A Systematic Review and Meta-analysis of Robotic Gripper

Zhang Long¹,², *, Qian Jiang¹, Tao Shuai¹, Feijuan Wen¹,² and Chunping Liang¹,²

¹School of Engineering, Southwest Petroleum University, Nanchong 637100, China
²Nanchong Key Laboratory of Robotics Engineering and Intelligent Manufacturing, Southwest Petroleum University, Nanchong 637100, China

*Corresponding author e-mail: longzhang@swpu.edu.cn

Abstract. With the rapid development of robotics, robots gradually replace people to complete various tasks. Grasping is one of the most common tasks in industry and daily life. In addition to typical pick-and-place task, grasping a tool is the basis for performing other tasks, such as grabbing the key to open the door, grabbing a hammer to nail, etc. The robotic grippers are the manipulator in which the robot completes the grasp. Their performance characteristics have a significant impact on work efficiency because they are the parts interacting with the grasping objects directly. Therefore, this paper researches on robotic gripper and its related technology from the following aspects. First of all, the current robotic gripper type is analyzed in detail. Second, the research status of the most promising robotic gripper is reviewed widely. Third, the critical technology of robotic gripper is studied deeply. Finally, the analysis of robotic gripper development trend is performed prospectively.

1. Introduction

Grasping has a wide range of applications and is one of the most basic tasks. The robotic gripper is the end-effector of the robot, which is the core device of grasping task [1]. In recent years, with the full application of robots in the fields of industry, agriculture, service industry, military, etc., the robotic gripper has been obtained extensive attention and numerous research. The conventional robotic grippers in the industrial scene are basically customized according to the work requirements, unable to adapt to multiple tasks [2, 3]. And they have the disadvantages of reduced flexibility, rigid impact and high control demands. As the range of applications expands, the traditional gripper is extremely limited. To overcome the above defect, abundantly new techniques have been applied to develop gripper, such as smart materials and compliance control [4, 5]. Although a mass of achievements have been made in the current research, few literatures have summarized the generic techniques for the development of robotic gripper.

A large number of related researches on robotic gripper are reviewed for further study. This paper reviews the research of robotic gripper, and mainly expounds the current domestic and foreign research status of the two main research directions of gripper mechanical structure and grasping control, and summarizes the existing difficulties and problems. On this basis, it finally analyzes the development trend and possible research direction of the robotic gripper, providing reference for the robotic gripper and related research.
2. Classification of Robotic Gripper

There are many types of robotic grippers, and they have different classification methods according to different gripper characteristics. In this section, types of robotic grippers are researched on the basis of their grasping principle, the material of gripper, and degree of freedom (DOF).

2.1. Grasping Principle

According to the principle of grasping, the robotic gripper can be divided into four types, including vacuum, magnetic, mechanical finger, and universal grippers [6]. Vacuum gripper is usually a suction cup, and it picks the object by pressure difference between the inside and outside of the suction cup. It is suitable for objects with flat and smooth surface, and a large number of handling operations can be carried out. Hence, it is widely used in transport robots for various fields, especially in the field of packaging. As a second type, magnetic gripper is only used for handling the magnet objects through electromagnetic attraction generated by energization of an electromagnet [7]. It is swift and can significantly improve the efficiency of loading and unloading and handling of workpieces. It can cause residual electromagnetic problems. Therefore, it is forbidden to use to grasp a part that does not allow remanence. And its scope of application has certain limitations. Mechanical finger grippers grasp the objects by fingers and these fingers either clamp them with friction force or enclose them [8]. The structure of the finger is often designed according to the shape and characteristics of the workpiece being clamped. According to the number of fingers, it can be divided into two fingers, three fingers and multiple fingers. Human hands have unparalleled grasp stability and flexibility. Researchers around the world have done a lot of attempts to replicate the shape and function of the human hand. A large number of multi-fingered hands have been studied. Finally, universal grippers are composed of deformable fingers, such as the shape memory alloy-actuated robotic gripper in [9]. They can adapt to the shape of captured object by gripper deformation. Therefore, they are able to grab a variety of objects with different shape, different materials and different fragility. The universal gripper is also a research hotspot in robotic gripper.

2.2. Material of Gripper

Robotic grippers can also be divided into soft gripper and rigid gripper according to the stiffness of the gripper material. Rigid grippers are designed from rigid body parts, and it is the earliest robotic gripper. They grasp the objects through the mechanism principle. Compared with traditional rigid gripper, soft grippers are inherently flexible body and composed of extensible or soft material. They can produce a series of deformations to adapt object shape during routine work. They have the advantages of high dexterity, conformability to workpiece. Therefore, some researchers focus on soft gripper instead of rigid gripper. Soft gripper is mostly the above universal gripper.

2.3. Degree of Freedom

According to the degree of DOF, there are two classification methods for robotic gripper. The first one is directly classified based on gripper’s DOF, and it can be divided into 0-DOF, 1-DOF, and multi-DOF robotic gripper [10]. 0-DOF gripper is an immobile gripper, and it does not have any DOF. 1-DOF gripper has a translational or rotational DOF, or a compound DOF combining rotational and translational DOF. Multi-DOF gripper has more than one DOF.

The second classification method is mainly aiming at multi-DOF gripper based on the number of gripper’s DOF and actuator, including two categories. The first type is the number of DOF equal to the actuator, called the entire driven hand. The majority of grippers are of this type. As a second group, under-actuated gripper is that the number of actuator is less than DOF. It can complete most grasping functions. Because the number of actuator is less than DOF, greatly simplifying the mechanical structure and system complexity. After the development of recent years, the under-actuated gripper has become increasingly mature.
3. Research Status of Robotic Gripper
As mentioned above, there are many types of the robotic gripper, therefore, please keep in mind that only promising and new gripper is taken into account in this paper.

3.1. Soft Gripper
The emergence of soft gripper provides new ideas and methods to solve the problems of rigid gripper such as lack of flexibility, poor compliance, limited DOF and poor adaptability to variable size objects. Currently, it has various driven methods, such as motor [11], pneumatic [12-15], hydraulic [16], cable [17-19], shape memory alloy (SMA) [13, 20-22].

The soft pneumatic gripper uses deformable material to design the special ventilation chamber. Therefore, the key points of gripper design are selection of elastic material and air cavity design. The structure of pneumatic actuators is mainly divided into fiber-reinforced type and multi-chamber type. The grasping motion is generated by positive pressure or negative pressure drive to deform the gripper. Whiteside research group of Harvard University designed and manufactured pneumatic network soft robotic gripper (Fig. 1 a) using elastic silicone rubber as produce material to design multi-chamber structure and combining 3D printing technology [23]. It has the performance of small loading capacity, large deformation, flexible movement, mutual accommodation with the environment and so on. Hao et al. [24] designed a four-fingered soft robotic gripper (Fig. 1 b), which can adjust its effective length according to the size and shape of the object being grabbed. The fiber-reinforced actuator is designed by the idea of fiber restraint, which is composed of super-elastic material and rigid material. Based on fiber-reinforced actuator, Wei. [25] designed a three-finger fiber-reinforced structure soft robotic gripper (Fig. 1 c). A typical example of a soft gripper that uses negative pressure to drive is the Universal Gripper (Fig.1 d) developed by Cornell University [26]. It consists of a soft material bag containing coffee beans. By applying the blocking principle, various objects can be grabbed by loading negative pressure on the coffee bag. Particle jamming is also an excellent way to achieve stiffness control [27].

Figure 1. Pneumatic soft gripper: (a) pneumatic network soft robotic gripper. (b) four-fingered soft robotic gripper. (c) Fiber-reinforced structure soft robotic gripper. (d) Negative pressure-driven soft gripper.

Figure 2. Typical cable-driven device.
The cable is a flexible component with high tensile strength in length, so it can go through a convoluted path in a soft structure and withstand tremendous forces without changing its size. The basic principle of cable-driven is to select some fixed points in the structure, and then connect them with cables, and drive the motor connecting with pulley, relying on the driven wire extension or retraction to drive the action of the cable-driven soft robotic gripper. Figure 2 shows a typical pull drive structure and auxiliary drive system [28].

Reference [29] introduces a wearable robotic hand, called SNU Exo-Glove (Fig. 3 a), which is actuated with cable and consist of a simple jointless mechanical structure. Xiong et al. [18] designed a novel cable-driven gripper (Fig. 3 b), which can open fingers to pick the strawberry. It can be obtained from the research status of cable-drive gripper that there is a massive displacement between adjacent finger joints, so when picking the objects, the grippers can only form a simple curved surface contact, and cannot grasp the objects with irregular shape in a wrapped method. And cable-driven needs a set of external cable pull device to assist the work, and this kind of cable pull device has a complex structure and needs a corresponding control system, which increases the difficulty of using the cable drive.

![Figure 3. Cable-driven soft gripper: (a) SNU Exo-Glove. (b) The cable-driven gripper of strawberry picker.](image)

![Figure 4. SMA gripper: (a) Curved shape memory alloy-driven gripper. (b) Large-stroke shape memory alloy actuated gripper.](image)
SMA as a new smart material deforms easily under external force, and the shape changes as the temperature changes. This characteristic of changing shape when heated makes it widely used as the actuator of soft gripper [30]. Hugo et al. [26] utilized shape memory alloy to design curved bending actuator, and applied it to soft gripper (Fig. 4 a). Comparing with the straight actuator with the same cross section configuration, it can gain larger maximum bending angles. Reference [20] proposed using large-stroke shape memory alloy as a soft gripper actuator. It is comprised of gripping claws, SMA linear actuator and cross-shear hinge coupler, as shown in Fig. 4 b. But these researches show that SMA takes a certain amount of time after heating to dissipate the heat for the next drive, which has a certain impact on drive efficiency.

Electro active polymer (EAP) is a kind of flexible intelligent material that is easily affected by electric field and produces deformation such as stretching, bending, tightening or expanding [31]. Usually, flexible electrodes are arranged respectively on both sides of the electrostatic film. When a voltage is applied to it, the electrostatic film will deform under the action of electric field [32]. It uses the principle of electrostatic adsorption to grab objects. Chen. [33] Developed a flexible electrostatic adsorption gripper (Fig. 5 a) using coulomb bipolar electrostatic adsorption electrode. It has the advantages of low production cost, low power consumption and low noise. A designed soft gripper (Fig. 5 b) with a pre-stretched elastomer membrane that embedded the compliant electrodes between two layers of passive silicone membrane [31].

![Figure 5. Electrostatic adsorption gripper: (a) Flexible electrostatic adsorption gripper. (b) Electro adhesion-enabled soft gripper.](image)

Due to the influence of different materials on the adsorption capacitance of the adsorption electrode, the demand for voltage is also different when grasping. The self-adaptability of electrostatic adsorption electrode grasping needs to be further studied. The essential difference between the soft gripper and rigid gripper is that the primary body material is flexible. Because soft material has more complex and costly response characteristics than rigid material, which brings about functional flexibility and compliance [34-36]. With good active and passive adaptability, the soft gripper will be widely used.

3.2. Multi-Fingered Dexterous Hand

Based on the idea of humanoid hands, researchers invented a series of human-like manipulators, called multi-fingered dexterous hands. The multi-fingered dexterous hand is similar to the human hand, which has the advantages of good adaptability, high DOF and abundant grasping modes [37-39]. Its emergence has made many demanding tasks possible. It is mainly driven by motor, pneumatic, cable and SMA. MPL dexterous hand (Fig. 6 a) is developed by Johns Hopkins University Applied Physics Laboratory [39]. Its finger abductor actuator is designed as an integrated unit, with a built-in motor controller, using low-speed speed and position control algorithms, and has dedicated electrical connections with the palm. Ham et al. [40] used cable-driven to design wind tendons. The dexterous hand (as shown in Fig. 6 b) has three variable stiffness structure consisting of wind tendons acting as fingers, and the difference between the lowest and highest stiffness values was 5.6 times the original. Gifu II dexterous hand is
designed by GiFu University in Japan [41]. It utilized a micro motor placed in the hand to drive and deployed some sensors for sensing functions, such as joint torque, fingertip touch and so on. The distribution density of measuring points exceeds 624 points. Luo et al. [42] made use of micro motor and SMA spring as actuator to design dexterous hand (Fig. 6 c). The composite driving system is used to drive the fingers of humanoid dexterous hand, which simplified the whole structure. On the basis of simulating the structure and function of human hand, a soft pneumatic gripper (Fig. 6 d) with human-like shape and motion was developed [43]. It can imitate the human hand movements and gestures, and can easily grasp eggs and other fragile objects with flexible movement. In a word, the performance of the dexterous hand is closely related to the structure of the dexterous hand, the collocation of sensors and the stability of the control system.

3.3. Under-Actuated Gripper

Although dexterous hands have the advantage of flexibility, their structures, control systems and sensing systems are very complex, and often have little grasping power [44]. To simplify the design, a number of researchers tried to use fewer motors to drive more joints and developed under-actuated hands [45-47]. However, a large number of studies show that the disadvantages of under-actuated manipulator lie in the lack of functionality, especially for the accurate control of fingers with high precision requirements, and the joints of a single finger cannot move independently, which is insufficient in grasping situations under specific requirements. One idea to improve it is to allocate more full-drive options on high-functioning fingers (like the forefinger) to improve functionality, and less under-actuated options on low-functioning fingers (like the ring finger) to keep the system simple [48].

4. The Key Technology of Robotic Gripper

The study of robotic gripper involves many techniques. Different types of manipulators have different research methods and development challenges, but they all have common problems. It can be seen from the research of robotic gripper at domestic and foreign that the key factors affecting the performance of robotic gripper mainly include the structural design, modeling analysis and control strategy according to the functional requirements.

4.1. Structure Design

The mechanical structure of the robotic gripper is directly in contact with the grasping objects, and its structure design is the first step in the development of gripper. The quality of the structure design clearly has a certain impact on the complexity of the control system.

Different from the traditional mechanical structure design, due to the limited space of the gripper, the sensor layout must be fully considered in the design, such as tactile sensor. Compact structure is a basic requirement for structure design. Reasonable under-actuation scheme setting is beneficial to simplify the gripper structure and reduce the cost and control difficulty. With the increasing requirements of grasping size-varied unknown objects, the gripper structure is required to have strong

---

Figure 6. Multi-fingered dexterous hand: (a) MPL dexterous hand. (b) Cable-driven dexterous hand. (C) Gifu II dexterous hand. (d) Pneumatic driven dexterous hand

---
motion flexibility. The rigid and flexible hybrid design plays an important role in increasing the gripper flexibility. Variable stiffness structure design is one of the significant ways to improve the performance of robotic gripper [49]. Based on varying stiffness, the gripper can grasp targets of various shapes and sizes. The selection of flexible materials and manufacturing process should also be considered in the design of soft grippers.

4.2. Modeling Analysis
Modeling analysis is the basis of robotic gripper motion control. By analyzing the relationship between the position and posture of the gripper and the objects, the kinematic model of objects picking is constructed, which is the basis of path planning and stable grasping control [50]. There are related theories for rigid robotic gripper modeling methods, but the system is relatively complex for under-actuated gripper, and its system model still has certain challenges. Compared to rigid robotic gripper, there is no mature modeling theory for soft robotic gripper. Because the soft gripper has the characteristics of multiple degrees of freedom and the complex nonlinear of the soft material, the dynamic model of the soft gripper is very complicated. On the one hand, the modeling method can learn from the continuous body model. On the other hand, we can make use of the experimental numerical analysis method to establish the functional relationship between the actuator output and the input. Due to the nonlinearity of the soft material and the multidisciplinary intersection, it is necessary to make further attempts to explore accurate modeling method.

4.3. Control Strategy
The flexibility of the gripper is crucial for the grasping operation, and the gripper which can be as flexible as a human hand is inseparable from the control system. When the robot grabs the object, the position and force information of the gripper are often the necessary feedback information for the control system [51]. Therefore, the control system based on the rigid component has higher requirements on the real-time and accuracy of the feedback information, which increases the difficulty of the control system. Due to the inability to meet Brockett conditions, it is not possible for an under-actuated system to have effective steady and smooth state feedback control. At present, there are many control strategies for under-actuated robots at home and abroad, which can be classified into six categories: energy method, partial feedback linearization, passivity-based control, hybrid control, mean method, intelligent control [52]. The soft gripper has unlimited degrees of freedom and limited actuators, which makes the control calculations large and cannot achieve precise and real-time control. Therefore, there is no general control theory applicable to soft gripper.

5. The Development Trend of Robotic Gripper
Through the current status of the domestic and foreign robotic gripper, its development trend is as follows:

(1) Bionics design. Natural creatures provide an excellent source of inspiration for people. The study of bionics will also be based on bionics from shape and structure to functional bionics, from functional bionics to materials and controlled bionics. Further exploration will also provide ideas for the development of robotic gripper.

(2) High dexterity for adaptive grasping. The traditional robotic gripper is usually designed according to specific task or process, and the way to hold the object is usually clamp or suction cup, which is the most extensive in practical application. However, with the continuous improvement of robot intelligence and operation level, higher requirements have been put forward for end-effector, such as grasping arbitrary irregular objects and accurate operation, etc [53]. The human hand has the characteristics of high flexibility, good compliance, wide range of grasping objects and high reliability. Therefore, the humanoid multi-finger dexterous hand with multiple DOF and joints has become the development direction of intelligent robot end-effector, which has very great research significance.

(3) Utilizing intelligent flexible material. With the development of robotic gripper, it is required to have the compliance to resist external impact. And adaptive grasping also requires gripper with the
performance of variable stiffness, especially for soft gripper. The fundamental solution is to use a variety of intelligent flexible materials to develop gripper. For gripper, the traditional sensors for detecting position and grasping force may not be suitable for flexible bodies, hence new soft material sensors are required to represent mechanical characteristic (such as compliance, extensibility and deformation) of compliant gripper.

(4) More compliant control strategy. With the development of micro-sensors, robotic gripper integrating sensors, actuator and bodies will gradually become a development trend, which makes it possible to establish distributed control and partial closed-loop control on the whole body. And the control of robotic gripper will also be towards a more compliant control system.

6. Conclusion
As an important part of robots, robotic grippers have attracted extensive attention from scholars and institutions at home and abroad. Robotic gripper involves the interdisciplinary integration of materials science, mechanical design and manufacturing, sensor, control and so on. Although the research on the gripper has made great progress and achievements, it is still in its infancy, and more in-depth research needs to be carried out. This paper analyzed the structural characteristics and action modes of the existing robotic gripper, summarized the classification of the grippers, and obtained the critical technologies for gripper research and development, and introduced the development direction of the grippers including bionics design, high dexterity for adaptive grasping, utilizing intelligent flexible material and more compliant control strategy, which provides ideas for the research of robotic gripper.

Acknowledgments
This work was supported by the Nanchong city and school science and technology strategic cooperation project (Grant No.18SXHZ0008, No.18SXHZ0045 and No.18SXHZ0054), Southwest petroleum university key project of extracurricular experiment in 2019 (Grant No. NKSZ19005).

References
[1] P. Yan, L. Y. Gan, Y. Yang, et al, “Research progress on application of soft robotic gripper in fruit and vegetable picking,” Transaction of the Chinese Society of Agricultural Engineering, vol. 34, no. 9, pp. 11 – 20, 2018.
[2] L. Birglen, T. Schlicht, “A statistical review of industrial robotic grippers,” Robotics and Computer-Integrated Manufacturing, vol. 49, pp. 88 – 97, 2018.
[3] M. Honarpardaz, M. Tarkian, J. Ölvander, X. Feng, “Finger design automation for industrial robot grippers: A review,” Robotics and Autonomous Systems, vol. 87, pp. 104 – 119, 2017.
[4] Z. M. Bi, Y. F. Liu, J. Krider, et al, “Real-time force monitoring of smart grippers for Internet of Things (IoT) applications,” Journal of Industrial Information Integration, vol. 11, pp. 19 – 28, 2018.
[5] G. Fantoni, S. Capiferri, J. Tilli, “Method for supporting the selection of robot grippers,” Procedia CIRP, vol. 21, pp. 330–335, 2014.
[6] F. Y. Chen, “Gripping mechanisms for industrial robots: an overview,” Mechanism and Machine Theory, vol. 17, no. 5, pp. 299 – 311, 1982.
[7] R. Debanik, “Development of novel magnetic grippers for use in unstructured robotic workspace,” Robotics and Computer-Integrated Manufacturing, vol. 35, pp. 16 – 41, 2015.
[8] T. Atakuru, E. Samur, “A robotic gripper for picking up two objects simultaneously,” Mechanism and Machine Theory, vol. 121, pp. 583 – 597, 2018.
[9] M. Modabberifar, M. Spenko, “A shape memory alloy-actuated gecko-inspired robotic gripper,” Sensors & Actuators A Physical, vol. 276, pp. 76 – 82, 2018.
[10] G. J. Monkman, S. Hesse, R. Steinmann, H. Schunk, “Robot Grippers,” Assembly Automation, vol. 29, no. 1, 2009.
[11] M. Tavakoli, A. T. de Almeida, “Adaptive under-actuated anthropomorphic hand: Isr-softhand,” in Proceedings of IEEE International Conference on Intelligent Robots and Systems, 2014, pp.
[12] A. Pettersson, S. Davis, J. Gray, T. Dodd, T. Ohlsson, “Design of a magnetorheological robot gripper for handling of delicate food products with varying shapes,” Food Engineering, vol. 98, no.3, pp. 332 – 338, 2010.

[13] Y. Chen, S. Guo, C. Li, et al, “Size recognition and adaptive grasping using an integration of actuating and sensing soft pneumatic gripper,” Robotics and Autonomous Systems, vol. 104, pp. 14 – 24, 2018.

[14] Z. G. Liang, H. Y. Dong, D. W. Qiang, “A soft pneumatic dexterous gripper with convertible grasping modes,” International Journal of Mechanical Sciences, vol. 153-154, pp. 445–456, 2019.

[15] Y. Li, Y. Chen, Y. Yang, et al, “Passive particle jamming and its stiffening of soft robotic grippers,” IEEE Transactions on Robotics, vol. 33, no. 2, pp. 446 – 455, 2017.

[16] K. C. Galloway, K. P. Becker, B. Phillips, et al, “Soft robotic grippers for biological sampling on deep reefs,” Soft Robot, vol. 1, pp. 23 – 33, 2016.

[17] W. Chao, “Dynamics and Control of Cable-Driven Silicone Soft Manipulator,” Master’s Thesis, Shanghai Jiaotong University, Shanghai, China, 2015.

[18] Y. Xiong, C. Peng, L. Grimstad, “Development and field evaluation of a strawberry harvesting robot with a cable-driven gripper,” Computers and Electronics in Agriculture, vol. 157, pp. 392 – 402, 2019.

[19] A. Martin, S. Caro, P. Cardou, “Design of a cable-driven parallel robot with grasping device,” Procedia Cirk, vol. 70, pp. 290–295, 2018.

[20] L. Y. Lu, X. Z. Jie, W. Jian, et al, “A novel design of a parallel gripper actuated by a large-stroke shape memory alloy actuator,” International Journal of Mechanical Sciences, vol. 159, pp. 74–80, 2019.

[21] A. Sinkar, A. Pandey, C. Mehta, “Design and Development of wall climbing Hexapod Robot with SMA actuated suction gripper,” Procedia Computer Science, vol. 133, pp. 222–229, 2018.

[22] H. Rodrigue, W. Wang, D. R. Kim, et al. “Curved shape memory alloy-based soft actuators and application to soft gripper,” Composite Structures, vol. 176, pp. 398 – 406, 2017.

[23] P. Polygerinos, S. Lyne, Z. Wang, et al, “Towards a soft pneumatic glove for hand rehabilitation,” in Proceedings of IEEE International Conference on Intelligent Robots and Systems, 2014, pp. 1512 – 1517.

[24] H. Y. Fei, G. Z. Yuan, X. Z. Xin, et al, “Universal soft pneumatic robotic gripper with variable effective length,” in Proceedings of IEEE Control Conference, 2016, pp. 6109 – 6114.

[25] W. S. Jun, W. T. Yu, G. G. Ying, “Design of a soft pneumatic robotic gripper based on fiber-reinforced actuator,” Journal of Mechanical Engineering, vol. 53, pp. 29 – 38, 2017.

[26] E. BROWN, et al. “Universal robotic gripper based on the jamming of granular material,” Proceedings of the National Academy of Sciences, vol. 107, no. 44, pp. 18809–18814, 2010.

[27] L. Y. Tian, C. Y. Hua, et al, “Passive particle jamming and its stiffening of soft robotic grippers,” IEEE Transactions on Robotics, vol. 33, pp. 446 – 455, 2017.

[28] H In, H. Lee, U. Jeong, et al, “Feasibility study of a slack enabling actuator for actuating tendon-driven soft wearable robot without pretension,” in Proceedings of IEEE International Conference on Robotics and Automation, 2015, pp. 1229 – 1234.

[29] U. Jeong, H. K. In, K. J. Cho, “Implementation of various control algorithms for hand rehabilitation exercise using wearable robotic hand,” Intelligent Service Robotics, vol. 6, pp. 181–189, 2013.

[30] C. Xiang, H. Yang, Z Sun, et al, “The design, hysteresis modeling and control of a novel SMA-fishing-line actuator,” Smart Material Structures, vol. 26, no. 3, pp. 1 – 14, 2017.

[31] J. Shintake, S. Rosset, B. Schubert, et al, “Versatile soft grippers with intrinsic electroadhesion based on multifunctional polymer actuators,” Advanced Materials, vol. 28, no. 2, pp. 1–28, 2016.

[32] S. Z. Gang, “Theory of dielectric elastomers,” Chinese Journal of Solid Mechanics, vol. 23, no.
[33] C. Y. Yun, “Research and design for mechanical gripper based on electrostatic adsorption mechanism,” Master’s Thesis, Hebei University of Engineering, Hebei, China, 2018.

[34] Z. Baohua, Z. Jun, M. Yimeng, et al, “Comparative study of mechanical damage caused by a two-finger tomato gripper with different robotic grasping patterns for harvesting robots,” Biosystems Engineering, vol. 171, pp. 245 – 257, 2018.

[35] R. Chen, R. Z. Song, Z. Zhang, et al, “Bio-inspired shape-adaptive soft robotic grippers augmented with electroadhesion functionality,” Soft Robotics, vol. 00, no. 00, pp. 1–12, 2019.

[36] Z. J. Hua, W. Tao, H. Jun, et al, “Review of soft-bodied manipulator,” Journal of Mechanical Engineering, vol. 53, no. 13, pp. 19 – 28, 2017.

[37] M. S. Arian, C. A. Blaine, G. E. Loeb, et al. “Using the Bio Tac as a tumor localization tool” in Proceedings of IEE Haptics Symposium (HAPTICS), 2014, pp. 443 – 448.

[38] M. M. Bridges, M. P. Para, M. J. Mashner, “Control system architecture for the modular prosthetic limb,” Johns Hopkins APL Technical Digest, vol. 30, no. 3, pp. 217 – 222, 2011.

[39] J. Zhou, J. Yi, X. Chen, et al, “BCL–13: A 13-DOF soft robotic hand for dexterous grasping and in-hand manipulation,” IEEE Robotics & Automation Letters, vol. 99, pp. 1 – 1, 2018.

[40] K. B. Ham, H. J. Ho, Y. J. Park, “Soft gripper using variable stiffness mechanism and its application,” International Journal of Precision Engineering and Manufacturing, vol. 19, no. 4, pp. 487 – 494, 2018.

[41] H. Kawasaki, H. Shimomura, Y. S. Mizu, “Educational–industrial complex development of an anthropomorphic robot hand’Gifu hand’,” Advanced Robotics, vol. 15, no.3, pp. 357–363, 2001.

[42] L. T. Hong, L. Lang, C. Cai, “Study on the composite driving system of dexterous hand,” Journal of Mechanical Transmission, vol. 3, pp. 20 – 25, 2017.

[43] X. Yu, “Design and experimental research of pneumatic soft robot hand,” Master’s Thesis, Southeast University, Jiangsu, China, 2016.

[44] L. D. Yao, Z. W. Zeng, “Parameters optimization and stability analysis for a parallel and self-adaptive underactuated hand,” Robot, vol. 39, no. 3, pp. 282 – 291, 2017.

[45] R. A. J. Stavenhui, L. Birglen, J. L. Herder, “A planar underactuated grasper with adjustable compliance,” Mechanism and Machine Theory, vol. 112, pp. 295 – 306, 2017.

[46] D. Petkovic, N. D. Pavlovic, et al, “Adaptive neuro fuzzy estimation of underactuated robotic gripper contact forces,” Expert Systems with Applications, vol. 40, no. 1, pp. 281 – 286, 2013.

[47] M. Beschi, E. Villagrossi, L. M. Tosatti, et al, “Sensorless model-based object-detection applied on an underactuated adaptive hand enabling an impedance behavior,” Robotics and Computer-Integrated Manufacturing, vol. 46, pp. 38 – 47, 2017.

[48] I. Cerulo, F. Ficuciello, V. Lippiello, et al, “Teleoperation of the SCHUNK S5FH under-actuated anthropomorphic hand using human hand motion tracking,” Robotics and Autonomous Systems, vol. 89, pp. 75 – 84, 2017.

[49] C. H. Liu, T. L. Chen, C. H. Chiu, et al, “Optimal design of a soft robotic gripper for grasping unknown objects,” Soft Robotics, vol. 00, no. 00, pp. 1 – 14, 2018.

[50] A. Hassan, M. Abomoharam. “Modeling and design optimization of a robot gripper mechanism,” Robotics and Computer-Integrated Manufacturing, vol. 46, pp. 94–103, 2017.

[51] L. T. Feng, L. G. Rui, L. Y. Ming, et al, “Review of materials and structures in soft robotics,” Chinese Journal of Theoretical and Applied Mechanics, vol. 48, no. 4, pp. 756–766, 2016.

[52] D. Y. Yun, L. Z. Ping, Z. L. Lan, et al, “Review on control strategy for under-actuated robots,” Sensor World, vol. 18, no. 12, pp. 7 – 10, 2012.

[53] F. Schreiber, M. Manns, J. M, “Design of an additively manufactured soft ring-gripper,” Procedia Manufacturing, vol. 28, pp. 142 – 147, 2019.