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Hydraulically driven joint for a force feedback manipulator

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ABSTRACT

Recently, surgical manipulators have been widely used to support human operations, such as surgical operations. These manipulator systems are suitable for careful work, but they have a few problems. One problem is that the manipulators are not equipped with haptic sensing functions. When a manipulator does not employ haptic sensing functions, an operator can only conduct an operation using visual feedback. Therefore, to substitute for visual detection, it is necessary for the operator to use advanced techniques to determine physical contact during an operation. We have developed a new mechanism to solve this problem. A hydraulically driven joint is constructed in a spherical bearing and bellows tubes that enables a haptic sense display for the operator. This system can measure the small forces acting on the tips of the manipulator using Pascal's principle. A model of the system is derived from the relationship between the internal pressure of the bellows tube and the refraction angles of the joint. In this study, we quantitatively investigated the relationship between the internal pressure of the bellows tubes and the refraction angles of the joint. To estimate the refraction angle, we measured the quantity of water that was provided from syringes. It was confirmed that the developed system allowed for an estimation of both the strength and direction of the external force applied to the manipulator by measuring the bellows tubes' internal pressure. This report describes the prototype joint.

1. Background and aim

Surgical manipulators have recently received widespread use in support of human operations [1–3]. When a manipulator is not equipped with haptic sensing functions, an operator must possess advanced techniques for visually detecting the physical contact state during surgical operations. We have developed a hydraulically driven joint with a spherical bearing and bellows tubes that convey the haptic sense to the operator [4], and [5]. Hydraulically driven mechanisms have generally been used for high load work. However, these mechanisms have recently been used in the medical field [6]. In this study, we quantitatively investigated the relationship between the internal pressure of bellows tubes and the refraction angles of a joint. To accomplish the investigation, we measured the quantity of water supply that was provided from syringes. It was confirmed that the developed system makes it possible to estimate both the strength and the direction of the external force applied to the manipulators by measuring the internal pressure of the bellows tubes. This report describes the prototype joint and the results of the force estimation experiment.

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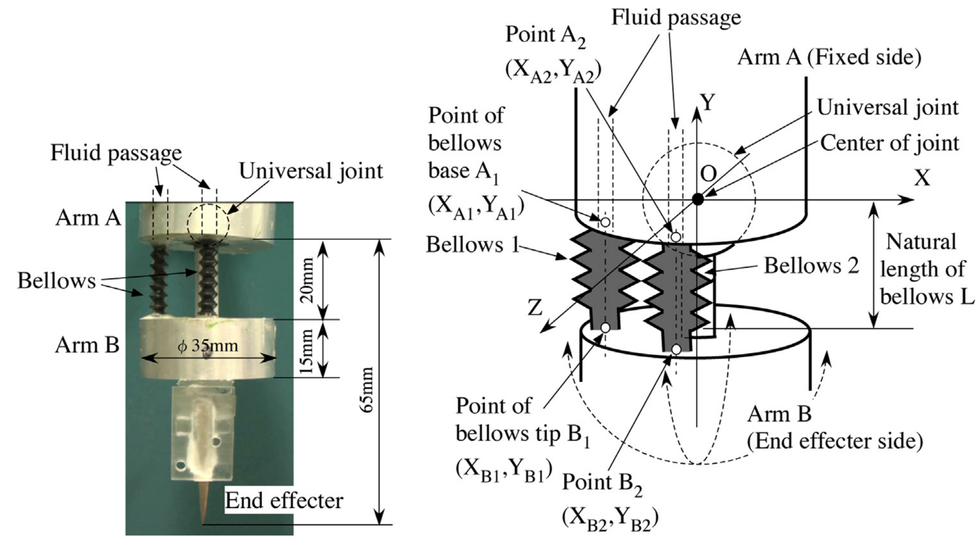
2. Mechanism

2.1. Hydraulically driven joint

An overview of the hydraulically driven joint is shown in Fig. 1(a). The arms of joint are made from aluminum alloy bar. The bellows tubes are made from nitrile rubber. Arm B is supported by columnar aluminum frames, and it is joined to arm A by a universal joint. A spherical bushings that have inner and outer rings with spherical sliding surfaces is used for a universal joint (Maximum angle is 16°). The bellows is made from nitrile rubber. It has 22 mm in length and an average of 2.5 mm in diameter. Two bellows tubes connect arm A and arm B. Bellows tube 1 and bellows tube 2 are separated by 90° about the universal joint.

The model of the hydraulically driven joint is shown in Fig. 1(b). Because of the geometrical constraint of the universal joint, the direction exercised by arm B is only on a hemispherical face of radius *L*. *L* is the natural length of the bellows tube, and it is same as the length of the universal joint rod. Therefore, the angle of the joint is obtained by the displacement of the bellows tubes. Let the coordinates of the ends of the bellows tube *i* on the arm A side be point A_i (X_{Ai}, Y_{Ai}, Z_{Ai}). In addition, let the coordinates of the ends of the bellows tube *i* on the arm B side be point B_i (X_{Bi}, Y_{Bi}, Z_{Bi}). The expansion and contraction of the bellows is expressed in this



(a) A prototype joint (b) Model of the joint

Fig. 1. Hydraulic drive joint.

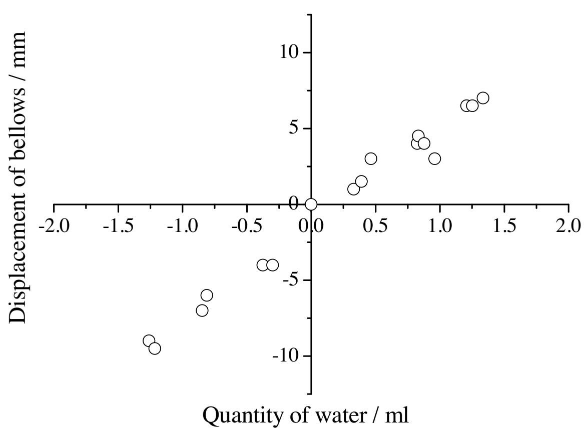


Fig. 2. Relation between displacement of bellows and the quantity of water supply.

distance between two points $A_i - B_i$, and the joint angle changes because the distance between two points changes. The angle of joint θ_i is obtained by the following expression.

$$\theta_i = \tan^{-1}\left(\sqrt{(X_{Bi} - X_{Ai})^2 + (Z_{Bi} - Z_{Ai})^2}/(Y_{Bi} - Y_{Ai})\right) \quad (1)$$

The displacement of the bellows tube δ is obtained by following expression.

$$\delta = \sqrt{(X_{Bi} - X_{Ai})^2 + (Y_{Bi} - Y_{Ai})^2 + (Z_{Bi} - Z_{Ai})^2} - L \quad (2)$$

Expression (1) can then be represented as expression (3).

$$\theta_i = \sin^{-1}\left((\delta/H)^2 + 2\delta/H\right)/2 \quad (3)$$

Fig. 2 shows result of basic motion experiment of bellows. The displacement of the bellows tube δ was measured when the syringe supplied water to the bellows tube. δ is linearly proportional to the quantity of water supply q. Following expression was obtained from this result.

$$\delta \fallingdotseq 6.31q \quad (4)$$

Therefore, the joint angle θ_i can be obtained by the quantity of water supply q without an angle sensor.

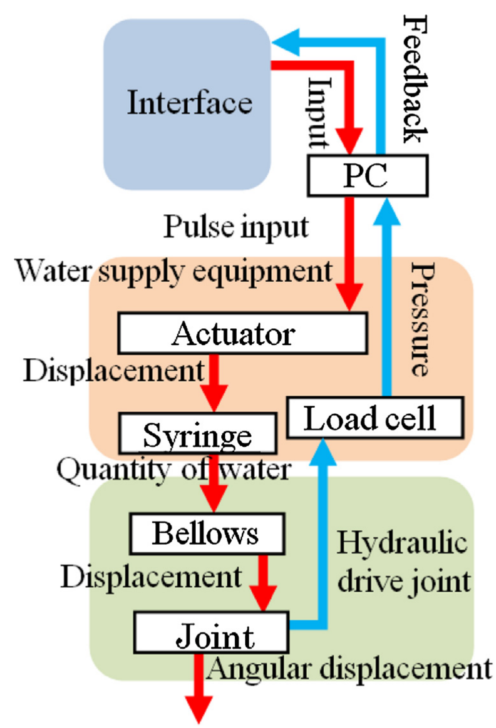


Fig. 3. Drive system.

2.2. Drive system

The drive system for the hydraulically driven joint is shown in Fig. 3. An operator gives a position command to a personal computer using the 3-dimensional haptic device. The personal computer thus controls the linear actuator using the position command. The linear actuator uses a stepper motor which incorporates a ground ball screw. Maximum force of linear actuator is 200 N and its position resolution is 20 µm. A water supply unit is shown in Fig. 4. The linear actuator moves by pulse control accurately. The syringe plunger is moved perpendicularly using a linear actuator. Resolution of water supply is 0.003 ml by the syringe with a diameter of 15 mm. When the syringe supplies water to the