6th International Conference on Recent Innovations in Science, Engineering and Management
IIMT College of Engineering (Approved by AICTE, New Delhi), Knowledge Park III, plot no. 20-A, Greater Noida, Uttar Pradesh (India) (ICRISEM)
20th August 2016, www.conferenceworld.in ISBN: 978-93-86171-03-0

KINEMATIC MODELING OF ROBOTIC HAND

Hussain M.Z[1], Garga R[2]

[1,2] *Associate professor, Department of Mechanical Engineering,*
IIMT College of Engineering,Greater Noida,(India)

ABSTRACT

This paper presented a kinematic and analysis of multi-fingered robotic hand. The paper has an insight toward the development of the theoretical framework and analytical results in this area of multi fingered robotic hands will be presented next publication. We mainly addressed research that has established the theoretical framework for kinematic 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

I. INTRODUCTION

A robot is an automatic mechanical device often resembling a human or animal. Modern robots are usually an electro-mechanical machine 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 & 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. The of Robotic hands are classified as two fingered robotic hand and multi-fingered robotic hand (MFRH)

The Multi-fingered robot hand have 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.

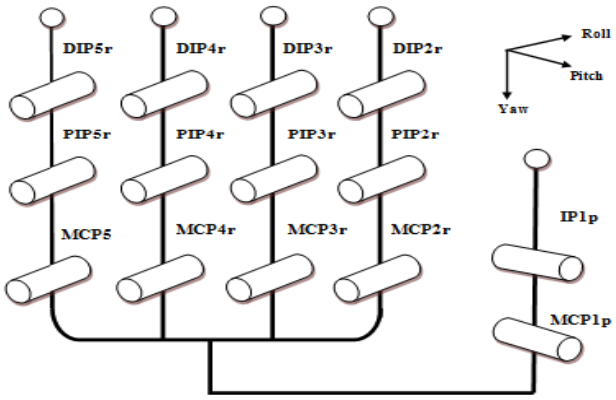

Fig.1. Model of MFRH

 ISBN: 978-93-86171-03-0

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, θ_i 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, Gregory P. Starr [3]** develops the kinematic and dynamic equations for one finger of the three-fingered Stanford/JPL robot hand and documents the physical parameters needed to implement the equations. **S. Parasuraman, and Ler Shiaw Pei [4]**, the bio-mechanical analysis of human joints is carried out and the study is extended to the robot manipulator.. **Valentin Grecu, et. Al. [5] They** articulate the finger consists of a set of rigid segments connected with joints. Each finger joint angles will be computed by the given fingertip position and orientation. **Izzeldin Ibrahim Mohamed Abdelaziz [6], they** 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. **Kazuhiro Kosuge, Katsuhisa Furuta [7], they have 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. **Wan Faizura Binti Wan Tarmizi, et al [8],** the complete derivation of the mathematical modeling comprising the kinematics and dynamic of multi fingered robotic hand was carried out by using Denavit Hartenburg (DH) algorithm[1] and Euler Langrange formula [2] to enable subsequent simulation work. **Ohol S. S. and Kajale S. R. [9], A** Biomimetic approach is adopted for the gripper design because the stable grasp can only be achieved with multi-fingered grippers. **S.Ramasamy and M.R.Arshad [10],** the work presented in this paper is 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. **E.A. Al-Gallaf [11],** present 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. **H. Jack, et. al. [12],** the use of feed forward neural networks to solve the inverse kinematics problem is examined for three different cases. A closed kinematic linkage is used for mapping input joint angles to output joint angles. **S. S. OHOL & S. R. KAJALE [13], they** 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. Abdallah, et al [14], they** presents 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], they** 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. **Guan Yisheng & Zhang Qixian [16],** the paper investigates manipulation of an object interacting with the environment. Position manipulation was accomplished by three kinematic algorithms, and force manipulation was fulfilled through position control.

III. FORWARD KINEMATICS

Fig. 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.

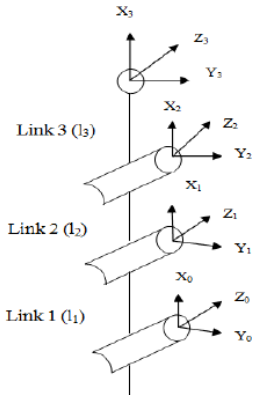

Fig. 4: Model of One Finger

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.

Where,

θ_i = Joint angle of the finger

d_i = joint distance of the finger

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

α_{i-1} = link twist angle

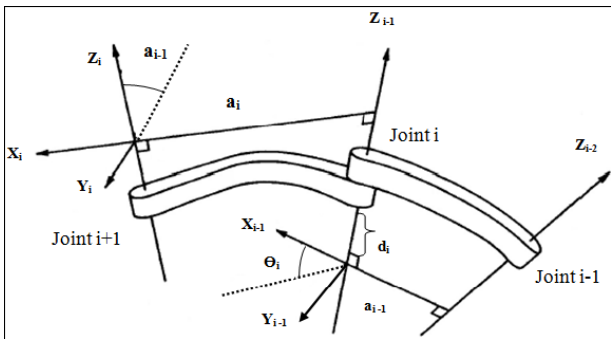

Fig.5. Denavit Hartenberg (DH) frame [1]

 ISBN: 978-93-86171-03-0

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.

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

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	θ_i	d_i	a_{i-1}	α_{i-1}
1	θ_1	0	0	0
2	θ_2	0	l_1 (MCP)	0
3	θ_3	0	l_2 (PIP)	0
4	$\theta_4 = 0$	0	l_3 (DIP)	0

$$ {}^{0}T_1 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{---(2)} $$

$$ {}^{1}T_2 = \begin{bmatrix} C_2 & -S_2 & 0 & l_1 \\ S_2 & C_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{---(3)} $$

$$ {}^{2}T_3 = \begin{bmatrix} C_3 & -S_3 & 0 & l_2 \\ S_3 & C_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{---(4)} $$

Therefore, we can calculate

$$ {}^{0}T_3 = {}^{0}T_1 {}^{1}T_2 {}^{2}T_5 {}^{0}T_3 \quad \text{--- (5)} $$

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

 ISBN: 978-93-86171-03-0

$$ {}^{3}T_4 = \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{---(7)} $$

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

$$ {}^{0}T_4 = {}^{0}T_1 {}^{1}T_2 {}^{2}T_3 {}^{3}T_4 \quad \text{--- (8)} $$

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

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 as, $\phi = \theta_1 + \theta_2 + \theta_3$ ------ (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

$$ {}^{i}T_n = \begin{bmatrix} C_\phi & -S_\phi & 0 & x \\ S_\phi & C_\phi & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{------ (11)} $$

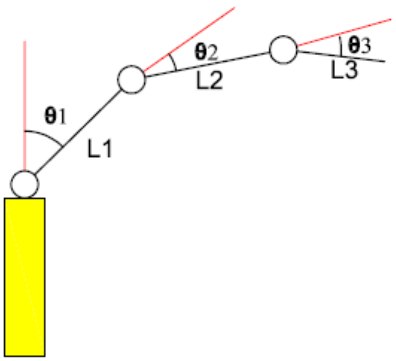

Fig. 6: Flexion Angles of Fingers

 ISBN: 978-93-86171-03-0

$$ {}^{0}T_{3} = \begin{bmatrix} C_\phi & -S_\phi & 0 & x \\ S_\phi & C_\phi & 0 & y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{------ (12)} $$

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

$$x = l_1 C_1 + l_2 C_{12}$$

$$x - l_1 C_1 = l_2 C_{12} \quad \text{------ (13)}$$

$$y = l_1 S_1 + l_2 S_{12}$$

$$y - l_1 S_1 = l_2 S_{12} \quad \text{------ (14)}$$

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

$$(x - l_1 C_1)^2 = (l_2 C_{12})^2$$

$$(y - l_1 S_1)^2 = (l_2 S_{12})^2$$

$$(x - l_1 C_1)^2 + (y - l_1 S_1)^2 = l_2{}^2$$

$$x C_1 + y S_1 = \frac{x^2 + y^2 + l_1^2 - l_2{}^2}{2 l_1} \quad \text{------ (15)}$$

Equation (15) is in similar form of

$$P\cos\alpha + Q\sin\alpha + R = 0 \quad \text{------ (16)}$$

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

$$y = r\sin\beta \quad \text{------ (18)}$$

i.e., $\beta = \arctan 2\left(\frac{y}{x}\right)$ ---- (19) $\qquad r = \sqrt{x^2 + y^2}$ ----- (20)

And by using above there are two solutions for θ_1

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

 ISBN: 978-93-86171-03-0

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

$$\Rightarrow \beta = \arctan 2(y, x) \quad \text{----- (23)}$$

Squaring and adding again equation (15) and (16) we have eliminate θ_2

$$x^2 = (l_1C_1 + l_2C_{12})^2$$

$$y^2 = (l_1S_1 + l_2S_{12})^2$$

$$x^2 + y^2 = l_1^2 + l_2^2 + 2l_1l_2C_2$$

$$C_2 = \frac{x^2 + y^2 - l_1^2 - l_2^{\,2}}{2l_1l_2} \quad \text{------ (24)}$$

Also we can calculate θ_3

$C_{12} = \frac{x - l_1C_1}{l_2}$ and $S_{12} = \frac{y - l_1S_1}{l_2}$

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

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

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

V. FINDINGS

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. 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.

 ISBN: 978-93-86171-03-0

VI. CONCLUSION

This paper presented akinematic modeling and analysis of multi-fingered robotic hand. 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 about kinematic modeling and analysis of multi-fingered robotic hand. In addition, we mainly addressed research that has established the theoretical framework for kinematic 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.

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, 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 Robo", 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", Proceedings of the International Multi-Conference of Engineers and Computer Scientists 2009 Vol II IMECS
6. Izzeldin Ibrahim Mohamed Abdelaziz., "A Low-Cost Smart Glove for Hand Functions Evaluation", International Journal of Robotics and Automation (IJRA) Vol. 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. [8] Wan Faizura Binti Wan Tarmizi, et al, "Kinematic and Dynamic Modeling of a Multi-Fingered robot Hand", International Journal of Basic & Applied Sciences Vol: 9 No: 10 page 89-96
9. OHOL S. S. and KAJALE S. R., "Biomimetic Approach for Design of Multifingered Robotic Gripper(MRG) & Its Analysis for Effective Dexterous Grasping", 2009 International Conference on Machine Learning and Computing IPCSIT vol.3 (2011),page-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, Proceedings of the World Congress on Engineering and Computer Science, October 22-24, 2008, San Francisco, USA.

14. Muhammad E. Abdallah, et al, Applied Joint-Space Torque and Stiffness Control of Tendon-Driven Fingers, IEEE-RAS International Conference on Humanoid Robots Nashville, TN, USA, December 6-8, 2010
15. Jasper Schuurmans et al, Grasp force optimization in the design of an underactuated robotic hand, Proceedings of the 2007 IEEE 10th International Conference on Rehabilitation Robotics, June 12-15, Noordwijk, The Netherlands pp.776-782
16. Guan Yisheng, Zhang Qixian, hybrid position/ force manipulation of multifingered hand , Chinese Journal Of Aeronautics, Vol. 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 Transactions On Robotics And Automation, Vol. 16, No. 2, April 2000 pp-124-134
18. S. K. Saha, Dynamics of Serial Multibody Systems Using the Decoupled Natural Orthogonal Complement Matrices, Transactions of the ASME, Vol. 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 39: pp-17–42, 2004.
21. Rajko Tomovic, et al, A Strategy For Grasp Synthesis With Multifingered Robot Hands, Proceeding of IEEE Conference on Robotics and Automation, pp-83-89, 1987.
22. Antonio Bicchi and Vijay Kumar, Robotic Grasping and Contact: A Review , Robotics and Automation, 2000. Proceedings. ICRA'00. Pp-348-353 IEEE International Conference
23. Thierry Laliberte, et al, Underactuation in robotic grasping hands , Machine Intelligence & Robotic Control, Vol. 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. of the 7th Int. Symposium Of Industrial Robots, 1977.
26. Okada, T.: "Computer Control of Multijoined Finger System for Precise Object Handling“, IEEE Trans. on Systems, Man and Cybernetics, vol. 12 (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", First Int. Conf. on Robotics Research, MIT Press, 1984.
28. Jacobson, S.C. et.al.: "Design of the Utah/MIT Dextrous Hand", Proc. of the 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. of 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.

 ISBN: 978-93-86171-03-0

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. of the IEEE Int. Conf. on Robotics and Automation, 1985.
34. Iberall, T.: "Grasp Planning for Human Prehension", Proc. of the 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, Proceedings of the 1986 IEEE International Conference on Robotics and Automation, pp 1520-1532, 1986.