International Conference on Global Trends in Academic Research, June 2-3, 2014. GTAR

MODELLING AND SIMULATION OF A HUMANOID ROBOT ARM

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ABSTRACT

Imitating similar function of a human arm can be very challenging task for a humanoid robot arm. A simple task such as pick and/or place requires the understanding of mathematical modelling, forward kinematics and control system. Hence, this paper presents a modelling and simulation of humanoid robot arm which is based on a human arm anatomy. The model of the humanoid robot arm is developed by using Simmechanics. The robot consists of two arm manipulators, a palm and five fingers. All fingers, i.e. index, middle, ring and small finger consist of three links and three joints except the thumb finger. The thumb has four joints and four links. A previous study has shown that a human hand can safely grasp any cylindrical and cube objects of the same size within approximately one second. This is a very important target to be achieved by a robot hand as the controller should be able to perform as close as possible to human hand speed. In order to control the grasping, a conventional PID control is proposed. The results show that the PID controller is accurately performed less than 5% error better than human grasping. Note that human grasping is limited to 10% error. In addition, the robot hand is able to realize grasping within one second. The results also show that the model of humanoid robot hand is successfully developed by using Simmechanics. A development of forward kinematics is provided based on Denavit-Hartenburg technique to show x, y and z position.

Keywords: Robot Arm, Robot Hand, Simmechanics, PID Controller.

1. INTRODUCTION

The hand is one of the most important sensory organs and actuators of the human body. It has the capability to distinguish a touched object in various forms such as object thickness, object softness and object weight. Eventually, the hand will respond accordingly when grasping such objects without damaging them. Likewise, a robot hand should be able to perform the same tasks before entering the human environment. Significant effort has been made to emulate as much as possible the functions and the size of a human hand: This can be found in Biggers, *et al.* (1986), ROBOT (2003), Zacharias (2009) and Grebenstein *et al.* (2011).

Grasping for the robot hand can be divided into two basic groups namely power grasping and precision grasping (Napier, 1956), (Al-Gallaf *et al.*, 1993), (Johan Tegin, 2005). Power grasping can be seen when a larger object is held up by a simple manipulation task. For example, grasping and lifting a chair and holding a heavy tool are much easier than holding an egg or a pen. Power grasping is usually performed using the palm of the hand and almost every area of each finger during grasping or holding. (Arimoto, 2004), in his survey on intelligent control of multi-fingered hands said that power grasping can be realized without using any sensory feedback if the contact force exerted on an object can be adequately controlled. In other words, we can simply say that power grasping is closing the hand around the object without knowing the final contact points between the hand and the object.

On the other hand, when it comes to precision grasping, more delicate objects such as an egg and a pen are considered. It requires the hand to be more sensitive when it touches the surface of the object. In many cases, precision grasping uses fingertips which are equipped with more powerful sensors. In contrast to power grasping, the contact points are known during precision grasping. In order to understand grasping techniques for a robot hand, a study based on a partial taxonomy of manufacturing grasps has been proposed by Cutkosky *et al.* (1986). The group has done an observation on single-handed operations by machinists which were working with metal parts and hand tools. They have found that power and precision grasping can be further detailed into smaller groups such as prehensile (clamping required) and non-prehensile (clamping not required). The study also showed that, in general, grasping can be easily achieved by a hand but hardly realized by a robot hand. A lot of effort has been devoted to copy a human hand such as in Vandeweghe *et al.* [2004] and [Thayer & Priya, 2011], however, none of the robot hand designs so far can beat the human hand.

2. OBJECTIVES OF THE PROJECT

It is not a trivial task to control the humanoid robot hand. It requires a preliminary study of human hand. In general, human hand can be separated into several parts namely upper arm, elbow, forearm, wrist and fingers. The study shows that the human hand is a complex system of bones, muscles, nerves, and vessels. Hence, a simple task such pick and/or place requires a study of modeling, joint space control, forward kinematics and etc.

It is very important to show that the robot hand is able to grasp an object within approximately one second. A study by Armstrong *et al.* (2009) has shown that a human hand can safely grasp any cylindrical and cube objects of the same size within approximately one second from opening to closing state. Moreover, it is to note that human grasping is limited to 10% error (Choi *et al.*, 2008). Thus, the speed and the grasping error of the robot grasping must be based on this performance. However, the work becomes more complex since the representation of robot hand consists of 19 joints. Besides, a highly sophisticated computer machine may be required for high level computation.

Hence, the objectives of this project are:

- To develop a humanoid robot hand model by using Simmechanics.
- To apply PID controller for grasping purpose.
- To achieve good motion control where the robot hand is able to realize grasping within one to two seconds.
- To attain less than 10% grasping error.
- The modeling and simulation of this project are implemented in Simmechanics MATLAB.

3. MODELLING AND CONTROLLER

In order to achieve the objectives as mentioned in Section II, a few steps are taken. The first step is to study a physical structure and movement of human arm and forearm as depicted in Figure 1. This is very important procedure due to the fact that human hand is versatile. Although, a simple task such as grasping a glass can be very easy for a human hand but it can be very complex for a humanoid robot hand.

The information such as the mass, link, muscle and the length from the arm to the end effector (i.e. fingers) can be very useful for modelling purpose. This will ensure that a developed humanoid robot model is sufficient for control purpose. The second step requires the understanding of Simmechanics/ Matlab.

Once a model is available in Simulink, the third step will consider a suitable choice of controller to ensure that a desired grasping position is achieved. However, for the preliminary control purpose, a well-known PID controller is considered. Figure 2 illustrates the flowchart of the development of robot hand model.

Figure 1: Human upper arm, forearm and hand

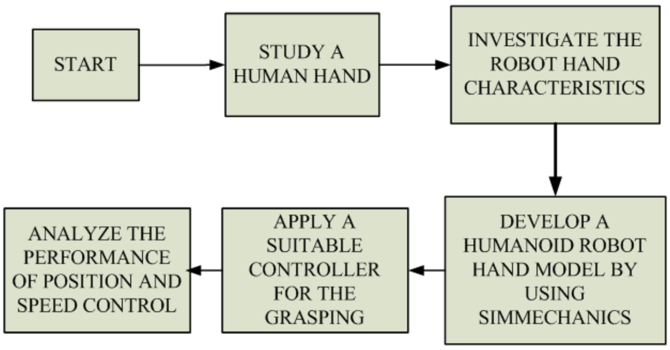

Figure 2: Development process of robot arm and hand model.

Designing the Model

The design of humanoid robot arm and hand for this project is fully developed by using Simmechanics.

Human Hand Size

From the anthropomorphism point of view, the size of the humanoid robot hand should be matching with the human's hand. In this study, the size of the human hand is based on the measurement of the author's hand. Table 1 shows details measurement for humanoid robot hand.

Controller

For controller design, the following model is used.

$$m\ddot{q} + f = u \qquad (1)$$

where m is the generalized mass/inertia, f is a lumped expression for the major nonlinearities i.e. gravity, friction and centrifugal/coriolis force.

Table 1: Arm parameter for the real arm

Part	Link 1	Link 2	Link 3
Shoulder	37 cm	N/A	N/A
Elbow	32 cm	N/A	N/A
Wrist	0.5 cm	N/A	N/A
Palm	8 cm	N/A	N/A
Thumb finger	3.5 cm	3 cm	N/A
Index finger	4 cm	3 cm	2 cm
Middle finger	5 cm	3 cm	2 cm
Ring finger	4 cm	3 cm	2 cm
Pinky finger	2.5 cm	2 cm	2 cm

Software

For modeling and simulation purpose Simmechanics MATLAB will be used, while PID controller will be control the hand robot movement.

Simmechanics and Simulink

Simmechanics is software that provides a multi-body simulation environment for 3D mechanical systems such as robots, vehicle suspensions, construction equipment and aircraft. By using Simmechanics, user can model the system using blocks representing joints, bodies, force element, constraints and solves the equations of motion for the complete mechanical system.

Moreover, SimMechanics from MathWorks is MATLAB library based on Simulink. SimMechanics allows us to build the robot hand model in a simulation environment. This will ensure that a controller can be verified before using it for real time implementation. In SimMechanics, we can quickly use this multibody simulation tool to build a model composed of bodies, joints, constraints, and force elements that reflect the structure of the system. Interestingly, the Simmechanics can also be integrated with Computer Aided Design (CAD) software such as Solidworks and ProE.

Controller

It is to note that a developed model of human robot hand consists of 19 joints. This is very complex and a few assumptions have been made to simplify the work. For instance, the friction and stiction are not taken into consideration for modeling. This allows the conventional PID control to perform a simple grasping task. In brief, the PID controller is a closed loop feedback mechanism system. It calculates an error value from the difference measured process variable and desired value. Figure 3 shows the schematic diagram of PID controller.

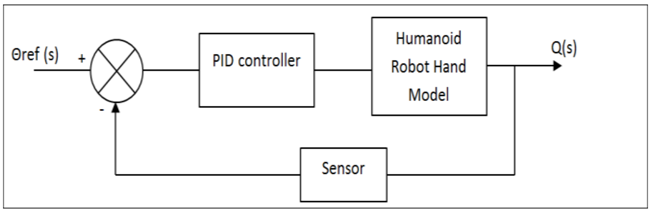

Figure 3: Schematic diagram of PID controller

The PID controller attempts to minimize the error by adjusting process control inputs. The PID controller algorithm involves three constant parameters called three-term control that is the proportional (P), the integral (I) and derivative (D) values.

Figure 4 shows the PID controller is applied to control the humanoid robot hand in Simulink Matlab. There are two options in order to tune the PID parameters either by automatically tuning or manually tuning. In this project the author was chosen manually tune *P*, *I* and *D* parameters. The parameters of PID controller are given in Table 2.

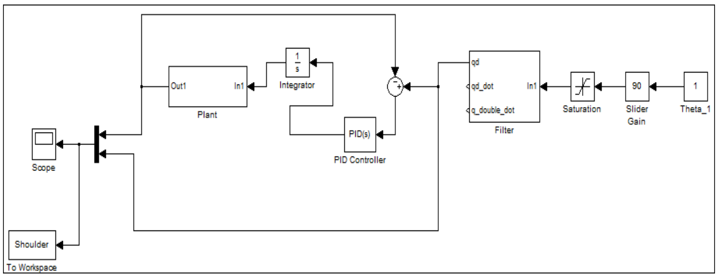

Figure 4: PID Controller in Simulink Matlab

Table 2: Parameters of the PID controller

Parameter	value
Proportional (P)	250
Integral (I)	30
Derivative (D)	15

4. RESULT AND DISCUSSION

Simmechanics Simulation

The end position of the robot hand is based on a different desired position. Figure 5 shows an initial condition of the robot hand. At this position, a demand of 0 degree is applied. The robot hand is basically straight and requires different joint angles to bend and grasp.

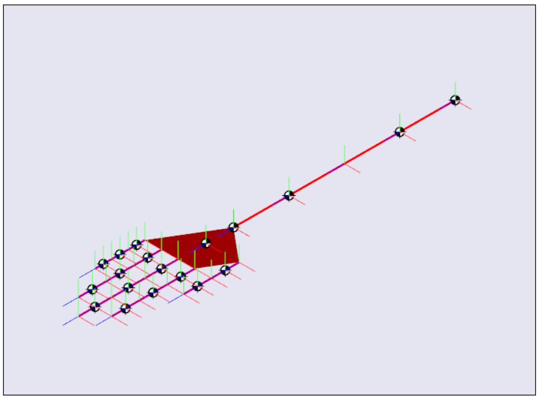

Figure 5 Initial position of humanoid robot hand model

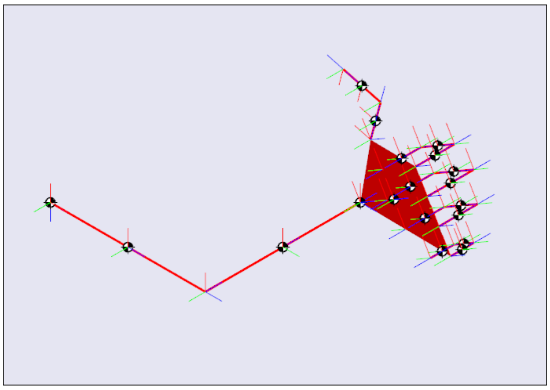

Figure 6 Position of humanoid robot hand for different theta values as given in Table 3.

Figure 6 shows the positions of the humanoid robot hand model for different theta (Θ) values. The values of theta are given in Table 3. At this position, the hand is grasping and the upper arm and forearm are bending. It is to note that the joint angles used for the thumb, index, middle, ring and small fingers are similar (i.e. 90 degree). It shows that the movement of all fingers are similar at the same direction. However, the thumb has different motion at joint 1. It allows 45 degree motion at different location. This makes the thumb finger more flexible during grasping. The length measurement of each link is depicted in Table 1

Performance of the PID Controller

The effectiveness of the PID controller can be seen in Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14 for shoulder joint, elbow joint, wrist joint, thumb joint, index joint, middle joint, ring joint and pinky joint respectively. The results show that the PID control is satisfactorily controlled the end effector of the humanoid robot hand in joint space control.

Table 4 shows the overall performance of the humanoid robot hand in terms of *rise time, settling time, overshoot* and *steady state error*. It shows that the maximum settling time is 1.5 seconds and the rise time is between 0.76 seconds and 0.77 seconds. Interestingly, there is no overshoot for all joints. The steady state error for the shoulder, elbow, index, middle, ring and small fingers are similar (i.e. 0.0463 deg.) except for the wrist and the thumb. The wrist and the thumb produce 0.0154 deg. and 0.0232 deg. respectively.

Table 3 Theta values for all model joints

The Parts of humanoid robot hand	
Part	Theta (deg)
Shoulder Joint 1	T1 = 90
Shoulder Joint 2	T2 = 90
Elbow	T3 = 90
Wrist Joint 1	T4 = -90
Wrist Joint 2	T5 = 30
Thumb Finger Joint 1	T6 = 45
Thumb Finger Joint 2	T7 = 90
Index Finger Joint 1	T8 = 90
Index Finger Joint 2	T9 = 90
Index Finger Joint 3	T10 = 90
Middle Finger Joint 1	T11 = 90
Middle Finger Joint 2	T12 = 90
Middle Finger Joint 3	T13 = 90
Ring Finger Joint 1	T14 = 90
Ring Finger Joint 2	T15 = 90
Ring Finger Joint 3	T16 = 90
Pinky Finger Joint 1	T17 = 90
Pinky Finger Joint 2	T18 = 90
Pinky Finger Joint 3	T19 = 90

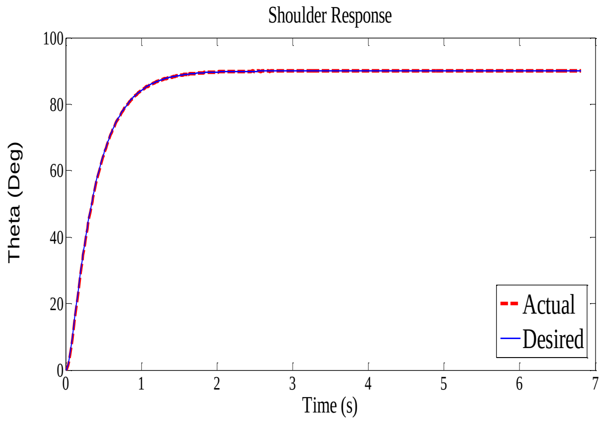

Figure 7: Shoulder joint response at Θ = 90°

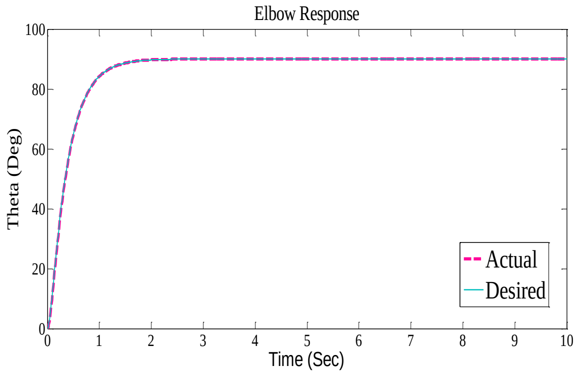

Figure 8: Elbow joint response at Θ = 90°

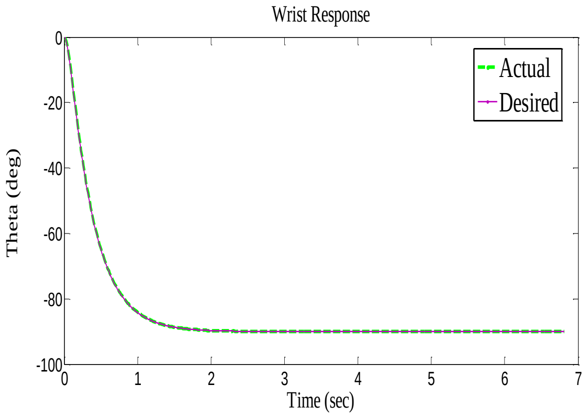

Figure 9: Wrist joint response at Θ = -90°

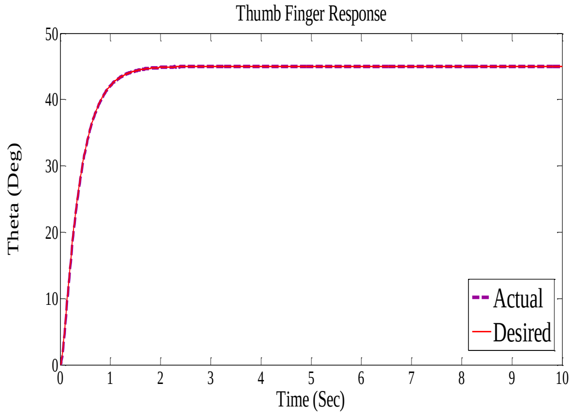

Figure 10: Thumb finger joint response at Θ = 90°

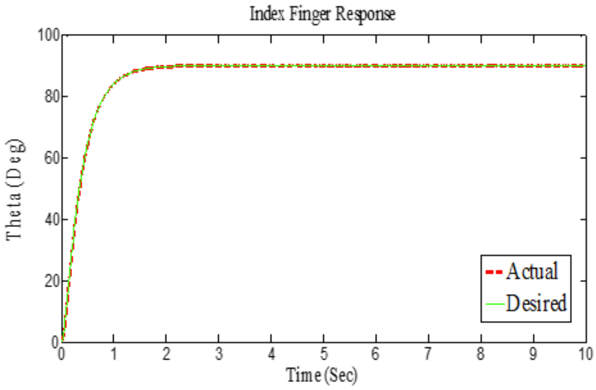

Figure 11: Index finger joint response at Θ = 90°

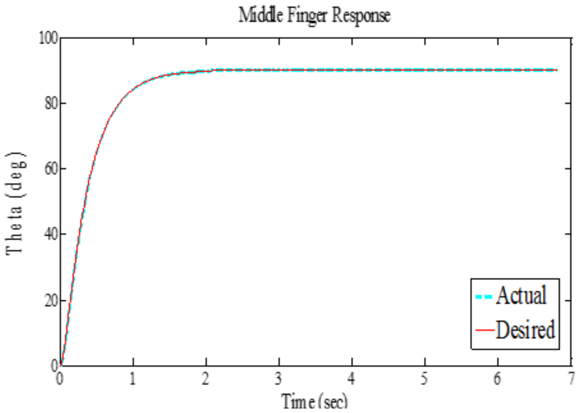

Figure 11: Middle finger joint response at Θ = 90°

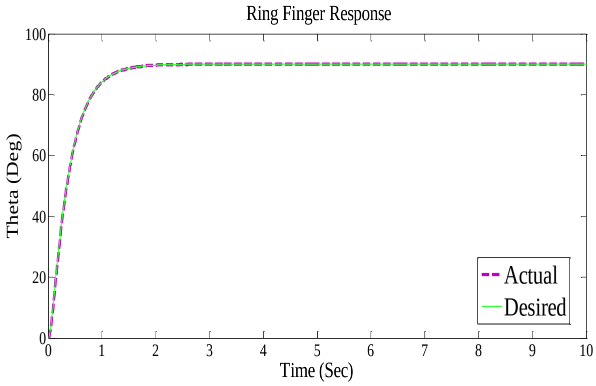

Figure 13: Ring finger joint response at Θ = 90°

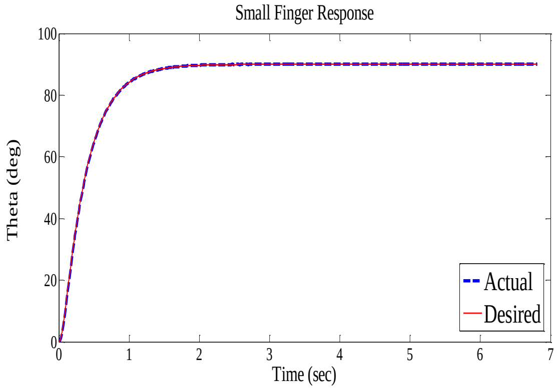

Figure 14: Pinky finger joint response at Θ = 90°

Table 4: Transient performance of the PID controller

Joints	Rise Time (Sec)	Settling Time (Sec)	Overshoot (Deg.)	Steady State Error (Deg.)
Shoulder	0.7694	1.4	0	0.0463
Elbow	0.7694	1.4	0	0.0463
Wrist	0.769	1.5	0	0.0154
Thumb	0.70	1.2	0	0.0232
Index	0.70	1.2	0	0.0463
Middle	0.77	1.5	0	0.0463
Ring	0.69	1.4	0	0.0463
Small	0.68	1.5	0	0.0463

5. CONCLUSION

A model of humanoid robot hand has been successfully developed by using Simmechanics. The effectiveness of the PID controller has been tested. The results show that the PID controller has satisfactorily controlled each joint via joint space control less than 2 seconds. The results also show that the PID controller is accurately performed less than 5% error better than human grasping. Due to the fact that the computation level is limited to calculate the forward kinematics, the Cartesian space control cannot be implemented. The Cartesian space control will be considered to show a more practical grasping for future work. Hence, the forward kinematics of robot hand will be provided.

6. ACKNOWLEDGEMENT

The project is funded by the Universiti Tun Hussein Onn Malaysia (UTHM) short grant (*Vot Number* 1295). The grant runs from September 2013 until March 2015.

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