Design and Simulating Five-Finger Robot Hand to Grasp Spherical Objects

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Abstract: Grasping and manipulation of objects, as well as the capability interacting safely with the environment (possibly including also humans), is a fundamental task for a humanoid robot. In order to tackle these issues a great effort has been put for over two decades to develop robot hands or mechanisms emulating the grasping capabilities of a human. However, grasping and manipulation control also rely the availability of suitable contact and force feedback. In this article being inspired by biological samples, we have proceeded to designing and simulating five-fingered robotic hand which has the capability of touch sensing. Thus in this paper, to achieve this goal, the degree of freedom of each fingers has been calculated, Heartenberg- Dynavit parameters' has been exploited. Afterward each fingers as a 3[rd] series robot has been modeled. Then using Lagrange method we calculated each joint torque and dynamic equation separately and considering non-linear manner of equations we solved them using Newton-Raphson numerical approach. Finally we modeled a robotic hand by using Solid Works and Visual Nastran engineering softwares. Dynamic and kinematic analysis results of this hand including linear and angular acceleration, linear and angular velocity and each finger joint spatial position and Torque in ratio of time was calculated. Moreover each finger movement was simulated in Matlab soft ware and in order to make sure of results, imitating human hand function, we made an experimental model of hand being able to grasp things. Obtained results showed that there is an acceptable accordance among modeling results performed in Nastran software, simulation results performed in Matlab and experimental conclusions.

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Key words: Kinematic analysis, sense of touch, robotic hand, dynamic equations, Newton-Raphson method.

1. Introduction

The human hand can serve as a model for a robotic interface with the environment. With over twenty-five degrees of freedom (DOF), its versatility provides motivation for artificial manipulation research. While the prehension and restraint capabilities of the human hand are objectives for industrial end-effectors, its manipulative and perceptive abilities prescribe basic determinants for medical, entertainment, and service systems. These applications require robots to perform anything from everyday activities to hazardous manual tasks. Prosthetic and tele-operated manipulators must possess many of these manual faculties because their control greatly relies on the mapping of a human user's natural conduct. Hands for humanoid robots must also express such compatibility if they are to promote intuitive human interaction and if developers are to converge on reliable research platforms. Robotic hand is an initial example of advanced final operation, having the ability of taking things with more struggles and using them as tools in different ways. Grasping and manipulation of objects, as well as the capability interacting safely with the environment (possibly including also humans), is a fundamental task for a humanoid robot. In order to tackle these issues a great effort has been put for over two decades to develop robot hands or mechanisms emulating the grasping capabilities of a human. The first skillful robotic hand was developed in 1980.Inspite of vast majority of researches done about robotic hand; still, in most universities and research institutes, other vast investigations are done in mechanical designing, kinematics and robotic hand control area. Most of these studies define optical mechanism designing to pick things as a basic aim which focuses on physical relation between robotic system and it's surrounding. With robotic industry development in 1982, different kinds of claw mechanisms were made. Robotic claws which are utilized in robotic arms are used to do repeated acts. Using claws in order to pick up ordered geometric things is limited. Moreover the act of picking in ordered things up or doing intricate operations is their noticeable deficiency. As a result of these limitations, some studies were done in the area of robotic finger development. In 1986, the skillful hand of Utah, related to Masochist research institute, was designed and made by engineering design center of Utah university in corporation with MIT artificial intelligence laboratory. In 2002 Kawasaki et al. proposed Gifu robotic hand which was similar to human hand. This hand had a thumb and four other hands. Its thumb had four joints with 4 degree of freedom, other fingers had also 4 joints but with 3 degree of freedom. In 2008, Byung, June Choi et al. through an investigation developed a humanoid robotic hand having touch sensor. In 2009, Seokwon Lee et al. presented development of a robotic hand, using paralleled mechanisms imitated from biological samples. In 2010, important architectures were proposed to develop robotic hand robotic finger. In 2011, Chiraz Walha et al. presented a 3 dimensional simulator through an article named New Simulator to Humanoid Grasping which predicts human grasping movement by suitable algorithms analyzed by data gloves of obtained data. In 2012 Ranjeet Ranjan et al. modeled and simulated humanoid robotic arm.

The main objective in this article is to design and simulate a robotic hand and it's optimization through imitating a biological one. Afterward we try to compare its function with a human hand function. To do this after doing kinematic equation analysis, Jakobin matrix exploitation and solving them by Newton-Raphson method (imitating human hand function) we proceeded to design a controller having touch sensor.

2. Kinematic Analysis

Fig.1 shows a three-link planar finger and a schematic representation of the same manipulator. Because all three joints are revolute, this manipulator is sometimes called an RRR (or 3R) mechanism. Note the double hash marks indicated on each of the three axes, which indicate that these axes are parallel. The corresponding link parameters are also shown in Table 1. Assign link frames to the mechanism and give the Denavit—Hartenberg parameters.

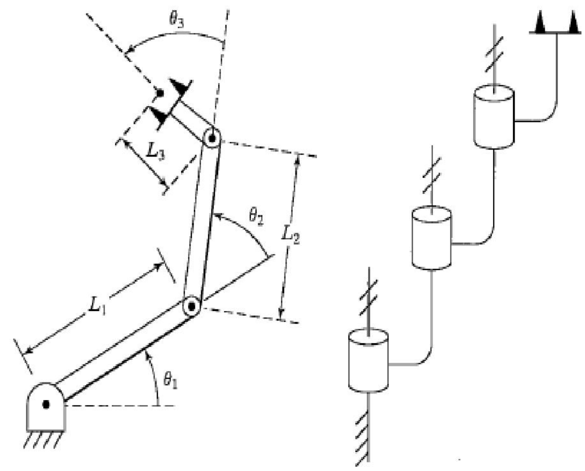


Fig.1 A three-link planar finger

Table 1. Link parameters of the three-link finger

I	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3

Solving the problem of finding the required joint angles to place the tool frame, {T}, relative to the station frame, {S}, is split into two parts. First, frame transformations are performed to find the wrist frame, {W}, relative to the base frame, {B}, and then the inverse kinematics are used to solve for the joint angles. Namely, the final orientation of {W} is given relative to {B} as:

$$ {}^{B}_{W}T = \begin{bmatrix} \cos\emptyset & -\sin\emptyset & 0 & x \\ \sin\emptyset & \cos\emptyset & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

where:

$$ \cos\emptyset = c_{123} \quad (2) $$
$$ \sin\emptyset = s_{123} \quad (3) $$
$$ x = l_1 c_1 + l_2 c_{12} \quad (4) $$
$$ y = l_1 s_1 + l_2 s_{12} \quad (5) $$
$$ c_{12} = c_1 c_2 - s_1 s_2 \quad (6) $$
$$ s_{12} = c_1 s_2 + s_1 c_2 \quad (7) $$

Dynamic Analysis:

There are various ways to dynamic analysis solution of mechanical systems. In this section we have used Lagrange method as a most common one. Lagrangian formulation is an "energy-based" approach to dynamics. In this method first independent variables and generalized forces made of non-static forces are recognized, then general relations of kinematic and potential forces of robotic fingers are calculated based on independent variables and their derivations and finally each finger joint torque is determined.

$$I_1 = I_2 = I_3 = 0 \quad (8)$$
$$\overline{L_1} = L_1 \; ; \; \overline{L_2} = L_2 \; ; \; \overline{L_3} = L_3 \quad (9)$$

Kinematic and potential energies are calculated as:

$$V = g\big[(m_1 l_1 \sin\theta_1) + m_2\big(l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2)\big) + m_3(l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2) + l_3 \sin(\theta_1 + \theta_2 + \theta_3)] + \frac{1}{2}k_1\theta_1^2 + \frac{1}{2}k_2\theta_2^2 + \frac{1}{2}k_3\theta_3^2 \quad (10)$$

$$T = \frac{1}{2}[m_1\big(l_1^2\dot{\theta}_1^2\big) + m_2(l_1^2\dot{\theta}_1^2 + l_2^2(\dot{\theta}_1 + \dot{\theta}_2)^2 + 2l_1l_2\dot{\theta}_1(\dot{\theta}_2 + \dot{\theta}_1) + m_3(l_1^2\dot{\theta}_1^2 + l_2^2(\dot{\theta}_1 + \dot{\theta}_2)^2 + l_3^2(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)^2 + 2l_1l_2\dot{\theta}_1(\dot{\theta}_1 + \dot{\theta}_2)cos\theta_2 + 2l_2l_3(\dot{\theta}_1 + \dot{\theta}_2)(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)cos\theta_3 + 2l_1l_3\dot{\theta}_1(\dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3)\cos(\theta_2 + \theta_3))] \quad (11)$$

where T is the indication of kinetic energy and V is the potential energy. Now, through forming Lagrangian and calculating Lagrange equation, we can exploit torque equations as follow:

$$\begin{aligned} & m_3l_2l_3\dot{\theta}_1\dot{\theta}_3 \sin\theta_3 - m_3l_1l_3\dot{\theta}_1\dot{\theta}_2 \sin(\theta_2 + \theta_3) - m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \sin(\theta_2 + \theta_3) \\ & - m_3l_2l_3\dot{\theta}_2\dot{\theta}_3 \sin\theta_3 + m_3l_2l_3\dot{\theta}_1^{\,2} sin\theta_3 + 2m_3l_2l_3\dot{\theta}_1\dot{\theta}_2 sin\theta_3 \\ & + m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \, sin\theta_3 + m_3l_2l_3\,\dot{\theta}_2^{\,2} sin\theta_3 + m_3l_2l_3\,\dot{\theta}_2\dot{\theta}_3 sin\theta_3 \\ & + m_3l_1l_3\dot{\theta}_1^{\,2} \sin(\theta_2 + \theta_3) + m_3l_1l_3\dot{\theta}_1\dot{\theta}_2 \sin(\theta_2 + \theta_3) \\ & + m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \sin(\theta_2 + \theta_3) + g[m_3l_3\cos(\theta_1 + \theta_2 + \theta_3)] + k_3\theta_3 \\ & = \boldsymbol{\tau}_3 \end{aligned} \quad (12)$$

$$\begin{aligned} & -m_2l_1l_2\dot{\theta}_1\dot{\theta}_2 \, sin\theta_2 - m_3l_1l_2\dot{\theta}_1\dot{\theta}_2 \, sin\theta_2 - 2m_3l_2l_3\dot{\theta}_1\dot{\theta}_3 \sin\theta_3 \\ & - m_3l_1l_3\dot{\theta}_1\dot{\theta}_2 \sin(\theta_2 + \theta_3) - m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \sin(\theta_2 + \theta_3) \\ & - 2m_3l_2l_3\dot{\theta}_2\dot{\theta}_3 \, sin\theta_3 - m_3l_2l_3\dot{\theta}_3^{\,2} \, sin\theta_3 + m_2l_1l_2\dot{\theta}_1^{\,2} \sin\theta_2 \\ & + m_2l_1l_2\,\dot{\theta}_1\dot{\theta}_2 sin\theta_2 + m_3l_1l_2\dot{\theta}_1^{\,2} sin\theta_2 + m_3l_1l_2\dot{\theta}_1\dot{\theta}_2 sin\theta_2 \\ & + m_3l_1l_3\dot{\theta}_1^{\,2} \sin(\theta_2 + \theta_3) + m_3l_1l_3\dot{\theta}_1\dot{\theta}_2 \sin(\theta_2 + \theta_3) \\ & + m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \sin(\theta_2 + \theta_3) \\ & + g[m_2 cos(\theta_1 + \theta_2) + m_3l_2 \cos(\theta_1 + \theta_2) \\ & + l_3 \cos(\theta_1 + \theta_2 + \theta_3)] = \boldsymbol{\tau}_2 \end{aligned} \quad (13)$$

$$\begin{aligned} & -2m_2l_1l_2\dot{\theta}_1\dot{\theta}_2 \, sin\theta_2 - 2m_3l_1l_2\dot{\theta}_1\dot{\theta}_2 \, sin\theta_2 - \\ & 2m_3l_2l_3\dot{\theta}_1\dot{\theta}_3 \sin\theta_3 - 2m_3l_1l_3\dot{\theta}_1\dot{\theta}_2 \sin(\theta_2 + \theta_3) - \\ & 2m_3l_1l_3\dot{\theta}_1\dot{\theta}_3 \sin(\theta_2 + \theta_3) - m_2l_1l_2\dot{\theta}_2^{\,2} sin\theta_2 - \\ & m_3l_1l_2\dot{\theta}_2^{\,2} \, sin\theta_2 - 2m_3l_2l_3\dot{\theta}_2\dot{\theta}_3 \, sin\theta_3 - m_3l_1l_3\dot{\theta}_2^{\,2} \sin(\theta_2 + \\ & \theta_3) - m_3l_1l_3\dot{\theta}_2\dot{\theta}_3 \sin(\theta_2 + \theta_3) - m_3l_2l_3\dot{\theta}_3^{\,2} \, sin\theta_3 - \\ & m_3l_1l_3\dot{\theta}_2\dot{\theta}_3 \sin(\theta_2 + \theta_3) - m_3l_1l_3\dot{\theta}_3^{\,2} \sin(\theta_2 + \theta_3) - 0 + \\ & g[m_1l_1cos\theta_1 + m_2(l_1cos\theta_1 + l_2 \cos(\theta_1 + \theta_2) + m_3(l_1cos\theta_1 + \\ & l_2 \cos(\theta_1 + \theta_2) + l_3 \cos(\theta_1 + \theta_2 + \theta_3))] + K_1\theta_1 = \boldsymbol{\tau}_1 \end{aligned} \quad (14)$$

Simulating and Modeling Robotic Hand:

Determining dynamic and kinematic equations of robot hand, using Nastaran and Solid Works software, we proceed to dynamic analysis, design and modeling and of robot hand.

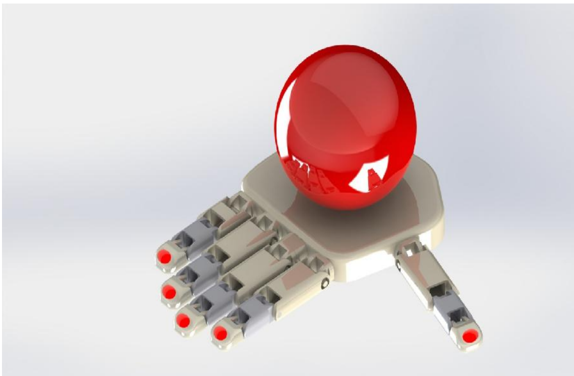


Fig.2 A robotic hand model using Solid Works software

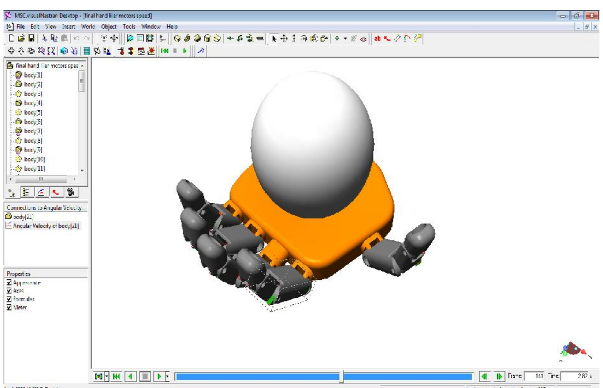
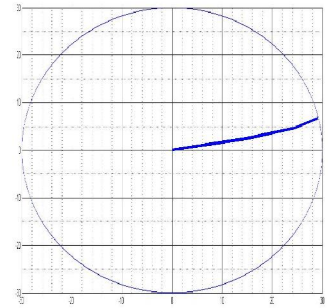
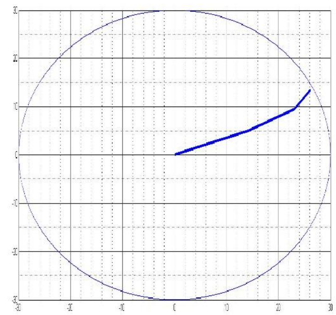


Fig.3 A robotic hand model using MCS.NASTRAN software

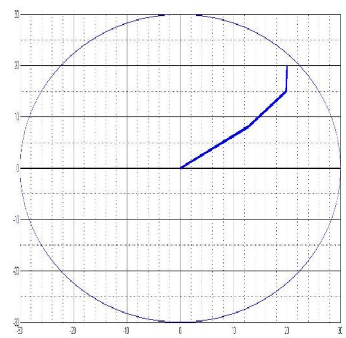
More over with the aid of Matlab software and dynamic-kinematic equations obtained for each finger, we simulated each finger movement and then proceeded to robot hand dynamic movement, kinematic plots and results exploitation. In this simulation we used the Newton-Raphson method to solve non-linear dynamic equations. Figures 4 (a-c) present robotic finger movement simulation.



(a)



(b)



(c)

Fig.4 A robotic finger movement simulation using in Matlab software

3. Results:

After exploiting kinematic and dynamic models and also performing simulation in Solid Work software and providing robot finger movement simulation, we draw kinematic and dynamic parameters of finger joints including linear and angular acceleration and spatial position and Torque of finger joints in ratio of time according to the following plots. Likewise an experimental sample of five finger robotic hand (Fig. 10- 11) was made and theoretical and experimental results were compared.

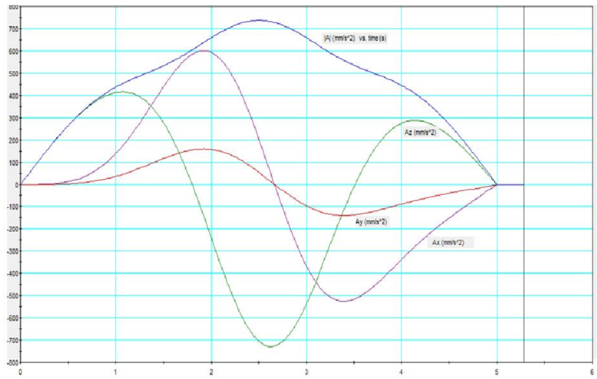


Fig.5 linear acceleration of finger joints

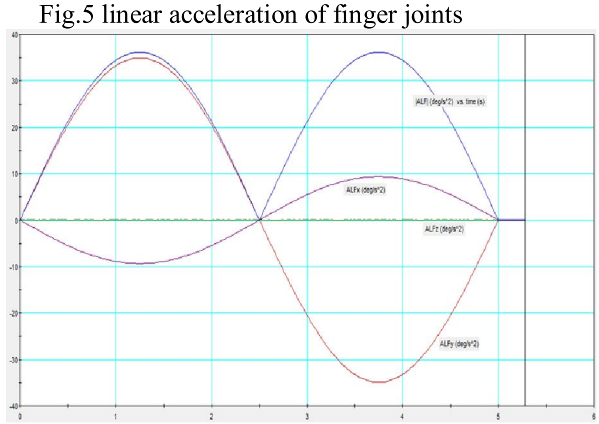


Fig.6 Angular acceleration of finger joints

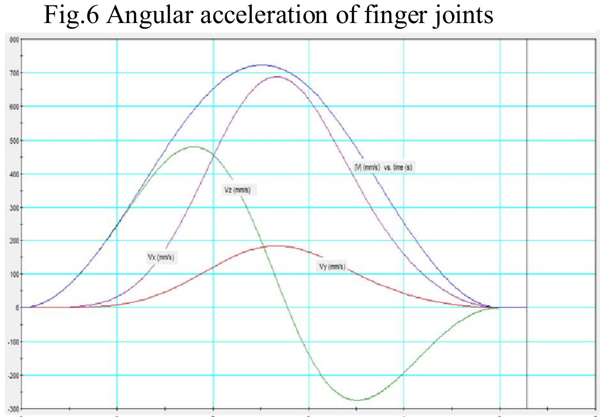


Fig.7 linear velocity of finger joints

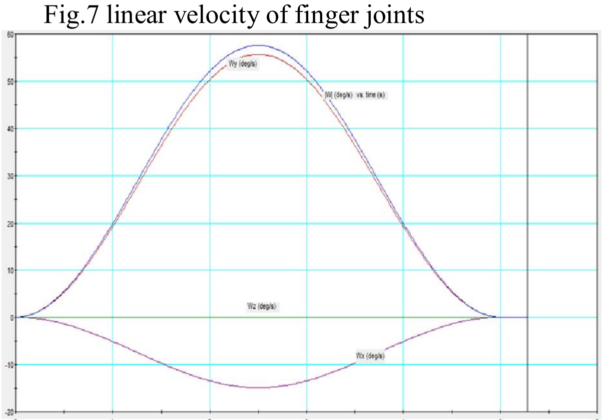


Fig.8 Angular velocity of finger joints

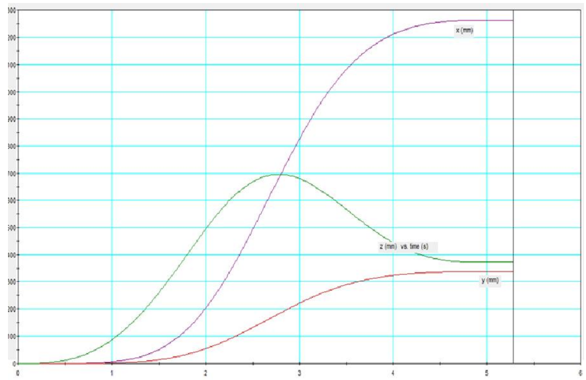


Fig.9 Spatial position of finger joints in ratio of time

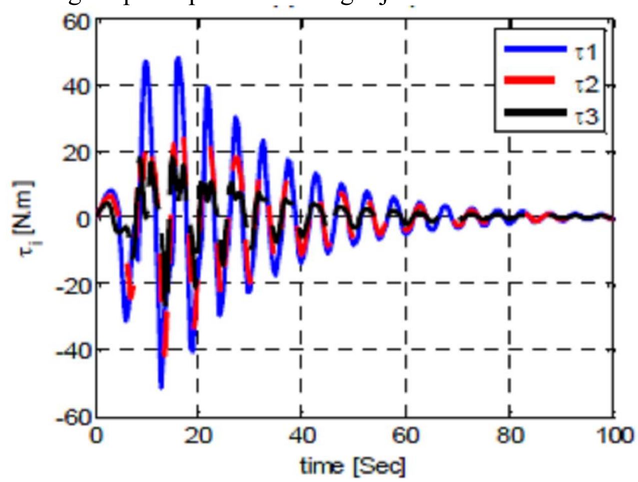


Fig.10 Torque of finger joints in ratio of time

4. Designing Robot Hand Controller

As the main aim of this investigation is to build a robot hand imitating a biological one, we have tried in this part to promote robotic hand capabilities including the way of grasping objects and touching related things as much as possible while keeping hand dimensions in normal size. As a result the designing way is so that fingers should be in opened form in resting manner. To do this we have used a main sensor in circuit until the hand would return to its initial position (opened form) when the sensor is off. Moreover we have installed several force sensing resistors in the palm of the hand, till it would be inert while it hasn't touched something and do grasping act whenever something is touched with palm of the hand. As soon as palm sensors recognized something, the fingers start to be closed. It should be noted that a touch sensor has been located on each finger joint. The closing way of fingers is so that till fingers' 1st joint related sensor has not been activated first joint keeps its movement and this is repeated till 90 degree angle. If sensor number 1 wouldn't be activated till 90 degree angle, then motor number 1 would be turned off and this operation would start on joint number 2. In this way the needed orders would be sent to motors number

2 and 3 through 2 and 3 related sensors. Figure 12 presents schematic circuit of controlling a finger.

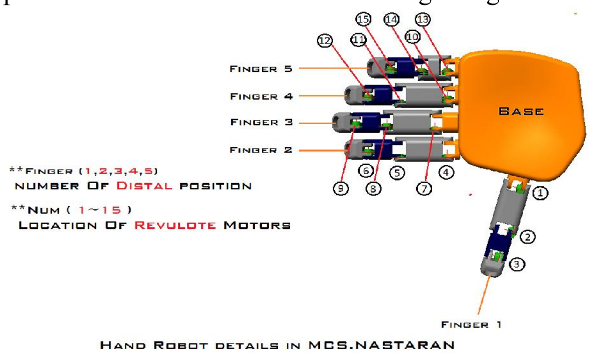


Fig.11 Schematic of a robot hand in MCS. Nastran

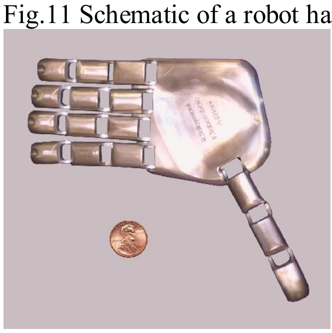


Fig.11 The manufactured model of robotic hand

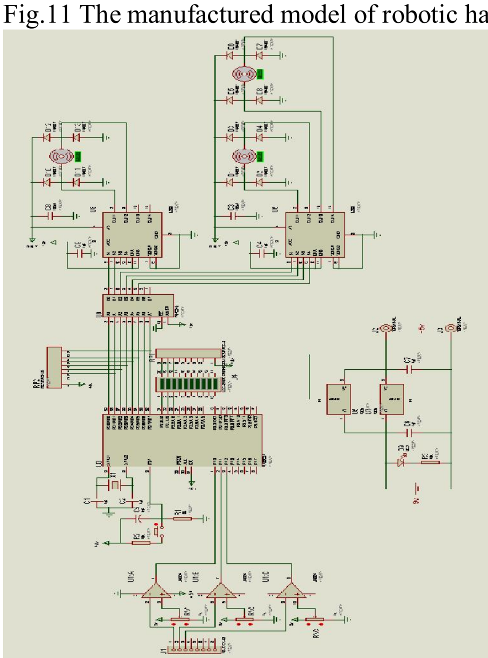


Fig.12 Schematic of the robot hand's system

5. Conclusion:

In this investigation our primary aim is to design and simulate a robotic hand and it's optimization through imitating a biological hand and comparing it's function with a human hand. To do this, we exploited dynamic and kinematic equations first and then solved them using Newton-Raphson method. Moreover simulated robotic hand, dynamic analysis results and also finger movement simulation obtained in Matlab soft ware. In this investigation imitating function of human hand we designed a controller having sense of touch capability. Results obtained from modeling in Nastran, simulating in Matlab, also experimental results obtained from making robot show acceptable accordance.

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