# Kinematic Modeling of a Multi-Fingered Robotic Hand - a Review

**M. Z. Hussain**[1] and **Dr. M. Suhaib**[2]
Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, 110025 India
[1]zafer.amu@gmail.com, [2]msuhaib@jmi.ac.in

*Abstract* — **This paper presents a survey of work in kinematic and dynamic modeling and analysis of multi-fingered robotic hand over the last several years. It provides an insight towards the development of theoretical framework.**

*Keywords: Kinematics, Dynamics, Modeling, Multi-Fingered Hand, Grippers and Jacobian.*

## I. INTRODUCTION

A ROBOT is an automatic mechanical device often resembling a human or animal. Modern robots are usually electro-mechanical machines guided by a computer program or electronic circuitry. Robots can be autonomous or semi-autonomous and range from humanoids to industrial robots, collectively programmed swarm robots, and even microscopic and nano robots. Robotic hand is the end effector, or robotic hand, can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. Robotic hands are classified as two fingered robotic hand and multi-fingered robotic hand (MFRH).

The multi-fingered robot hand has already been designed and fabricated to accommodate a variety of tasks such as grasping and manipulation of objects in the field of industrial applications. The first step in realising a fully functional multi-fingered robot hand is mathematical modeling. A multi fingered robotic hand model is studied based on the biological equivalent of human hand.

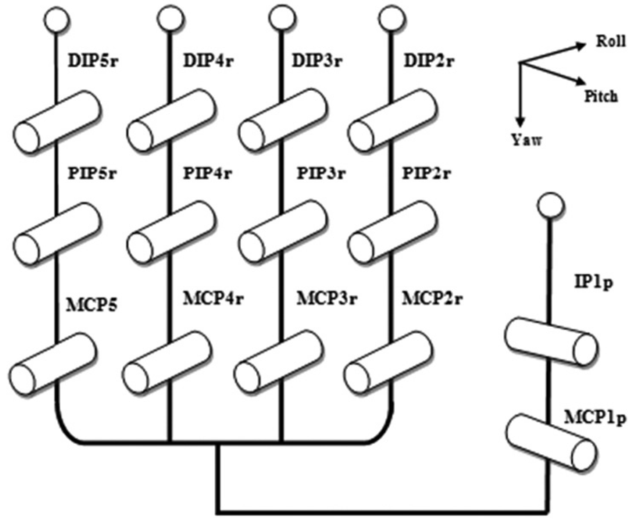

Figure 1. Model of MFRH.

## II. LITERATURE REVIEW

J. Denavit and R.S. Hartenberg [1] described any robot kinematically by giving the values of four quantities for each link. Two describe the link itself, and two describe the link‘s connection to a neighboring link. In the usual case of a revolute joint,  is called the joint variable, and the other three quantities would be fixed link parameters. For prismatic joints, $d_i$ is the joint variable, and the other three quantities are fixed link parameters. The definition of mechanisms by means of these quantities is a convention usually called the Denavit-Hartenberg notation.

John J. Craig. [2] presented a technique for convention and notation which can be used to develop the kinematics and dynamics equation. Victor J. Johnson and Gregory P. Starr [3] develop the kinematic and dynamic equations for one finger of the three-fingered Stanford/JPL robot hand and document the physical parameters needed to implement the equations. The equations can be used in control schemes for position and force control of the Stanford/JPL robot hand. S. Parasuraman, and Ler Shiaw Pei [4] carry out the bio-mechanical analysis of human joints and the study is extended to the robot manipulator. The paper focused on the kinematics of human arm which include the movement of each joint in shoulder, wrist, elbow and finger complexes. Those analyses are then extended to the design of a human robot manipulator.

Valentin Grecu *et al*. [5] articulate that the finger consists of a set of rigid segments connected with joints. Each finger joint angle will be computed by the given fingertip position and orientation. Izzeldin Ibrahim Mohamed Abdelaziz [6] focus on the design of compact five fingers real time smart glove to emulate the human hand functions that can be used as a prototype model for hand rehabilitation systems for patients suffering from paralyze or contracture. This work tried to emulate the grip function and develop a prototype model. Kosuge and Furuta [7] presented a quantitative measure of controllability of robot arms. This measure is representative of the input-output relation of a robot arm at a point, and related to both kinematic and dynamic properties of the arm including actuators. The analysis presented in this paper is efficient for the design of an arm and also seems to be useful for control problems such as the optimum path planning, the singularity and obstacle avoidance. Wan Faizura Binti Wan Tarmizi, *et al.* [8], gave the complete derivation of the mathematical modeling comprising the kinematics and dynamic of multi fingered robotic hand which was carried out using Denavit Hartenburg (DH) algorithm[1] and Euler Langrange formula [2] to enable subsequent simulation work.

In this paper, a robotic hand model is proposed based on the biological equivalent of human hand where each links interconnect at the meta-carpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints respectively. Ohol S. S. and Kajale S. R. [9], adopt a Biomimetic approach for the gripper design because the stable grasp can only be achieved with multi-fingered grippers. This work provides information on design of Multi-fingered Robot Gripper (MRG) with biomimetic approach. The study elaborates various aspects of design while developing the universal dexterous grasping system.

Ramasamy and Arshad [10] presented technique to simulate a robotic hand that emulates the shape and performance of a human hand (*i.e.* palm and fingers section). The graphic design is used as a foundation to find the kinematics and dynamic properties of the robotic hand. The paper gives insight to find the properties such as velocity, acceleration and torque for a desired movement or coordinates of the robotic hand graphics.

E.A. Al-Gallaf [11], presents a novel neural network for dexterous hand-grasping inverse kinematics mapping used in force optimization. This is done by considering the inverse hand Jacobian, in addition to the interaction between hand fingers and the object. Their neural-network approach has the advantages that the complexity for implementation is reduced, and the solution accuracy is increased, by avoiding the linearization of quadratic friction constraints. Simulation results show that the proposed neural network can achieve optimal grasping force.

Jack *et al.* [12] use feed-forward neural networks to solve the inverse kinematics problem which is examined for three different cases. A closed kinematic linkage is used for mapping input joint angles to output joint angles. A three-degree-of-freedom manipulator in 3D space is used to test mappings from both Cartesian and spherical coordinates to manipulator joint coordinates. This paper also shows the use of a new technique which reduces neural network mapping errors with the use of error compensation networks. Ohol and Kajale [13] focused on enhancing the grasping ability with better sensors backup, which can enable the robot to deal with real life situations. to design gripper by experimenting with various designs for developing the universal dexterous grasping.

Muhammad E. Abdalla*, et al*. [14], present a joint-space torque control law that demonstrates both a decoupled and significantly faster response than an equivalent tendon-space formulation. A tension distribution algorithm is presented here to allocate forces from the joints to the tendons. The control law and tension distribution algorithm are implemented on the robotic hand of Robonaut-2.

Jasper Schuurmans *et al.* [15] discussed the optimization of the ratio between highest and lowest force on the proximal phalanges from 4.0 to 2.9 which tend to drive objects out of the grasp when the finger flexes. An extra bi-articular tendon was added to the mechanism, which further improved this ratio to 1.5 with stably grasps and holds objects.

Guan Yisheng and Zhang Qixian [16], investigate manipulation of an object interacting with the environment. Position manipulation was accomplished by three kinematic algorithms, and force manipulation was fulfilled through position control. The feasibility and efficacy of the proposed approach have been verified experimentally on Hkust Hand.

Nakamura and Yamane [17] explore the dynamic computation of structure varying kinematic chains which imply mechanical link systems whose structure may change from open kinematic chain to closed one and vice versa. The computation is developed on the foundation of the dynamics computation algorithms established in robotics, which is superior in efficiency due to explicit use of the generalized coordinates to those used in the general-purpose motion analysis softwares.

Saha [18] discusses constrained dynamic equations of motion of serial multi-body systems consisting of rigid bodies in a serial kinematic chain. Armstrong and Green [19] presented the dynamics of articulated rigid bodies, an efficient method for solving their equations of motion, and a technique for developing human figure models based on these dynamics. They developed the human figure model and showed that these equations can be solved almost in real time.

Al-Gallaf [20] demonstrates the proposed algorithm for a four fingered robot hand motion, where inverse hand Jacobian plays an important role in the hand dynamics. This paper investigates the employment of a neurofuzzy system for a multi-finger robot hand manipulation tasks. The developed neurofuzzy system approach has been trained for several object training patterns and hand postures within a Cartesian based palm dimension.

Rajko Tomovic *et al*. [21], presented an approach to synthesizing grasping strategies for multi-fingered robot hands, based on biological principles. The fundamental idea behind this approach is reduction of the dimensionality of the world by concentrating on target description using geometric primitives, standard grasping configurations and specific strategies for global and local control.

Antonio Bicchi and Vijay Kumar [22] presented a survey of work in robotic grasping over the last many years. The paper focused on issues that are central to the mechanics of grasping and the finger-object contact interactions. In addition, the review mainly addressed research that has established the theoretical framework for grasp analysis, simulation and synthesis.

Laliberte *et al*. [23] present the development of self adaptive and reconfigurable hands which are versatile and easy to control. These hands have three fingers and each of the fingers has three phalanges. The reconfigurability of the hands is obtained by reorienting the fingers. The design of a three-degree-of-freedom (dof) under-actuated finger, used in all the hands, is first introduced. A first hand, which has 12 DOFS and 6 motors is then presented. Subsequently, by including underactuation among the fingers and coupling their orientation, a second hand with 10 DOFS and 2 motors is obtained. Finally, control issues and experimental results are presented in the paper.

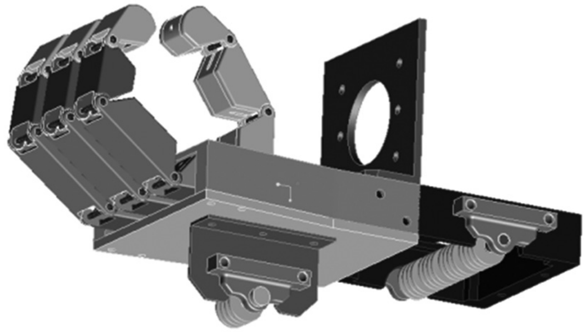

Figure 3. Solid model of the proposed hand.

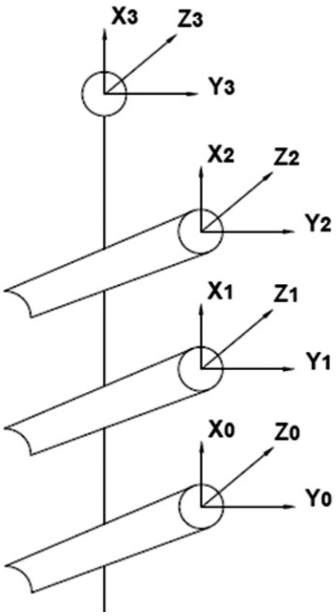

Figure 4: Model of one Finger.

## II. SOLID MODEL

Figure 3 illustrates the solid model of the proposed robot hand. It has four fingers; three fingers are in series and other one opposes the middle of three series fingered. There are three phalanges (links) in each finger. The palm link has fixed joint and consider being the base. Median and distal links have one degree of freedom (dof) rotational joints. The material selected for the hand prototype is aluminum.

Figure 4 shows the model of a finger which has four frames attached to its joints. The base frame is referring the fixed joint, which is indicated as $X_0$, $Y_0$, $Z_0$. $X_1$, $Y_1$, $Z_1$ and $X_2$, $Y_2$, $Z_2$ are representing joint 2 and joint 3 respectively, whereas $X_3$,$Y_3$, $Z_3$ is representing the fingertip position.

## III. FORWARD KINEMATICS

Forward kinematic is used to determine the position and orientation of the fingertip relative to the robot base coordinate system. The derivation of forward kinematic equation is done as follows.

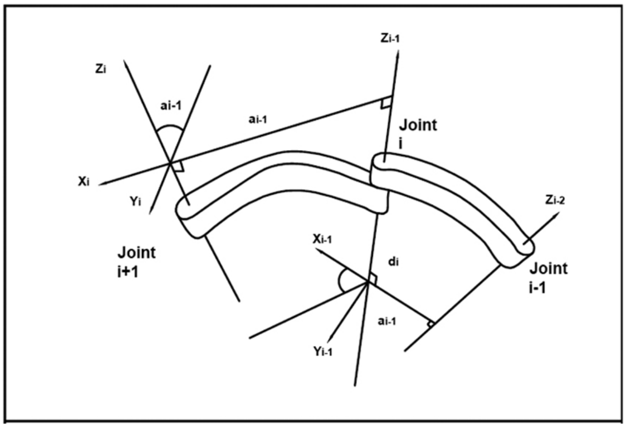

Figure 5. Denavit Hartenberg (DH) frame [1].

Let

$\theta_i$ = Joint angle of the finger

$d_i$ = joint distance of the finger

$a_{i-1}$ = link length of the each joint

$a_{i-1}$ = link twist angle.

The following Homogeneous transform equations are used to determine the transform between base frame $X_0$, $Y_0$, $Z_0$ to the finger tip frame $X_4$, $Y_4$, $Z_4$. Equation (1) is the generalized equation representing the transformation between the frames i-1 and i.

$$
{}^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i & 0 & a_{i-1} \\ S\theta_i C\alpha_{i-1} & C\theta_i C\alpha_{i-1} & -S\alpha_{i-1} & -S\alpha_{i-1} d_i \\ C\theta_i S\alpha_{i-1} & C\theta_i S\alpha_{i-1} & C\alpha_{i-1} & C\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}
$$

Forward Kinematic is used to determine the position and orientation of multi fingered robotic hand to determine the position and orientation of the robot hand relative to the robot base (Palm) coordinate system. The derivation of forward kinematic equation based on following Table1.

TABLE 1
FINGER PARAMETERS

| $i$ | $\theta_i$ | $d_i$ | $a_{i\text{-}1}$ | $\alpha_{i\text{-}1}$ |
|---|---|---|---|---|
| 1 | $\theta_i$ | 0 | 0 | 0 |
| 2 | $\theta_2$ | 0 | $l_1$ (MCP) | 0 |
| 3 | $\theta_3$ | 0 | $l_2$ (PIP) | 0 |
| 4 | $\theta_4 = 0$ | 0 | $l_3$ (DIP) | 0 |

$$
{}^{0}T_1 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}
$$

$$
{}^{1}T_2 = \begin{bmatrix} C_2 & -S_2 & 0 & l_1 \\ S_2 & C_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}
$$

$$
{}^{2}T_3 = \begin{bmatrix} C_3 & -S_3 & 0 & l_2 \\ S_3 & C_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}
$$

Therefore, we can calculate

$$
{}^{0}T_3 = {}^{0}T_1\,{}^{1}T_2\,{}^{2}T_5\,{}^{0}T_3 \tag{5}
$$

$$
{}^{0}T_3 = \begin{bmatrix} C_{123} & -S_{123} & 0 & l_1C_1 + l_2C_{12} \\ S_{123} & C_{123} & 0 & l_1S_1 + l_2S_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}
$$

$$
{}^{3}T_4 = \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}
$$

Therefore, the forward kinematic for the fingers of robot hand are given by:

$$
{}^{0}T_4 = {}^{0}T_1\,{}^{1}T_2\,{}^{2}T_3\,{}^{3}T_4 \tag{8}
$$

$$
{}^{0}T_4 = \begin{bmatrix} C_{123} & -S_{123} & 0 & l_1C_1 + l_2C_{12} + l_3C_{123} \\ S_{123} & C_{123} & 0 & l_1S_1 + l_2S_{12} + l_3S_{123} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}
$$

## IV. INVERSE KINEMATICS

For inverse kinematic, we are given Cartesian coordinates, x, y, and φ. We will be finding the value for $\theta_1$, $\theta_2$, $\theta_3$

such that, $\varphi = \theta_1, \theta_2, \theta_3$ (10)

Inverse kinematics has multiple solutions for a specific position and orientation of the finger tip. If there is a no solution that means the finger cannot attain the given position and orientation because it lies outside of the finger workspace. The existence or nonexistence of a kinematic solution defines the workspace of a given finger.

Let the given orientation be

$$
{}^{i}T_n = \begin{bmatrix} C_\varphi & -S_\varphi & 0 & x \\ S_\varphi & C_\varphi & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}
$$

$$
{}^{0}T_3 = \begin{bmatrix} C_\varphi & -S_\varphi & 0 & x \\ S_\varphi & C_\varphi & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}
$$

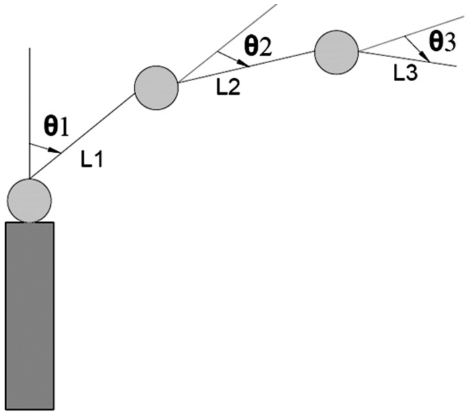

Figure 6. Flexion angles of fingers.

First of all we compare equation (6) and (12) for the fingers.

$$x = l_1C_1 + l_2C_{12}$$
$$x - l_1C_1 = l_2C_{12} \tag{13}$$

$$y = l_1S_1 + l_2S_{12}$$
$$y - l_1S_1 = l_2S_{12} \tag{14}$$

Squaring both side and adding equation (15) and (16) we have to eliminate $\theta_1 + \theta_2$

$$(x - l_1C_1)^2 = (l_2C_{12})^2$$
$$(y - l_1S_1)^2 = (l_2S_{12})^2$$
$$(x - l_1C_1)^2 + (y - l_1S_1)^2 = l_2^2$$
$$xC_1 + yS_1 = \frac{x^2 + y^2 + l_1^2 - l_2^2}{2l_1} \tag{15}$$

Equation (15) is in similar form of

$$P\cos\alpha + Q\sin\alpha + R = 0 \tag{16}$$

Let $x = r\cos\beta$ (17)

$$y = r\sin\beta \tag{18}$$

i.e., $\beta = \arctan 2\left(\frac{y}{x}\right)$ (19)

$$r = \sqrt{x^2 + y^2} \tag{20}$$

And by using above there are two solutions for $\theta_1$

$$\theta_1 = \beta + \sigma\cos^{-1}\left(\frac{x^2 + y^2 + l_1^2 - l_2^2}{2l_2\sqrt{x^2 + y^2}}\right) \tag{21}$$

$$\beta = a\tan 2\left(\frac{y}{\sqrt{x^2 + y^2}}, \frac{x}{\sqrt{x^2 + y^2}}\right) \tag{22}$$

$$\Rightarrow \beta = \arctan 2(y, x) \tag{23}$$

Squaring and adding again equation (15) and (16) we eliminate $\theta_2$

$$x^2 = (l_1C_1 + l_2C_{12})^2$$
$$y^2 = (l_1S_1 + l_2S_{12})^2$$
$$x^2 + y^2 = l_1^2 + l_2^2 + 2l_1l_2C_2$$
$$C_2 = \frac{x^2 + y^2 - l_1^2 - l_2^2}{2l_1l_2} \tag{24}$$

Also we can calculate $\theta_3$

$$C_{12} = \frac{x - l_1C_1}{l_2}$$

and

$$S_{12} = \frac{y - l_1S_1}{l_2}$$

$$\theta_1 + \theta_2 = A\tan\left(\frac{y - l_1S_1}{l_2}, \frac{x - l_1C_1}{l_2}\right) \tag{25}$$

$$\Rightarrow \theta_3 = \varphi - A\tan\left(\frac{y - l_2S_2}{l_3}, \frac{x' - l_2C_2}{l_3}\right) \tag{26}$$

$$\theta_2 = \varphi - (\theta_1 + \theta_3)$$

## V. SOME FINDINGS OF REVIEW

The report [3] has not developed the kinematic and dynamic equations for four-fingered robotic hand and the computation of their dynamics has not been discussed in literature. The study [4] limited to the movement of each joint in shoulder, wrist, elbow and finger complexes and has not done any analysis on the hand finger. The methodology and analysis of human upper arm of the paper [5] can be use and incorporate to the any fingered robotic hand. The three most significant functions of the human hand are to explore, move, and to grip objects. The paper [6] left explore and move function of the human hand. Also it can use for modeling of many fingered robotic hand.

The paper [7] has not considered nonlinear properties such as the effect of the Coriollis and centrifugal term. For the design of the controller of such an arm, this nonlinearity is very important. The results of the paper [8] have not published in till now. Other work such as Newton Euler formulation has not been used. The presented mechanism [9] posses scope of development. It can grip odd size and odd shape object, and further it can be developed for universal gripper system. The grasp system can be designed to get perfect grasp points using a vision sensors input can offer a universal biomimetic gripper system.

The results presented in paper [10] will be helpful in utilizing the existing graphic software for conducting robotic hand simulation, and understanding how to relate the kinematic and dynamic analysis to the actual simulation procedure. The article [11] is computing both the optimal set of fingertip force distribution and an updating mechanism for the interrelated kinematics relation in a multi-fingered robot hand system. The paper [12] has not used an open kinematic linkage for mapping input joint angles to output joint angles. The structure-varying kinematic chains are commonly found in computing human and animal motions, the computation of their dynamics has not been discussed in literature [17]. The work [19] suggests a number of topics for further research. One possible topic is reducing the time required to solve the equations of motion.

## VI. CONCLUSION

This paper presented a survey of work in kinematic and dynamic modeling and analysis of multi-fingered robotic hand over the last many years. It is not possible to justify to all the work in this area, particularly throughout the field and its dexterous manipulation, explore, move, and to grip objects. We presented here a survey on kinematic and dynamic modeling and analysis of multi-fingered robotic hand.

In addition, the review mainly addressed research that has established the theoretical framework for kinematic and dynamic analysis, simulation and synthesis. Because of the limitations on space, we have not given the algorithmic aspects and the applications the attention that they deserve. We hope that this paper find application for further work in the field of robotics hand modeling and analysis.

## VI. REFERENCES

[1]. J. Denavit and R.S. Hartenberg, “A Kinematic Notation for Lower-Pair Mechanisms Based on Matrices,” *Journal of Applied Mechanics*, pp. 215—221, June 1955.

[2]. John J.Craig. *Introduction to Robotics.* 2nd ed. Pearson Education International.

[3]. Victor J. Johnson and Gregory P. Starr., “Kinematic and Dynamic Analyses of the Stanford/ JPL Robot Hand”, Sandia report presented by Sandia National Laboratories, November 1987.

[4]. S. Parasuraman and Ler Shiaw Pei., “Bio-mechanical Analysis of Human Joints and Extension of the Study to Robot”, World Academy of Sc., Engg and Tech, 2008.

[5]. Valentin Grecu, *et al.*, “Analysis of Human Arm Joints and Extension of the Study to Robot Manipulator”, *Proc. International Multi-Conference of Engineers and Computer Scientists 2009,* Volume II IMECS 2009, March 18-20, 2009, Hong Kong

[6]. Izzeldin Ibrahim Mohamed Abdelaziz., “A Low-Cost Smart Glove for Hand Functions Evaluation”, *International Journal of Robotics and Automation,* Volume 3, No. 1, March 2014, pp. 39~51.

[7]. Kazuhiro Kosuge, Katsuhisa Furuta., “Kinematic And Dynamic Analysis Of Robot Arm”, IEEE pp-1039-1044, 1985

[8]. Wan Faizura Binti Wan Tarmizi, et al, “Kinematic and Dynamic Modeling of a Multi-Fingered robot Hand”, *International Journal of Basic & Applied Sciences,* Volume 9, No. 10, pp. 89-96.

[9]. OHOL S. S. and KAJALE S. R., “Biomimetic Approach for Design of Multifingered Robotic Gripper(MRG) and Its Analysis for Effective Dexterous Grasping”, *Proc. 2009 International Conference on Machine Learning and Computing IPCSIT, V*olume 3 (2011), pp. 213-221, Singapore.

[10]. S.Ramasamy and M.R.Arshad,“Robotic hand simulatlon with kinematics and dynamic analysis”, IEEE (2000) page-178-183

[11]. E.A. Al-Gallaf, Multi-fingered robot hand optimal task force distribution Neural inverse kinematics approach, International Journal of Robotics and Autonomous Systems 54 (2006) page-34–51.

[12]. H. Jack, D. M. A. Lee, R. O. Buchaland W. H.Elmaraghy, Neural networks and the inverse kinematics problem, Journal of Intelligent Manufacturing (1993) 4, 43-66.

[13]. S. S. OHOL, S. R. KAJALE, Simulation of Multifinger Robotic Gripper for Dynamic Analysis of Dexterous Grasping, *Proc. World Congress on Engineering and Computer Science*, October 2008, San Francisco, USA.

[14]. Muhammad E. Abdallah, *et al.*, Applied Joint-Space Torque and Stiffness Control of Tendon-Driven Fingers, *Proc. IEEE-RAS International Conference on Humanoid Robots*, Nashville, TN, USA, December 2010.

[15]. Jasper Schuurmans *et al.*, Grasp force optimization in the design of an underactuated robotic hand, Proceedings of the *Proc. IEEE 10th International Conference on Rehabilitation Robotics,* 2007. Noordwijk, The Netherlands pp.776-782

[16]. Guan Yisheng, Zhang Qixian, hybrid position/ force manipulation of multifingered hand , *Chinese Journal Of Aeronautics*, Volume 11, No.2, pp-143-151, May 1998.

[17]. Yoshihiko Nakamura and Katsu Yamane, Dynamics Computation of Structure-Varying Kinematic Chains and Its Application to Human Figures, *IEEE Trans. Robotics and Automation*, Volume 16, No. 2, April 2000 pp. 124-134.

[18]. S. K. Saha, Dynamics of Serial Multibody Systems Using the Decoupled Natural Orthogonal Complement Matrices, *Trans. ASME,* Volume 66, pp-986-996, December, 1999.

[19]. William W. Armstrong and Mark W. Green, The dynamics of articulated rigid bodies for purposes of animation , The Visual Computer (1985) I: pp-231-240.

[20]. E. A. AL-GALLAF, Neurofuzzy Inverse Jacobian Mapping for Multi-Finger Robot Hand Control, *Journal of Intelligent and Robotic Systems*, Volume 39, pp-17–42, 2004.

[21]. Rajko Tomovic, et al, A Strategy For Grasp Synthesis With Multifingered Robot Hands, *Proc. IEEE Conference Robotics and Automation*, pp-83-89, 1987.

[22]. Antonio Bicchi and Vijay Kumar, Robotic Grasping and Contact: A Review , Robotics and Automation, 2000. *Proc. IEEE International Conference. ICRA'00*. pp-348-353

[23]. Thierry Laliberte, *et al.*, Underactuation in robotic grasping hands , *Machine Intelligence & Robotic Control,* Volume 4, No.3, pp-1–11, 2002.

[24]. Panagiotis K. Artemiadis and Kostas J. Kyriakopoulos , “EMG-based Position and Force Control of a Robot Arm: Application to Teleoperation and Orthosis.

[25]. Okada, T.; Tsuchiya, S. : “On a Versatile Finger System”, *Proc. 7th Int. Symposium of Industrial Robots,* 1977.

[26]. Okada, T.: “Computer Control of Multijoined Finger System

for Precise Object Handling", *IEEE Trans. Systems, Man and Cybernetics*, Volume 12, No.3, May/June 1982.

[27]. Jacobson, S.C.; Wood, J.E.; Knutti, D.F.; Biggers, K.B.: "The Utah/MIT Dextrous Hand: Work in Progress", *Proc. First Int. Conf. on Robotics Research*, MIT Press, 1984.

[28]. Jacobson, S.C. et.al.: "Design of the Utah/MIT Dextrous Hand", *Proc. IEEE Int. Conf. on Robotics and Automation,* 1986.

[29]. Narasiham, S.: "Dextrous Robotic Hands: Kinematics and Control", Master thesis, Department of Electrical Engineering and Computer Science, MIT, 1988.

[30]. Salisbury, K.; Brock, D.; Chiu, S.: "Integrated Language, Sensing and Control for a Robot Hand", *Proc. Int. Symp. on Robotics Research*, MIT Press, 1986.

[31]. Nguyen, V.: "Constructing Stable, Force-Closure Grasps", Master Thesis, Department of Electrical Engineering and Computer Science, MIT, 1986.

[32]. Arbib, M.A.; Iberall, T.; Lyons, D.: "Coordinated Control Programs for Movements of the Hand" Center of Systems Neuroscience and Laboratory for Perceptual Robotics, COINS Technical Report 83-25, Massachusetts, 1983.

[33]. Lyons, D.M.: "A simple Set of Grasps for a Dextrous Hand", *Proc. IEEE Int. Conf. on Robotics and Automation,* 1985.

[34]. Iberall, T.: "Grasp Planning for Human Prehension", *Proc. Int. Joint Conf. on Artificial Intelligence,* 1987.

[35]. S.C. Jacobsen, E.K. Inversen, D.F. Knutti, R. T. Johnson and K.B. Biggers, "Design of the Utah/MIT Dexterous Hand, *Proc. 1986 IEEE International Conference on Robotics and Automation*, pp 1520-1532, 1986.

[36]. Man Zhihong, *Robotics for Computer Engineering Students*, Prentice Hall, 2004.

[37]. J. K. Salisbury M.T. Mason: "*Robot Hands and the Mechanics of Manipulation*", MIT Press, Cambrige, MA, 1985.

[38]. Pernell A. Jordan, "Feedback Control Of A Three-LinkPlanar Under-Actuated Manipulator using A "Surge" Velocity", Thesis of Naval Postgraduate School Monterey, California, September 1995.

[39]. Cole, A.; Hauser, J.; Sastry, S.: "Kinematics and Control of Multifingered Hands with Rolling Contact", *Proc. IEEE Int. Conf. on Robotics and Automation*, 1988.

[40]. Hsu, P.; Li, Z.; Sastry, S.: "On Grasping and Coordinated Manipulation by a Multifingered Robot Hand" *Proc. IEEE Int. Conf. on Robotics and Automation,* 1988.

[41]. J.M. Hollerbach and T. Flash, "Dynamic Interactions Between Limb Segments During Planar Arm Movements," *Biol. Cyber.* Volume 44, No. 1, pp. 67-77, 1982.

[42]. R.P. Paul and C.N.Stevenson, "Kinematics of Robot Wrists," *International Journal of Robotics Research, Volume* 2, No. 1, 1983.

[43]. M.H. Raibert and J.J. Craig, "Hybrid Position/Force Control of Manipulators", *Trans. ASME J. Dyn. Sys., Measurement, Contr., Volume* 103, No. 2, pp. 126-133, 1981.

**Md. Zafer Hussain** received the B. Tech. degree in Mechanical Engineering from Aligarh Muslim University Aligarh, Uttar Pradesh in 2004, and the M. Tech. degree in Mechanical Engineering with specialization in Machine Design from the same university in 2007. Pursuing Ph.D. in Mechanical Engineering from Jamia Millia Islamia (A Central University), New Delhi. His teaching and research areas include Vibration, Robotics, Mechatronics, Mechanism and Automation, Nonlinear Dynamics, System Identification, etc. He is currently writing a Textbooks and authored many research papers.

**Dr. M. Suhaib** received the B.Sc. Engg degree in Mechanical Engineering from the Aligarh Muslim University, Aligarh, U.P, in 1990, the M.Sc. Engineering degree in Machine Design from the same university in 1993, and the Ph.D. degree in Mechanical Engineering from the Jamia Millia Islamia (A Central University), New Delhi, 2004. Currently, He is a Professor of Mechanical Engineering at Jamia Millia Islamia. His teaching and research areas include Robotics, Mechatronics, Mechanism and Automation. He has authored/co-authored two textbooks and approximately fifty research papers.