International Journal of Robotics and Automation (IJRA)
Vol. 1, No. 2, June 2012, pp. 69~77
ISSN: 2089-4856

Design and Analysis of a Multifingered Robot Hand

Pramod Kumar Parida, Bibhuti Bhusan Biswal
Department of Mechanical Engineering
National Institute of Technology
Rourkela-749008, Odisha, India, telp/fax (+91)661 2474840

Article Info

Article history:

Received Apr 12, 2012
Revised May 20, 2012
Accepted May 27, 2012

Keyword:

robot hand
anthropomorphic
kinematic analysis
manipulation
simulation

ABSTRACT

With the advent of new control techniques and development of microactuators, manipulator designers have gained inpetus todevelop manipulators and the related devicesthat is more flexible, responsive, smart and anthropomorphic.Taking cue from the work of a number of researchersover a couple of decades, the present work is a systematic attempt to develop a five fingered anthropomorphic robotic hand with 25 DoFs. The hand closely follows the anatomy of a typical human hand. The paper presents the structure of the proposed hand and its model for kinematic analysis. The kinematic analysis has been carried out using conventional method using MATLab software. The result obtained through the analysis confirmed that the robot hand conforms to the objective.

Corresponding Author:

First Author
Department of Mechanical Engineering, National Institute of Technology Rourkela-749008, Odisha, India,
telp/fax (+91)661 2474840
e-mail: pramodparida71@yahoo.com

1. INTRODUCTION

An effective robot hand should be multifunctional, adaptive and flexible. It is always desirable to develop a robotic hand which can mimic a human hand. Over last few decades researchers have been trying to develop various multi-fingered robot hands, which can be used for a specific set of applications. In these days the multi-fingered hands find their potential applications in many applications in industrial, domestic, allied services and medical environments. Especially in case of assistive and artificial limbs the hand should be anthropomorphic. However as the number of fingers increases and the number of degrees of freedom on a single finger or on the whole of hand increase, the actuation mechanism and the associated control architecture become complicated. Therefore most of the multi fingered hands with large number of DoFs are underactuated. Stable grasping and fine manipulation with the multi finger rodot hands are playing an important role in the field of manufacturing, rehabilitation and other applications that require precision and dexterity[1]. Dexterous grasping is the specific task and it has been accepted and adopted by many researchers as apriority issue while designing the hands. The essential modifications related to the robotic grippers such as improved force sensing capacity and improved flexibilities at the gripping are to be implemented.The multi-fingered robot hand acts as a multipurpose gripping device for various tasks with multiple-degrees-of-freedom. Some of the important multi-fingered hands are WENDY hand [2], Utah/MIT hand [3], DLR hand [4], Shadow Dexterous Hand [5], Robonaut hand [6], NAIST-Hand [7] and Gifu hand [8].

Vardy proposed a hand model that is based on Denavit-Hartenberg convention [9]. The structure of all the fingers of the model is same, so the convention is applied to all fingers in the same manner. Each finger has five DoFs: one DoF corresponding to the part of carpometacarpal articulation considered as belonging to the respective finger, two DoFs corresponding to metacarpophalangeal articulation, one DoF corresponding to proximal-interphalangeal (PIP) articulation and one DoF corresponding to distal-interphalangeal (DIP). The thumb has a different structure: three DoFs corresponding to the carpometacarpal (CMC) articulation, two DoFs corresponding to metacarpophalangeal (MCP) articulation, and one DoF corresponding to the interphalangeal (IP) articulation. Very similar with the model of Vardy, Yasumuro [10] proposed a hand model. This model has the same structure, only the CMC articulation of the thumb has two DoFs. Also, the wrist is modeled as having six DoFs with three rotations and three translations. The fixed coordinate system with respect to which the whole motion is analyzed is placed outside of the hand's area. Yasumuro used this model to create, from surfaces, a 3D model of the human hand and animated it based on a dynamic model in a human like manner. Albrecht [11] followed the models of Vardy. But unlike the Vardy’s model the number of DoFs in CMC area is different; the thumb has three DoFs, the ring and little fingers have two DoFs and index and middle fingers have no motion. Wu and Huang [12] treated the hand as a set of sub-objects, each of them being separately modeled. The skeleton of a hand is abstracted as a stick figure so that the dimension of each sub-object was reduced to its link length. Each finger is modeled as a kinematical chain with the palm as its base reference frame. The model does not consider the radio carpal articulation (wrist). Each fingertip is the end-effector of the respective finger kinematical chain. Based on the two models, developed by Wu [12] & Kuch[13], a kinematical model intended to be suited for measuring and displaying fine fingertip manipulations was developed. The base coordinate system was located in the hand at the point where the thumb and the index metacarpal meet. The index finger was defined similarly to that presented by Rohling [14].The model studies only these fingers, the three others adopting the index model. Such type of hand has advantage that the hand can be used with various types of robot arms because the robot hand has independant structure. Most of this type of robot hand has equal or less than four fingers [15]. Even those with five fingers are not equal with human hand because they have less number of joints or degrees of freedom.The robot hands with five fingers and anthropometric structure are helpful for the patients who are partially paralyzed due to neurological or orthopedic impairment [16]. The need for improving the multi-fingered robot hand arises from the desire forhandling objects of complicated shapes effectively.Therefore the mechanical design plays an importtant role in the development of the present hand.In this paper we only concentrate on the kinematic analysis of the anthropomorpphic robot hand and consider the wrist as a fixed. The hand is an articulated structure. All fingers in the model have the same essential structure, having different degrees of freedom, so the same convention is applied to all fingers. The fixed coordinate system with respect to which the whole motion is analyzed is placed outside of the hand's areai.e. at wrist. DoFs in CMC area is different with thumb having two DoFs, the ring and little fingers have two DoFs and index and middle fingers have no motion. The skeleton of a hand is abstracted as a stick figure so that the dimension of each sub-object is reduced to its link length. Each finger is modeled as a kinematical chain with the palm as its base reference frame. The model does not consider the radio carpal articulation (wrist). Each fingertip is considered to be the end-effecter of the respective finger kinematical chain.

The aim of the present study is to obtain a kinematic model of the anthrpomorphic robot hand, as natural as possible and to make it capable of realizing various tasks in 3D environment. The analysis of the forward kinematics of the proposed model is studied by representing the active space as a complex surface (reach envelope) with respect to wrist.

2. KINEMATIC MODEL

The multi-fingered robot hand acts as a multipurpose gripping device for various tasks. Since it is designed to mimic the human hands, most anthropomorphic robot hands duplicate the shape and functions of human hands. The structure of the designed anthropomorphic hands is almost the same as that of a human hand as shown in Fig. 1. The finger segments in human hand give us the inspiration to design an independently driven finger segment to construct a whole finger. The segmental lengths of the thumb and fingers are taken proportionately to hand length and hand breadth with a fixed wrist.Typically the hand motion is approximated to have 27 DoFs, which includes 2 DoFs at wrist. In the present study we consider the wrist as a fixed origin and hence the two DoFs at this point are not considered and other 25 DoFs are considered. The thumb is modeled with 5 DoFs.The index and middle fingers are modeled with 4 DoFs each. The ring and little fingers are modeled with 6 DoFs each considering two degrees of freedom each at Carpometacarpel (CMC) joint for palm arch. The Trapeziometacarpal (TM) joint, all five Mecapophalangeal (MCP) joints and two CMC jointsare considered with two rotational axes each for both abduction-adduction and flexion-extension. The Interphalangeal (IP) joint on the thumb, the Proximal-Interphalangeal (PIP) and Distal- Interphalangeal (DIP) joints on the other four fingers possess 1 DoF each for the flexion-extension rotational axes. Fig.1 illustrates the proposed hand model while the parameters of the thumb and other fingers are tabulated in Table 4 and Table 5 respectively.

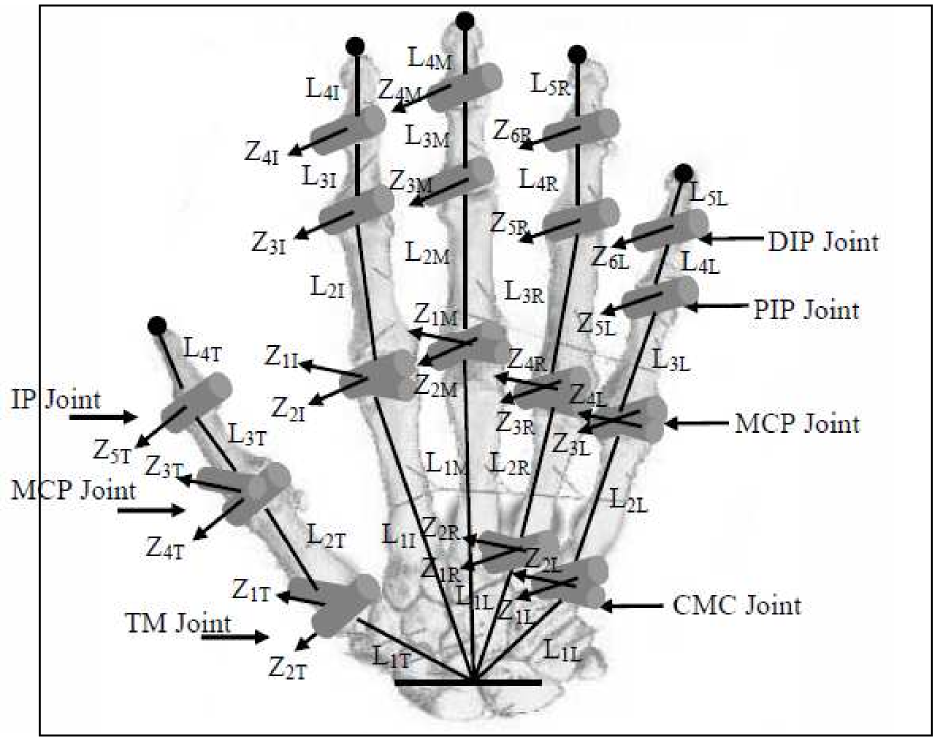

Figure 1. Kinematic model of hand

Table 1. DH Table of thumb.

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint Distance(d_i)	Joint angle(θ_i)
1T	0^0	L_{1T}	0	θ_{1T}
2T	-90^0	0	0	θ_{2T}
3T	90^0	L_{2T}	0	θ_{3T}
4T	-90^0	0	0	θ_{4T}
5T	0^0	L_{3T}	0	θ_{5T}
ε_T	0^0	L_{4T}	0	0

Table 2 DH Table of index and middle fingers

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint distance(d_i)	Joint angle(θ_i)
1F	0^0	L_{1F}	0	θ_{1F}
2F	-90^0	0	0	θ_{2F}
3F	0^0	L_{2F}	0	θ_{3F}
4F	0^0	L_{3F}	0	θ_{4F}
ε_F	0^0	L_{5F}	0	0

Table 3 DH Table of ring and little fingers

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint Distance(d_i)	Joint angle (θ_i)
1F	0^0	L_{1F}	0	θ_{1F}
2F	-90^0	0	0	θ_{2F}
3F	90^0	L_{2F}	0	θ_{3F}
4F	-90^0	0	0	θ_{4F}
5F	0^0	L_{3F}	0	θ_{5F}
6F	0^0	L_{4F}	0	θ_{6F}
ε_F	0^0	L_{5F}	0	0

2.1. Anthropometric data and joint limits

As there were no exact anthropometric data for the segmental lengths of the human hand, the estimated measurement are made following standard formulae as tabulated in table 4 and table 5, where HL is Hand Length and HB is Hand Breadth [17] as shown in Fig. 2.

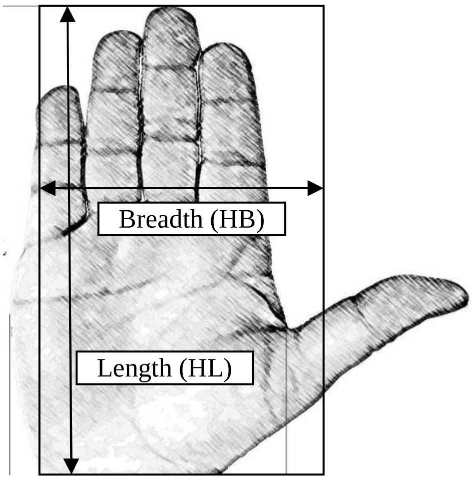

Figure 2. Parametric lengths of hand

Table 4. Segment length for thumb

Finger	Metacarpal bones	Length
Thumb	0.251**HL*	L_{2T}
Index	$\sqrt{(0.374 * HL)^2 + (0.126 * HB)^2}$	L_{2I}
Middle	0.373**HL*	L_{2M}
Ring	$\sqrt{(0.336 * HL)^2 + (0.077 * HB)^2}$	L_{2R}
Little	$\sqrt{(0.295 * HL)^2 + (0.179 * HB)^2}$	L_{2L}

Table 5. Segment length for fingers

Fingers	Proximal	Length	Middle	Length	Distal	Length
Thumb	0.196**HL*	L_{3T}	-	-	0.158**HL*	L_{4T}
Index	0.265**HL*	L_{3I}	0.143**HL*	L_{4I}	0.097**HL*	L_{5I}
Middle	0.277**HL*	L_{3M}	0.170**HL*	L_{4M}	0.108**HL*	L_{5M}
Ring	0.259**HL*	L_{3R}	0.165**HL*	L_{4R}	0.107**HL*	L_{5R}
Little	0.206**HL*	L_{3L}	0.117**HL*	L_{4L}	0.093**HL*	L_{5L}

The angle limits for different joints tabulated in Table 6, Table 7, Table 8, Table 9 and Table 10 for different fingers, considered from work of Parsuramna and Zuen [18].

Table 6. Joint Limits of Thumb

Joints	Rotation	θ_i	θ_{min}	θ_{max}
TM	Abduction-Adduction	θ_{1T}	0	π/3
	Flexion-Extension	θ_{2T}	-5π/36	7π/36
MCP	Abduction-Adduction	θ_{3T}	0	π/3
	Flexion-Extension	θ_{4T}	-π/18	11π/36
IP	Flexion-Extension	θ_{5T}	-π/12	4π/9

Table 7. Joint limits of index finger

Joints	Rotations	θ_i	θ_{min}	θ_{max}
MCP	Abduction-Adduction	θ_{1I}	-π/6	π/6
	Flexion-Extension	θ_{2I}	-π/18	π/2
PIP	Flexion-Extension	θ_{3I}	0	π/2
DIP	Flexion-Extension	θ_{4I}	0	π/3

Table 8. Joint limits for middle finger

Joints	Rotations	θ_i	θ_{min}	θ_{max}
MCP	Abduction-Adduction	θ_{1M}	-2π/45	7π/36
	Flexion-Extension	θ_{2M}	0	4π/9
PIP	Flexion-Extension	θ_{3M}	0	5π/9
DIP	Flexion-Extension	θ_{4M}	-π/18	π/2

Table 9. Joint limits for ring finger

Joints	Rotations	θ_i	θ_{min}	θ_{max}
CMC	Abduction-Adduction	θ_{1R}	0	π/18
	Flexion-Extension	θ_{2R}	π/90	π/18
MCP	Abduction-Adduction	θ_{3R}	-14π/180	π/9
	Flexion-Extension	θ_{4R}	0	4π/9
PIP	Flexion-Extension	θ_{5R}	0	5π/9
DIP	Flexion-Extension	θ_{6R}	-π/6	π/2

Table 10. Joint limits for little finger

Joints	Rotations	θ_i	θ_{min}	θ_{max}
CMC	Abduction-Adduction	θ_{1L}	0	π/12
	Flexion-Extension	θ_{2L}	π/36	π/12
MCP	Abduction-Adduction	θ_{3L}	-19π/180	11π/60
	Flexion-Extension	θ_{4L}	0	4π/9
PIP	Flexion-Extension	θ_{5L}	0	5π/9
DIP	Flexion-Extension	θ_{6L}	-π/6	π/2

3. KINEMATIC ANALYSIS

Forward kinematics is used to determine the position and orientation of the proposed hand model with respect to fixed point i.e. wrist. For this purpose a kinematic model is developed using the given joint angles, the fingertip position in the palm frame is calculated with respect to MCP joints of Middle and Index finger, TM joint of thumb and CMC joint of ring and little finger.The origins are located at the respective joints marked as O_1,O_2,O_3 , O_4 and O_5 as shown in Fig. 3.

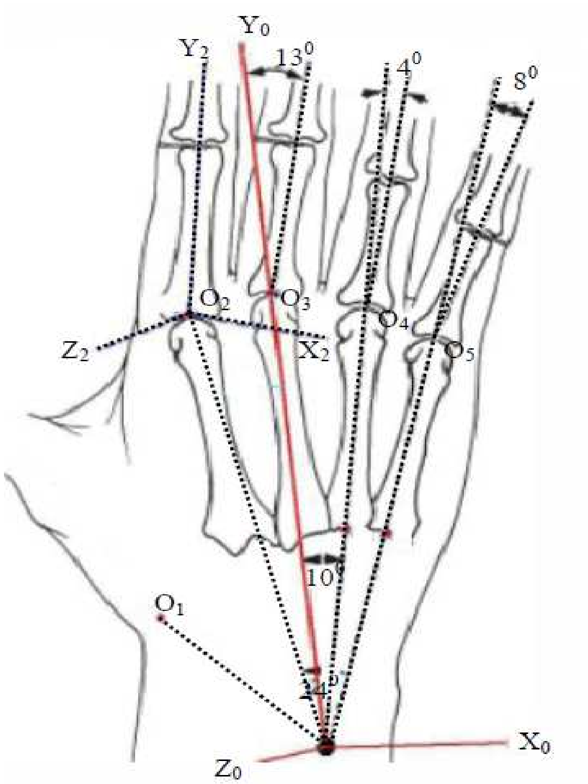

Figure 3. Global co-ordinate system

The DH method is implemented to determine the DH parameters for all the fingers which are tabulated in Table 1, Table 2 and Table 3. The global coordinate system for hand is located in the wrist as shown in Fig.2. In order to carry out the mikematic analysis and find out the reachability of the individual fingers as well as the workspace of the entire hand, it is essential to make use of a suitable algorithm and transfer process. The present work uses the DH algorithm and following transformation matrix for the purpose.

$$^{i-1}T_i = \begin{bmatrix} \cos q_i & -\sin q_i \cos\alpha_i & \sin q_i \sin\alpha_i & L_i \cos q_i \\ \sin q_i & \cos q_i \cos\alpha_i & -\cos q_i \sin\alpha_i & L_i \sin q_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where, i= Joint Number

T= Transfer matrix at a particular joint.

q= Joint angle.

α= Link twist angle.

L=Link or finger segment length.

d= Joint distance

By multiplying the corresponding transfer matrices of joints of each finger as presented

$$^{0}T_n = {}^{0}T_1 \, {}^{1}T_2 \, {}^{2}T_3 \cdots\cdots\cdots {}^{n-1}T_n \quad (2)$$

Where, n= Nubmber of joints of one finger.

By multiplying the corresponding transfer matrices written for every finger as in Eq. 2,the kinematical equations describing the fingertip motion with respect to the general coordinate system can be determined.It is now possible to develop a model using Eq.1 and Eq.2. A computer program using these equations in MATLAB is developed to capture the motion of the fingers. Every joint variable range as per data is divided to an appropriate number of intervals in order to have enough fingertips positions to give confident images about the spatial trajectories of these points. By connecting these positions and the complex surface bordering the active hand model workspace is obtained. The complex surface could be used to verify the model correctness from the motion point of view, and to plan the hand motion by avoiding the collisions between its active workspace and obstacles in the neighborhood.

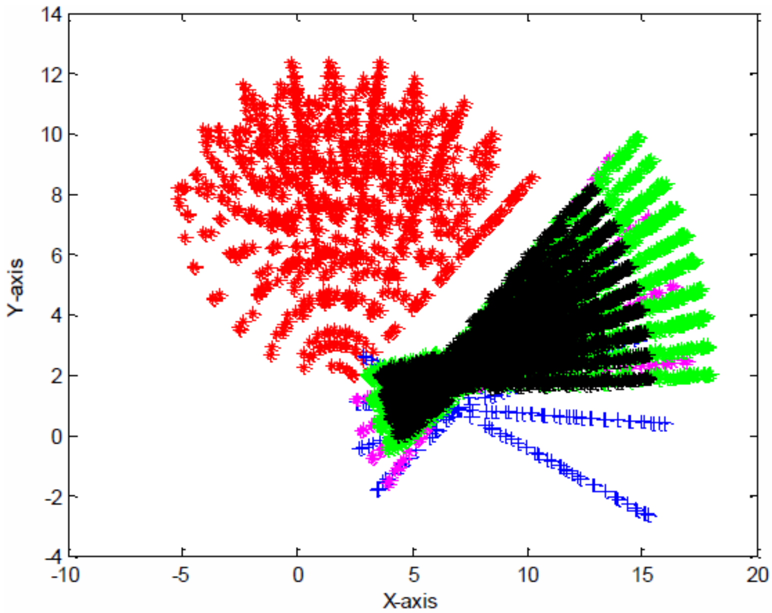

Figure 4. Profile of fingertips in the X-Y plane

4. RESULTS

Using the Eq.1and Eq.2 along with the parametric data of human fingers presented in Table 4 and Table 5 the complex surface described by each finger tip is generated. In all the cases each angular range is divided into equal divisions. The profiles generated through the simulation of the independent finger tips are spatial. The different colour specifies for different fingers i.e. red for thumb, blue for Index finger, magenta for middle finger, green for ring finger and black for little finger.However, for the purpose of understanding and simplicity, these are presented in X-Y, X-Z and Y-Z planes in Fig. 4, Fig. 5 and Fig. 6 respectively. The profiles of the five finger tips in the 3-D plane are presented in Fig.7.

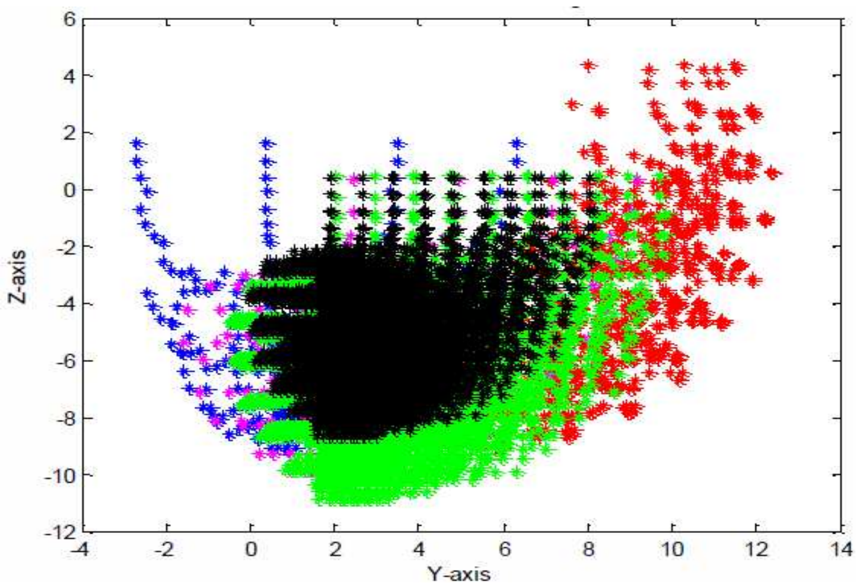

Figure 5. Profile of fingertips in the Y-Z plane

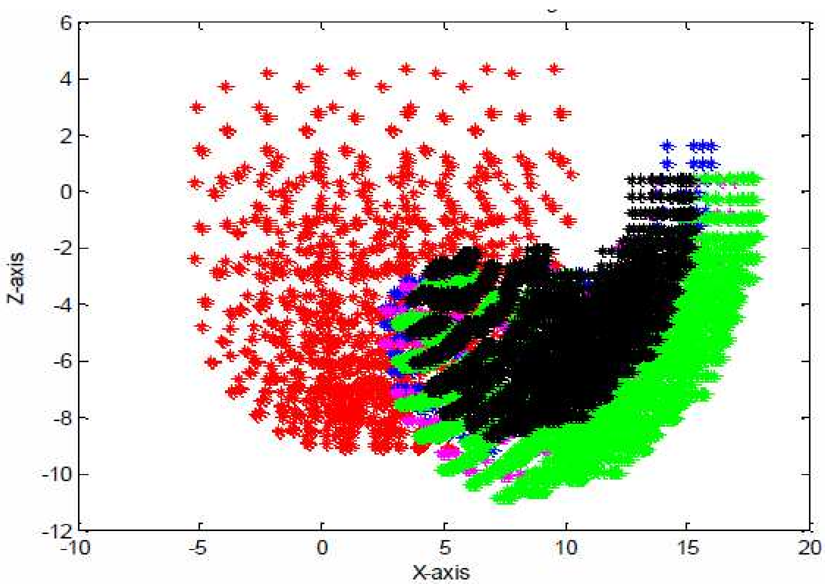

Figure 6. Profile of fingertips in the X-Z plane

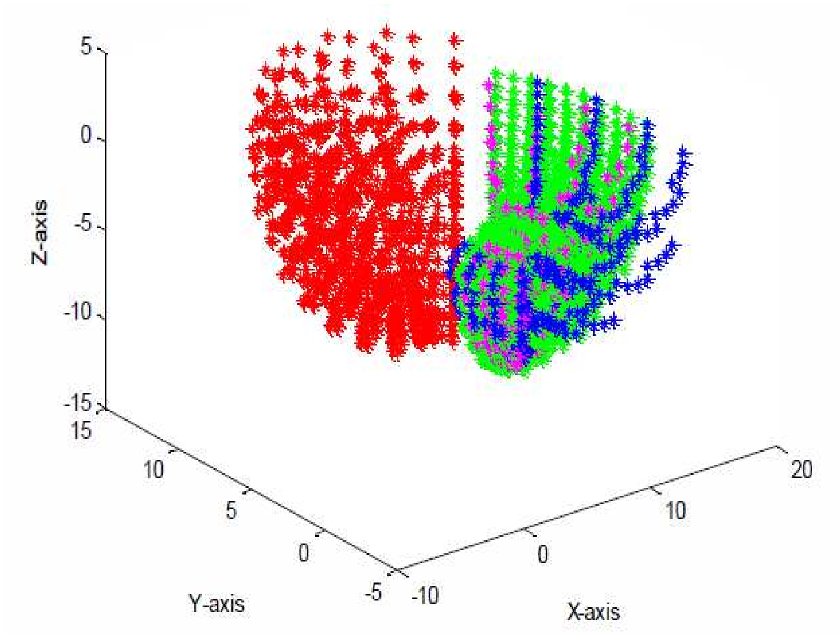

Figure 7. Profile of fingertips in the 3-D space

5. CONCLUSION

The work presented here is a part of the research work for developing a multi-fingered, adaptive, anthroporphic robot hand. A systematic process for developing the kinematic model and confirming its effectiveness through virtual testing is presented. The model considers five fingers similar to human hand for manipulating objects securely. The joints, links and other kinematic parameters are chosen in such a way that they replicate a human hand. The virtual testing has been carried out through a simulation using MATLab and care has been taken to have a profile of the finger motion as smooth as possible to ensure a near net shape. Ir is observed from the simulation that the developed hand is flexible and adaptive and it can very effectively be used for the intended purpose.

REFERENCES

[1] Kazuo Tanie: Design of Robot Hands, Industrial Robotics, Ed, S. Y. Nof, John Wiley & Sons, pp.112-137, (1982).

[2] Toshio Morita, Hiroyasu Iwata, Fhingeki Sugano, *Human Symbiotic Robot Design based on Division and Unification of Functional Requirement* , Proceedings of the IEEE International conference on Robotics and Automation,pp.2229-2234,(2000).

[3] S.C. Jacobsen, J.E. Wood, D.F. Knutti, and K.B. Biggers, *The UTAH/M.I.T dexterous hand: Work in progress*, Int. J. Robot. Res.,vol.3, no.4, pp.21–50(1984).

[4] J. Butterfass, M. Grebenstein, H. Liu, G. Hirzinger, *DLR-Hand II: next generation of a dextrous robot hand*, Proc. IEEE International Conference onRobotics and Automation, Taibei, Taiwan, pp.109-114(2003).

[5] R.Walkler, *Developments in dexterous hands for advanced robotic applications*, Proc. the Sixth Biannual World Automation Congress, Seville, Spain, pp.123-128(2004).

[6] C.S.Lovchik, M.A.Diftler, *The Robonaut hand: a dexterous robot hand for space*, Proc. IEEE International Conference on Robotics and Automation," Detroit, USA, pp.907-912, (1999).

[7] U.Jun, Y.Ishida, M.Kondo, T. Ogasawara,"Development of the NAIST-Hand with Vision-based Tactile Fingertip Sensor," in: Proc. IEEE International Conference onRobotics and Automation, Barcelona, Spain, pp.2332-2337,(2005).

[8] H. Kawasaki, T. Komatsu, T. Uchiyama,"Dexterous anthropomorphic robot hand with distributed tactile sensor: Gifu hand II," IEEE/ASME Transactions on Mechatronics, vol.7, no.3, pp.296-303(2002).

[9] Vardy A: Articulated Human Hand Model with Inter-Joint Dependency Constraints. *Computer Science 6755* 1998 [http://www.scs.carleton.ca/~avardy/software/hand/hand_doc.pdf].

[10] Yasumuro Y, Chen Q, Chihara K: 3D Modeling of Human Hand with Motion Constraints. *Proceedings of the International Conference on Recent Advances in 3-D Digital Imaging and Modeling; IEEE Computer Society* 1997:275-282.

[11] Albrecht I, Haber J, Seidel HP: Construction and Animation of Anatomically Based Human Hand Models. *Eurographics/SIGGRAPH Symposium on Computer Animation* 2003:98-109.
[12] Wu Y, Huang TS: Human Hand Modeling, Analysis and animation in the Context of human computer interaction. *IEEE Signal Processing Magazine, Special issue on Immersive Interactive Technology* 2001, 3:51-60.
[13] Kuch JJ, Huang TS: Human Computer Interaction via the Human Hand: A Hand Model. *Asilomar Conference on Signals, Systems and Computers* 1995:1252-1256.
[14] Rohling RN, Hollerbach JM: Calibrating the Human Hand for Haptic Interfaces. *Presence* 1993, 2:281-296.
[15] IkuoYamano, KenjiroTakemura and Takhasimaeno, " Five Fingered Robot Hand using Ultramotors and Elastic elements" , proceedings of the 2003 IEEE/RSJ International conference on Robots and System, October 2003.
[16] R. A. Cooper, H. Ohnabe, and D.A. Hobson, Eds., An Introduction to Rehabilitation Engineering. USA, FL: CRC Press, Taylor & Francis Group, 2007.
[17] B.Buchcholz, T.Armstrong and S.Goldstein, *Anthropometric data for describing the kinematics of the human hand*, Ergonomics, 35(3): 261-273, (1992.)
[18] S. Parasuraman and C. Zhen, *Development of Robot Assisted Hand Stroke Rehabilitation System*,International Conference on Computer and Automation Engineering, Mar., pp. 70-74,(2009).

BIOGRAPHIES OF AUTHORS

Pramod Kumar Parida graduated from Department of Mechanical Engineering, CET, Bhubaneswar, India. He has worked in Department of Mechanical Engineering as faculty member from year 2000 to till date. Presently continuing his Ph.d. in Department of Mechanical Engineering, National Institute of Technology, Rourkela, India Under QIP scheme.

Dr. B. B. Biswal graduated in Mechanical Enginnering from UCE, Burla, India in 1985. Subsequently he completed his M.Tech. and Ph.D. from Jadavpur University, Kolkata. He was in faculty of Mechanical Engineering at UCE Burla from 1986 till 2004 and then joined National Institute of Technology, Rourkela as Professor and currently he is the Professor and Head of Department of Industrial Design. He has been actively involved in various research projects and published more than 90 papers at National and International levels, the areas of research being robotics, automation, maintenance engineering and industrial organization. He was a visiting Professor at MSTU, Moscow and a visiting scientist at GIST, South Korea.