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STUDY ON A NEW DEXTEROUS HAND ACTUATED BY PNEUMATIC MUSCLE ACTUATORS

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ABSTRACT

Research on the robot hand actuated by pneumatic muscle actuators is significative for its complaisance and dexterity. In this paper, a new kind of dexterous hand is designed and produced. The layout of tendon is analyzed and optimized. Furthermore, a single finger is controlled by Fuzz-PID and the good control precision is achieved. And, the master-slave control of the whole dextrous hand is realized simulating the movement of human hand with a cyber-glove.

KEY WORDS

dexterous hand, pneumatic muscle actuator, fuzzy-PID control, master-slave control

INTRODUCTION

Dexterous robot hand is a highly integrated electrical and mechanical system, involving machinery, electronics, computers, control, and other subject areas. Since the 1980s, the technology on the pneumatic muscle actuator (for short, PMA) has been developing. The PMA as a kind of robot actuators attracts more and more attention from researchers.

After a great deal of research on the PMA, the author and colleague of the laboratory design a humanoid dexterous robot hand, driven by PMAs, transited by tendons. The single-finger is controlled by fuzzy PID, and the whole hand planning and master-slave control is based on the cyber glove. It is achieved initial results.

STRUCTURE

System View

The dexterous hand equipment (Figure 1) is constructed from 4 parts. They are dexterous fingers as the controlling object, PMA as the actuator, tendons as the transmission device and proportional pressure valves.

Humanoid dexterous hand is designed into an integrated structural system (hand + arm): the hand and the arm are jointly designed and cannot be conceived as separate subsystems (examples of this approach are the Utah Hand [1], the Robonaut hand [2], the Shadow Hand [3] and the ZAR hand [4]). An integrated system can distribute these actuators in the whole structure, placing them where room is available. Pneumatic muscles which are used to drive fingers are placed in the forearm muscle and the drivers of the wrist are placed in the upper arm. The power and movement of pneumatic muscles are transited by tendons, which enhance the effectiveness of the bionic, and effectively reduce the size of the palm and fingers.

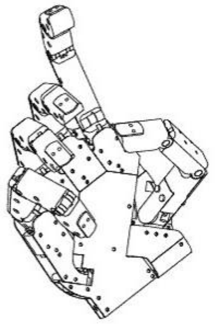


Figure 1 BIT hand

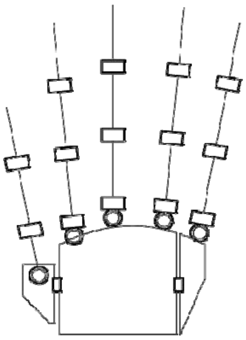


Figure 2 DOF of hand

The PMA of the Shadow company, is 6 mm in diameter, 200 mm in a total length and 10 grams in weight , as Figure 3 shows. It can contract 30 mm, and provide 70N at maximum force. The proportional pressure valve is the ITV0050 from the SMC.

Figure 3 PMA of Shadow Company

Mechanical Profile

As a humanoid dexterous hand, it has 5 fingers. Although the four-fingered dexterous hands, or even three-fingered dexterous hands can make grasp equally well, but the five-fingered dexterous hand, which make control simple, do grasp better. When hold objects in hand, each finger would not have a very clear task demarcation, that control algorithm will be correspondingly simple [5].

Dexterous hand composed by a palm and 5 fingers. The palm is connected with metacarpals of the thumb and the little finger and the near sections of the index finger, the middle finger and the ring finger (Figure 4).

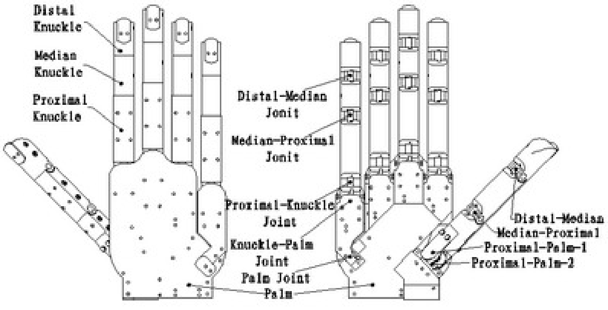


Figure 4 Hand components

The dexterous hand with five fingers, except wrist, has a total of 17 degrees of freedom as shown in Figure 2. The thumb has 4 joints, 4 degrees of freedom; the index finger has 4 joints, 3 degrees of freedom; the middle finger has 4 joints, 3 degrees of freedom; the ring finger has 4 joints, 3 degrees of freedom; the little finger has 5 joint, 4 degrees of freedom. There are 34 PMAs in all. The wrist has 2 joints and 2 degrees of freedom, which driven by 4 PMAs.

Except the thumb, the 2 remote joints of other 4 fingers are coupled by tendons. The coupled joints are combined for a degree of freedom respectively, that is, to reduce the driver number of fingers and to make the movement of fingers more like human fingers as shown in Figure 5.

Each PMA transits the movement and the power through a tendon. The tendon is fixed on the end of knuckle. A couple of PMAs and tendons make up of a degree of freedom shown in Figure 6. The index finger, as an example, has 3 independent degree of freedoms and driven by 6 PMAs.

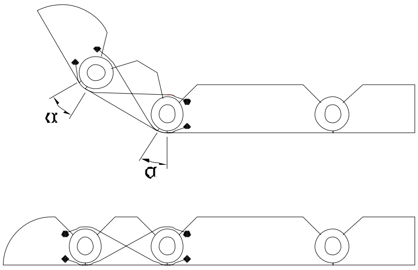


Figure 5 Linkage of joints

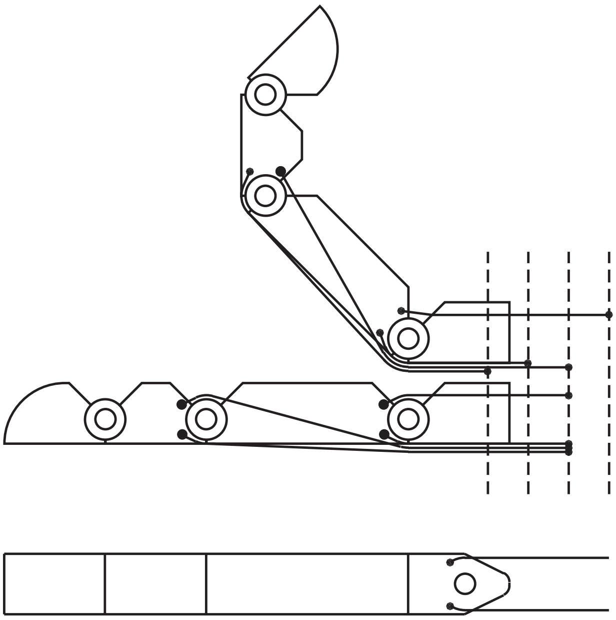


Figure 6 Tendons in a finger

The shape of the dexterous hand has a high imitation of human nature. It was designed in the size of the scope of the general human hands, and it has the same dimension with real hand (Table 1).

SINGLE FINGER CONTROL

System View

The movement of the dexterous finger in each degree of freedom is actuated by PMAs. Through accommodating the compressed air in pneumatic muscles, we can control the contractile capacity of muscle. Using tendons, the joint movement is towed by muscle contractility.

The control system of dexterous finger, as shown in Figure 7 is comprised by pneumatic muscles, an industrial computer, a PCI-1710 analog input card, a PCL-727 analog output card, SMC ITV-0050 valves and position sensors.

Table 1 Dimension of the hand

Thumb [mm]	Index finger [mm]	Middle finger [mm]	Ring finger [mm]	Little finger [mm]	Palm length [mm]	Palm width [mm]	Palm thickness [mm]
77	105	105	105	105	100	88	17

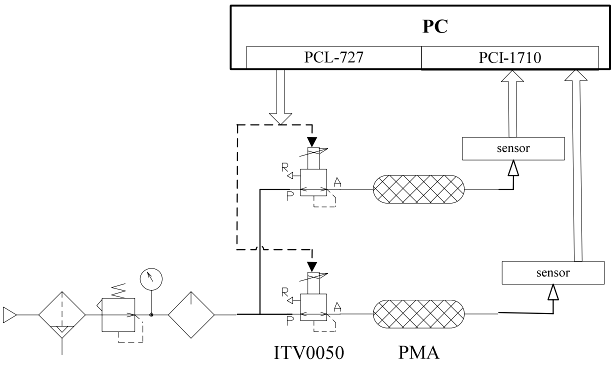


Figure 7 Control system of the dexterous finger

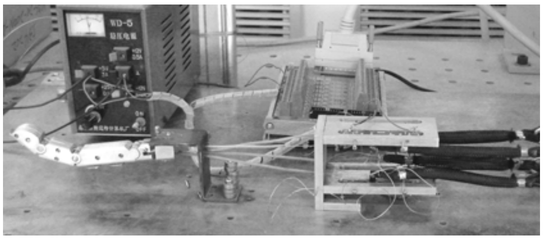


Figure 8 Experiment system of single finger control

In the control system of single finger, we measure the constriction of the PMA in order to calculate the joint angle indirectly. The position sensor adopts the linear potentiometer with 50KΩ.

Fuzzy PID

In the fuzzy-PID controller, PID parameters are adjusted referring to the fuzzy rule and the fuzzy inference. The detail control algorithm is indicated as follow (Figure 9): the inputs are error and the rate of error, noted by e and e_c. According to the fuzzy rule, the PID control parameters K_p, K_i and K_d are adjusted on-line, to meet the performance requests of controller parameters for different errors and different rates of error. After that, the controlled object performs preferable static performance and dynamic performance, according with the demands of control system.

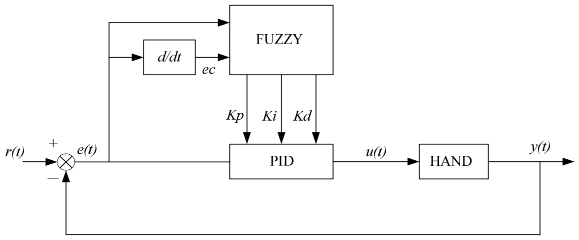


Figure 9 Fuzzy-PID position control system

The algorithm of the integral separation PID position controller is as following:

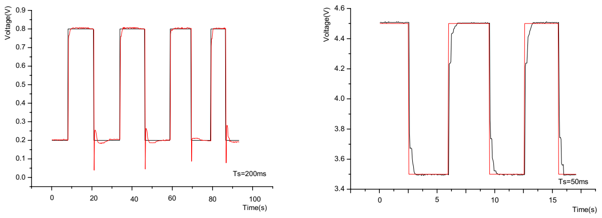
$$u(k) = K_p e(k) + \beta K_I \sum_{j=0}^{k} e(j) + \frac{K_d}{6}\left[3e(k-1) - 3e(k-2) + e(k) - e(k-3)\right]$$

$$\text{where,}\ \beta = \begin{cases} 0, & |e(k)| > \zeta \\ 1, & |e(k)| \le \zeta \end{cases}$$

we program and calculate by Matlab to produce control decision table for K_p, K_i and K_d which is stored in computer. During the control process, using the fetch table method to read the data from control decision table reduces on-line computing time and increases processing velocity of system.

Control result

For the dexterous hand joint actuated by pneumatic muscles, using PID and fuzzy-PID respectively to track the square wave, the contrast experiment result is as Figure 10.



(a) PID (b) fuzzy-PID

Figure 10 Contrast of PID and fuzzy-PID control effort

In the contrast experiment for tracking the square wave, we can find that by using PID control, there is much more overshoot in the descending portion of the curve. However, fuzzy-PID control performs the faster response and the smoother curve. The system sampling frequency goes up from 100ms to 50ms. Therefore, it not only can track the signals with higher frequencies, but also increase processing velocity of system

MASTER SLAVE CONTROL

System View

Current control system is comprised as following: a humanoid dexterous hand with five fingers, 34 pneumatic muscles, 34 pressure proportional valves, a cyber-glove, an industrial computer and 3 pieces of PCL-727 analog output cards.

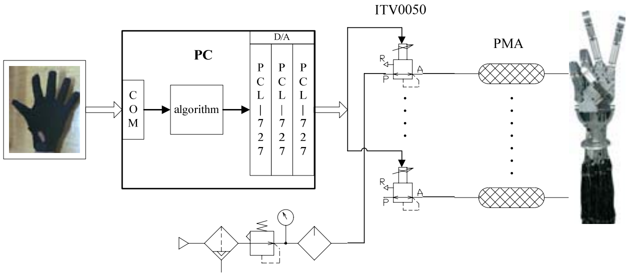


Figure 11Sketch map of control loop

Cyber-Glove

We need to gather all the real-time information about every joint angle, when any of them is changing. As one of the common equipments in virtual reality system, the cyber-glove is the preferred equipment to gather and output signals (Figure 12). In this cyber-glove, there are 15 flexible sensors fixed on each joint (Figure 13).

Figure 12 Cyber-glove

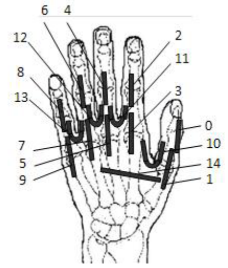


Figure 13 Sensors on glove

Control Strategy

For representing the control effects of dexterous hand intuitively, each joint of dexterous hand follows the movements that each joint of human hand performs, as real-time master-slave control. Because of lacking sensors fixed on the dexterous hand, the system control structure is not a closed loop control. Currently, we use the master-slave open loop control strategy, based on the model analysis (Figure 14).

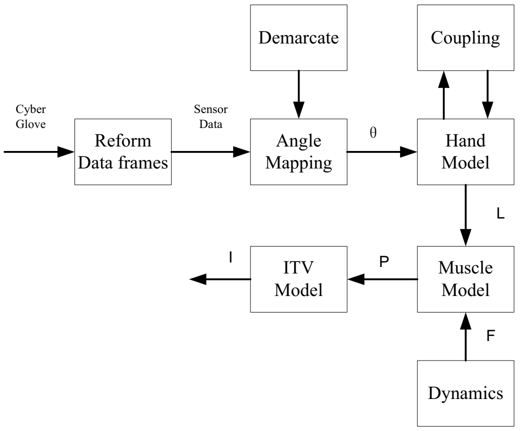
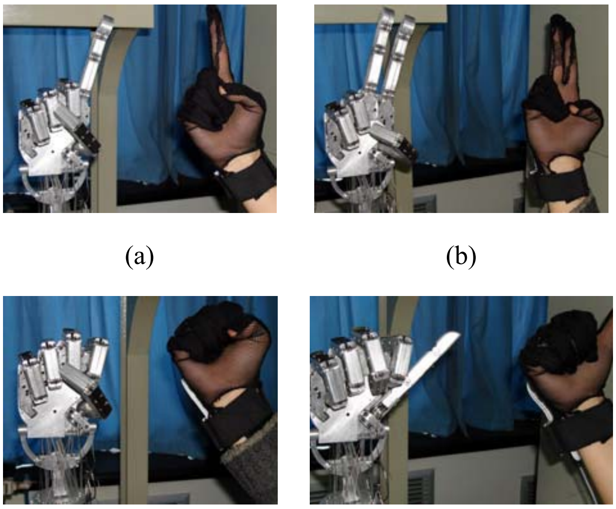


Figure 14 Master-slave control based on model

Control Effect

The actual control effects indicate that the dexterous hand is able to pose common gestures just as the human hand, as shown in Figure 15.

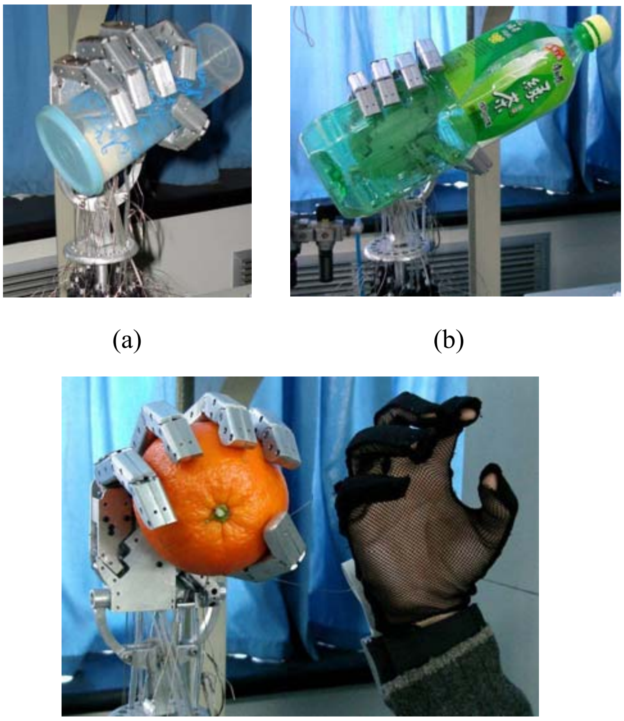


(a) (b)

(c) (d)

Figure 15 Gestures just as the human hand

The power grasping demonstration (Figure 16) includes grasping a cylinder object (16-a), an angle column object (16-b) and a spherical object (16-c). The cylinder object is a capped bottle. The angle column object is an empty bottle. The spherical object is an orange. The actual control effects indicate that the dexterous hand is able to steadily grasp objects with different shapes, sizes and qualities, by using its five fingers.



(a) (b)

(c)

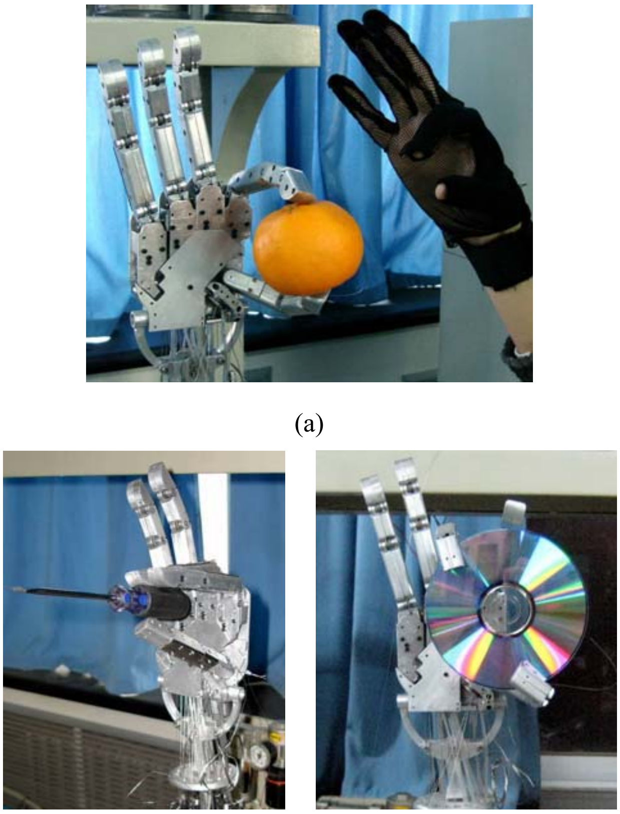
Figure 16 Power grasping

The precision grasping demonstration (Figure 17) includes seizing an orange with the thumb and the forefinger in Figure 17-a, or seizes a screwdriver with the thumb, the forefinger and the middle finger in Figure 17-b, or grasps a compact disc with the thumb, the forefinger and the middle finger in Figure 17-c. The actual control effects indicate that the above dexterous hand possesses potential abilities for grasping objects and manipulating instruments accurately.

CONCLUSIONS

This paper deals with a new kind of dexterous hand actuated by PMAs. Following conclusions can be summarized:

1. The dexterous hand actuated by PMAs is designed and manufactured.
2. A single finger is controlled by Fuzz-PID and the good control precision is achieved.
3. The master-slave control of the whole dextrous hand is realized simulating the movement of human hand with a cyber-glove. The dexterous hand has the grasp ability as the human does, which can be seen from the master-slave control results.



(a)

(b) (c)

Figure 17 Precision grasping

However, much future work shoud be done. For example, to further improve the system response rate, the process of increasing friction compensation algorithm is needed. The current system of whole hand is still open-loop control system. In the future, to form a position close-loop system, angle sensors are needed; to form a force close-loop system, tactile sensors are needed. And the adoption of distributed signal acquisition and processing can reduce system complexity.

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