Engineering

Industrial & Management Engineering fields

Okayama University *Year* 2003

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Proceedings of the 2003 IEEE
International Conference on Robotics & Automation
Taipei, Taiwan, September 14-19, 2003

Application of Artificial Pneumatic Rubber Muscles to a Human Friendly Robot

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Abstract - **When robots work together with a human or contact with a human body directly in such as a medical welfare field, in order to avoid an accident from crash and so on , a flexibility is required for the robot.**

The purpose of this study is to realize a safe mechanism for a human-friendly robot. In this paper , the structure and the fundamental characteristics of a pneumatic rubber muscle and soft mechanism are described . and then the structure and the fundamental operation of the developed soft hand are shown. Finally, the shaking hands is discussed as an example of force communication tasks between a robot and a human.

I. Introduction

For the coming advanced age society, there may not be enough working people in various fields. Especially, in the high physical burden field such as medical welfare , agriculture and so on , the lack of working people may become a serious problem. In order to deal with such a situation, it is effective to introduce a human friendly robot.

Differently from conventional robots, robots are required a safety for a human because robots operate around a human and contact with a human body directly[1]. In addition, the robot has to prepare with various communication functions such as vision, audition, tactile sensation and so on[2][3].

A wide usability of human hand is paid attention, various humanlike robot hands have been developed such as the Utah/MIT Dextrous Hand[4],the Stanford/JPL hand[5] and so on. Their hands are operated by a tendon mechanism. The tendon mechanism needs to adjust a tension force so that the tension adjuster is incorporated into the mechanism. Therefore the mechanism becomes complicated.

In this study , to realize a robot which can work together with human or handle fragile objects , a soft robot hand constructed with two types of pneumatic rubber muscle and a tactile soft sensor[6][7] has been developed. The developed robot hand is made of silicone rubber body and driven with a pneumatic power .

A pneumatic rubber muscle and a soft mechanism provided with the flexibility owing to silicone rubber can easily achieve bending and torsion motions without joint , bearing and so on. Depending on the flexibility of the hand , this hand can accomplish almost the same motion as a human hand, therefore this hand can contact with a fragile and shapeless object without complicated control law. In addition, since this hand is directly driven by pneumatic rubber muscles, the mechanism of hand can be made simpler than the above robot hands.

In this paper , the structures and the fundamental characteristics of a pneumatic rubber muscle and soft mechanism are described , and then the structure and the fundamental operation of the soft hand are shown. Finally, a method of force communication task is proposed, which controls a mutual communication based on the operating force between a robot and a human. This method is applied to their shaking hands motion.

II. Pneumatic Rubber Muscle

Linear-Type Actuator

To realize components for a complicated motion such as the root of thumb , the small size linear-type soft actuator is developed. Since deformation of mechanism (bending , torsion) can be realized by the small sized linear-type soft actuator easily, many kinds of complicated motions become possible.

In the following , the structure and the fundamental property of this linear-type soft actuator is described.

Fig.1 shows the structure of the linear-type soft actuator. It consists of silicone rubber tube (outer diameter 4[mm] , inner diameter 3[mm]). The tube is reinforced with polyester fibers.

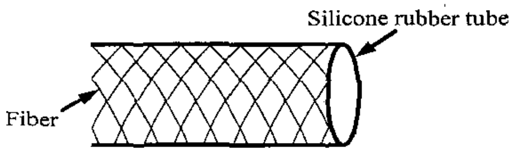
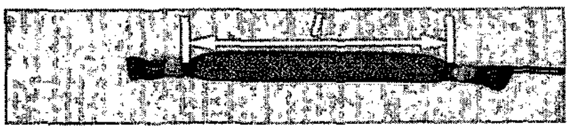


Fig.1: Structure of linear-type soft actuator

Fig.2(a) shows the initial state of the developed actuator. When the compressed air is supplied to this actuator , it contracts in the axial direction as shown in **Fig.2**(b).

(a) Initial state



(b) Pressurized state

Fig.2: Operation of linear-type soft actuator

Three kinds of linear-type soft actuators (l_0 = 40,70,95mm]) have been experimentally examined. l_0 is the initial length of this actuator. The displacement when the compressed air is supplied to the linear-type soft actuator from 0[kPa] to 500[kPa] at 50[kPa] interval is measured. **Fig.3** shows the relations between the inner pressure and the displacement. The experimental results show that the displacement saturates with an increase in the inner pressure . The elastic limit of silicone rubber causes this saturation.

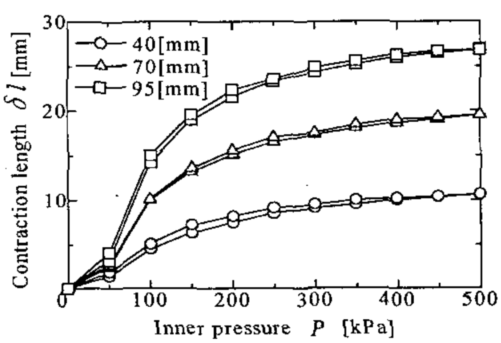


Fig.3: Relation between P and δl

The relation between the inner pressure and the contraction force of the linear-type soft actuator is measured. The actuator is fixed at the initial length in the measurement. The experimental result shown in **Fig.4**, it proves that the contraction force increases with an increase in the length of the actuator.

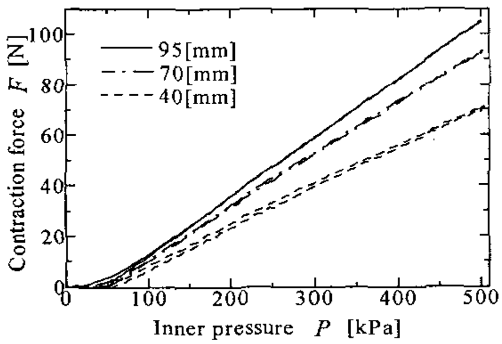


Fig.4: Relation between P and F

The relations between the contraction ratio and the contraction force of each actuator are shown in **Fig.5**. In the measurement , the fixed distance of this actuator is decreased at $\delta l/l_0$ =0.5 intervals at the constant inner pressure of 500[kPa]. It is shown that the contraction force decreases almost linearly along with an increase in the contraction ratio.

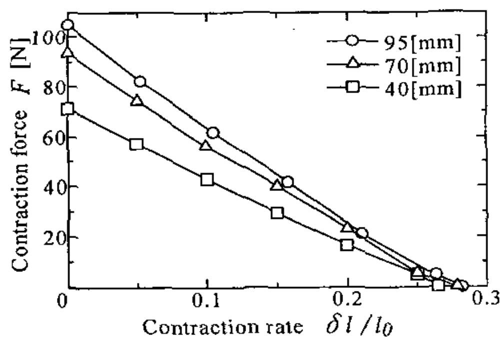
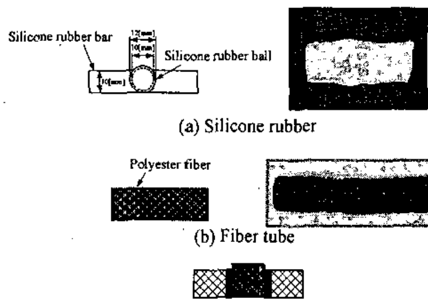


Fig.5: Relation between $\frac{\delta l}{l_0}$ and F

Rotary-Type Actuator

Fig.6 shows a structure of the developed actuator. This actuator consists of a silicone rubber ball with an outer diameter of 12[mm] , an inner diameter of 10[mm] and a silicone rubber bar with an outer diameter of 10[mm]. The silicone rubber ball is made by forming a liquid silicone rubber with a metal mold. A rotary-type soft actuator of which the ball and the bar are covered with a fiber tube. This fiber tube is made from polyester fiber tube as shown in **Fig.6**(b). The bended side of actuator is reinforced with fiber to inhibit expanding in the axial direction. Therefore , when the compressed air is supplied into the actuator , it bends in only the circumferential direction without expanding in the axial direction as shown in **Fig.7**.

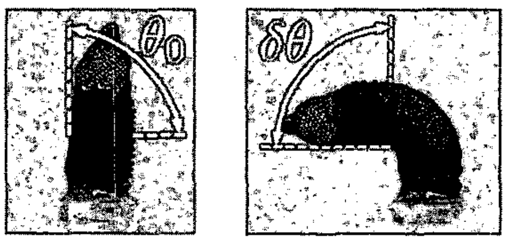


(a) Silicone rubber

(b) Fiber tube

(c) Rotary-type soft actuator

Fig.6: Structure of rotary-type soft actuator



(a) Initial state (b) Pressurized state

Fig.7: Operation of rotary-type soft actuator

Fig.8 shows the relation between the inner pressure and the bending angle. The change of the angle becomes small over 300[kPa] , because the extention of the silicone rubber gradually nears the elastic limit . Enough large bending angle can be obtained.

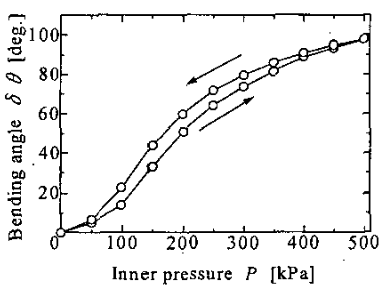
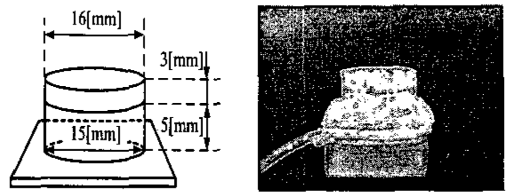


Fig.8: Relation between P and $\delta\theta$

III. Tactile Soft Sensor

Sensors used in the soft hand should be provided with the flexibility to keep the softness of the mechanism. For this purpose , the pressure measurement type tactile soft sensor is developed. **Fig.9** shows the developed tactile sensor.

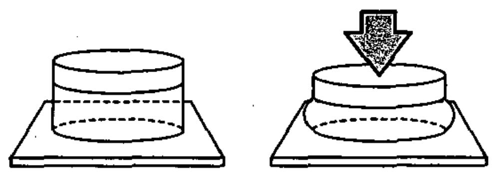


(a) Structure (b) Outlook

Fig.9: Tactile soft sensor

This sensor consists of cylindrical silicone rubber with an outer diameter 16[mm] , inner diameter 15[mm]. The cylindrical silicone rubber is made by forming a liquid silicone rubber with a metal mold.

Fig.10(a) shows the initial state of the sensor. When the external force is applied to it , the inner pressure of the sensor increases according to the deformation of cylindrical silicone rubber as shown in **Fig.10**(b). A tactile information can be detected by measuring the inner pressure change with a pressure sensor.



(a) Initial state (b) Force applied state

Fig.10: Principle of tactile soft sensor

Fig.11 shows the relation between the applied external force and the inner pressure of the sensor. It is difficult for this sensor to detect the applied force smaller than 1.0[N] , where the inner pressure is very small. Almost linear relation is obtained over 1.0[N].

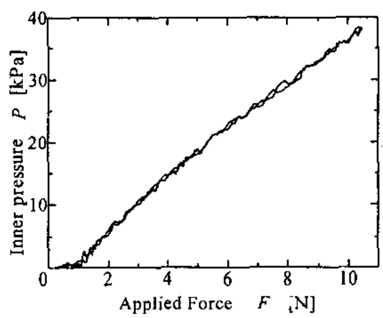
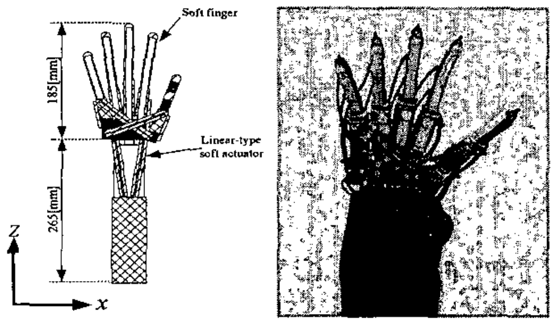


Fig.11: Relation between F and P

IV. Soft Hand

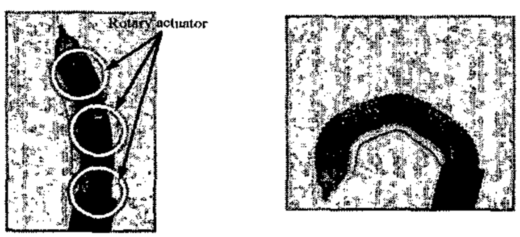
Fundamental Operation

Fig.12 shows the structure and the outlook of the soft hand. This soft hand consists of the soft finger and the linear-type soft actuator. The mass of hand is 900[g]. The length is 185[mm]. It has the same size as human. The soft finger has three joints as shown in **Fig.13**. The rotary-type soft actuators are put in position at intervals of 25[mm]. The disposition of the linear-type soft actuator is decided by referring the human muscle. This hand can operate almost same as a human hand as shown in **Fig.14**.



(a) Structure (b) Outlook

Fig.12: Soft hand



(a) Initial state (b) Pressurized state

Fig.13: Outlook of soft finger

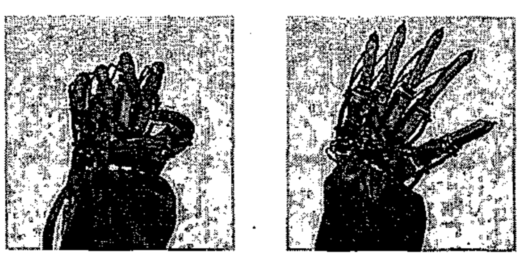


Fig.14: Fundamental operation of soft hand

The scene when the hand grasps three kinds of objects is shown in **Fig.15**. The grasping objects are a soft ball with an outer diameter of 90[mm] , a mass of 170[g] , a cubical wood with a length of 50[mm] , a mass of 75[g] and a balloon with an outer diameter of 95[mm] , a mass of 2[g]. The common and constant inner pressures are applied to the linear-type soft actuator and the actuator. The inner pressures are 400 and 150 [kPa] , respectively. This hand can grasp objects with various characteristics such as a shape and a weight , depending on the flexibility of the mechanism.

Softball

Cubical wood

Balloon

Fig.15: Scene of grasping motion

Contact Motion

By installing tactile soft sensor at the top of the finger , the soft hand can detect contact force. In the following , the contact motion with a constant force is discussed.

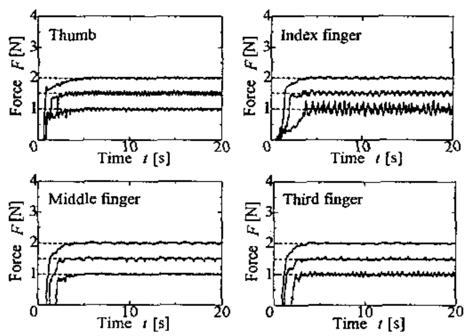
This hand contacts with a soft ball and a balloon at the constant force as shown in **Fig.16**.

Softball Balloon

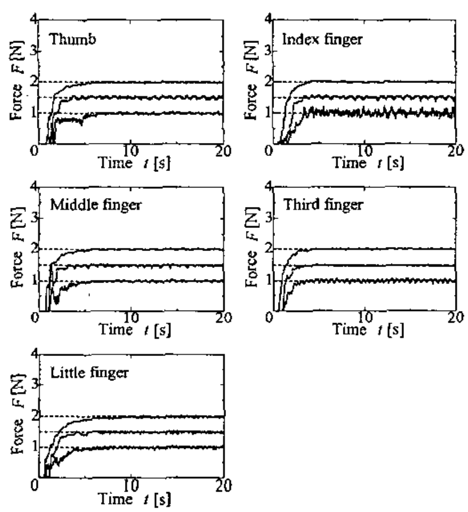
Fig.16: Scene of contact motion

In the experiment , the inner pressure of the rotary actuator is defined by the force control system as shown in **Fig.17**. The inner pressure of the linear-type soft actuator is constant value. F_r , P_r represent the desired contact force and the reference inner pressure of the rotary actuator , respectively. F , P represent the measured values of the rotary actuator. F , P are detected by the tactile soft sensor and the pressure sensor. C represents PI controller. In the case of the softball and the balloon, the inner pressures of the linear-type soft actuator are 150 and 50[kPa] , respectively.

Fig.18 shows the experimental results of contact motion. The desired contact force F_r is 1.0,1.5,2.0[N]. In the case of the softball , the little finger can not contact with the object , then the little finger is not used in this experiment. As shown in the figures , this hand can contact with a objects with various characteristics , depending on detecting contact force. Especially , where this hand can contact with a softness object such as a balloon , this hand is effective to contact with a fragile object.



(a) Softball



(b) Balloon

Fig.18: Contact motion with object

Fig.19 shows the experimental results of contact motion when a vibration is applied to the softball in the x axis direction. In the experiment , the vibration with an amplitude of 2.5[mm] , a frequency of 5[Hz] starts at 10[s]. When the vibration is applied to the object, the contact forces agree with the desired contact force. From the results mentioned above , when the external force is applied to this hand , this hand can grasp objects certainly too.

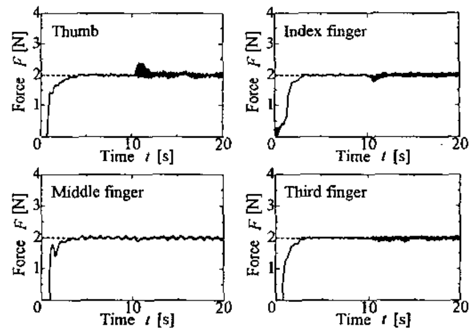


Fig.19: Contact motion with softball

Force Communication Task with Human

When a human communicates with someone through physical contact. A human can recognize some informations such as a feeling , a physical condition and so on. Then, the contact force is one of important informations. That is the same about a communication between a human and a robot.

In this section, a force communication with a human is proposed. In the following, the shaking hands is discussed as one of fundamental force communication tasks with a human.

This hand shakes with a human one as shown in **Fig.20**.

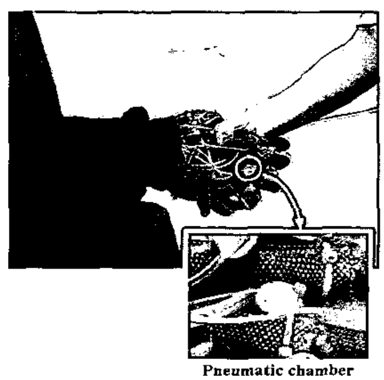


Fig.20: Scene of Shaking hands

The small size pneumatic chamber is installed between the fingers as shown in Fig.20. This pneumatic chamber is connected with the pressure sensor. When the human shakes with this hand, this pneumatic chamber is deformed by the grasping force. The inner pressure of the pneumatic chamber increases according to this deformation. Therefore, the inner pressure expresses the magnitude of the grasping force.

The desired contact force F_r is defined as shown in **Fig.21**. When the human applies the grasping force F_h to the soft hand, F_r is calculated from the force communication law. It is difficult to detect F_h directly, then the inner pressure of the pneumatic

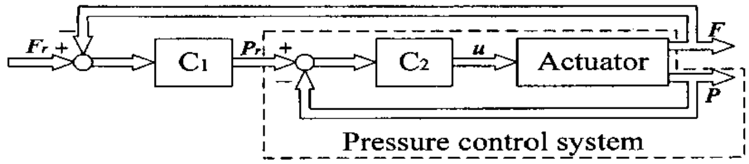


Fig.17: Force control system

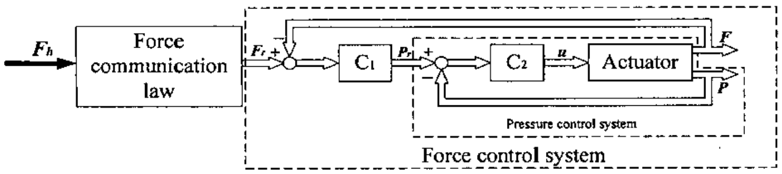


Fig.21: Block diagram for force communication

chamber defines as F_h, which expresses the magnitude of grasping force.

In this experiment, the magnitude of the contact force is changed according to the grasping force of human. Where, the force communication law is defined as a simple proportional factor $\alpha(=.0.2)$.

Fig.22 shows the inner pressure of the pneumatic chamber. From the figure, it is shown that the human changes the force intensity with time.

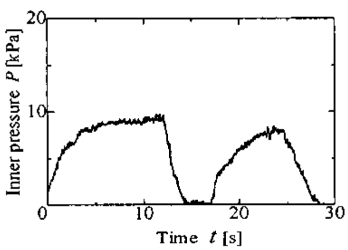


Fig.22: Inner pressure of pneumatic chamber

Fig.23 shows the contact force of each finger. The desired force and the measured one are shown by a dashed line and a solid one, respectively. From the figure, it is shown that this soft hand can change the magnitude of the contact force according to the grasping force intensity of the human.

V. Conclusion

In the paper , the structures and the fundamental characteristics of pneumatic rubber muscles and tactile soft sensor have been described , and then the structure and the fundamental operation of the soft hand have been described. After that, the force communication with a human have been proposed as an application of this hand.

By applying the flexibility to the hand , the hand can operate almost same as a human hand.

When a robot contacts with a fragile object such as a human body or fruits , a robot is required a delicate motion. In this case , the soft hand is effective because this hand with a flexibility can contact with a fragile object without complicated control method.

Finally, in this paper, the force communication law is defined as a simple proportional factor. The various responses of the force contact can be realized by changing the force communication law. It is the next subject to investigate the force communication law for a highly human communication.

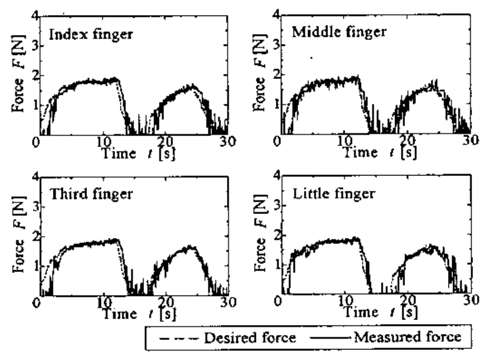


Fig.23: Shaking hands

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