x}_1 = -\frac{1}{2} l_1 S_1 \dot{\theta}_1$$
$$\dot{y}_1 = \frac{1}{2} l_1 C_1 \dot{\theta}_1$$
$$\dot{x}_2 = -l_1 S_1 \dot{\theta}_1 - \frac{1}{2} l_2 S_{12} (\dot{\theta}_1 + \dot{\theta}_2)$$
$$\dot{y}_2 = l_1 C_1 \dot{\theta}_1 + \frac{1}{2} l_2 C_{12} (\dot{\theta}_1 + \dot{\theta}_2)$$
$$\dot{x}_3 = -l_1 S_1 \dot{\theta}_1 - l_2 S_{12} (\dot{\theta}_1 + \dot{\theta}_2) - \frac{1}{2} l_3 S_{123} (\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)$$
$$\dot{y}_3 = -l_1 C_1 \dot{\theta}_1 - l_2 C_{12} (\dot{\theta}_1 + \dot{\theta}_2) - \frac{1}{2} l_3 C_{123} (\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)$$

The equation of the velocity linear above should be square and sum of the equations to find V1 , V2 and V3,

$$v_1 = \dot{x}_1^{\,2} + \dot{y}_1^{\,2}$$

$$= (-\frac{1}{2}l_1 S_1 \dot{\theta}_1)^2 + (\frac{1}{2}l_1 C_1 \dot{\theta}_1)^2$$
$$= \frac{1}{4}l_1^2 \dot{\theta}_1^2$$

$$v_2 = \dot{x}_2{}^2 + \dot{y}_2{}^2$$
$$= \left(-l_1 S_1 \dot{\theta}_1 - \frac{1}{2}l_2 S_{12}\left(\dot{\theta}_1 + \dot{\theta}_2\right)\right)^2 + \left(l_1 C_1 - \frac{1}{2}l_2 C_{12}\left(\dot{\theta}_1 + \dot{\theta}_2\right)\right)^2$$
$$= l_1^2 \dot{\theta}_1^2 + \frac{1}{4}(\dot{\theta}_1 + \dot{\theta}_2)^2 + l_1 l_2 C_2 \dot{\theta}_1 (\dot{\theta}_1 + \dot{\theta}_2)$$
$$= l_1^2 \dot{\theta}_1^2 + \frac{1}{4}\left(\dot{\theta}_1^2 + 2\dot{\theta}_1 \dot{\theta}_2 + \dot{\theta}_2^2\right) + l_1 l_2 C_2 \left(\dot{\theta}_1^2 + \dot{\theta}_1 \dot{\theta}_2\right)$$
$$v_3 = \dot{x}_3{}^2 + \dot{y}_3{}^2$$
$$= \left(-l_1 S_1 \dot{\theta}_1 + l_2 S_{12}(\dot{\theta}_1 + \dot{\theta}_2) + l_3 S_{123}(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)\right)^2$$
$$+ \left((l_1 C_1 \dot{\theta}_1 + l_2 C_{12}(\dot{\theta}_1 + \dot{\theta}_2) + l_3 C_{123}(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)\right)^2$$
$$= l_1^2 \dot{\theta}_1^2 + l_2^2(\dot{\theta}_1 + \dot{\theta}_2)^2 + \frac{1}{4}l_3^2(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2$$
$$+ 2l_1 l_2 C_2 \dot{\theta}_1(\dot{\theta}_1 + \dot{\theta}_2) + l_1 l_3 C_{23}(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2$$
$$+ l_2 l_3 C_3(\dot{\theta}_1 + \dot{\theta}_2)(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3) + l_1 \dot{\theta}_1^2$$
$$+ l_2(\dot{\theta}_1 + \dot{\theta}_2)^2 + l_3(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2$$

And the link kinetic energy ,

$$(K) = K_i = \frac{1}{2}\sum_1^3 (m_i v + l_i \omega_i^2)$$
$$K = \frac{1}{2}m_1(v_1) + \frac{1}{2}m_2(v_2) + \frac{1}{2}m_3(v_3) + \frac{1}{2}l_1 \omega_1^2$$
$$+ \frac{1}{2}l_2 \omega_2^2 + \frac{1}{2}l_3 \omega_2^2$$
$$= \frac{1}{2}m_1\left(\frac{1}{4}l_1^2 \dot{\theta}_1^2\right) + \frac{1}{2}m_2(l_1^2 \dot{\theta}_1^2 + \frac{1}{4}l_2^2(\dot{\theta}_1 + \dot{\theta}_2)^2 + l_1 l_2 C_2(\dot{\theta}_1 + \dot{\theta}_2)$$
$$+ \frac{1}{2}m_3[l_1^2 \dot{\theta}_1^2 + l_2^2(\dot{\theta}_1 + \dot{\theta}_2)^2 + \frac{1}{4}l_3^2(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2$$
$$+ 2l_1 l_2 C_2 \theta_1(\dot{\theta}_1 + \dot{\theta}_2) + l_1 l_3 C_{23}(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2$$
$$+ l_3 l_3 C_3(\dot{\theta}_1 + \dot{\theta}_2)(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2 + \frac{1}{2}l_1 \dot{\theta}_1^2 + \frac{1}{2}l_2(\dot{\theta}_1 + \dot{\theta}_2)^2$$
$$+ \frac{1}{2}l_3(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2 + \frac{1}{2}l_1 \dot{\theta}_1^2 + \frac{1}{2}l_2(\dot{\theta}_1 + \dot{\theta}_2)^2$$
$$+ \frac{1}{2}l_3(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2 + l_1 \dot{\theta}_1^2 + l_2(\dot{\theta}_1 + \dot{\theta}_2)^2$$
$$+ l_3(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2]$$

The kinetic energy in matrix form is referring this formula [24] Below:

$$K = \frac{1}{2}\left(\dot{\theta}_1 \dot{\theta}_2 \dot{\theta}_3\right)\begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix}$$

$$A_{11} = \frac{1}{4}m_1 l_1^2 + m_2\left(l_1^2 + \frac{1}{4}l_2^2 + l_1 l_2 C_2\right) + m_3\left(l_1^2 + l_2^2 + \frac{1}{4}l_3^2 + 2l_1 l_2 C_2 + l_1 l_3 C_{23} + l_2 l_3 C_3\right) + l_1 + l_2 + l_3$$

$$A_{12} = \frac{1}{2}\left[m_2\left(\frac{1}{2}l_2^2 + l_1 l_2 C_2\right) + m_3\left(2l_2^2 + \frac{1}{2}l_3^2 + 2l_1 l_2 C_2 + l_1 l_3 C_{23} + l_2 l_3 C_3\right) + l_2 + l_3\right]$$

$$A_{13} = \frac{1}{2}m_3\left(\frac{1}{2}l_3^2 + l_1 l_3 C_{23} + l_2 l_3 C_3\right) + l_3$$

$$A_{21} = A_{12}$$

$$A_{22} = \frac{1}{4}l_2^2 m_2 + m_3\left(l_1^2 + \frac{1}{2}l_3^2 + l_2 l_3 C_3\right) + l_2 + l_3$$

$$A_{23} = \frac{1}{2}m_3\left(\frac{1}{2}l_3^2 + l_2 l_3 C_3\right) + l_3$$

$$A_{31} = A_{13}$$

$$A_{32} = A_{23}$$

$$A_{33} = \frac{1}{4}m_3 l_3^2 + l_3$$

The kinematic energy

$$K = \frac{1}{2}\left(A_{11}\dot{\theta}_1^2 + 2A_{12}\dot{\theta}_1\dot{\theta}_2 + 2A_{13}\dot{\theta}_1\dot{\theta}_3 + A_{22}\dot{\theta}_2^2 + 2A_{13}\dot{\theta}_2\dot{\theta}_3 + A_{33}\dot{\theta}_3^2\right.$$

$$K = 0.5\left(A_{11}\dot{\theta}_1^2 + 2A_{12}\dot{\theta}_1\dot{\theta}_2 + 2A_{13}\dot{\theta}_1\dot{\theta}_3 + A_{22}\dot{\theta}_2^2 + 2A_{13}\dot{\theta}_2\dot{\theta}_3 + A_{33}\dot{\theta}_3^2\right.$$

The potential energy is

$$(\mathrm{p}) = p_i = \frac{1}{2}\sum_{1}^{3}(m_i g y_i)$$

$$p_1 = \frac{1}{2}m_1 g l_1 S_1$$

$$p_2 = m_2 g(l_1 S_1 + \frac{1}{2}l_2 S_{12})$$

$$p_3 = m_3 g(l_1 S_1 + l_2 S_{12} + \frac{1}{2} l_3 S_{123})$$

$$p = p_1 + p_2 + p_3$$

$$p = \frac{1}{2} m_1 g l_1 S_1 + m_2 g(l_1 S_1 + \frac{1}{2} l_2 S_{12}) + m_3 g(l_1 S_1 + l_2 S_{12} + \frac{1}{2} l_3 S_{123})$$

The Langrangian is computed as:

$$L = K - P$$

By using the Lagrange-Euler Formulation, The equation of motion for three degree of freedom finger can be written as:

$$\frac{d}{dt}\left(\delta / \delta \dot{\theta}_i \right) - \delta / \delta \theta_i = \tau_i \quad (i = 1 - 3)$$

Thus, this completes the Dynamic modeling of Anthropomorphic Robotics Finger Mechanisms (ARFM). These equations are used in the simulation of the design of Anthropomorphic Robotics Finger Mechanisms (ARFM). The results of the simulation shall be communicated in the next publication.

IV. Conclusion

The Dynamic Modeling plays an important role in simulation of Anthropomorphic Robot Finger Mechanisms (ARFM). In this paper, the complete derivation of the dynamic modeling of Anthropomorphic Robot Finger Mechanisms (ARFM) was carried out to enable subsequent simulation work. The results will be published in future. Other work such as development of control algorithm and development of Anthropomorphic Robot Finger Mechanisms (ARFM) will be addressed in the next phase of study.

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