TELKOMNIKA, Vol.17, No.1, February 2019, pp.1~7
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i1.11006

Nature grasping by a cable-driven under-actuated anthropomorphic robotic hand

Li Tian[1], Nadia Magnenat Thalmann[2]*, Daniel Thalmann[3], Jianmin Zheng[4]
[1,2,4]Nanyang Technological University (NTU), Singapore
[3]École Polytechnique Fédérale de Lausanne, Switzerland
*Corresponding author, e-mail: nadiathalmann@ntu.edu.sg

Abstract

Human hand is the best sample for humanoid robotic hand and a nature grasping is the final target that most robotic hands are pursuing. Many prior researches had been done in virtual and real for simulation the human grasping. Unfortunately, there is no perfect solution to duplicate the nature grasping of human. The main difficulty comes from three points. 1. How to 3D modelling and fabricate the real hand. 2. How actuated the robotic hand as real hand. 3. How to grasp objects in different shapes like human hand. To deal with these three problems and further to provide a partial solution for duplicate human grasping, this paper introduces our method to solve these problems from robotic hand design, fabrication, actuation and grasping plan. Our modelling progress takes only around 12 minutes that include 10 minutes of 3D scanning of a real human hand and two minutes for changing the scanned model to an articulated model by running our algorithm. Our grasping plan is based on the sampled trajectory and easy to implement for grasping different objects. Followed these steps, a seven DOF robotic hand is created and tested in the experiments.

Keywords*: 3D modelling, cable-driven, grasping plan, kinematics, motion control*

1. Introduction

Human hand has 21 Degree of Freedom (DOF) for five fingers. However, due to the cost and complexity, almost all of the existing robotic hand [1, 2] are under-actuated [3] robotic hand which has less than 21 actuators. Cable driven is a common and simple actuate solution to control the under-actuated robotic. The cable-driven under-actuated robotic hand usually has a limited motion range which very different from the real hand. Thus there is not much prior research on the kinematic of it. Human grasping is the perfect combination of speed, accuracy and strength. The development of robotics and virtual reality has promoted the research of human hand movement. Since the first appearance of Virtual Humans in the early 1980s, many types of research related to grasping plan have been conducted in a virtual environment [4, 5]. As hand is the most flexible part of the human body [6], the unique structural features and cognitive factors of the brain determine the complexity of its movement. At present, the research on human hand grasping is particularly prominent in the field of humanoid robot [7-9]. The researchers found that the joints of the human joints were in motion with certain movement rules and could be used to control the grasping of multiple fingers. In the virtual hand research, Rezzonico et al first defined this motion rule as automatic grasping, and grabbed it into two categories: automatic grasping and interactive grasping. They also proposes a general framework to enhance grasping interactions [10]. Further research about individual robotic hand kinematics can be found in [11-13].

With the help of 3D scanning and 3D printing technologies, we model our robotic hand based on a real hand's 3D scanning model. We create an algorithm to convert this scanned 3D mesh model into an interlocked articulated 3D model. Next we printed out 3D model as shown in Figure 1 (A) and test it with seven strong but tiny servo motors. The size and weight of the motors are 20x18x30 mm and 12.7 grams. At last we analyze the trajectory of each finger and provide grasp plan to a basic grasp gesture, Tripod grasp. Figure 1 shows our robotic hand, Nadine hand version 3. Our previous study of robotic hand can be found in [14-16].

In this paper, we first created a new cable-driven under-actuated robotic hand by 3D modelling and 3D printing. Normally the trajectory of the cable-driven robotic hand is not easy to acquire as the uncertainly during build the cable driven system. So we provide a new method to

Received August 28, 2018; Revised October 31, 2018; Accepted November 18, 2018

analyses its kinematics by sampling the end effector of the touch point. We also test the robotic hand in the experiment part to prove that the under-actuated robotic hand could also capable for grasp different size of objects using "Tripod grasp" gestures from the grasp taxonomy [17].

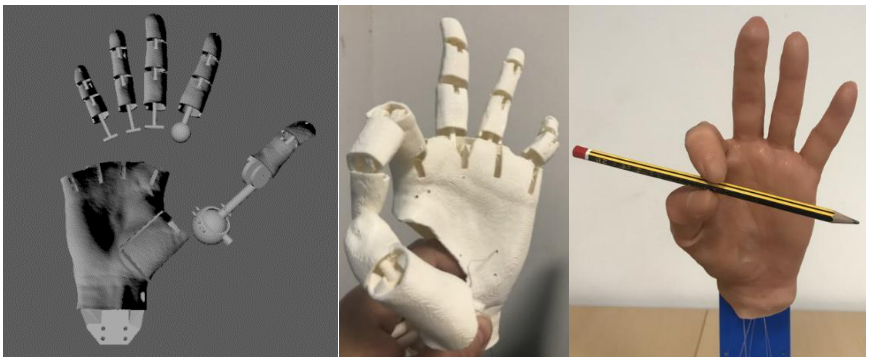

Figure 1. Nadine hand version 3
(A) 3D model (B) 3D printed robotic hand (C) inside the artificial skin

2. Research Method
2.1. Trajectories of the Fingers Esearch Method

The trajectory of each finger is a basic property of the robotic hand. In [18] and [12], researchers also provide the trajectory of their robotic hand. They captured the motion of the fingertips by the motion capture system. Pitarch draws the workspace of thumb in 3D space [19]. Yang et al propose a method to visualize and analyse the intersection workspaces of multi-finger hands [20]. All of them construct the motion in a virtual environment. From the Figure 2, we can conclude that the trajectories of the fingers from a cable-driven robotic hand are continuous irregular curves. The irregular curved working surface is generated if the finger has more than one DOF. Compare to these methods, our method is easy and practical. We also provide the approximate linear equations to represent the trajectories.

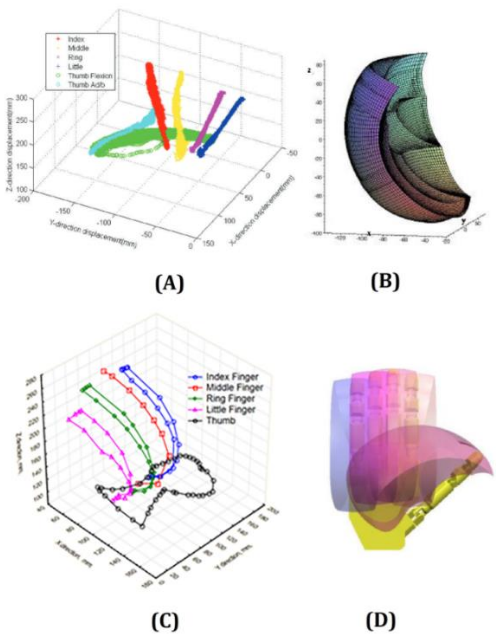

Figure 2. (A) The trajectory of fingertips of Xu et al's highly biomimetic robotic [12]
(B) Thumb's work space [18] (C) Trajectory of a prothetic hand [19] and
(D) Whole workspace of ZSTU Hand [20]

2.2. Robotic Hand 3D Modelling

3D scanning is a fast and precise way of getting a 3D hand model compared to manually modelling. The scanned target can be a real human hand or even an artificial silicon hand skin. We scanned a real human hand using a hand-held 3D scanner “Artec Space Spider”. The 3D scanned model can be represented in different data formats. Here, we use triangle mesh in stereolithography (STL) format. The first step we need to take is to make the hand hollow. This step not only reduces the weight but also a prerequisite of adding joints inside the hand. We use software “MeshMixer” to extract the hand model from the scanned model and set the thickness to 1.5 mm. The thickness will greatly affect the strength and the weight of the final robotic hand. We tested the case of 2 mm, 1.5 mm and 1 mm, and we conclude that 1.5 mm is sufficient in strength for print with Acrylonitrile Butadiene Styrene (ABS).

To make the 3D hand articulate, we need to divide the hand into segments and apply joints to link these segments. Based on the placement of hand bones, we can segment the hand into several linked sections [21]. Prior research shows that these segments are rather proportionate with small deviations [21, 22]. Therefore, we can either estimate the dimension of each segment by the proportions or measure them simply with a ruler. Additional with angle of each joint, we can calculate the coordinates of each joints and tips just by transformation and rotation in a 3D space. For example in Figure 3, we can calculate the end effect of index finger by (1). With these parameters, we implement a Python script which can generate joints structure to correct position in our scanned hand model asthmatically.

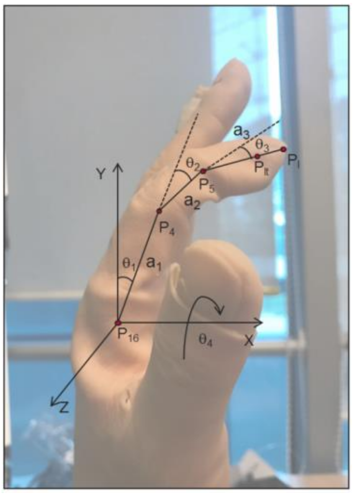

Figure 3. 3D system of index finger

$$Tpl=R(\theta1)T(a1)R(\theta2)T(a2)R(\theta3)T(a3) \quad (1)$$

We also use Maya to simulate the collision caused by the finger motion. As our hinge joint target range of motion is 0 to 90 degrees, we simulate the motion of fingers with the same range of motion to identify overlapping of the neighbouring parts. Then, we remove the colliding parts, which could obstruct the motion. Finally, we add holes to all five fingertips for the control cables, and we get the interlocked robotic hand model ready for 3D printing. The result is shown in Figure 1 (A). We 3D printed the model and shown in Figure 1 (B).

2.3. Sampling the Points

Servo motors are commonly used as actuators in the cable driven system. We choose HS-5070 MH servo motors with active pulse width modulation (PWM) range 0.75-2.25 millisecond. We sample the motion from 0.70 to 2.20 millisecond with 0.1 millisecond interval. During the motion test of Nadine hand, we record down the angle changed after each steps of the motion and thus calculated the pose of the fingers. The Table 1 show the result of the middle finger. The data under column “touch-point.x” and “touch-point.y” shows the coordinate changes when the motor moves from one limit value to another.

Table 1. Kinematic Analyse of Middle Finger

PWM	Horn-position	dip.deg	pip.deg	mcp.deg	mcp.x	mcp.y	pip.x	pip.y	dip.x	dip.y	touch-point.x	touch-point.y
8	27	0	5	25	16.9047305	36.25231148	29.40473	57.9029466	43.40473	82.15166	38.40473047	73.49140384
9	38	0	5	25	16.9047305	36.25231148	29.40473	57.9029466	43.40473	82.15166	38.40473047	73.49140384
10	49	5	7	27	18.15962	35.64026097	32.139443	56.3662003	49.76041	78.12629	43.46720962	70.35482759
11	59	8	11	30	20	34.64101615	36.401476	53.5087557	57.53334	71.87841	49.98624817	65.31781818
12	72	15	22	38	24.626459	31.52043014	46.277094	44.0204301	73.32302	51.26736	63.66375898	48.67917296
13	84	20	25	40	25.7115044	30.64177772	48.369199	41.2072343	76.26265	43.6476	66.30070363	42.77603764
14	96	31	33	49	30.1883832	26.24236116	54.945085	29.7216887	80.71922	18.78122	71.51417229	22.68852837
15	106	33	38	52	31.5204301	24.62645901	56.52043	24.626459	80.00321	9.376566	71.61650037	14.82295638
16	116	36	41	55	32.7660818	22.94305745	57.629129	20.3298459	78.43718	1.594189	71.00573601	8.285494958
17	125	40	43	60	34.6410162	20	59.000268	14.3762236	75.85109	-7.98557	69.83293819	0.000784461
18	133	43	48	65	36.2523115	16.90473047	59.264933	7.13645226	70.65356	-18.4428	66.58619239	-9.30736598
19	140	46	50	70	37.5877048	13.68080573	59.23834	1.18080573	66.01215	-25.9875	63.59293405	-16.28451734
20	151	62	60	75	38.6370331	10.3527618	56.314703	-7.3249077	48.12829	-34.1014	51.0520119	-24.53839333
21	162	62	63	78	39.125904	8.316467633	54.858914	-11.112181	43.91844	-36.8863	47.82575349	-27.68126877
22	173	62	63	80	39.3923101	6.945927107	54.437686	-13.019961	42.60437	-38.3966	46.83055699	-29.33350081

Use the same method, we can get the trajectory of index finger and thumb. For the index finger, we sample the trajectory in three conditions, when the abduction angel is 0, 20 or 40 degree. For the thumb, we sample the trajectory in two conditions, which is maximum abduction and maximum adduction.

3. Results and Analysis

3.1. Working Space of Three Fingers

Since the first appearance of Virtual Humans in the early 1980s, many types of research related to grasping plan have been conducted in a virtual environment [23, 24]. To simulate the grasping of our robotic hand virtually, we draw the six set sample data of trajectories get from above section in lines and show them in a 3D space with the help of MatlabTM “plot3 function”. We also estimate the motion area of the index and thumb by the by construct a surface based on their trajectories as shown in Figure 4.

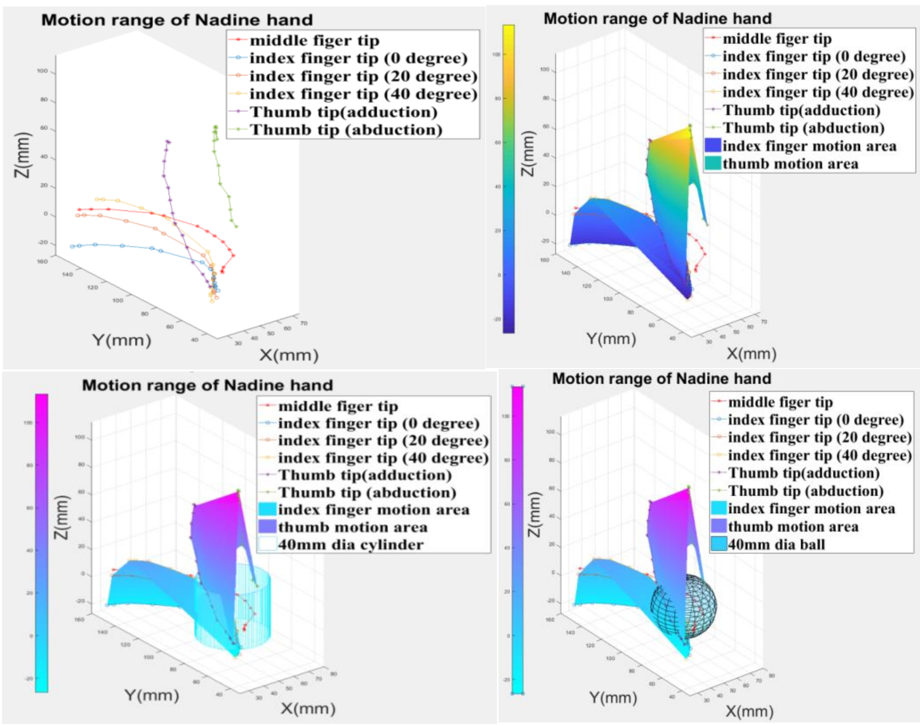

Figure 4. 3D trajectories and estimated working space

3.2. Dimension-reductions and Data Fitting

From the above 3D drawing, we can understand that a 40 mm dimension object can be placed in a suitable position which touches all trajectories of these three fingers at the same time. However, it is complex to calculate the precise position where we should put the target, and how the three finger need to move to form the Tripod gestures. From the test data of grasping objects within 10-60 mm cross section dimension, we conclude the difference of three fingers in X-axis is smaller than 13m. With the condition of objects' height is more than 20 mm, we reduce the X-dimension. The Figure 5 shows the all trajectories are liner or close to polynomial. With the help of curve fitting function in MatLab TM, a degree-3 polynomial curve is generated to represent the trajectory of Index finger. From the below figure, the root-mean-square error (RMSE) is 0.4697 mm. The curve's fitting function is in (2). The other trajectories also can use same method to generate the fitting functions.

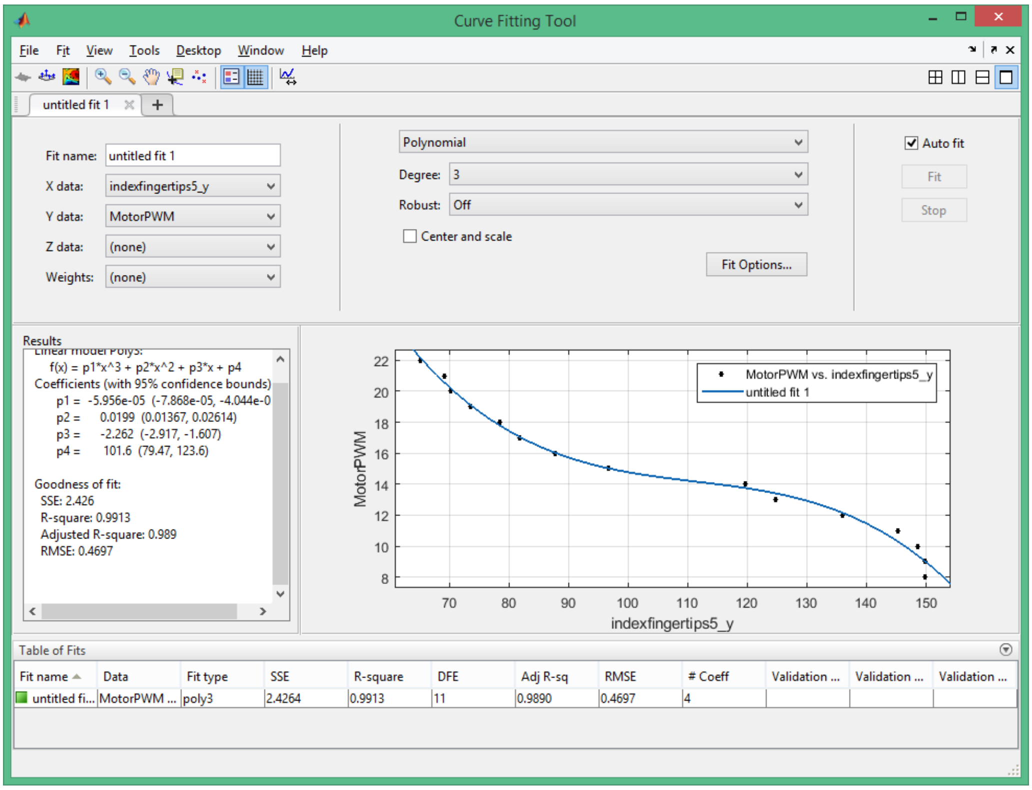

Figure 5. Data fitting result of index finger

p1=-5.956e-05;p2=0.0199;p3=-2.262;p4=101.6 ;
y=p1*x.^3+p2*x.^2+p3*x+p42) (2)

3.3. Grasping plan for Tripod Gesture

For grasping an object using Tripod grasp gesture, we assume the hand or the target can be move to the ideal position for grasp. In the case of 40 mm diameter ball, the ideal position is 106 mm high (Y-axis) from the original point of the robotic hand. This value is get from the result of real human hand grasping. As the width of the middle finger's distal is 14 mm, the touch point of the middle finger is (7,106). Then we calculated the other two expected touch point based on the definition of Tripod grasp which located at (47,106) and (27,126). Touch point and estimation trajectory as shown in Figure 6. The touch point of index finger is landed within the working space of index finger. So we can estimate the trajectory of index finger which goes through the point. And calculate the PWM value based on the (2). The touch point of thumb is out of the working space of the thumb. So we use the closest trajectory and calculated the PWM value.

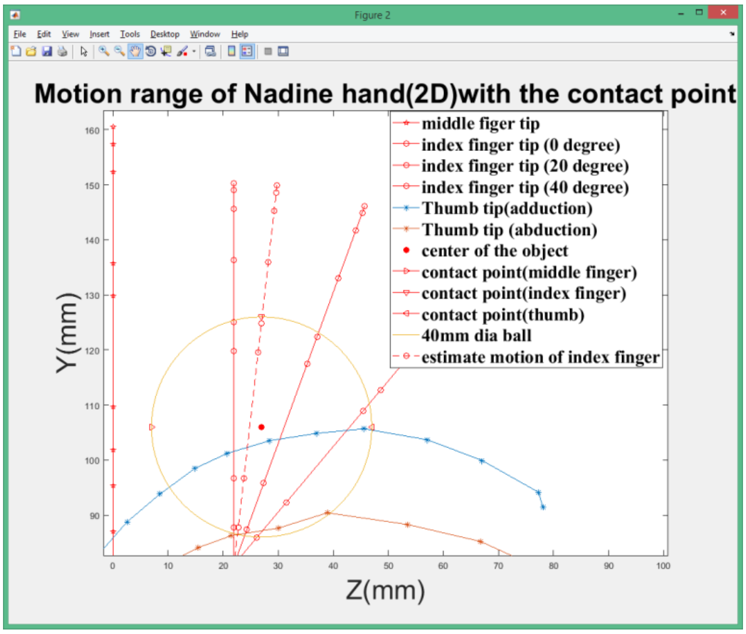

Figure 6. Touch point and estimation trajectory

With the calculated PWM values, we test our robotic hand as well as demonstrated that our robotic hand works well with artificial skin in Figure 7. The customized artificial hand skin uses silicon of 0-degree hardness in 1-2 mm thickness. The result shows our hand and grasp plan algorithm works fine. For Tripod grasp, the Target objects include cylinder which 10-60 mm dimension, 40 mm cube, cone and triangular prism.

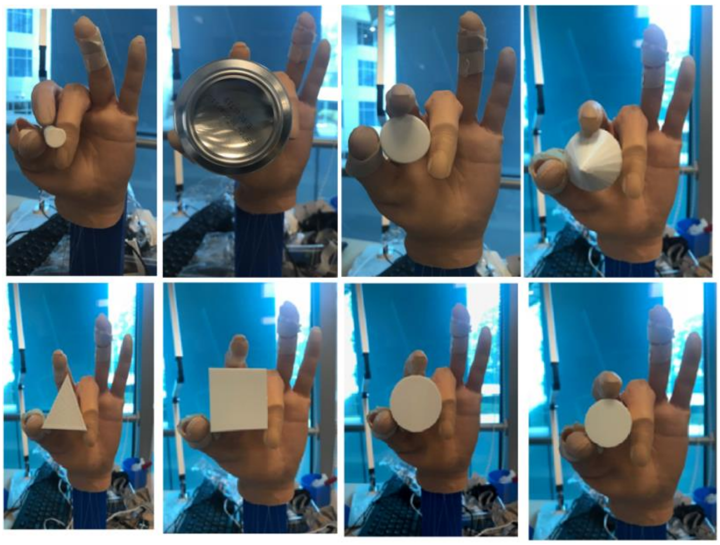

Figure 7. Tripod grasp test

4. Conclusion

We have described a new method to create a personalized robotic hand as well as drive it approach to a nature grasp. We start with studying how human hand functions, and try to replicate the important features to the 3D hand model using our algorithm. Our robotic hand has 15 joints, seven DOFs and similar motion range as real human hand. We also show the trajectory of each fingers in a 3D space in continues line segments by sampling method. We use data fitting function to represent the relations between teach trajectory and the move of the driven motor. We tested this functions in real environment grasping test. The experiments show that our robotic hand is able to do the Tripod grasp on different shape of objects with dimension from 5 to 60 mm. Compared to other robotic hands and actuated modelling methods, we have provided a comprehensive procedure on how to automatically create a personalized robotic hand.

References

[1] Belter, J.T., et al. Mechanical Design and Performance Specifications of Anthropomorphic Prosthetic Hands: A review. *Journal of Rehabilitation Research and Development*. 2013. 50(5): 599-617.
[2] Mattar, E. A survey of bio-inspired robotics hands implementation: New Directions in Dexterous Manipulation. *Robotics and Autonomous Systems*. 2013. 61(5): 517-544.
[3] Birglen, L., T. Laliberté, and C.M. Gosselin. Underactuated Robotic Hands. *Springer*. 2007; 40.
[4] Magnenat-Thalmann, N. and D. Thalmann. The Direction of Synthetic Actors in the Film Rendez-vous à Montréal. *IEEE Computer Graphics and applications*. 1987. 7(12): 9-19.
[5] Magnenat-Thalmann, N. and D. Thalmann, *Handbook of Virtual Humans*. 2005: John Wiley & Sons.
[6] Agur, A.M. and A.F. Dalley. *Grant's Atlas of Anatomy*. Lippincott Williams & Wilkins. 2009.
[7] Boulic, R., S. Rezzonico, and D. Thalmann. *Multi-finger Manipulation of Virtual Objects*. in Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST. 1996. Citeseer.
[8] Cutkosky, M.R. On Grasp Choice, Grasp Models, and the Design of Hands for Manufacturing Tasks. *IEEE Transactions on Robotics and Automation*. 1989. 5(3): 269-279.
[9] Salisbury, J.K. and B. Roth. Kinematic and Force Analysis of Articulated Mechanical Hands. *Journal of Mechanisms, Transmissions, and Automation in Design*. 1983. 105(1): 35-41.
[10] Rezzonico, S., et al. Consistent Grasping Interactions with Virtual Actors based on the Multi-sensor Hand Model. *Springer*. 1995.
[11] Xiong, C.-H., et al. Design and Implementation of an Anthropomorphic Hand for Replicating Human Grasping Functions. *IEEE Transactions on Robotics.* 2016. 32(3): 652-671.
[12] Xu, Z. and E. Todorov. *Design of a Highly Biomimetic Anthropomorphic Robotic Hand towards Artificial Limb Regeneration*. 2016 IEEE International Conference on Robotics and Automation (ICRA), 2016: 3485-3492.
[13] Agrawal, K. and S.R. Chowdhury. *FPGA based Accelerated Orientation Calculation in SIFT using LUTs*. in Microelectronics and Electronics (PrimeAsia). 2013 IEEE Asia Pacific Conference on Postgraduate Research in. 2013.
[14] Tian, L., et al. The Making of a 3D-printed, Cable-driven, Single-model, Lightweight humanoid Robotic Hand. *Frontiers in Robotics and AI*. 2017; 4: 65.
[15] Thalmann, N.M., L. Tian, and F. Yao. Nadine: a Social Robot that Can Localize Objects and Grasp Them in a Human Way. in Frontiers in Electronic Technologies. *Springer*. 2017: 1-23.
[16] Tian, L., et al. *A Methodology to Model and Simulate Customized Realistic Anthropomorphic Robotic Hands*. in Proceedings of Computer Graphics International 2018. 2018. ACM.
[17] Feix, T., et al. The Grasp Taxonomy of Human Grasp Types. *IEEE Transactions on Human-Machine Systems*. 2016; 46(1): 66-77.
[18] Owen, M., C. Au, and A. Fowke. Development of a Dexterous Prosthetic Hand. *Journal of Computing and Information Science in Engineering*. 2018; 18(1): p. 010801.
[19] Peña Pitarch, E. Virtual Human Hand: Grasping Strategy and Simulation. Universitat Politècnica de Catalunya. 2008.
[20] Wenzhen, Y., et al. Intersection Workspace Visualization of Multi-finger Hands. *The Visual Computer*. 2017. 33(10): 1253-1263.
[21] Li, Z., et al. Validation of a Three-dimensional Hand Scanning and Dimension Extraction Method with Dimension Data. *Ergonomics*. 2008; 51(11): 1672-1692.
[22] Alexander, B. and K. Viktor. Proportions of Hand Segments. *Int. J. Morphol*. 2010. 28(3): 755-758.
[23] Magnenat-Thalmann, N. and D. Thalmann. The Direction of Synthetic Actors in the Film Rendez-vous à Montréal. *IEEE Computer Graphics and applications*, 1987; 7(12): 9-19.
[24] Magnenat-Thalmann, N. and D. Thalmann. Handbook of Virtual Humans. John Wiley & Sons. 2005.