Design and Production of a 3D Printing Robot Hand with Three Underactuated Fingers

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1 Introduction

Robot hand is an important part of the robot, most functions are achieved through hand operation. On one hand, Robot hand generally should have more joint freedom for a better and high anthropomorphic performance. On the other hand, in order to reduce the difficulty of control and the volume and weight of robot hand, it is necessary to minimize the number of drives. Designing robot finger with underactuated mechanism can drive these two requirements and allow robot finger to grasp objects with different shapes and sizes adaptively. At the same time, the underactuated robot finger has a lower control difficulty and production cost, and the feature of self-adaptive grasping is also suitable for envelope grasping and strong grasping [1], so the underactuated finger mechanism becomes an important aspect of the robot hand.

The tendon drive and the link drive are two main types of underactuated finger, but link drive is better than the tendon drive [2]. Paper [3] proposes a number of underactuated fingers based on link drive, which uses combination of the linear spring and the torsion spring to achieve a passive mechanical limit of the free joint. The link drive finger has many advantages such as large output force, strong load capacity, compact structure and so on.

At present, domestic and foreign research institutions have developed a number of link drive robot hands. For example, the SARAH underactuated hand (Fig. 1a) developed by the Canadian MD ROBOTICS company and the University of Laval has been successfully applied in the International Space Station [4, 5]; The underactuated robot hand designed by Nazarbayev University [6] (Fig. 1b); The MPJ hand developed by Tsinghua University and Beihang University in 2016

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Z. Deng (ed.), *Proceedings of 2017 Chinese Intelligent Automation Conference*,
Lecture Notes in Electrical Engineering 458,
https://doi.org/10.1007/978-981-10-6445-6_10

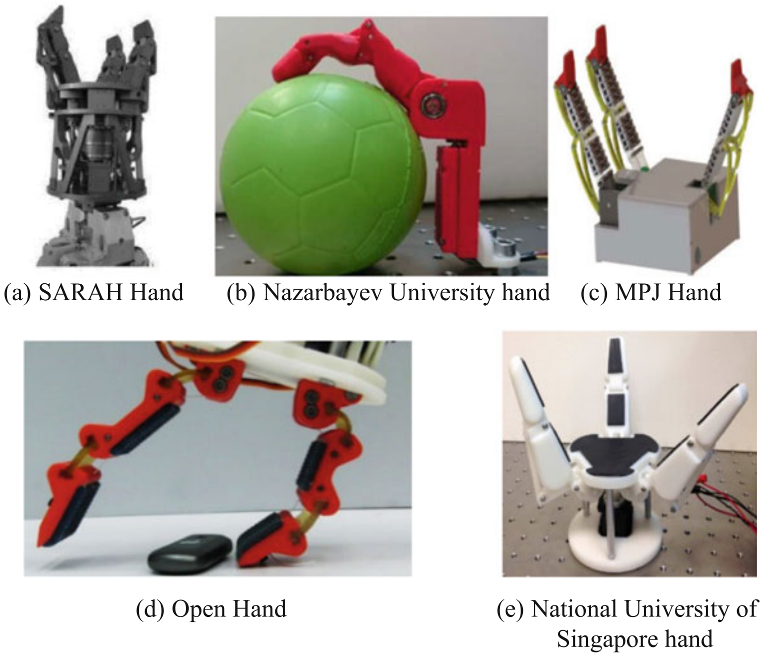


Fig. 1 The robot hand of domestic and foreign institutions

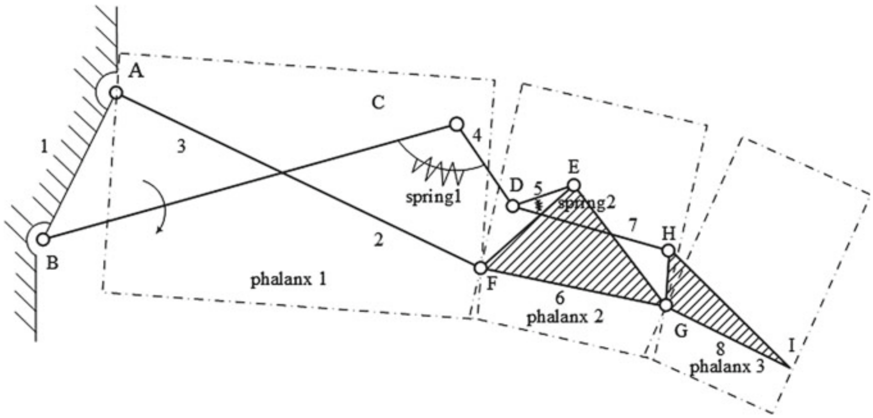
(Fig. 1c) also uses the link drive mechanism [7]. But there also exists many problems such as complex institutions, large size, high cost of manufacturing and maintenance [3].

The cost of the prototype with machining is high, and it is not conducive to update the parts in design process. Producing parts by 3D printing not only greatly reduces the costs, but also increases the flexibility of the design, which is easy to update parts at any time. At present, more and more research institutions chose 3D printing to manufacture prototypes, such as Open Hand [8] designed by Yale University (Fig. 1d), The underactuated robot hand designed by Nazarbayev University (Fig. 1b) The robot hand designed by National University of Singapore [9] (Fig. 1e).

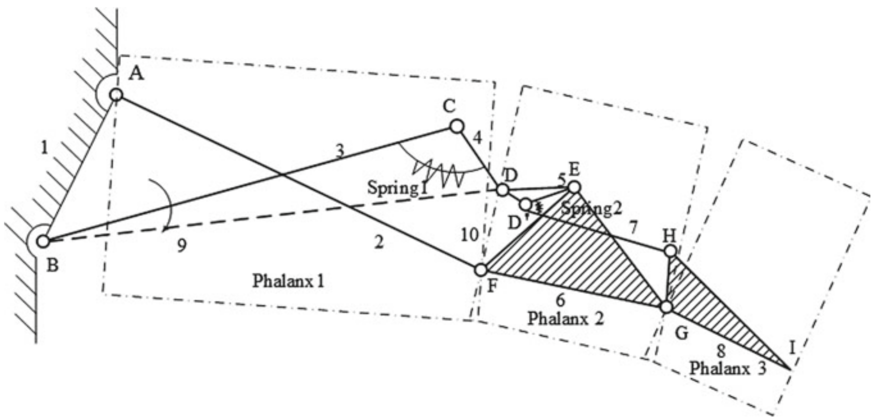
In this paper, we design a finger based on a new type of underactuated link mechanism proposed by the research group and a 3-finger hand with large grasping force, compact structure, simple mechanism and large grasping range. And the robot hand is produced by 3D printing in order to reduce cost. And we consider the characteristics of 3D printing in the design of parts, which can avoid adding supports for improving the accuracy of parts and saving cost. Finally we make grasping experiments to verify the rationality of the design.

2 Full Rotation Joint-Linkage Underactuated Finger and Its Improvement

The designed finger of this paper is a kind of full rotation joint-linkage underactuated finger proposed by research group [10, 11]. As shown in Fig. 2a, the finger mechanism consists of eight links and two springs. Link 1 is the base, Links 2, 6, 8 respectively represent phalanx 1, 2 and 3. Points A, B, C, D, D, E, F, G, H are rotational joints. Spring 1 is fixed between link 3 and link 4 while Spring 2 is fixed between link 5 and link 7. The motor is mounted on point B to drive link 3.



(a) Full rotation joint-linkage underactuated finger



(b) Underactuated finger after improving

Fig. 2 Finger mechanism

It is found that CD link is easy to contact with the shaft that fixed DE link, which significantly reduces the grasping range of the finger. In order to avoid the situation, we change DE link from straight link to triangular link DD′E (Fig. 2b), and it can avoid above situation and allow links to remain inside during the movement.

3 Three Finger Robot Hand Design

3.1 Finger Design

In this paper, the hand can be divided into fingers and the palm. The main function of fingers is to grasp the object while the palm is to determine the distribution position of fingers. The size of fingers and each phalanxes are designed according to the ratio of 1:1 simulated by human index finger [12]. The sizes of each phalanxes are as shown in Table 1. We design the 3D model of finger (Fig. 3) according to the finger mechanism (Fig. 2b). Where A and B are fixed points, points E, F, G whose relative positions with the joints are fixed are connected with the phalanxes by the shaft.

The finger connecting link mechanism BCADE and ED′H are relatively independent by using the triangular link DD′E. As long as the relative position between E and second phalanxes is constant, the relative distance between points D and E does not affect the relative trajectory of the point D′ with the second phalanxes in motion, that is, the relative motion trajectory of point D′ and the second phalanxes is point E as the center of the circle, ED′ radius of the arc. In a similar way, the relative distance between points D′ and E does not affect the relative trajectory of point D with the first phalanxes in motion. So the use of triangular link DD′E not only can solve the problem if link mechanism can hide inside the fingers, but also increase the flexibility of finger design.

In order to ensure that the finger has underactuated characteristic, the elastic deformation of spring 2 should be in an increasing state during the motion when

Table 1 Size of phalanxes

Parts	Phalanx 1 (AF)	Phalanx 2 (FG)	Phalanx 3 (GI)
Length (mm)	47.0	22.0	25.0

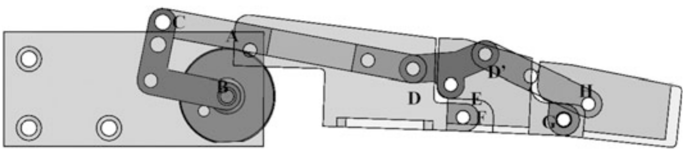


Fig. 3 Finger model

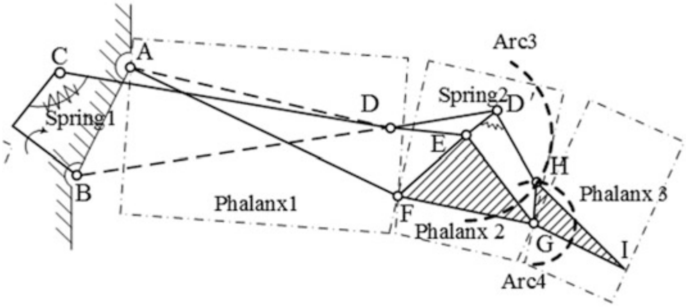


Fig. 4 The trajectory of point H

Table 2 Size of links

Parts	AB	BC	CD	D′E	DE	D′H	HG
Length (mm)	11.2	21.4	55.6	10.0	8.9	25.0	5

second phalanx contacts the object. The second phalanx will no longer move after it contacts object, and third phalanx continues to move, then the trajectory of point H (Fig. 4) should be G as the center, the initial distance of GH as radius. At the same time, the angle change between ED′ and D′H determines the elastic deformation of spring 2, and the elastic deformation of spring increases as ∠ED′H increases. ED′ and D′H are fixed in length, the greater the distance of EH, the greater the ∠ED′H. In the unconstrained state, the trajectory of H-point should be E as the center, the initial distance of EH as radius. In order to ensure that the distance EH is increasing during motion, the part of arc 4 should be on right side of arc 3 in order to keep EH growing during motion. The simulation results show that the size of link in Table 2 meets above conditions.

3.2 Grasping Simulation for Finger (Fig. 5)

In order to verify the design rationality and properties of the finger, we use Solidworks to simulate. We put 10 mm diameter cylindrical object in the root of fingers, where points 1, 2, 3 are contact points for phalanxes and object. It is simulated that the finger designed can achieve good motion coherence and stability grasping. And the finger can produce 5 times of hand grasping force by using the small electromotor which means the finger can produce a larger grasping force.

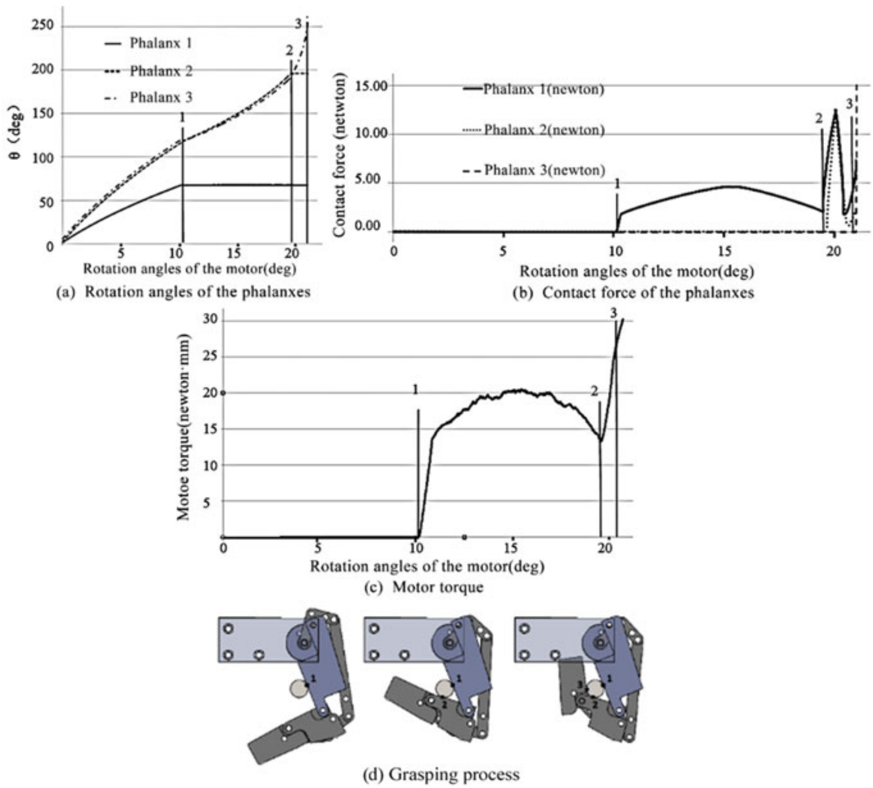
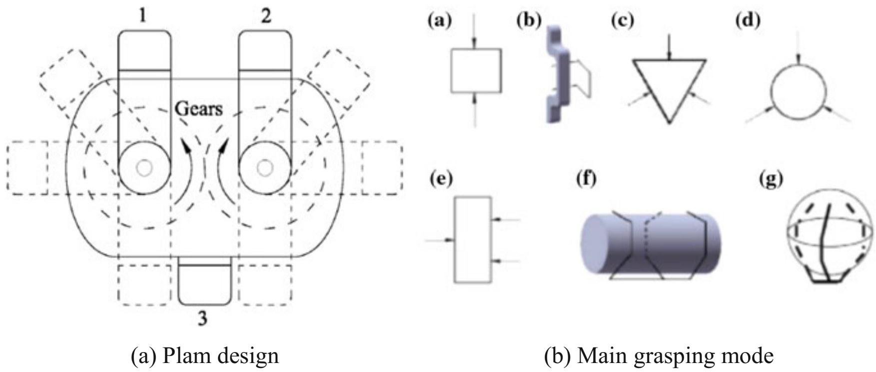


Fig. 5 Changing curve and process of grasping

3.3 *Palm Design*

In order to meet the needs of grasping, we design a robot palm which can change finger's Position, and a finger displacement device at the bottom of the palm, which can flexibly adjust the finger Position.

The robot hand consists of three fingers and a palm, we can see the palm design program in Fig. 6a. Finger 1 and 2 can be driven by a pair of gears to achieve the rotation and finger 3 position is fixed. As finger 1, 2 can be free to turn, the hand can achieve six kinds of main grasp mode combined with the main mode of human grasp (Fig. 6b). We can see 3D design of the robot hand in Fig. 7, the robot hand has 10° of freedom, 4 input drivers, each finger has a drive motor, while the palm is equipped with a dive motor which is placed in the bottom of the palm.



(a) Plam design (b) Main grasping mode

Fig. 6 Palm design and the main grasping mode

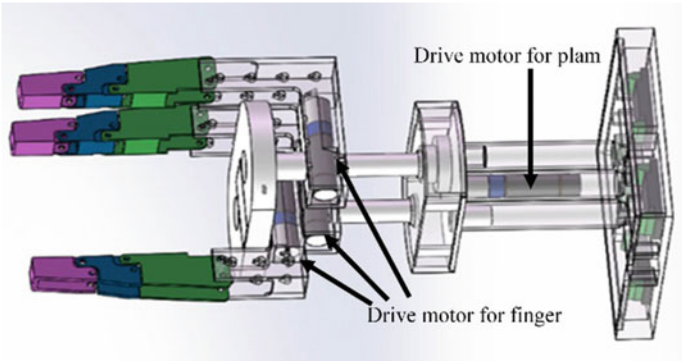


Fig. 7 Assembly diagram of robot hand

4 The Production of Robot Hand by 3D Printing and Experiments

In order to ensure the efficiency of the robot hand, some of the necessary gears still use standard machining metal gears to ensure the accuracy and strength, which can still reduce costs effectively. The parts of hand are produced by 3D printing except for gears, screws, optical axis and springs. We finally produce a higher accuracy prototype hand in this way, while the costs are significantly reduced.

The performances of robot hand on grasping different objects are shown in Fig. 8a–c are the performance respectively on grasping the larger (232 mm × 63 mm), medium (97 mm × 38 mm), small (81 mm × 19 mm) cylindrical objects; Fig. 8d is the performance on grasping the irregular columnar object; Fig. 8e, f are the performance on grasping the larger (Diameter 136 mm),

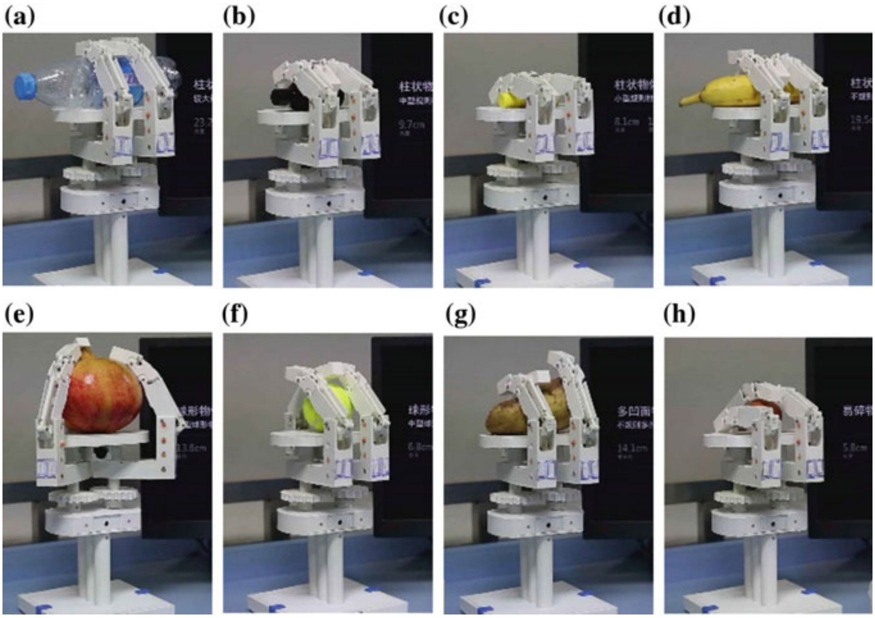


Fig. 8 The results about grasping different objects by robot hand

medium (Diameter 68 mm) spherical objects; Fig. 8g is the performance on grasping the Irregular multi-concave object; Fig. 8h is the performance on grasping the Fragile objects such as raw egg.

In order to verify the reliability of grasping, we make a greater rocking test after the grasping is completed. The results show that the robot hand can make a stable grasping (Experimental video can be seen in [13]). We also make the experiment for raw eggs (Fig. 8h), the results show that the robot hand can grasp raw egg stablely while make any damage to it, which means it has good underactuated characteristics, the mechanism is reasonable and parameters of springs are moderate.

5 Conclusion

In this paper, a kind of linkage underactuated mechanical finger is improved. The rationality of the size design is verified by simulation. The palm of a robot hand is designed, which can change the relative position between the fingers, increase the grasping range. And we design the parts of the hand by Solidworks, the design also meets 3D printing principles, which has advantages such as low cost, flexible design and so on. And we make experiments to verify the performance of the hand produced by 3D printing. The results show that the robot hand can grasp the objects with different sizes stablely, and verify the rationality of the design and the feasibility of making robot hand by 3D printing.

Acknowledgements This work was funded by the National Nature Science Foundation of China projects No. 51375504 and 61602539.

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