Electronic Coupled and Self-adaptive Grasp Robotic Finger

Conference Paper · December 2013

DOI: 10.1109/ROBIO.2013.6739690

4 authors:

Hui Xiao
University of Connecticut

Demeng Che
Caterpillar Inc.

Wenzeng Zhang
Tsinghua University

Zhenguo Sun
Tsinghua University

Proceeding of the IEEE
International Conference on Robotics and Biomimetics (ROBIO)
Shenzhen, China, December 2013

Electronic Coupled and Self-adaptive Grasp Robotic Finger

Hui Xiao[1], Demeng Che[2], Wenzeng Zhang[1,2], Zhenguo Sun[1]

***Abstract*—Current self-adaptive hands are always complex in mechanical structure and they have only fixed grasping mode and cannot be adjusted easily. To overcome these disadvantages, this paper proposed a novel scheme of making use of close loop in lower controller to fulfill coupled and self-adaptive grasp. A 2-DOF Electronic Coupled and Self-adaptive finger, E-COSA finger was designed in this paper. E-COSA finger has two joints driven by two motors separately, five sensors, one lower control module and E-COSA control algorithm. E-COSA control algorithm means that the control module receives signal from sensors to control two motors, thus make the finger grasp object with two stages: one is the coupling process, the next stage is self-adaptation when the proximal phalanx touching object. This grasp mode is better than traditional under-actuated grasping and the mechanism is simple, although the sensing and control system is added into finger but the control algorithm is fixed, do not need any complex computation, which make the finger could apply under unknown and complicated environment.**

I. INTRODUCTION

ROBOTIC hand is one of pivotal components of humanoid robot. Looking for an efficient, stable, and able to be widely used robotic hand is one of hot spots of robot research in recent decades. The study on robotic hands can be divided into two main directions: dexterous hands and self-adaptive hands. Dexterous hand has more than 9 degrees of freedom (DOFs). Each DOF is controlled by one motor. Dexterous hand can grasp object perfectly but they need to compute in real time to adapt different situation. Because of existing plenty of sensors and motors, its programs are always huge and difficult to design and compute, and there should be advanced hardware to support it, thus its cost is quite high. A plenty of dexterous hands were developed. For example, Utah/MIT Dexterous Hand [1], Gifu Hand II [2] by Gifu University, High-speed hand [3] by Tokyo University, LARM Hand III[4] by University of Cassino and DLR-Hand II [5] belong to dexterous hands. The future of dexterous hand will towards more powerful hardware and sophisticated algorithms.

Manuscript received on Aug 31, 2013. This paper was supported by National Natural Science Foundation of China (No.50905093) and Foundation of National Training Programs of Innovation for Undergraduates (No.201310003015).

1. Key Lab. for Advanced Materials Processing Technology (Ministry of Education), Dept. of Mechanical Engineering, Tsinghua University, Beijing 100084, P. R. China.
2. Dept. of Mechanical Engineering, Northwestern University, Evanston 60201, USA
Hui Xiao's email is xiaohuits@163.com,
Demeng Che's email is dche@u.northwestern.edu,
Wenzeng Zhang's email is wenzeng@tsinghua.edu.cn.

Self-adaptive hands can fulfill self-adaptive grasp and releasing, which means a self-adaptive hand can be used in different situations without reprograming. For example, T. Laliberte's under-actuated hand [6], the SPRING Hand [7] by Stanford University, the high-performance hand [8] by Tokyo Institute of Technology, and the AR Hand III [9] by Harbin Institute of Technology, belong to self-adaptive hands.

In recent years, Underactuated Robots and Grasping Lab (URGL) in Tsinghua University developed multiple anthropomorphic self-adaptive robotic hands, such as TH-1 Hand [10], TH-2 Hand [11], LISA Hand [12], TH-3R Hand [13], DSUA Hand [14], GCUA Hand I [15, 16], GCUA Hand II [17], CDSA Hand [18], COSA-L Finger [19], COSA-GRS Hand [20], HAG Hand [21].

There is one disadvantage from the growing of self-adaptive mechanical hands that their mechanical structures are becoming more and more complex and the manufacturing of which has become increasingly difficult. Because of complex mechanical structure, the transmission chain in any finger is longer, thus the grasping force of fingertip is smaller. There is another disadvantage in traditional under-actuated finger: any finger can only execute one fixed grasp mode due to the limit of mechanical structure. They cannot be adjusted easily after produced.

Through the description mentioned above about dexterous hands and self-adaptive hands, one can know that each one has its own advantages and disadvantages. Therefore, there should be one path between dexterous hand and self-adaptive hand, if there is a way to combine both advantages and eliminate both disadvantages, which should be an important growing direction of both.

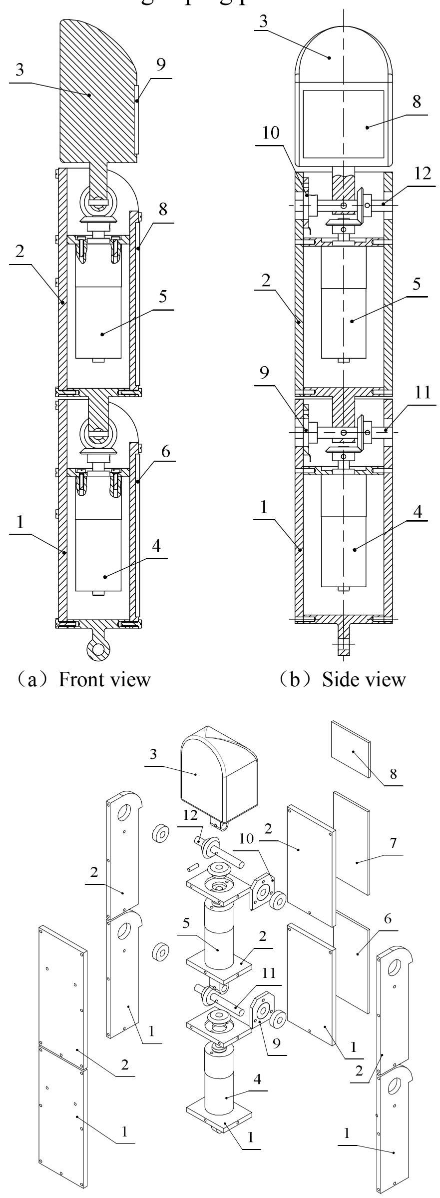
This paper proposed a novel scheme of robotic finger, Electronic Coupled and Self-adaptive (E-COSA) finger. The E-COSA finger is simple in mechanical structure as traditional dexterous hands, and has the same grasp mode as traditional mechanical coupled and self-adaptive hands. The E-COSA finger makes use of multisensory close loop control and simple and fixed grasping algorithm to fulfill coupled and self-adaptive grasp.

II. DESIGN OF THE E-COSA FINGER

2.1 Mechanical Design of E-COSA Finger

An E-COSA finger with two joints is designed, shown in Fig. 1. The finger contains three phalanxes and two motors. The two motors are embedded separately into the first and second phalanx, connected with the 1st and 2nd joint shaft by bevel gear. The second phalanx is fixed with 1st joint shaft and the third phalanx is fixed with 2nd joint shaft. In this way, the 1st motor is used to achieve the rotational motion of the second phalanx while the 2nd motor drives the third phalanx to rotate. The forward rotation of the motors will yield the bending of the finger, while the backward rotation yields the finger extension. Five E-COSA fingers with similar structures can be used to compose a self-adaptive hand by adding one motor to rotate the proximal joint for each of them.

The above-mentioned motors can be DC, stepper, or servo motors. The corresponding reducer is proposed to be used with these motors, which can provide a static resistant force aiming to enhance the grasping performance of the finger.



（a）Front view （b）Side view

(c) Exploded view

1-1st-phalanx; 2-2nd-phalanx; 3-3rd-phalanx; 4-1st-motor; 5-2nd-motor; 6-1st trigger sensor (TS1); 7-2nd trigger sensor (TS2); 8- Stop sensor (SS); 9-1st Potentiometer (PS1); 10-2nd Potentiometer (PS2); 11-1st joint shaft; 12-2nd joint shaft

Fig.1. Mechanical structure of E-COSA finger

The dimensions of the fingers are proposed to be determined from the biological point of view, aiming to perform similar gestures and grasping motions as human beings.

The E-COSA finger is supposed to grasp the objects in the following way: First of all, the first or the second phalanx of the finger has to be touched the object first to activate the two motors indicated in Fig. 1, i.e., to initiate the self-adaptive grasping process; and then the finger will keep bending until the third phalanx touches the object with a required compression force. In order to achieve this grasping process, five sensors with three different functions are proposed to be embedded into an E-COSA finger. Three different functions are introduced as follows:

(1) ***Triggering function*** is defined to activate one (i.e., when the second phalanx touches the object firstly) or two (i.e., the first phalanx touches the object firstly) of the embedded two motors in order to start bending, which can be achieved by two specific pressure sensors, i.e., trigger sensor (TS1 and TS2). These two sensors will be placed on the whole surface of the first and second phalanxes facing to sense the contact of the phalanxes and the object respectively.

(2) ***Terminating function*** is defined to deactivate the embedded motors aiming to end the grasping process. Similar to the first function, another pressure sensor, i.e., stop sensor (SS), will be fixed on the surface of the third phalanx facing to sense the compression force exerted by the third phalanx to the object. The terminating function will be achieved as long as the compression force has exceeded certain threshold.

(3) ***Positioning function*** is defined to monitor the rotation angles of the embedded motors aiming to enable the prediction of finger gesture. To meet this goal, two angle sensors, i.e., potentiometer (PS1 and PS2), will be fixed on the two joints, i.e., the 1st and 2nd joints, in order to record rotation angles of motors and in turn to predict the finger gesture.

2.2 Control Algorithm Design of E-COSA Finger

As shown in Fig. 2, the control system of the E-COSA finger includes a control module, two motor driving circuits, and the above-mentioned five sensors. The control module can be fully functioned based on certain control unit, e.g., PLD, PLC, microcontroller, DSP, or FPGA. The motor driving circuit is designed to receive, process, and deliver signals between the control module and the sensors.

Three pressure sensors mentioned in Section 2.1, can detect the contact pressures between object and phalanxes and feed them back to the control module. Certain threshold for each of the sensors can be determined based on the requirement of grasping applications and be achieved in program. Displacement or torque sensors can also be used to replace pressure sensors for certain applications. Two rotation potentiometers are proposed to be used as PS1 and PS2. The electrical resistance of these potentiometers changes linearly with the rotational angle of motors as follows:

$$\alpha = \frac{R - R_{0^\circ}}{R_{90^\circ} - R_{0^\circ}} \times 90^\circ \tag{1}$$

where α is the motor's rotational angle, R is the in-situ electrical resistance of the potentiometer, and $R_{0°}$ and $R_{90°}$ stands for potentiometer's resistance for 0º and 90º angle between two phalanxes connected with the potentiometer embedded joint respectively.

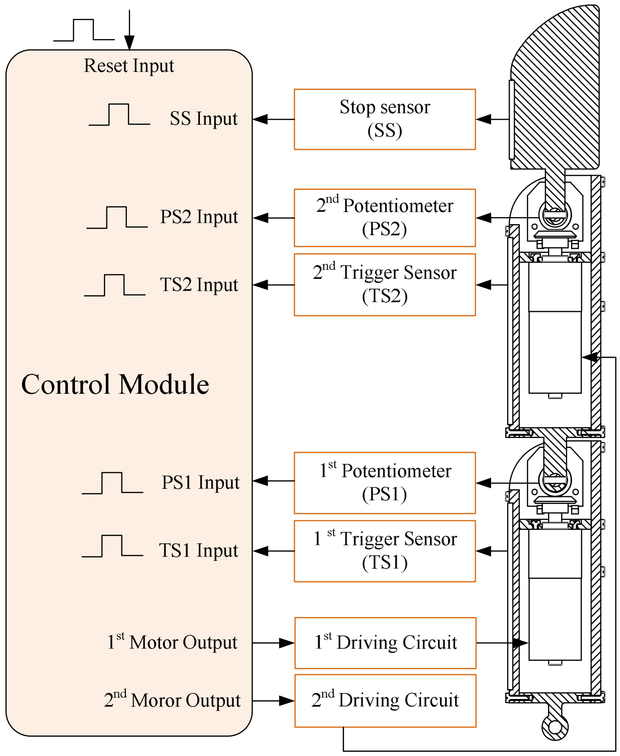


Fig.2. Electronic components of the E-COSA finger

The main control algorithm of E-COSA finger is shown in Fig.3. The core task of this algorithm is to achieve the following process: the motors will be activated forcefully until either the 1st or the 2nd phalanx touches the object at the beginning of the grasping process, and then will be controlled under the above-designed control system. The main control algorithm can be divided into two subprograms, i.e., the coupling and the reset subprograms.

As shown in Fig. 4, the coupling control algorithm is governed by two parameters, i.e., K and M, aiming to keep the coupling relationship between two joints. K, as a scale of the joint angle determines the significance of the joint angle effect on grasping performance, i.e., stability and accuracy, while M describe the threshold in terms of grasping performance in certain grasping process.

The coupling control algorithm can be well understood as follows: As the motors are rotating, the control module will calculate the term ($\alpha - K\beta$) and compare it with parameter M. If $\alpha - K\beta$ is bigger than M, which indicates the forward relative rotation between two joints (i.e., 2nd motor rotates faster than 1st motor) has exceeded a specific angle, the 1st motor will stop immediately. Contrarily, if $\alpha - K\beta$ is smaller than -M, which indicates the reverse relative rotation between two joints (i.e., 2nd motor rotates faster than 1st motor) has exceeded a specific angle, the 2nd motor will stop immediately. We can also use the PID algorithm to fulfill this work as a more complex thrust.

The reset control algorithm of E-COSA finger, as shown in Fig.5, aims to recover the finger to the original gesture after detecting a reset signal. This subprogram is embedded into the main control algorithm multiple times, as shown in Fig.3, in order to the reset signal can be understood by the control system at any period of time during grasping process.

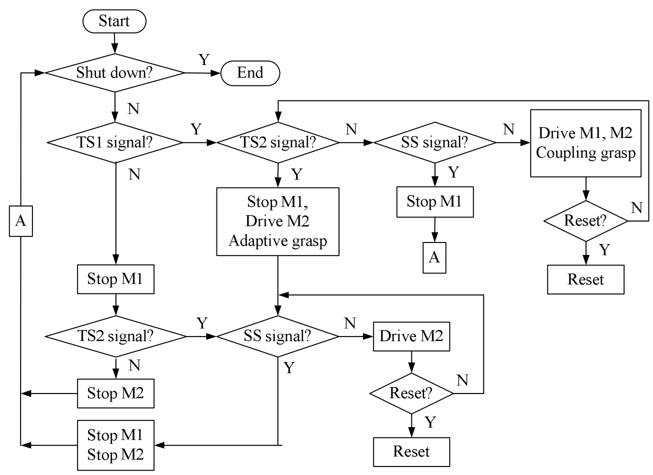


Fig. 3. Flow chart of main control algorithm of the E-COSA finger

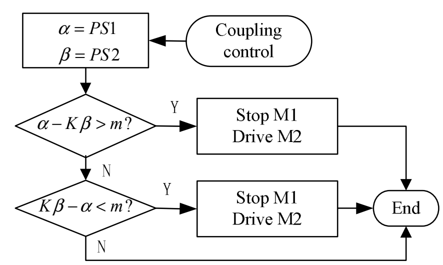


Fig. 4. Flow chart of coupling control algorithm of the E-COSA finger

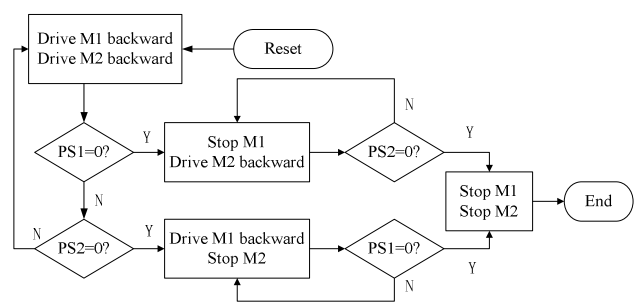


Fig.5. Flow chart of reset control algorithm of the E-COSA finger

Finally, specific programming language, e.g., C, C++, etc., corresponding to the application of the control module, has to be exploited to achieve the flow charts depicted in Figs. 3, 4 and 5.

III. Grasp Patterns of E-COSA Finger

The E-COSA finger has two kinds of grasp patterns. The first kind of grasp pattern is shown in Fig.6. The 1st phalanx is supposed to touch the object first. After that, the 1st and 2nd motors will start to rotate forward simultaneously, during which α and β will evolve in a coupling relationship. The 1st motor will stop after the 2nd phalanx has applied certain force on the object, while the 2nd motor will keep rotating forward until the object the 3rd phalanx contacts with certain force. In this way, the object is fully grasped by the finger.

The second kind of grasp pattern is described in Fig. 7. The 2nd phalanx is assumed to touch the object first, and then 1st and 2nd motors will start to rotate in a coupling relationship similar to the first pattern. When the object contact the 3rd or 1st phalanx, correspondingly, 2nd or1st motor will stop and the other one of these two motors will keep rotating until the last phalanx also presses the object with certain force.

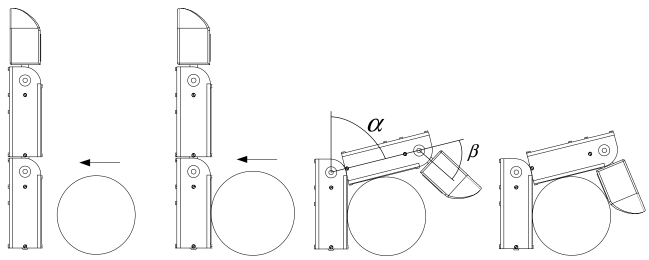
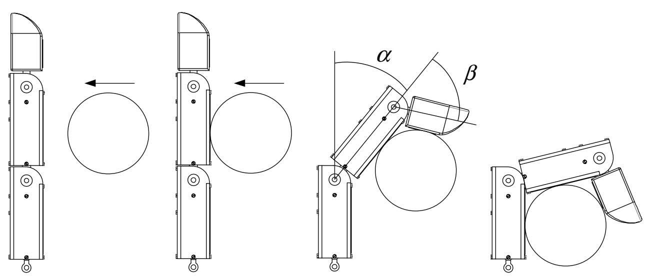
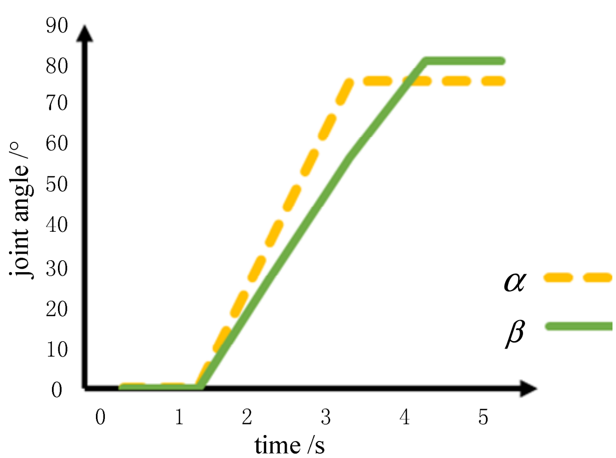


Fig. 6. The first kind of grasping process of E-COSA finger

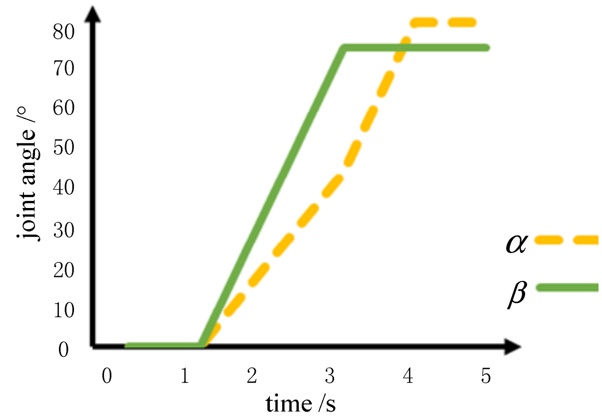


(a) (b) (c) (d)

Fig. 7. The second kind of grasping process of E-COSA finger



(a) The first grasp pattern



(b) The second grasp pattern

Fig. 8. The angle change process in two kinds of grasp patterns

The evolution of included angles between joints with respect to time was simulated in MATLAB, as shown in Fig. 8. The explicit difference between these two grasp patterns can be easily detected, which can be used to identify the grasp pattern of certain grasping process based on data derived from angle sensors introduced in Section 2.

IV. Grasp Analysis of E-COSA Finger

The mathematical analysis of robotic hands is essential to achieve in-depth understanding of various grasping processes. The comprehensive analysis of 2-DOF fingers is very complex, which draws much attention in this area. The grasp space of E-COSA finger is given in this section, as an importation indication of the finger performance. The E-COSA finger can be simplified as a physical model shown in Fig. 9. For the sake of simplicity, the object is assumed to be a cylinder.

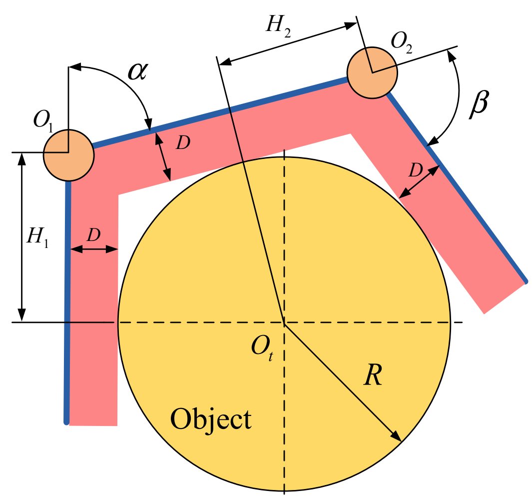


Fig. 9. Schematic of the grasping process

Relevant parameters are listed as follows:

H_1: the distance between the 1st joint shaft and the contact point of the object on 1st phalanx, mm.

H_2: the distance between the 2nd joint shaft and the contact point of the object on 2nd phalanx, mm.

R: the radius of the spherical object, mm.

α: the tilting angle of the 2nd phalanx, °.

β: the tilting angle of the 3rd phalanx, °.

D: the distance between the joint shaft and the grasping surface of the phalanx, mm.

The geometrical relationship between the finger and the object yields:

$$\alpha = 180^\circ - 2\arctan\frac{R+D}{H_1} \tag{2}$$

$$\beta = 180^\circ - 2\arctan\frac{R+D}{H_2} \tag{3}$$

Due to the space limitation of the finger's mechanical structure, both α and β must not greater than 90º, i.e.:

$$R \geq H_1 - D \tag{4}$$

$$R \geq H_2 - D \tag{5}$$

Fig. 10 indicates the relationships among parameters α, H_1 and R, while Fig. 11 indicates the relationships among β, H_2 and R. The points locating on curved surface between two flat surfaces in blue and yellow respectively represent all the parameter sets which can lead to a successful grasp (i.e., all three phalanxes have contacted the object) by the E-COSA finger.

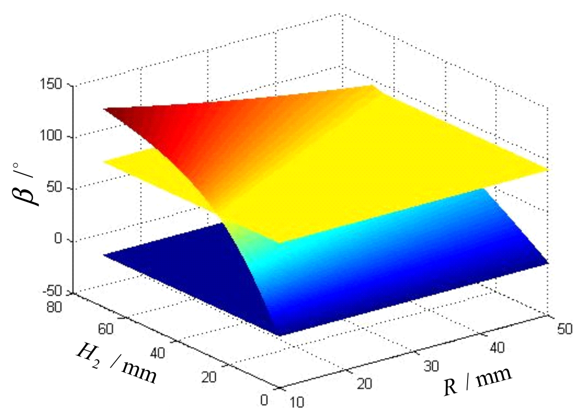


Fig.10. Relationships between α, H_1 and R.

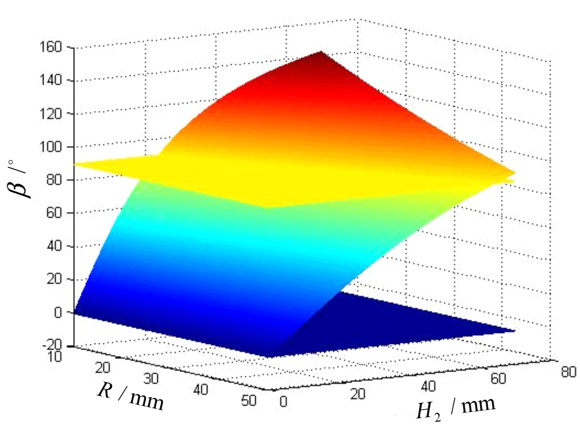


Fig.11. Relationships between β, H_2 and R

V. CONCLUSIONS

Several conclusions are summarized as follows:

(1) The new design of a robotic finger, i.e., E-COSA finger, was presented in this paper, including the mechanical and control system design and control algorithm formulation.

(2) Two grasp patterns with an emphasis of self-adaptive grasp function were introduced to describe the grasping process given by the newly designed robotic finger.

(3) The mathematical analysis of the grasping process under simplified conditions was conducted to evaluate the grasping performance of the E-COSA finger. The E-COSA finger was found to be possible to fulfill successful grasping under self-adaptive grasp patterns.

(4) The E-COSA finger can be used to construct coupled self-adaptive hands without complex mechanical structures and sophisticated control algorithms, which leads to a promising lower cost in comparison with other self-adaptive hands and dexterous hands.

(5) In the near future, the prototype of this newly designed robotic finger will be manufactured to fully evaluate the grasping performance. Static and dynamic analysis on the grasping process will also be pursued aiming to optimize the design factors, e.g., the finger dimensions, force thresholds for sensors, the included angles between adjacent phalanxes, etc., and process parameters, e.g., torque and rotational angle of motor, the in-situ compression forces applied to the object, etc.

REFERENCES

[1] S. C. Jacobsen, E. K. Iversen, D. F. Knutti, et al., "Design of the Utah/MIT dexterous hand," *IEEE Int. Conf. on Robotics & Automation*, San Francisco, CA, USA, Apr, pp.1520-1532, 1986.

[2] H. Kawasaki, T. Komatsu, K. Uchiyama, et al., "Dexterous anthropomorphic robot hand with distributed tactile sensor: Gifu hand II," *IEEE Inter. Conf. on Systems, Man, & Cybernetics*, Tokyo, Japan, Oct. 12-15, vol.2, pp. 782-787, 1999.

[3] A. Namiki, Y. Imai, M. Ishikawa, et al., "Development of a high-speed multifingered hand system and its application to catching," *Int. Conf. on Intelligent Robots & Systems*, Las Vegas, Nevada, USA, Oct. 27-31, pp. 2666-2671, 2003.

[4] G. Carbone, S. Iannone and M. Ceccarelli: "Regulation and control of LARM Hand III," *Robotics & Computer-Intergrated Manufacturing*, vol. 26, no. 2, pp. 202-211, 2010.

[5] J. Butterfass, M. Grebenstein, H. Liu, et al., "DLR-Hand II: next generation of a dextrous robot hand," *IEEE Int. Conf. Robotics & Automation*, Seoul, Korea, May 21-26, pp. 109-114, 2001.

[6] T. Laliberte, L. Birglen., and C. M. Gosselin, "Underactuation in robotic grasping hands," *Machine Intelligence & Robotic Control*, vol. 4, no. 3, pp. 1-11, 2002.

[7] M. C. Carrozza, C. Suppo, F. Sebastiani, et al., "The Spring Hand: development of a self-adaptive prosthesis for restoring natural grasping," *Autonomous Robots*, vol. 16, no. 2, pp. 125-141, 2004.

[8] T. Takaki, T. Omata, "High-performance anthropomorphic robot Hand with grasping-force-magnification mechanism," *IEEE/ASME Trans. Mechatronics*, vol. 16, No.3, pp. 583-591, 2011.

[9] D. Yang, J. Zhao, Y. Gu, et al., "An anthropomorphic hand developed on underactuated mechanism and controlled by EMG signals," J. of Bionic Engineering," vol. 6, no.3, 255-263, 2009.

[10] W. Zhang, Q. Chen, Z. Sun, et al, "Under-actuated passive adaptive grasp humanoid robot hand with control of grasping force," *IEEE Int.*

Conf. on Robotics and Automation. Taipei, China, Sep, pp. 696-701, 2003.

[11] W. Zhang, Q. Chen, Z. Sun, et al., "Passive adaptive grasp multi-fingered humanoid robot hand with high under-actuated function," *IEEE Int. Conf. on Robotics & Automation*. New Orleans, LA, USA. Apr, pp. 2216-2221, 2004.

[12] J. Jin, W. Zhang, Z. Sun, et al., "LISA Hand: indirect self-adaptive robotic hand for robust grasping and simplicity," *IEEE Int. Conf. on Robotics & Biomimetics*, Guangzhou, China, Dec. 11-14, pp. 2393-2398, 2012.

[13] W. Zhang, D. Che, H. Liu, et al., "Super under-actuated multi-fingered mechanical hand with modular self-adaptive gear-rack mechanism," *Industrial Robot: An Int. J*. vol. 36, no. 3, pp. 255-262, 2009.

[14] G. Li, B. Li, J. Sun, W. Zhang, Z. Sun, Q. Chen, "The development of a directly self-adaptive robot Hand with pulley-belt mechanism," *Int. J. of Precision Engineering and Manufacturing*, vol. 14, no. 8, pp. 1361-1368, 2013.

[15] W. Zhang, D. Che, Q. Chen, et al., "Study on gesture-changeable under-actuated humanoid robotic finger," *Chinese J. of Mechanical Engineering*, vol. 23, no. 2, pp. 142-148, 2010.

[16] D. Che, W. Zhang, "A dexterous and self-adaptive humanoid robot hand: GCUA Hand," *Int. J. of Humanoid Robotics*, vol. 8, no. 1, pp. 73-86, 2011.

[17] D. Che, W. Zhang, "GCUA humanoid robotic hand with tendon mechanisms and its upper limb," *Int. J. of Social Robotics*, vol. 3, no. 4, pp. 395-404, 2011.

[18] G. Li., H. Liu., and W. Zhang, "Development of multi-fingered robotic hand with coupled and directly self-adaptive grasp," *Int. J. of Humanoid Robotics*, vol. 9, no. 4, pp. 1250034.1-18, 2012.

[19] W. Zhang, D. Zhao, H. Zhou, et al., "Two-DOF coupled and self-adaptive (COSA) finger: a novel under-actuated mechanism," *Int. J. of Humanoid Robotics*. vol. 10, no. 2, pp. 1330001-1-26, 2013.

[20] J. Sun., W. Zhang, "A novel coupled and self-adaptive under-actuated multi-fingered hand with gear-rack-slider mechanism," *J. of Manufacturing Systems*, vol. 31, pp. 42-49, 2012.

[21] C. Zhang, W. Zhang, Z. Sun, Q. Chen, "HAG-SR Hand: highly-anthropomorphic-grasping under-actuated hand with naturally coupled states," Int. Conf. on Social Robotics. Chengdu, China, Oct, 29-30, pp. 475-484, 2012.