Proceeding of the IEEE
International Conference on Robotics and Biomimetics
Dali, China, December 2019

A Novel Grasping Control Method for Dexterous Prosthesis based on Eye-tracking*

Jie Li, Chunyuan Shi, Dapeng Yang, Hong Liu
State Key Laboratory of Robotics and System, Harbin Institute of Technology
Harbin 150081, China
lijie3701759@gmail.com, {chunyuan_shi, yangdapeng, hong.liu}@hit.edu.cn

Abstract **– The state-of-art dexterous prosthetic hand with multi-degree-of-freedom urgently requires a control method to match its dexterity. The purpose of this paper is to develop a method on rapid grasp control of prosthetic hand based on eye-tracking and verify its effectiveness by experiments. Firstly, an interactive experiment platform was established. Based on the platform, the operator can select the necessary grasping pattern from a graphic interface through eye movement and trigger the selected pattern by gazing the target for a short time (~300ms). The selected grasp pattern will be fed back to the operator during the hand prosthesis performing reach-and-grasp tasks. Finally, to verify the effectiveness of this method, experiments were conducted by an able-bodied participant wearing the prosthesis to grasp some daily-used objects. Our result shows that, by adopting the eye tracking technology in the human visual channel, the grasp control of the prosthesis can be supervised and regulated in real-time and thus an effective interaction between the dexterous prosthesis and the operator can be achieved.**

Index Terms – eye-tracking, grasp control, human computer interface

I. INTRODUCTION

For patients with forearm amputation, the lack of hand not only brings great inconvenience to their life, but also causes great psychological trauma. In order to compensate for this inconvenience, they need to wear the prosthetic hand for daily activities. Prosthetic hands are expected to perform complex movements, which depends highly on the design of mechanical structure and control algorithm. Over the past decades, several modern prosthetic hands have been developed in the market to restore the motions for the lost upper limb, such as i-Limb, Bebionic, Vincent, etc. They have implemented independent control of each finger that enables a sufficient mechanical flexibility to realize different grasp patterns [1, 2]. However, in the aspect of prosthesis control, the encoding control method [3] has poor sensuousness, the pattern recognition method [4-6] is not robust, and the multi-degree-of-freedom (multi-DOF) simultaneous control method [7-8] is difficult to achieve more than three DOFs. The performance of these current control methods are strongly limited, some aspects still need be be improved. These control methods can detect the intent of the user but with no sensory feedback. Therefore, a new stable and robust method with sensory feedback is urgently needed for the grasp control of prosthetic hand.

As a rising technology, the eye-tracking has been booming in the fields such as psychology and neuroscience, immersive virtual reality (VR) research, marketing and human-computer interaction in recent years [9-13]. With the maturity of eye-tracking technology, some low-cost eye tracker with low time latency have been produced by several companies in the market [14], such as Tobii's EyeX tracker, SMI's MI RED250 eye tracker and NAC's EMR-9 eye tracker. Using the human visual channel, the eye-tracking can be regarded as a more nature way to interact with outer environment compared with the other means as using mouse or keyboard, which provides an alternative interactive way for people with upper limb disability.

Several scholars have made research combining eye-tracking technology and prosthesis control. Duvinage et al. [15] used eye-tracking techniques in the control of leg prosthesis. The sequences of eye movements were converted into commands and implemented by the prosthesis actuator control unit. McMullen et al. [16] developed a brain-machine interface to control the prosthesis grasping, in which computer vision and eye-tracking were used to identify and select target objects. Through this method, the operator can perform complex object grasping with prosthesis using eye-tracking and EMG signals.

Our motivation is to configure multi-fingered prosthesis with different grasp patterns, and use the eye-tracking to rapidly select a proper grasp pattern when grasping various objects. Based on the grasp taxonomy summarized in [17], we firstly selected several key grasp patterns (cylindrical, spherical, tripod, lateral, index, hook), based on which the dexterous prosthesis can handle a large variety of daily-life objects (85% of our daily grasp activities) [3]. By using eye-tracking, the grasp patterns were rapidly selected through eye moving and gazing. The advantages of using this method include its high speed (less than 300 ms), high stability, strong robustness and good interactivity. It also has wide applications in robotic exoskeletons and other rehabilitation systems for those patients caused by cerebral palsy or spinal cord injury.

* This work is partially supported by the National Key R&D Program of China Grant #2018YFB1307201 to L. Jiang, and the NSF Grant #51675123 and Postdoctoral Scientific Research Development Fun (LBH-W18058) to D.Yang . Corresponding author: Dapeng Yang (yangdapeng@hit.edu.cn).

978-1-7281-6321-5/19//$31.00 ©2019 IEEE

II. METHODS AND MATERIALS

A. *Experiment Platform*

The experiment platform is shown in Fig. 1, which comprises the following components: (1) a computer (8GB RAM, i3@3.90GHZ), (2) eye-tracker (Steelseries, 60HZ), (3) Kinect 2 (Microsoft, USA), (4) Myo armband (Thalmic Labs, USA), (5) a robot hand prosthesis (HITAPH 5) with bypass.

A self-developed anthropomorphic prosthetic hand, HITAPH V [18], was used, which has five fingers actuated by six motors (finger extenstion/flexion and thumb abduction/ adduction). In the platform, the prosthesis was mounted on the forearm using a 3D-printed bypass. The main controller of the prosthesis communicates with computer via Bluetooth and receives velocity command from the computer, according to which the prosthesis actuator control unit drives each finger to move.

The Myo armband was used to control the opening and closing of the HITAPH V in the experiment. It can read raw myoelectric signals on forearm muscles and recognize several hand gestures. A total of five hand gestures (double tap, spread fingers, wave left, wave right, make a fist) can be recognized. Among them, we chose waving left and waving right to map a pair of antagonism movements (wrist flexion and extension), which drives the hand to close and open, respectively. The armband was fitted around operator's arm according to the suggested configuration. The Python scripts were written with the official SDK to directly extract the hand opening/closing command in real-time (12.5 HZ).

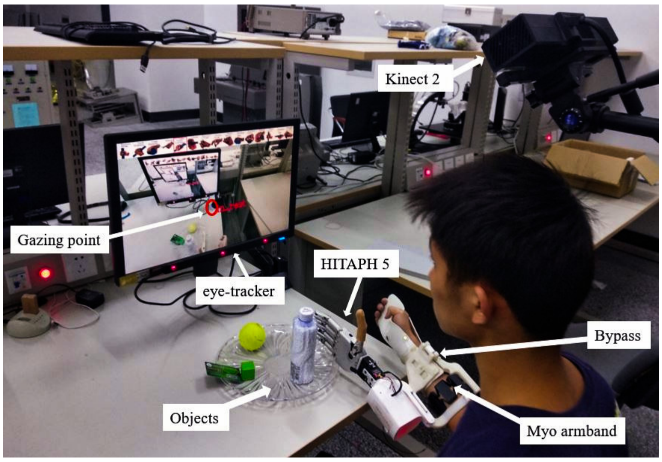


Fig. 1 System architecture. The system comprises the following components: (1) user interface implemented on a computer with eye-tracker; (2) a multi-grasp prosthetic hand with bypass; (3) a Kinect 2 to provide the vision of multi-objects; (4) Myo armband used for collecting surface EMG.

Once a command of hand open/close was received, each individual finger of the prosthetic hand started to move according to the grasp pattern selected by eye-tracking. In our preliminary experiment, four key grasps were implemented: cylindrical, spherical, lateral and tripod grasp. Different grasp patterns would adopt different velocity configurations, as shown in Table 1.

TABLE 1 Finger speed of four grasp patterns. Thumb 1 and Thumb 2 represent thumb adduction/abduction and extension/flexion, respectively. The values are represented as percentage of the maximum velocity of each finger (45 degrees per second).

	Thumb 1	Thumb 2	index	middle	ring	little
Cylindrical	47%	21%	45%	45%	45%	45%
Spherical	48%	29%	33%	33%	33%	33%
Tripod	56%	31%	39%	45%	-	-
Lateral	21%	33%	50%	50%	50%	50%

Fig. 2 summarizes the operation procedure using the control system. The operator was seated in front of the experiment table, facing the interactive interface based on eye-tracking. The eye tracker beneath the monitor collected user's gaze point and displayed it in the interface in form of a circular cursor with red color. The Kinect camera was installed directly above the operator's head, transferring the scene of the experiment table to the computer. The interactive interface was composed of two parts: the scene of platform retrieved from Kinect camera, and the grasping types menu on the top of interface. The menu was composed of a series of pictures being indicative of different grasping types covered on the scene provided by Kinect. As the operator moved the cursor to the expected grasping type menu by eye movements, the chosen part was highlighted and the corresponding grasping type was triggered. Accordingly, the interface sent a preshaping command to the hand, which defined the velocity of each individual finger. The selected grasp pattern was fed back to the operator in the form of text alongside the cursor, while the menu with regarded to the selected grasp pattern was also kept highlighted. Eventually the operator implemented hand closing to grasp the object and hand opening to release the object, in response to the recognized gesture acquired by Myo armband.

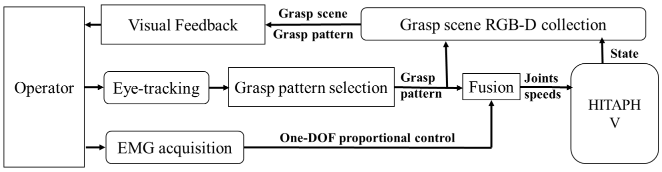


Fig. 2 The system workflow

B. *Eye-tracking Interaction*

The process of selecting a targeted grasp pattern using the eye-tracking is detailed in Fig. 3. At the beginning, there was a text label alongside the cursor indicating that the initial state was in rest (Fig.3-a). When the operator moved the cursor to the grasp pattern menu via eye-tracking and then gazed the target after a very short duration (< 0.3 s, Fig.3-b), the selection command would be triggered and the text label starts to indicate the current grasp pattern immediately (Fig.3-c). The box containing the selected grasp type was also highlighted. The controller configured the speed ratio of fingers of the prosthesis according to the selected grasping mode, and the operator controlled the closing and opening of hand through the myoelectric signal, eventually completed the grasp task.

a) b) c)

Fig. 3 Process of grasp pattern selection: (a) the initial state is in rest as shown in the interface; (b) when gazing grasp pattern menu (cylinder), the menu will be highlighted and the grasp pattern will be fed back immediately with red text (cylinder); (c) after selection, the prosthesis will grasp the object with planned grasp pattern.

C. Experiment Protocol

The effectiveness of this method was verified by an able-bodied subject completing a series of grasp tasks. The experiment setup is shown in Fig. 4. The subject was 23 years old, seated on an adjustable chair in front of the experiment table. Three positions were marked on the experiment table: the initial position for the hand (A), the initial position for the target objects (B) and the position to which the target object will be transported by the operator (C).

At the beginning of experiment, the subject received several training trials about how to operate the system and got familiar with the experiment prototype. This process took about 20 minutes. Four daily-used objects of different sizes and shapes (see Table 2) were used as target objects and randomly placed on a plate. In the experiment, subject raised his left hand to indicate the start of timing, subject was asked to select the grasp pattern using eye-tracking, then reach, grasp, transport and release each of the objects by operating the prosthetic hand. Timing ends when the subject placed the prosthetic hand to the initial position (position A) after all the operations. The task was repeated 10 times. There was a 2-minute break between each trial for getting rid of muscle fatigue.

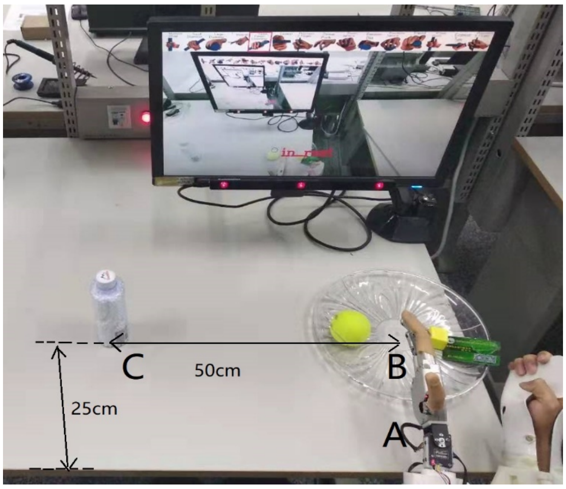


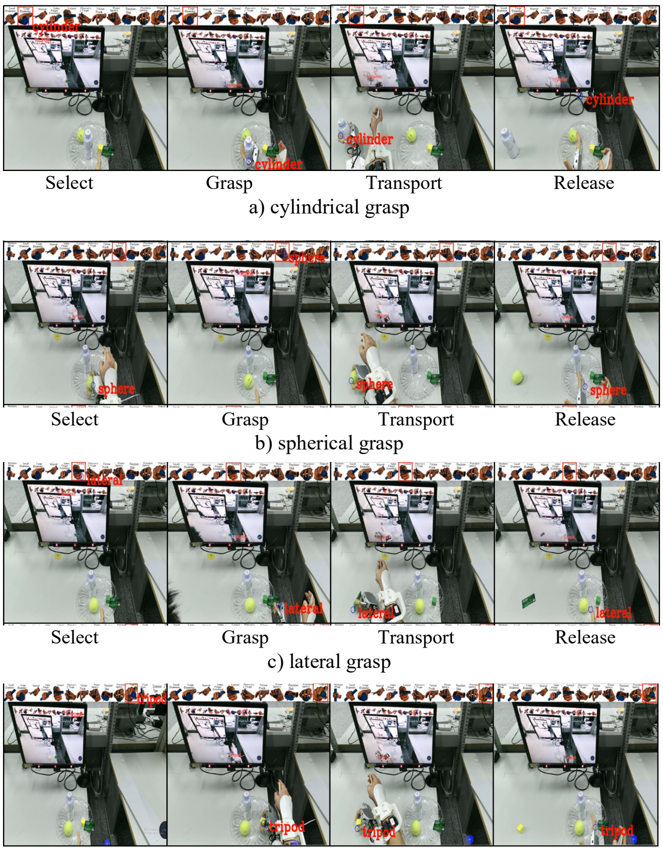
Fig. 4 The experiment setup. The operator was seated in front of the experiment table with three positions marked: (A) initial position for the prosthetic hand; (B) initial position for the target objects; (C) position to which the object had to be transported by the operator.

TABLE 2 Target objects in the experiment

Object	Size (cm)	Grasp pattern
Orange	6.5(diameter)	Spherical
Card	8.5(length) x 6.5(width) x 0.1(height)	Lateral
Block	3(length) x 3(width) x 3(height)	Tripod
Bottle	6(diameter) x 18.5(height)	Cylindrical

III. RESULTS AND DISCUSSIONS

The snapshots on using the prosthesis grasping target objects with eye-tracking are shown in Fig. 5. In each grasp task, the subject can alternatively use cylindrical grasp, spherical grasp, tripod grasp and lateral grasp in random order, depends on the size and shape of target object. The grasping process is divided into four phases: select correct grasping type from the menu, grasp the target object with correct grasp type, transport the target object to the destination, release and return to the initial position.



Select Grasp Transport Release
a) cylindrical grasp

Select Grasp Transport Release
b) spherical grasp

Select Grasp Transport Release
c) lateral grasp

Select Grasp Transport Release
d) tripod grasp

Fig. 5 Snapshots of a trial of experiment on grasping four objects.

The statistical chart of ten experiments is shown in Fig. 6. The total time to complete grasping of four target objects in the plate averaged to 55.4 s, in which 15.6 s is required for cylindrical grasp, 12.8 s for spherical grasp, 15.2 s for tripod grasp and 15.2 s for lateral grasp. The total time to select a proper grasp pattern averages about 1 s, including the time of moving gaze point from previous grasping menu to current one (takes almost 70% of total selection time), the time of gazing (~300 ms) and necessary communication time. The time required to complete the spherical grasp and tripod grasp is slightly less than the cylindrical grasp and lateral grasp. The reason might be that some details need to be taken in the process of grasping and releasing of the bottle and card, such as placing the bottle upright, etc.

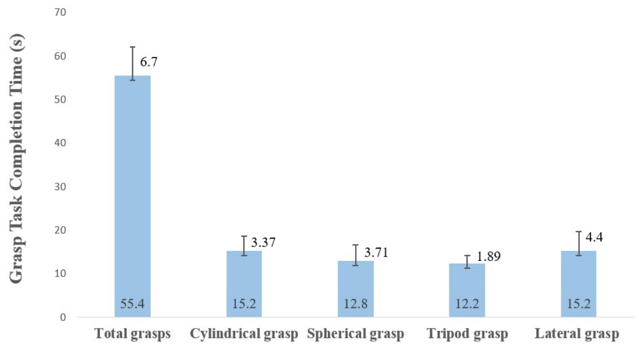
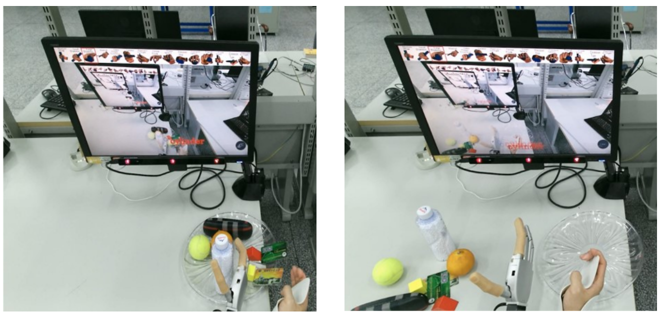


Fig. 6 Statistics on grasp task completion time

In addition to this 4-object experiment, grasps experiments on multiple objects (8) continuously was also taken to show the rapidity and convenience of the eye-tracking-based grasp selection. Objects were placed on the plate randomly, and grasp patterns should be different from trial to trail. The result shows that it took about 140 s to complete the transferring task of all eight items. As the number of the objects is doubled, muscle fatigue might be caused due to the continuous manipulation that the task completion time could be increased.

In addition to those 4 grasp patterns shown in the experiment, here we exhibit two other grasp patterns, index grasp (by clicking the keyboard) and hook grasp (by carrying the bag), as shown in Fig. 8.

Comparing with the encoding method proposed in Ref. [3], our method can be used on more grasp patterns besides those we showed in the paper. It has a superior switching speed of grasp patterns, and the switching speed is not affected by the number of grasp patterns. The switching time of grasp patterns by encoding method is more than 4 s, while our method decreases the switching time to 1 s. The use of the human vision also provides a more nature way to realize grasping.



a) b)

Fig.7 Grasp experiment on multiple items (8): a) before grasping; b) after grasping

a) b)

Fig. 8 Some exemplary grasp patterns can be realized: a) index grasp; b) hook grasp

IV. CONCLUSIONS

This paper proposed a new method for controlling the multi-DOF transradial prosthesis, wherein the eye-tracking was adopted as an effective interface for rapidly and intuitively selecting the proper grasp pattern for various hand operations. An experimental platform was established to validated the method, and the efficacy of the method was verified by object reach-and-grasp task.

This method also have some drawbacks. First, the system is very inflexible and not convenient to use. In the experiment platform, a desktop eye-tracker was used with a computer, which means the operator must seated in front of the computer screen to collect his/her eye movements. Second, the grasping experiment was conducted by a healthy subject. Whether the method shows its effectiveness on amputees needs further validation. Our future work includes implementing this method on the VR glass with eye-tracking integrated (such as the HTC Vive Pro EYE). The hardware will be upgraded and we will use the first-person perspective (pass-through sight), as well as augmented reality, to make a flexible and convenient system with tests on amputees.

REFERENCES

[1] J. T. Belter, J. L. Segil, A. M. Dollar, and R. F. Weir, “Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review,” J. Rehabil. Res. Dev., vol. 50, no. 5, pp. 599–618, 2013.

[2] O. van der Niet, R. M. Bongers, and C. K. van der Sluis, “Functionality of i-LIMB and i-LIMB Pulse hands: Case report,” *J. Rehabil. Res. Dev.*, vol. 50, no. 8, pp. 1123–1128, 2013.

[3] H. Liu, D. Yang, L. Jiang, and S. Fan, “Development of a multi-DOF prosthetic hand with intrinsic actuation, intuitive control and sensory feedback,” *Ind. Rob.*, vol. 41, no. 4, pp. 381–392, 2014.

[4] T. A. Kuiken, L. A. Miller, K. Turner, and L. J. Hargrove, “A Comparison of Pattern Recognition Control and Direct Control of a Multiple Degree-of-Freedom Transradial Prosthesis,” *IEEE J. Transl. Eng. Heal. Med.*, vol. 4, no. December, pp. 1–8, 2016.

[5] S. Zhang, X. Zhang, S. Cao, X. Gao, X. Chen and P. Zhou, "Myoelectric Pattern Recognition Based on Muscle Synergies for Simultaneous Control of Dexterous Finger Movements," *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 4, pp. 576-582, Aug. 2017.

[6] T. A. Kuiken, L. A. Miller, K. Turner, and L. J. Hargrove, “A Comparison of Pattern Recognition Control and Direct Control of a Multiple Degree-of-Freedom Transradial Prosthesis,” *IEEE J. Transl. Eng. Heal. Med.*, vol. 4, no. December, pp. 1–8, 2016.

[7] P. Geethanjali, “Myoelectric control of prosthetic hands: State-of-the-art

review," *Med. Devices Evid. Res.*, vol. 9, pp. 247–255, 2016.

[8] A. Fougner, O. Stavdahl, P. J. Kyberd, Y. G. Losier, and P. A. Parker, "Control of upper limb prostheses: Terminology and proportional myoelectric controla review," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 20, no. 5, pp. 663–677, 2012.

[9] X. Zhang, X. Liu, S. M. Yuan, and S. F. Lin, "Eye Tracking Based Control System for Natural Human-Computer Interaction," *Comput. Intell. Neurosci.*, vol. 2017, 2017.

[10] A. T. Duchowski, "A breadth-first survey of eye-tracking applications," *Behav. Res. Methods, Instruments, Comput.*, vol. 34, no. 4, pp. 455–470, 2002.

[11] M. A. Eid, N. Giakoumidis, and A. El Saddik, "A Novel Eye-Gaze-Controlled Wheelchair System for Navigating Unknown Environments: Case Study with a Person with ALS," *IEEE Access*, vol. 4, pp. 558–573, 2016.

[12] A. Poole and L. J. Ball, "Eye tracking in human-computer interaction and usability research: Current status and future. Prospects", Chapter in C. Ghaoui (Ed.): Encyclopedia of Human-Computer Interaction. Pennsylvania: Idea Group," *Inc, Citeseer*, 2005.

[13] M. Nehete, M. Lokhande, and K. Ahire, "Design an Eye Tracking Mouse," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 2, no. 2, pp. 1118–1121, 2013.

[14] O. Ferhat and F. Vilarino, "Low Cost Eye Tracking: The Current Panorama," *Comput. Intell. Neurosci.*, vol. 2016, no. iii, 2016.

[15] M. Duvinage, T. Castermans, and T. Dutoit, "Control of a lower limb active prosthesis with eye movement sequences," *IEEE SSCI 2011 - Symp. Ser. Comput. Intell. - CCMB 2011 2011 IEEE Symp. Comput. Intell. Cogn. Algorithms, Mind, Brain*, pp. 136–142, 2011.

[16] D. P. McMullen *et al.*, "Demonstration of a semi-autonomous hybrid brain-machine interface using human intracranial EEG, eye tracking, and computer vision to control a robotic upper limb prosthetic," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 22, no. 4, pp. 784–796, 2014.

[17] T. Feix, J. Romero, H. B. Schmiedmayer, A. M. Dollar, and D. Kragic, "The GRASP Taxonomy of Human Grasp Types," *IEEE Trans. Human-Machine Syst.*, vol. 46, no. 1, pp. 66–77, 2016.

[18] H. Liu, D. Yang, S. Fan, and H. Cai, "On the development of intrinsically-actuated, multisensory dexterous robotic hands," *ROBOMECH J.*, vol. 3, no. 1, 2016.