Multijoint Robot Hand Design for Puppet Operations

Chien-Hsing Chou[1,*], Chi-Hung Tseng[1], Wei-Tse Chang[1], Wei-Jin Lin[1], and Ching-Chang Wong[1]

[1] *Department of Electrical Engineering, Tamkang University 151 Yingzhuan Road, Tamsui district, New Taipei City 25137, Taiwan*
[*] *Corresponding author. E-mail: chchou@mail.tku.edu.tw*

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The popularity of traditional puppet shows has been decreasing. To preserve and promote this traditional cultural art form, this study proposes a puppet operation system and 23-degree-of-freedom robot hand to operate a puppet. The system can be employed to retain and retrieve the 3D gestures of professional puppet operators and control the proposed robot hand for complete imitation of the gesture trajectory of puppeteers. Moreover, the system can be used to help users learn correct puppet operations.

Keywords: Robot hand; Multi-joint; Operating puppet; 3D gesture

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1. Introduction

As a crucial aspect of the Chinese cultural heritage, puppetry became a symbol of lifestyle, recreation, and religious support for Taiwanese people after the 1950s. However, with the rapid of technology, people can now access different multimedia content on various devices, including televisions, radios, and smartphones, and traditional puppet shows are losing their popularity. To attract audiences, some traditional puppetry groups have combined augmented reality and 3D movie techniques to develop new styles of puppetry performance [1, 2]. In this study, we introduced a novel technique to draw the attention of people to this valuable form of the cultural art.

Robotic arms and legs have been designed and applied widely [3–8]. Vishal Ramaswamy and Angel Deborah investigated various factors that are used for human robot interaction in robotic hand arm systems, including the controlling methods, grasping ability, and human–robotic hand interactions [3]. Rathan et al. [4] introduced several techniques for robotic arm movements, user interface, transmission modes and the related limitations. Lee et al. [5] designed a robotic leg by using a PID controller and pneumatic artificial muscles. The developed robotic leg does not dump in a limited range under virtual constraints. Ciullo et al. [6] developed a supernumerary hand system (SoftHand X) to assist people with reduced hand functionalities and assessed several healthy individuals with standard clinical tests, and experimental results revealed that two positions of human hands are the most suitable placement locations for robotic hands. In addition to industrial and medical services, social robotics has received considerable attention recently. Peng et al. [7] categorized and discussed the research of robotic dance into four types, which were a cooperative human–robot dance, imitation of human dance motions, music synchronization, and development of robotic choreography.

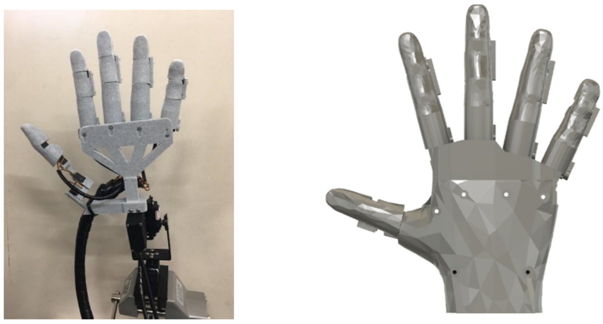
Besides the research related to variety robotic techniques, in this study, we focus on how to design a robot hand to operate puppets. Kawasaki and Mouri reviewed several humanoid robot hands and their applications [9]. For instance, Endo and Kawasaki designed a VR-based haptic training system and HIRO robotic hand to help beginners for studying in medical, industrial, and other fields [10, 11]. The HIRO comprises a haptic hand with five haptic fingers and a controller. This robot hand can exert a three-directional force at each fingertip. Kadhim et al. [12] developed a low-cost 3D-printed wearable prosthetic hand for people with disability. The prosthetic hand exhibits an 18-degree-of-freedom (DOF) design and five fingers capable of moving and gripping objects. Jeong et al. [13] designed a 15-DOF robot hand capable of gripping different items, and Heisnam and Suthar developed a 20-DOF robot hand capable of performing highly precise actions [14]. Furthermore, researchers have used robot hands for artistic creation, such as in painting [15, 16] and playing the piano. However, controlling a puppet is a complex and challenging task, which has not been explored in many studies.

Although a "robotized puppet" for a puppet performance could be developed, this study aims to create a puppet operation system and 23-DOF robot hand that can not only operate the puppet through a robotic mechanism but also demonstrate correct hand gestures for puppet performances and teach users these gestures. Fig. 1 presents the system flowchart. First, the motion data of 3D hand gestures were captured using a leap motion sensor. The proposed system was employed to retrieve 3D gesture data from puppet operators and transfer the data as control signals to operate a puppet with the robot hand. Our system can be used to control the robot hand to imitate five gestures performed by puppeteer. The main three functions of the system are as follows: (a) **Preservation**: To help professional puppeteers preserve their 3D gesture data when operating a puppet. (b) **Education**: To assist users in learning puppet operating. (c) **Demonstration**: To control the robot hand for operating puppets and to demonstrate gestures for teaching correct hand gestures.

Fig. 1. System flowchart.

2. Mechanical design

A 23-DOF robot hand was designed to imitate the gestures used for operating puppets. The design principle was established on the basis of the human hand for factors such as shape, contour line, and bone structure. Fig. 2 illustrates the proposed robot hand. Hand frameworks and shells were developed through 3D printing [gray parts in Fig. 2(a)]. PLA was used as the 3D-printing material because of its high strength and stiffness. Approximately 30 hours were required for printing complete framework and shells by using a 3D printer. The weight of the puppet was 200–300g. For stability and rigidity, the wrist of the hand was designed using an aluminum alloy. To imitate a puppet operator's gestures, each joint of the hand was equipped with a servo motor. Fig. 3 illustrates a single finger and the corresponding 3-DOF mechanism hardware design.



(a) (b)

Fig. 2. Robot hand's (a) Appearance; (b) 3D rendered result.

Fig. 3. The design of single finger and its 3-DOF mechanism hardware.

3. Hand gesture imitation

To control the robot hand for operating puppets, we first recorded the 3D hand gesture motion data of a professional puppeteer by using the leap motion sensor. The professional gestures of nodding and turning the puppet head from the puppeteer and the 3D hand gesture motion data were recorded (Fig. 4). A leap motion controller was used to install three infrared LEDs and two monochromatic IR cameras to detect motion objects. Infrared LEDs were employed to generate IR light, and the light was projected on the motion object. Subsequently, IR cameras were used to receive and collect the data reflected from the motion object. The reflected data were then analyzed using the leap motion tracking software [17]. When the puppeteer operates a hand gesture, the tracking software can be used to locate the 3D position of fingers and palms and record the 3D direction of each phalange. Our puppet operation system was then used to calculate the angles between two consecutive phalanges to obtain the spread angles of corresponding knuckles. The spread angles of knuckles represented the rotation angles of 23 motors in the robot hand operating system. Finally, five operation gestures were transformed into the corresponding rotation angles of 23 motors for controlling the robot hand. Fig. 5 presents the corresponding control results of imitating the correct hand gesture for nodding and turning puppet head by using the robot hand.

Fig. 4. Gestures of nodding and turning the puppet head.

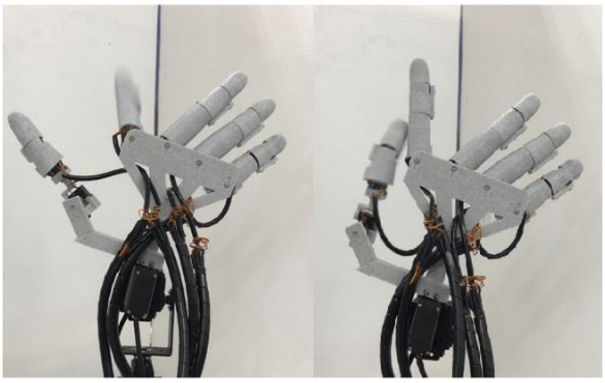


Fig. 5. Imitating the hand gesture for nodding and turning puppet head by using the robot hand.

In this study, we used the leap motion sensor to record the 3D hand gesture motion data; Fig. 6 presents the 3D coordinates of the leap motion and corresponding robot hand. The y and z axes represent the direction of the middle finger and back of the hand, respectively. Our puppet operation system was then used to transform the 3D motion data into a series of the corresponding rotation angles for 23 motors. In the puppet operation system, a Raspberry Pi 3 computer was used as the computational core for motor control. However, during the recording of the 3D gesture data of the puppet operations, noise interference often influenced the motion data because of a subtle hand tremor. Therefore, we applied a median filter to remove noise interference and smoothen robot control signals. Consequently, the robot hand highly resembled a human hand during gesture imitation.

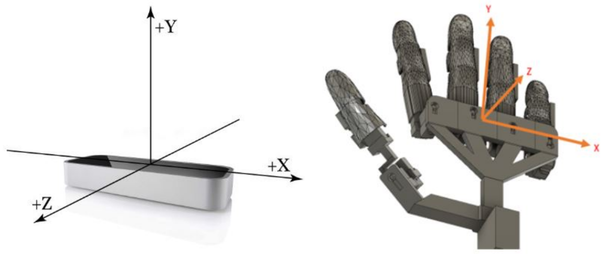


Fig. 6. 3D coordinate of leap motion and the corresponding robot hand.

4. Experimental simulation

The proposed puppet operation system was developed for both employing correct hand gestures during puppet performances and teaching users to perform these gestures. First, a user selected the puppet operation action and referred to the operation process (Fig. 7). As the example in Fig. 7(d), without acquiring any feedback and information from a video acquisition system, our system was employed to control the robot hand for imitating the waving gesture of the puppeteer. These control commands were analyzed and recorded beforehand according to the gestures of the puppeteer. The video acquisition system was applied only when our system was employed to retain and retrieve the 3D gesture data of professional puppeteers. Puppet actions, including nodding and turning the puppet head and waving puppet hands, were performed. The puppet operation speed could be adjusted. In addition, the user could select a sequence of puppet actions for demonstration; five puppet actions and a pause function (a pause of three seconds) were selected, (Fig. 8).

Unlike the human hand, our system presented with limitations. When puppeteers attempt to makes a gesture, they can control their finger joints angels and gesture speed. Moreover, they can accurately adjust even the slightest forces of each finger. Our system can be used to imitate the gesture of the puppeteer and adjust its operation speed; however, reproducing the force adjustment performed by puppeteers' fingers accurately by using the system is dificulty. During actual tests, all nodding and waving hand actions were successfully performed. However, the action of turning the puppet head required accurate control force. When our system was used to turn the puppet head, one of three attempts resulted in failure.

Generally, Taiwanese puppets are mainly used to perform six roles, namely elder men, women, scholars, soldiers, clowns, and others. Each role has its own gesture for actions. For example, a soldier puppet waves its hand in exaggerated action. In this study, a professional pup-

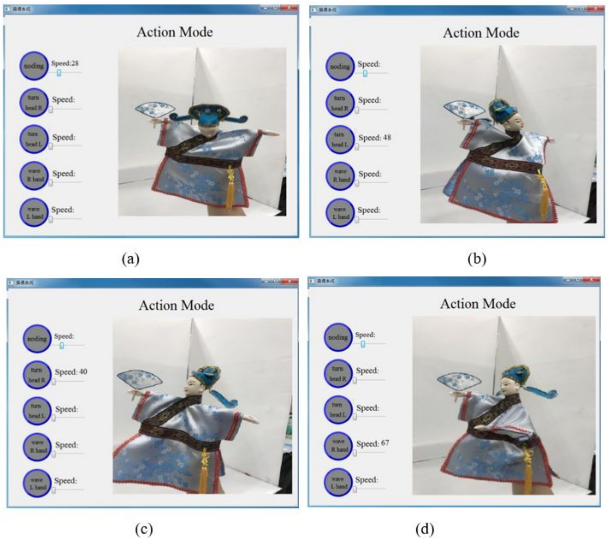


Fig. 7. (a) Nodding puppet head; (b) Turning puppet head to left; (c) Turning puppet head to right; (d) Waving puppet right hand.

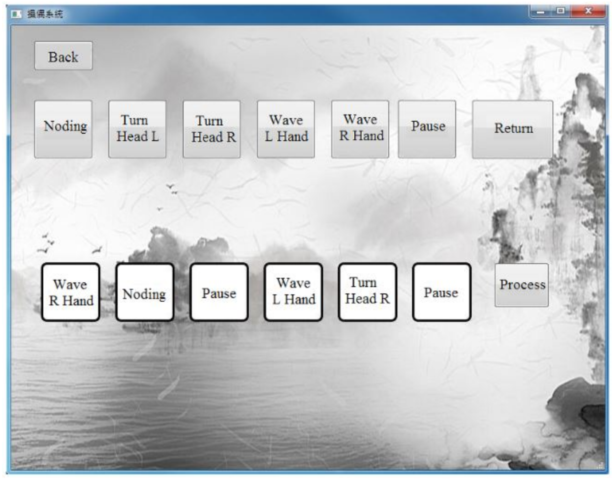


Fig. 8. Assigning a sequence puppet actions for demonstration.

Fig. 9. (a) The robot hand makes the puppet wave its left hand; (b) The action of waving hand by a professional puppet operator.

peteer operated the puppet gestures of scholars, and the corresponding 3D hand gesture motion data were recorded. Therefore, our puppet operation system was used to perform each action as the role of a scholar. As illustrated in Figs. 9(a) and 10(a), the puppet operator system was used to demonstrate the process of making the puppet wave its hand and nod its heads. A video of our system in operation is available at [18]. Our system can be used to completely simulate the actions of a professional puppeteer [Figs. 9(b) and 10(b)].

To determine whether the puppet operation system facilitates the process of learning puppet operating, a field trial was performed (Fig. 11). We examined whether participants understood puppet operating after using our system. The participants were 10 individuals aged 20–24 years. After the field trial, all the participants provided positive feedback. They provided the following comments: "Using a robot hand to operate a puppet is quite exceptional," "This kind of learning method is very interesting," and "A robot hand operating a puppet is new and surprising."

In addition, the system was tested by professional puppeteers. The following is a summary of their comments.

1. Robot hand use for an actual puppet performance still presents difficulties. First, the action of the human hand is more intricate than that of the robot hand. Second, the puppet could not always remain in the same location during a performance. This system requires a robot arm or moving platform to allow puppets to move and perform.

2. During a show, puppets may be required to perform large movements or minute actions, depending on the plot of plays. In addition, during a performance, the operating speed of puppets must be adjusted to control them move faster or slower. Therefore, the system is only suitable to be used for playing a supporting role.

3. Although using the robot hand for an actual puppet show is extremely difficult, the puppet operation system can still be used for demonstrations and as a teaching aid. In an exhibition, using the robot hand to operate a puppet can attract the attention of people and potentially lead them to enjoy glove puppetry. Further development in this technique can be valuable for the preservation of puppetry culture in Taiwan.

5. Conclusions

This study proposed a system to analyze the trajectory of human hands and to control a 23-DOF robot hand to imitate the gesture trajectory of professional puppeteers. The

(a) (b)

Fig. 10. (a) The robot hand makes the puppet nod its head; (b) The action of nodding head by a professional puppet operator.

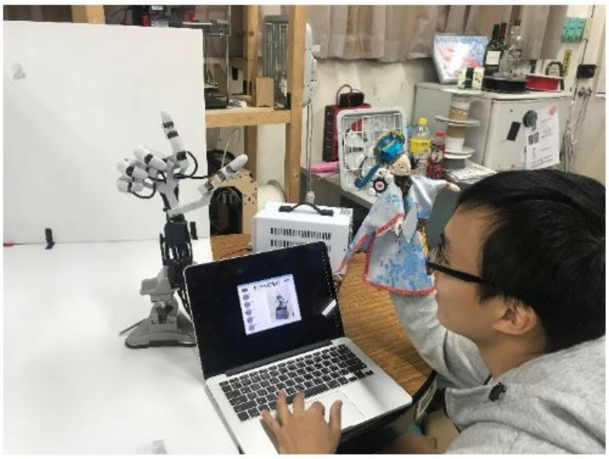


Fig. 11. Field trial of the puppet operation system.

proposed puppet operation system can be used to retain and retrieve the 3D gestures of professional puppeteers. Our puppet operation system can be used to transform these data into the corresponding rotation angles of 23 motors on the robot hand. The simulation results indicated that this system can be used to operate puppet and demonstrate gestures for teaching correct hand gestures. In the future, the current system may facilitate in the preservation of puppetry culture.

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References

[1] AR APP. Available: https://www.arplanet.com.tw/.

[2] TimeWarner. The Arti: The Adventure Begins, 2016.

[3] C. V.VishalRamaswamy and S. Angel Deborah. A Survey of Robotic Hand- Arm Systems. *International Journal of Computer Applications*, 109(8):26–31, 2015.

[4] K. Keerthana Rathan, Ayana Ajith, S. Aswathi, and V. M. Silpa. Survey of robotic arm controlling techniques. In *Proceedings of the International Conference on Intelligent Sustainable Systems, ICISS 2017*, pages 759–763, 2018.

[5] I. Feng Lee, Chin I. Lin, Hsin Che Wu, Ling Chia Wu, Pei Chun Lin, Mao Hsiung Chiang, and Wen Pin Shih. Squat and standing motion of a single robotic leg using pneumatic artificial muscles. *Journal of Applied Science and Engineering*, 18(4):363–370, 2015.

[6] Andrea S. Ciullo, Federica Felici, Manuel Giuseppe Catalano, Giorgio Grioli, Arash Ajoudani, and Antonio Bicchi. Analytical and Experimental Analysis for Position Optimization of a Grasp Assistance Supernumerary Robotic Hand. *IEEE Robotics and Automation Letters*, 3(4):4305–4312, 2018.

[7] Hua Peng, Changle Zhou, Huosheng Hu, Fei Chao, and Jing Li. Robotic dance in social robotics - A taxonomy. *IEEE Transactions on Human-Machine Systems*, 45(3):281–293, 2015.

[8] Rahul Gautam, Ankush Gedam, Ashish Zade, and Ajay Mahawadiwar. Review on Development of Industrial Robotic Arm. *International Research Journal of Engineering and Technology(IRJET)*, 4(3):1752–1755, 2017.

[9] Haruhisa Kawasaki and Tetsuya Mouri. Humanoid robot hand and its applied research, 2019.

[10] T Endo and H. Kawasaki. A fine motor skill training system using multi-fingered haptic interface robot. *International Journal of Human Computer Studies*, 84:41–50, 2015.

[11] Takahiro Endo, Satoshi Tanimura, and Haruhisa Kawasaki. Development of Tool-Type Devices for a Multifingered Haptic Interface Robot. *IEEE Transactions on Robotics*, 29(1):68–81, 2013.

[12] Abd N. Kadhim, Muhammed Abdulsattar, and Ali Abdulghani. Low Cost Design of 3D printed Wearable Prosthetic Hand. *American Journal of Engineering Research*, (10):110–117, 2018.

[13] Seok Hwan Jeong, Kyung Soo Kim, and Soohyun Kim. Designing Anthropomorphic Robot Hand with Active Dual-Mode Twisted String Actuation Mechanism and Tiny Tension Sensors. *IEEE Robotics and Automation Letters*, 2(3):1571–1578, 2017.

[14] Lamyanba Heisnam and Bhivraj Suthar. 20 DOF robotic hand for tele-operation:-Design, simulation, control and accuracy test with leap motion. In *International Conference on Robotics and Automation for Humani-*

tarian Applications, RAHA 2016 - Conference Proceedings, 2017.

[15] Josh H.M. Lam, K. W. Lo, and Y. Yam. Robot drawing techniques for contoured surface using an automated sketching platform. In *Proceedings of the 3rd IEEE International Conference on Automation Science and Engineering, IEEE CASE 2007*, pages 735–740, 2007.

[16] Fenghui Yao and Guifeng Shao. Painting brush control techniques in Chinese painting robot. In *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication*, volume 2005, pages 462–467, 2005.

[17] LEAP Motion. Leap Motion Developer: https://developer.leapmotion.com/, 2018.

[18] Perform Puppet with Robot Hand - YouTube: https://www.youtube.com/watch?v=0Vn54WKU-Gk.