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Research Paper

AN INTERACTIVE TELE-OPERATED ANTHROPOMORPHIC ROBOT HAND: OSAKA CITY UNIVERSITY HAND

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In this paper we present a design of an anthropomorphic robot hand called Osaka-City-University-Hand (OCU-Hand). In our proposed hand the size and weight have been compromised in order to achieve human-like performance with the prime objective of grasping different shapes firmly. Our proposed hand is composed of five fingers with total 15 degrees of freedom (DOF). In addition, 3 DOF are given for a dexterous designed wrist. All the joints of the OCU-Hand are driven by servomotors built into the fingers. The thumb finger in our proposed hand has a special design that improves the implementation of the hand. Also in our proposed hand, the palm has a unique design so as to improve the hand grasping and handling of different shape objects. The size of the hand is almost the same as a human hand. Distributed tactile and force sensors are appended to the OCU-Hand as a feedback system in order to grasp an object firmly. A new control strategy is to be adopted, in which a master light-weight glove is to be used to drive the OCU-Hand as a slave. A novel and unique interactive and assistive mode is included within master-slave control strategy, in which the OCU-Hand is assisting its operators in order to reduce the load on the operator and perform the usual operations in a better manner or even faster than the usual. During the assistive mode the operator is enabled to perform other tasks than the master-slave driving while he has the master-glove on.

Keywords: Anthropomorphic robot hand, Tele-operating, Interactive mode, Feedback sensors

INTRODUCTION

In many operations humans wish to have an assistive person or an assistive device to give us additional support. The existence of such an assistive device helps and encourages us to perform better achievements in the all-day endeavors. As a result scientists in different fields have been trying to develop many mechanisms similar to the human hand. Some of the developed mechanisms are

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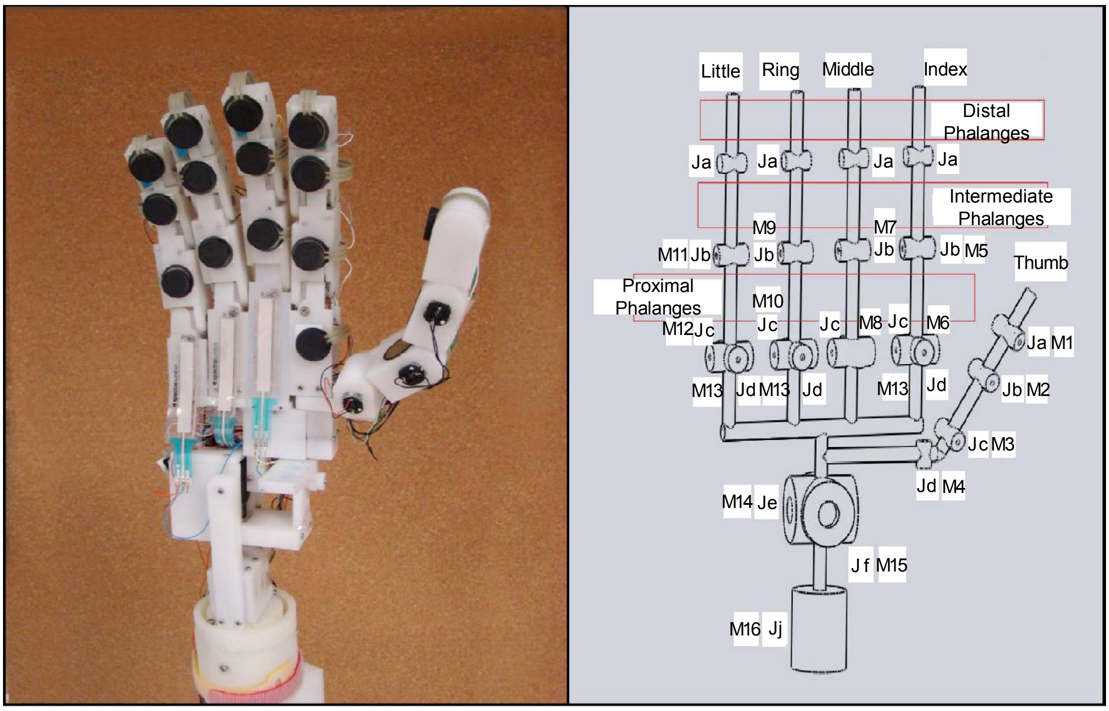
used as prosthetic parts and also are used in hazard fields in addition to be used in the research fields as an open architecture platform. In order to make these mechanisms accepted as interactive parts in human-oriented environment, they must mimic the human hand. Therefor their anthropomorphic factors which are mainly related to their external appearance must be considered. However it is insufficient to build a robot hand which resembles the human hand only in appearance, because other dexterity factors which are related to the functionality must be considered also. However it is very difficult to consider all the factors in one mechanism. For example, an approach has been proposed with a highly anthropomorphic robot hand (Fukaya *et al.*, 2000), but the hand has a very poor dexterity level in which the performable tasks are very limited. Also another approach with highly sophisticated manipulation procedures, without any level of anthropomorphism, was proposed (Antonio *et al.*, 2000). A number of robot hands have been developed which focus on either anthropomorphic design or dexterous design. Usually they have sacrificed one of the characteristics for the other. This comes out due to the obvious complexity of developing a hand that closely emulates the human hand. Some anthropomorphic designs include the Utah/MIT hand (Kenneth *et al.*, 2003), Anthrobot Hand (Rosell *et al.*, 2009), Robonaut Hand (Lovchik and Diftler, 1999; Engelberger, 2001), DLR-Hand I and II (Butterfass *et al.*, 2001; and Liu *et al.*, 2007) and Ultra-light hand (Schulz *et al.*, 2001). Examples of hands whose main focus is on dexterity are a three fingers robotic hand (Zollo *et al.*, 2007), the Salisbury hand (Salisbury *et al.*, 1985), the Karlsruhe hand (Wöhlke, 1990), the hand developed at the Technical University of Darmstadt (Paetsch and Kaneko, 1990; and Weigl and Seitz, 1994), the LUCS Haptic hand (Johnsson and Balkeniuse, 2010) and the Delft University hand (Jongkind, 1993). A proposed dexterous hand (Thayer and Priya, 2011) that implements a wire as tendon which leads to inaccuracy positioning in the fingers joints angle. Another portion must be considered is the control strategy of the developed mechanism. Recently, tele-operated control strategy comes to prominence in different fields such as aerospace, underwater exploration, military and surgery fields. In order to enable a robot hand to be remotely operated, the control system must be designed to track and reflect the movements of its master in a proper speed. The tracking system in some of these robot mechanisms are operated by joysticks or space ball (Borst *et al.*, 2003; and Thayer and Priya, 2011). Their main goal is to map the tip position of the human hand and the robot hand one by one, neglecting the mapping of the remaining links and completing the mapping using a neural net. However, these approaches are not suitable for power grasps, because the positions of the links are not directly controlled. Another tele-operating control strategy was proposed using master-slave (Song *et al.*, 1999). This strategy is based on the contact/non-contact condition of the slave mechanism followed by the switching of unilateral feedback control between position and force. However the force feedback to the control system is applied mechanically as a force of the elastic elements instead of electrical feedback control. Another approach following a bilateral master-slave system for tele-robotics was proposed in Yamano *et al.* (2002), is composed of electro-hydraulic servo systems with force sensors attached to the actuator. Unfortunately, the design of master units proposed in both the papers Kudomi *et al.* (2000) and Chua *et al.* (2006) are complex and expensive. In this paper we present a dextrous mechanism with considered anthropomorphic factors called OCU-Hand which composed of 5-finger driven by +5 volt DC motor and with total 15 degrees of freedom (DOF) in addition to the wrist joints which has additional 3 DOF with a dexterous design. By using a light-weight glove, a new tele-operating control strategy is being performed accompanied with an assistive mode through interaction strategy. The main mechanical design and control system of OCU-Hand explained in the following section followed by an explanation of tele-operating system and assistive mode experiments. Finally a discussion and the conclusion are to be presented.

OCU-HAND

Our proposed hand has 5 fingers with total 18 DOF. An overview of our developed anthropomorphic robot hand called OCU-Hand is shown in Figure 1a and its schematic explanation of the joints and motors arrangement is shown in Figure 1b. The joints are named as J_a joint, J_b joint, and J_c from the fingertip to the wrist. The motors are named as M_n(n = 1, 2, ..., 16) starting from the thumb finger to the little finger.

Figure 1: Osaka-City-University-Hand and its Schematic

(a) (b)



Finger Design

As in human hands [19] fingertip joints of the four fingers are linked to the middle joint. In our design, the fingertip joint is actuated by the middle joint's actuator through a planar bar linkage mechanism. More detail about the fingers construction and their assembly is shown in Figure 2 and the main characteristics of OCU-Hand are explained in Table 1. Every finger is accompanied with a part of the palm and has an independent stand-alone design, which simplifies maintenance requirements by replacing only the damaged finger without recalibrating the whole system. It also facilitates replacing individual fingers when better materials become available.

Figure 2: Schematic Description of the Finger Construction

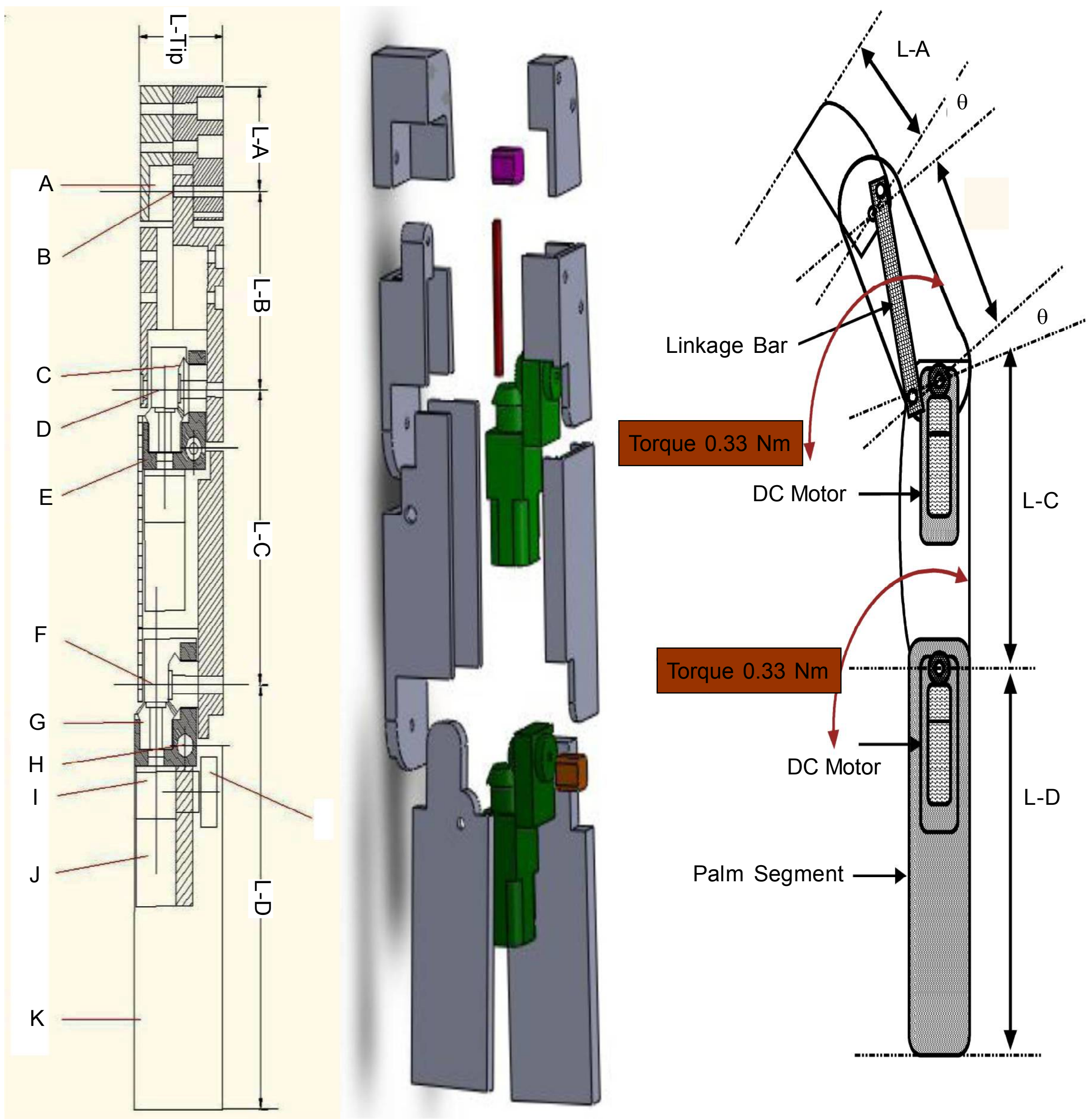


Table 1: The Main Characteristics of the OCU-Hand

Symbol	Index	Middle	Ring	Little
L-Tip	19 (mm)	19 (mm)	19 (mm)	19 (mm)
L-A	19 (mm)	19 (mm)	19 (mm)	19 (mm)
L-B	34 (mm)	34 (mm)	34 (mm)	34 (mm)
L-C	50 (mm)	53 (mm)	50 (mm)	48 (mm)
L-D	59 (mm)	69 (mm)	59 (mm)	44 (mm)
Ja	0-89°	0-89°	0-89°	0-89°
Jb	0-89°	0-89°	0-89°	0-89°
Jc	0-89°	0-89°	0-89°	0-89°
Jd	0-14°	–	0-14°	0-13°
Je	–90-90°			
Jf	–9.18-9.180°			
Palm Width	89 mm			
Palm Thickness	24 mm			
A	Position Sensor			
B	Joint Shaft			
C	Final Output Bevel Gear			
D	Knuckle Joint Shaft			
E	Gear Train Fixation Seat			
F	Joint Shaft			
G	Bevel Gear			
H	Gear Train Fixation Seat			
I	Reduction Gear Box			
J	DC Motor			
K	Finger Base			
L	Position Sensor			
Total Weight (Fingertip to Wrist Base)	895 grams			

Kinematics of the Proximal Phalanges Mechanism

At the Jd of the little, ring and index fingers are activated by following a simple conn-rod mechanism as shown in Figure 3.

Where *P*1 is the home position of Hinge1 when the Stud is at position *C*1 and *S*1 is the stroke traveled resulting when the Stud position is rotated by an angle on the Disk to be at the position *C*2. The length of the stroke *S*1 is given by the following formula.

$$S1 = R(1 - \cos\phi) + (\lambda/2)R\sin^2\phi \qquad ...(1)$$

where,

R = The distance between the Stud center and the disk center *PI*(0.009 m)

λ = The crank ratio (*R*/*L*1)

L_1 = For ring and index fingers = 0.012 m, and for little finger = 0.018 m

ϕ = The rotated angle (0:40 degree)

And the velocity of the Hing1 is given by the following formula

$$v = \omega R\sin\phi(1 + \lambda\cos\phi) \qquad ...(2)$$

where,

ω = Is the angular velocity ($2\pi n/60$)

n = Is the rotational speed in revolutions per minute

The angle θ rotated by the proximal phalanges of the fingers is given by the following formula

$$\theta = S1/L2$$

$$\theta(R(1 - \cos\phi) + (\lambda/2)R\sin^2\phi)/L2 \qquad ...(3)$$

*L*2 = For ring and index fingers = 0.012 m, and for little finger = 0.018 m

Calculations of the resulted swapped angles of the fingers to the input motor angle are shown in Table 2. The aim for the developing such a mechanism is to approximate the range of motion to those of the human hand through increasing the swapped volume of each finger of OCU-Hand.

Figure 3: Proximal Phalange Kinematics

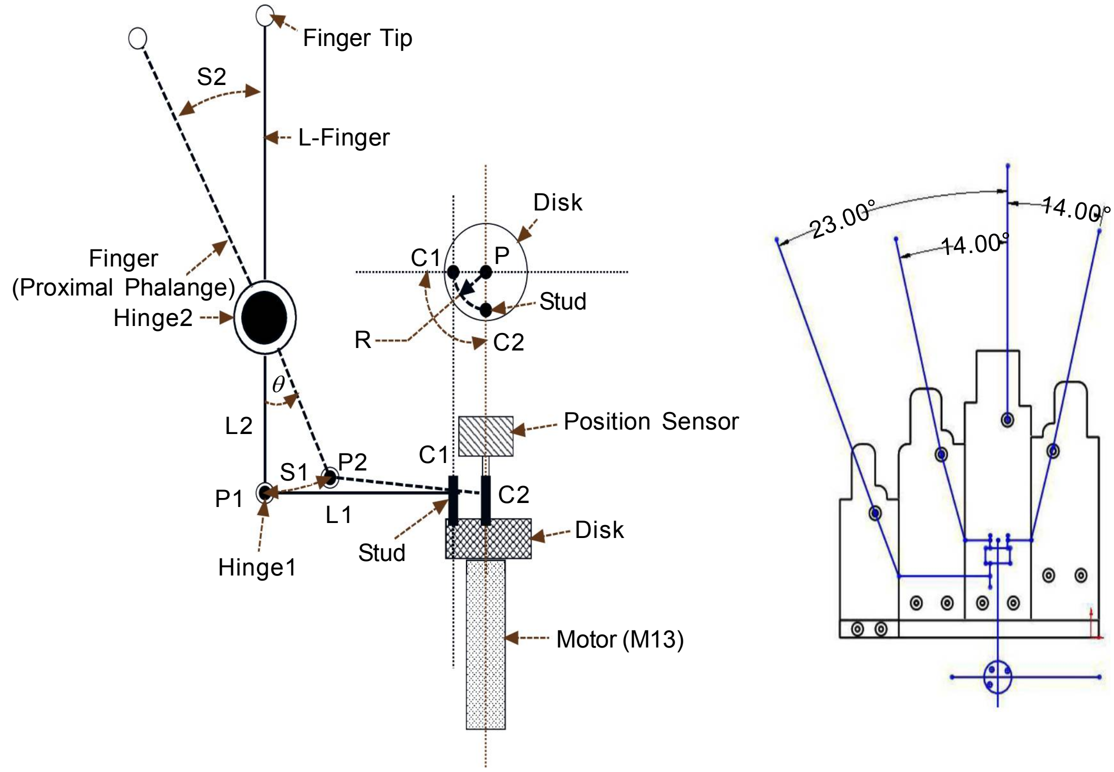


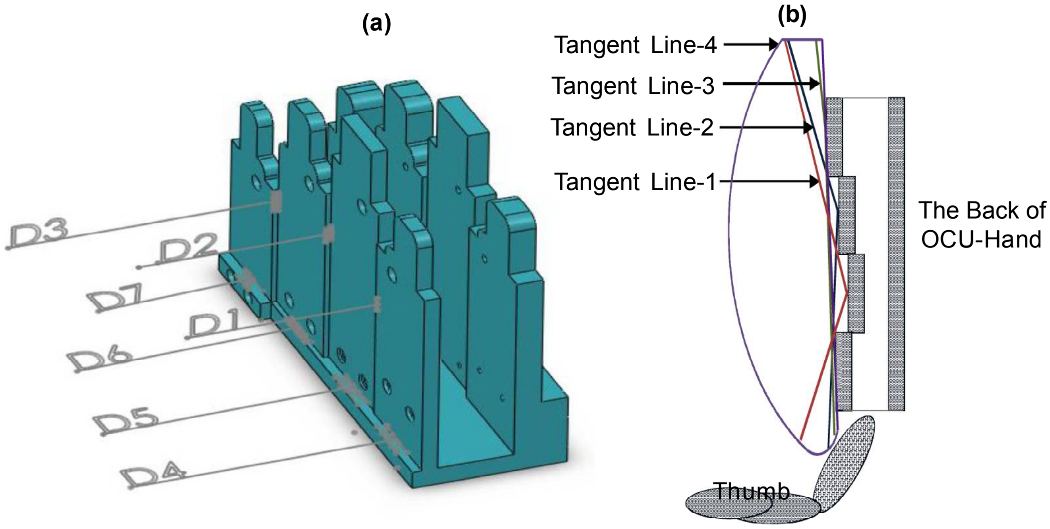
Table 2: Swapped Fingers Angles

Input Motor M13 Angle (ϕ degree)	Output Little Finger Angle (ϕ degree)	Output Ring and Index Finger Angle (ϕ degree)
0	0.43523	0.652839
10	1.94364	3.077430
20	4.67588	7.642170
30	8.49283	10.831440
40	13.19250	14.082110

Palm Design

The dexterity level of a robot hand is mainly measured by the capability of grasping an object whose configurations are substantially varied with time. This property is affected by the palm design which is an important part of the human hand that serves as a structural mounting base for the thumb, fingers, and the wrist. We should make a robot palm resembles that of the human hand, which has a unique structure in order to enable the hand to grasp and manipulate different shaped objects with high dexterity, by forming firm contact surface with distributed force over the object. In order to achieve this dexterity, we divided the palm into four segments (see Figure 4). Each segment is connected to the base segment of every finger. In addition to this division we incorporated 3mm level differences (D1, D2, D3, D4, D5, D6, and D7) between each segment emulating of the human hand as Figure 4a shows. The purpose of these differences is to enable the OCU-Hand to perform a dexterous grasping and manipulating different shape objects whose contain one or more points laying on the working tangent lines line one till tangent line three or any object contained in the contour of tangent line 4 as Figure 4b shows.

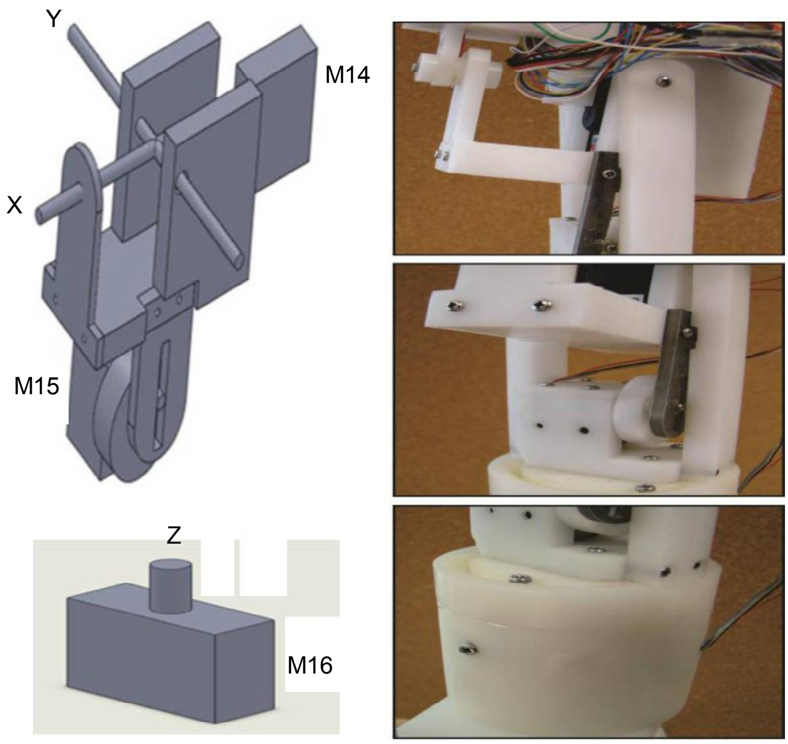
Figure 4: OCU-Hand Palm Design



Wrist Design

In the human hand there are 3DOF at the wrist level. In other words, the human hand is able to pitch, yaw and roll around a single point. These facilities provide the human hand with dexterous manipulation activities. Important examples are hand shaking and hand-waving; these activates are very important because

Figure 5: OCU-Hand Wrist Design



they are means of communication between humans. Hence, when designing an artificial anthropomorphic hand, it must be capable of performing such movements. As far as we know, there is no proposed artificial hand has the ability of performing such movements on the same level of space. In our proposed hand, we have designed a mechanism which enables the OCU-Hand to perform such movements in similar ways of the human hand. Figure 5 shows the wrist design and an explanatory schematic. The movement about the *X*, *Y*, and *Z*, axes produced by motor 14, motor 15 and by motor 16 respectively at joints Je, Jf and Jj are performed around a single point just as human wrist. Motor 14 provides the palm with angles from –85 to 90 degrees around the *X*-axis with torque of 0.945 Nm, motor 15 provides the hand to inclined around the *Y*-axis with angles –9.3 to 9.3 degrees with torque of 0.22 Nm and the rotation angle around Z-axis ranges from –133 to 133 with torque of 0.22 Nm. The actuator with torque 0.9945 is used to move (pitch) the palm and the fingers and the distance between actuator center (joint je) and the fingertip is 210 mm. That is why we need high torque actuator, however the diameter of the wrist is 65 mm therefore in order to rotate (yaw) the OCU-Hand around (joint jj) the wrist an actuator of 0.22 Nm is enough (see Figure 5).

Thumb Design

The dexterity of grasping and manipulating objects in the human hands is highly increased by the opposability of the thumb. The opposable thumb in OCU-Hand has 4 joint links with 4 DOF (see Figure 6) and its characteristics are shown in Table 3. High torque can be generated at joint Ja, Jb and Jc which in return increases force at the fingertip compared to other fingers. The wide operating angles at Ja, Jb and Jc maximize the capability of orienting the thumb fingertip more correctly and normally to the object surface, providing stable pinching force on the object surface.

Figure 6: OCU-Hand Thumb Design

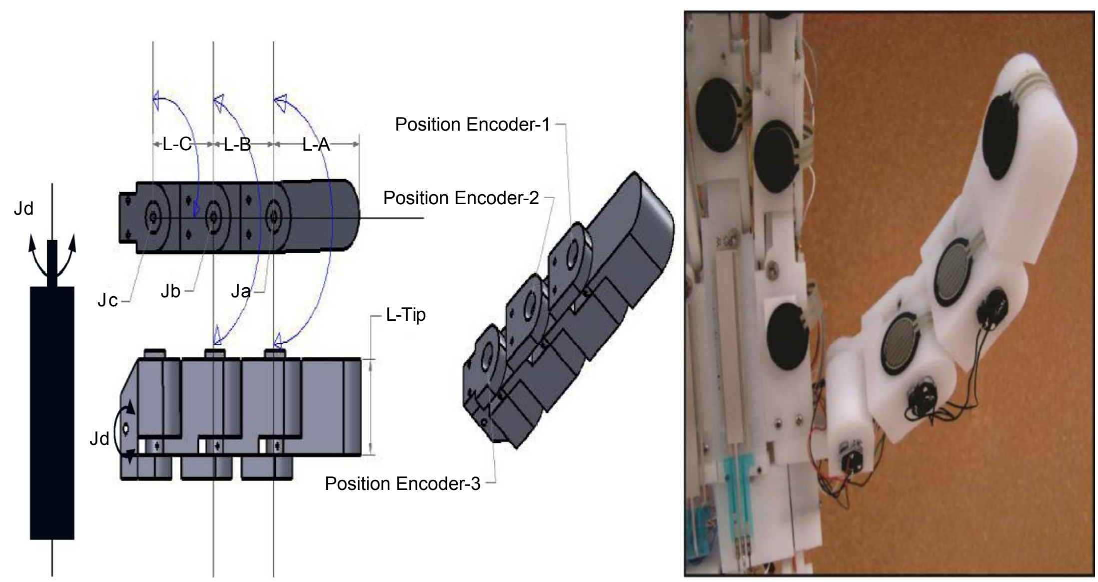


Table 3: Thumb Characteristics

Part	OCU Hand
L-Tip(mm)	27.5
L-A(mm)	51
L-B(mm)	36
L-C(mm)	36
Ja°	–90-90°
Jb°	–90-90°
Jc°	0-90°
Jd°	0-92°
J_a-torque	0.33 Nm
J_b-torque	0.33 Nm
J_c-torque	0.33 Nm
J_d-torque	0.33 Nm

Sensor System

Besides a delicate mechanical configuration, dexterous manipulation requires an adequate sensory system. One of the main purposes of the sensory system is to provide the main system with the precise information about the state of the interaction with the environment. The human dexterity is mainly due to its richness of tactile information. Therefore, if the sensing system of the human hand is the desired target, unfortunately current technologies are still far inferior to those in the human hand, in particular, in resolution of touch sensations. In OCU-Hand, with specification shown in Table 4. The force sensor interface circuit is shown in Figure 7; the signal is entered into a USB port through a NI-DAQ-6501.

TELE-OPERATING SYSTEM

Glove Design

Many proposed approaches use a readymade CyberGlove® (Kudomi *et al.*, 2000; and Yamano *et al.*, 2002). In our lab we managed to construct a light-weighted glove (95 grms) that includes 6 bending sensors 4 as shown in Figure 8. The signal is entered into a USB port through a NI-DAQ-6008.

Tele-Operation Strategy

A tele-operation system includes a human operator. If the human operator has to manually control every joint angle of the tele-operated hand, then they can easily become overwhelmed by the minutiae of low-level control actions, to the detriment of the high-level movement.

Table 4: Membrane Potentiometer Characteristics

<table>
<tr><th colspan="2">Parameter</th><th colspan="2">Value</th></tr>
<tr><td rowspan="8">Membrane Potentiometer-
(–40 to +50 °C)</td><td>Resistance</td><td colspan="2">10 KΩ(Length >300 mm 20 KΩ)</td></tr>
<tr><td>Resistance Range</td><td colspan="2">1 KΩ to 100 KΩ</td></tr>
<tr><td>Resistance Tolerance</td><td colspan="2">±20%</td></tr>
<tr><td>Effective Electrical Travel</td><td colspan="2">8 to 2400 mm</td></tr>
<tr><td rowspan="4">Actuation Force</td><td>–40 °C</td><td rowspan="2">0.8 to 1.8 N</td></tr>
<tr><td>–25 °C</td></tr>
<tr><td>+23 °C</td><td>0.6 to 1.5 N</td></tr>
<tr><td>+75 °C</td><td>0.5 to 1.4 N</td></tr>
</table>

Figure 7: Feedback Sensors Distribution and Interface

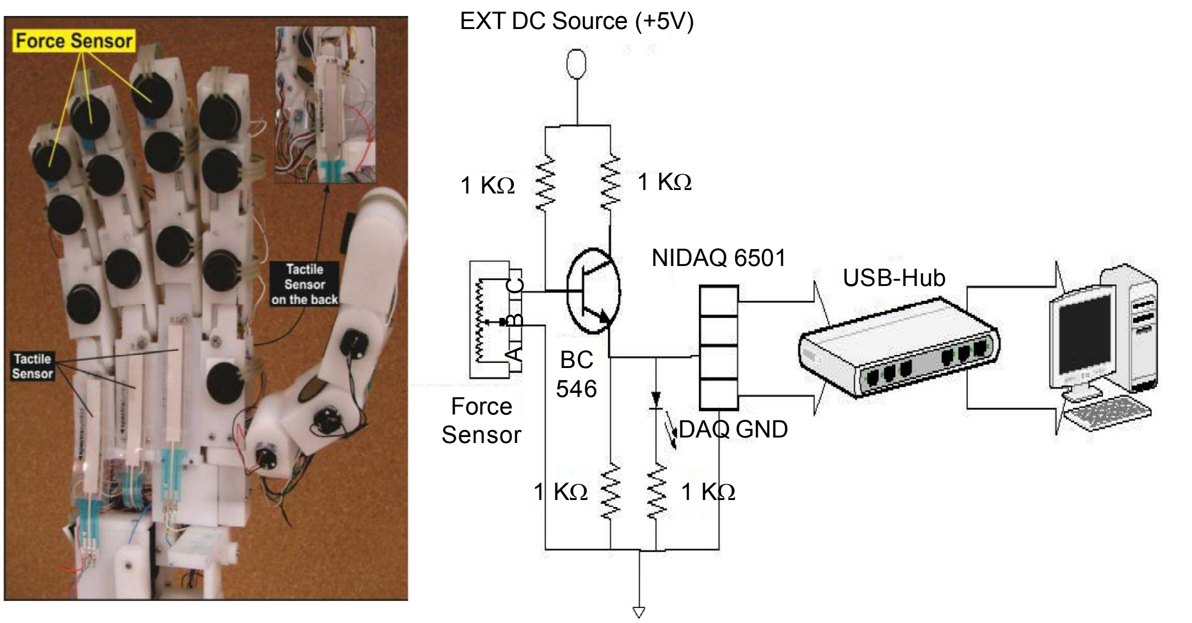
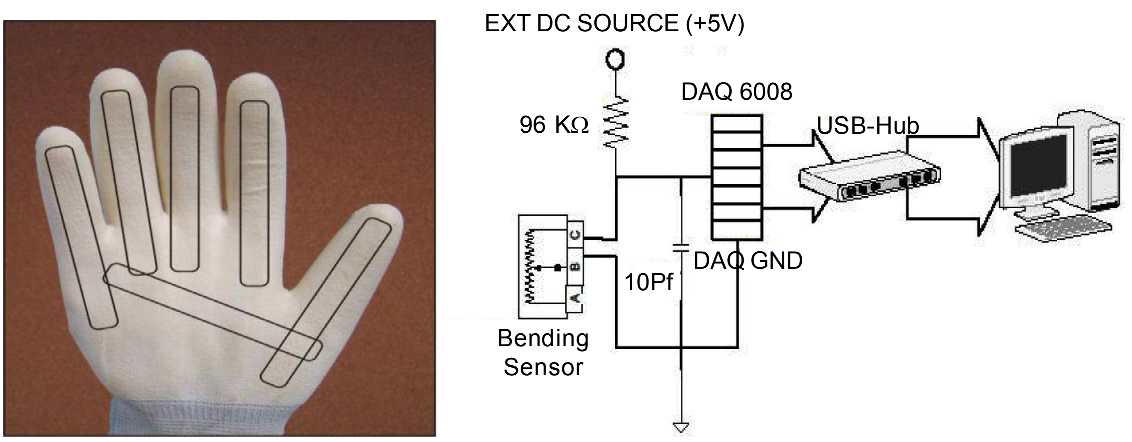
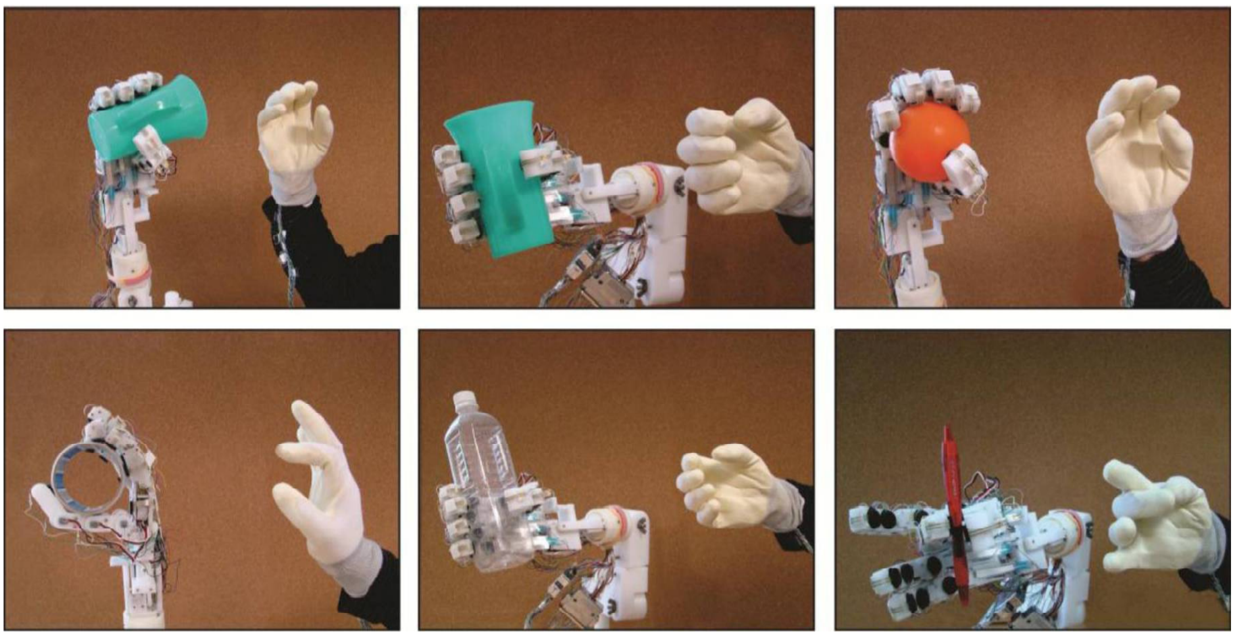


Figure 8: Light-Weight Tele-Operating Glove and Interface



A far better solution is to provide the operator with a single manual control for all the joints angle of the robot hand, and to rely on a control system to process the input angles and produce the high-level task applied to the tele-operated robot hand. In OCU-Hand, we have applied a single bending sensor to read the angle of each finger of the operator and developed a unique control strategy by mathematically processing and comparing the bending sensor output and the present angle of the corresponding OCU-finger in order to obtain a high accuracy results for controlling all the fingers of the OCU-Hand. The maximum and minimum output volts from bending sensor are 2.5 and 1.46 volts respectively. In order to be able to use these very small volts values we need to amplify them. Many approaches use hardware op-amp techniques. However in our approach we scale the bending by software arithmetic operations by multiply these two outputs by 40. In which the result maximum and minimum numeric values are 100 and 58.4 respectively. On the other hand, the position encoders of the figures joints maximum and minimum are 2.3 and .35 volt respectively. In order to obtain a high accurate position point we rescaled the position encoder too by the multiplying the resultant volts value 20 times. The difference between the maximum and minimum output of the bending sensor is 41.6. The difference between the maximum and the minimum output of the position encoder is 39, which is approximately the same as the bending sensor's value. This enabled us to perform a one value of the bending sensor to one value of encoder sensor's output. The resolution of the joints J_a, J_b and J_c is 39 (volts unit)/89 (angle degree) = 0.438. In which increases the accuracy of specifying the position point. The results from the comparison process are sent in the form of two bit digital signals via NI-USB-6221 DAQ to TA7291P DC motor driver H-bridge. Three cases are carried to the TA7291P; greater than, less than or equal. For every case TA7291P sends the appropriated signals to the DC motor. In which increases the accuracy of specifying the position point. The process of controlling each motor is as follows: a 2-bit signal is sent via NI-USB-6221 DAQ to TA7291P DC motor driver H-bridge. Three cases are resulted from the comparison process greater than, less than or equal. For every case TA7291P sends the appropriate signal to the DC motor. Figure 9 shows examples of tele-operation mode in OCU-Hand in which objects of different shape and weight are manipulated.

Figure 9: OCU-Hand in Tele-Operating Mode



ASSISTIVE-MODE TECHNIQUE

The main objective of the assistive system design is to reduce the workload on a human operator in order to he/she be able to focus on the main task. Our assistive mode is depending on the resultant tele-operation strategy. Consider the situation in which the human operator controls OCU-Hand and make it grasp an object. Then the operator touches a Membrane Potentiometer on the back of OCU-Hand. A sound buzzer is triggered to inform the operator that the OCU-Hand is in the assistive mode. In this mode, the operator is totally free to use the glove for performing other tasks. The OCU-Hand will keep grasping and holding the object until either one of the next two conditions occurs: the operator touches the Membrane Potentiometer on the back of OCU-Hand again, or the contact state between the OCU-Hand and the object is changed which means the object has moved in the hand or dropped off. During the assistive mode, a buzzer is triggered every 2 seconds informing the human operator that the system is still in the mode.

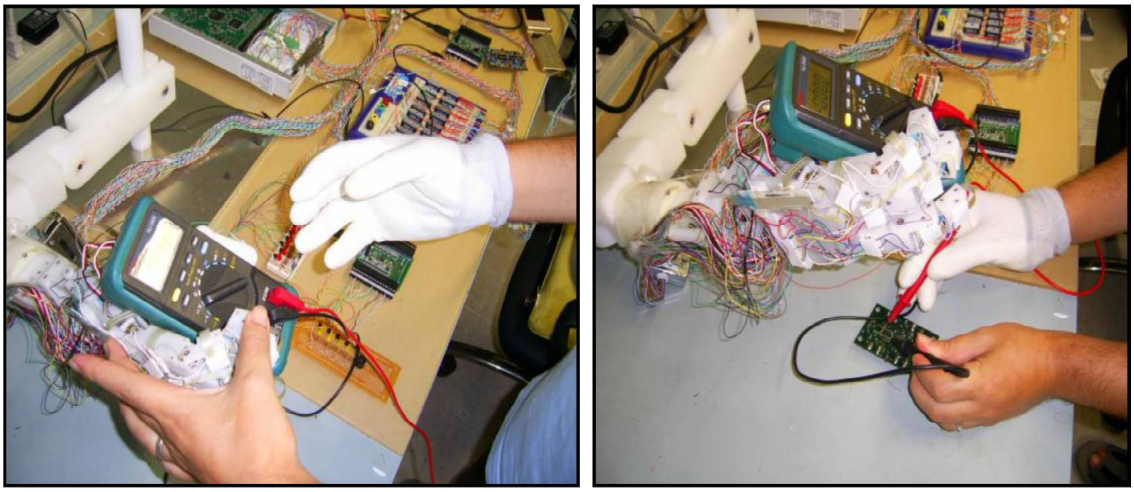
Contact-State Matrix

A contact state is represented in a form of matrix, a contact-state matrix. An example of such a matrix is shown in Figure 10. Each cell represents the contact state for the corresponding sensor circuit shown in Figure 7, means the sensor is contacting with the object and 0 means it is non-contacting. We use two types of contact-state matrices; the reference matrix X_r and the present matrix X_p. X_r is used for storing the contact state at the beginning of the assistive mode. X_p is used for representing the present contact state. The system compares these two matrices at regular interval. If any of the values in the 19 cells in X_p is changed from the values in Xr, the system concludes that the object has moved in the hand, dropped off or the object shape has changed and quits the assistive mode. In order to get the correct contact state, we use an active sensing technique. When the system demands a new Xp, it activates all the motors in sequence. When each motor is activated and attempts to rotate to the grasp direction, the sensor outputs are checked at the sensors on the two segments adjacent to the motor. Thus, if the object does not move, a sensor contacting with the object can sense reactive force clearly. Figure 11 shows an example of the assistive mode. First the operator controlled the OCU-Hand with the glove and grasp an object (Avometer) firmly. Then he touched the Membrane Potentiometer on the back of the OCU-Hand as in Figure 11a, the assistive mode began. In this mode, he can move his glove hand for other tasks without moving the OCU-Hand as shown in Figure 11b. After he completed his tasks he just touched the Membrane Potentiometer on the back again, and he was back to the tele-operating control mode.

Figure 10: Example of Feedback Sensors Output Matrix

Little	Ring	Middle	Index	thumb	
0	1	0	0	1	Distal Phalanges
1	0	1	1	0	Intermediate Phalanges
0	0	1	1	0	Proximal Phalanges
0	0	1	1	non	Palm

Figure 11: OCU-Hand in Assistive Mode



DISCUSSION

Our proposed OCU-Hand has five fingers and a wrist with total 18 DOF. Many others proposed artificial hands use (Lovchik *et al.*, 1999; Kenneth *et al.*, 2003; and Rosell *et al.*, 2009) at most three finger system. All fingers in our robot hand are independent in design, so that this hand system provides the facility of maintaining every finger independently without affecting the whole system. It also can exchange each finger when it breaks or a better design is available in the future. By containing the actuation and sensor systems inside the hand, we could overcome the problems of tendon-actuation design such as position inaccuracy as in the proposed mechanisms (Thayer and Priya, 2011) while keeping the size similar to the human hand. Also using the servomotor overcomes the need of applying elastic elements within the mechanism which leads to keep the motor running on the other to retain the joint angle is considered as output power loss when applying ultrasonic motors as in the proposed hand (Yamano and Maeno, 2005). The maximum length of our proposed hand is the length from the fingertip of the middle finger to the palm base, and it is 175 mm; the maximum width of OCU-Hand is 88 mm. These dimensions resemble the human hand size. It is clear that the dimensions of OCU-Hand is almost 54.9% compact compared to other proposed robot hand such as (Mouri *et al.*, 2011), 52.7% compact compared to another proposed hand in Shadow (2005). An important factor for improving hand performance is the reduction in weight. As Figure 2 shows, our hand is mainly made of polypropylene copolymer. The properties of this material endow the hand with light weight which is total 895 grams (709(grams) fingers+palm mechanisms and 186(grams) for the wrist mechanism), which is considered as lightest proposed robot hand so far and which in total (fingers+palm+wrist) is 63.92% less than the proposed hand in Mouri *et al.* (2011), and is 22.94% less than other proposed robot hand (Shadow, 2005) and is 57.04% less than other proposed robot hand (Li-Ren and Han-Pang, 1997). The palm of the human hand has the important function of supporting objects manipulated by the hand. In our proposed robot hand we have improved the manipulation performance by designing of delicate palm, which enables the hand to manipulate objects with various shapes. The wrist design in OCU-Hand enables it to pitch, roll and yaw around single point, for our best knowledge, no such mechanism design have been proposed. OCU-Hand has a novel and easy interactive tele-operating strategy with assistive mode, which enables the hand to work effectively as an assistive hand. One of the main modules in the assistive mode is contact state matrix, and the reference matrix is referred to a specific shape of an object, which enables us to teach the OCU-Hand how to recognize an object through it shape.

CONCLUSION

We have presented a robot hand in which the anthropomorphic and dexterous factors are compromised, and controlled by a simple light weight glove. A new interactive control strategy has been appended to the tele-operating system which is considered as a very unique useful technique for teaching OCU-Hand the shape of the objects and also helps the operator to use the OCU-Hand as an assistive person that always obeys, or a clever machine.

REFERENCES

1. Antonio B and Alessia M (2000) "Dexterous Grippers: Putting Nonholonomy to Work for Fine Manipulation", *The International Journal of Robotics Research*, Vol. 21, p. 427.
2. Borst Ch, Fischer M, Haidacher S, Liu H and Hirzinger G (2003), "DLR Hand II: Experiments and Experience with an Anthropomorphic Hand", Proc. of the IEEE International Conference on Robotics & Automation, September 14-19, pp. 702-707, Taipei, Taiwan.
3. Butterfass M, Grebenstein H, Liu H and Hirzinger G (2001), "DLR-Hand II: Next Generation of a Dexterous Robot Hand", Proc. IEEE Int. Conf. on Robotics and Automation.
4. Chua P Y, Bezdicek M, Davis S, Caldwell D G and Gray J O (2006), "Sch. of Comput., Sci. & Eng., Salford Univ. Tele-Operated High Speed Anthropomorphic Dexterous Hands with Object Shape and Texture Identification Intelligent Robots and Systems", Proc. IEEE/RSJ International Conference on Issue Date: October 9-15, pp. 4018-4023, Beijing.
5. Engelberger G (2001), "NASA's Robonaut", *Industrial Robot: And International Journal*, Vol. 28, No. 1, pp. 35-39.
6. Fukaya N, Toyama S, Asfour T and Dillmann R (2000), "Design of the Tuat/Karlsruhe Humanoid Hand", Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, IROS'00, pp 1754-1759.
7. Johnsson M and Balkeniuse C (2010), "Haptic Perception with Self-Organizing ANNs and an Anthropomorphic Robot Hand", *Journal of Robotics*.
8. Jongkind W (1993), "Dexterous Gripping in a Hazardous Environment", Ph.D. Thesis, Delft Uvi. of Technology.
9. Kenneth P, James Demmela W and Paul K Wrighta (2003), "Simulation Software for the Utah/MIT Dexterous Hand,

A Robotics Research Laboratory, February 14, Courant Institute of Mathematical Sciences, New York University, New York, USA.

10. Kudomi S, Yamada H and Muto T (2000), "Development of A Hydraulic Master-Slave System for Telerobotics", Proc. of 1st FPNI-PhD Symposium, pp. 467-474, Hamburg.

11. Li-Ren Lin and Han-Pang Huang (1997), "Mechanism and Computer Simulation of a New Robot Hand for Potential Use as an Artificial Hand", *Plastic International Society for Artificial Organ*, pp. 59-69, Boston.

12. Liu H, Meusela P, Seitza N *et al.* (2007), "The Modular Multisensory DLR-HIT-Hand", *Journal of Mechanism and Machine Theory*, Vol. 42, pp. 612-625.

13. Lovchik C S and Diftler M A (1999), "The Robonaut Hand: A Dexterous Robot Hand for Space", Proc. of the IEEE Int. Conf. on Robotics and Automation, pp. 907-912.

14. Mouri T, Endo T and Kawasaki H (2011), "Review of Gifu Hand and its Applications", *Journal of Mechanics Based Design of Structure Machines*, Vol. 39, pp. 210-228.

15. Paetsch W and Kaneko M (1990), "A Three Finger Multi Jointed Gripper for Experimental Use", Proc. IEEE Int. Works on Intelligent Robots and Systems, IROS'90.

16. Rosell J, Suarez R, Rosales C, Garcia J A and Perez A (2009), "Motion Planning for High DOF Anthropomorphic Hands Source", Procs. of the IEEE International Conference on Robotics and Automation Table of Contents Kobe, pp. 770-775.

17. Salisbury J K, Brock D L and Chiu S L (1985), "Integrated Language, Sensing and Control for a Robot Hand", Proc. 3rd ISRR, MIT Press, Gouvieux, France, Cambridge MA.

18. Schulz S, Pylatiuk C and Bretthauer G (2001), "A New Ultrahigh Anthropomorphic Hand", Proc. of the IEEE Int. Conf. on Robotics and Automation.

19. Shadow (2005), "Shadow Dexterous Hand", Shadow Robot Company Ltd., available at http://www.shadow.org.uk/products/newhand.shtml, Accessed on 2005-05-08.

20. Song Y, Tianmiao W, Jun W, Yang Fenglei and Zhang Qixian (1999), "Share Control in Intelligent Arm/Hand Teleoperated System", Proc. of the IEEE International Conference on Robotics and Automation, May, pp. 2489-2494.

21. Stansfield S A (1990), "Knowledge-Based Robotic Grasping", IEEE Conf. Robotics Automat, April, pp. 1270-1275.

22. Thayer N and Priya S (2011), "Design and Implementation of a Dexterous Anthropomorphic Robotic Typing (DART) Hand", *Journal of Smart Materials and Structures*, Vol. 20, p. 12.

23. Weigl A and Seitz M (1994), "Vision Assisted Disassembly Using a Dexterous Hand Arm System: An Example and Experimental Results", Proc. IFAC Int. Symp. on Robot Control, pp. 314-322, Capri, Itali.

24. Wöhlke G (1990), "A Programming and Simulation Environment for the Karlsruhe Dextrous Hand", *Journal of Robotics and Autonomous Systems*, Vol. 9, pp. 243-263.

25. Yamano I, Takemura K, Endo K and Maeno T (2002), "Method for Controlling Master-Slave Robots using Switching and Elastic Elements", Proc. of the IEEE International Conference on Robotics and Automation, May, pp. 1717-1722, Washington DC.

26. Yamano I and Maeno T (2005), "Five-Fingered Robot Hand Using Ultrasonic Motors and Elastic Elements", Proc. IEEE International Conference on Robotics and Automation, pp. 2684-2689.

27. Zollo L, Roccella S, Guglielmelli E, Carrozza M C and Dario P (2007), "Biomechatronic Design and Control of an Anthropomorphic Artificial Hand for Prosthetic and Robotic Applications", *Journal of IEEE/ASME Transactions on Mechatronics*, Vol. 12, pp. 418-429.