Force Control of 6-DOF Pneumatic Joystick

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Abstract

In this study we develop a new type joystick with force control. A developed joystick consists of a six-degree-of-freedom (6DOF) Stewart platform type[1] of joystick using pneumatic actuated parallel link mechanism. The thrust force of the cylinder is controlled by the PWM of the solenoid valve that uses PIC. When the thrust force of the cylinder is controlled, the control characteristic of the cylinder is improved by the effect of the accumulator so that it might make amends for the influence on the compressibility of air exerted on the characteristic of the thrust force of the cylinder. It is confirmed that the thrust force of the cylinder can be applied to the pneumatic joystick, and the z-axial force control is possible in the experiment.

1 Introduction

The necessity of the rehabilitation work support the technology expected for the social life independence of senior citizen nowadays. The function to support the multi degree of freedom movement of the rehabilitation equipment is necessary corresponding to the patient with various symptoms [2],[3]. Then, we paid attention to a parallel mechanism with high rigidity that has a flexible motor function and performs high-speed and highly accurate six degree of freedom movement. We developed the force control system of 6-DOF Pneumatic Joystick and implemented it to the prototype model[3],[4]. Force control system makes up a compact composition that consists of the small air pressure cylinder and the solenoid valve, and achieves the control of the thrust force of the cylinder by the PWM control of the solenoid valve.

This system was applied to the test pneumatic joystick, and the result of controlling force will be reported.

2 Force control of 6-DOF joystick

2.1 Parallel mechanism

Parallel and serial mechanisms are illustrated in Fig.1[5]. As shown in Fig.1 (a), parallel mechanism typically consists of a moving platform that is connected to a fixed base by several limbs[2]. Typically, the number of limbs is equal to the number of degrees of freedom such that every limb is controlled by one actuator and all the actuators can be mounted at or near the fixed base. Two plates (upper and base plates) are connected through six articulated links in which a linear actuator can change the link length. The links are jointed by universal joints. The length of links controls the position and orientation of the upper plate with respect to the base plate. The individual errors in the active links are not cumulative. The external forces applied to the upper plate are distributed among all parallel links and actuators. The parallel mechanism has usually the basic advantages of high positioning accuracy, high rigidity, high operational speed and very high load capacity compared to serial mechanisms as shown in

(a) Parallel mechanism

(b) Serial mechanism

Fig.1 Parallel and serial mechanisms

Fig.1 (b). The disadvantage of the parallel mechanism is to have a small volume of its working range relative to the dimensions of the links[4].

2.2 System configuration

Fig.2 shows the force control system configuration of the pneumatic joystick that consists of a parallel mechanism. An arbitrary signal is given from PC, and the on-off values of solenoid valve are controlled by the PWM control with PIC. Then, the thrust force of six cylinders that compose the joystick is changed. The force control of the joystick is achieved by controlling the thrust force of each cylinder.

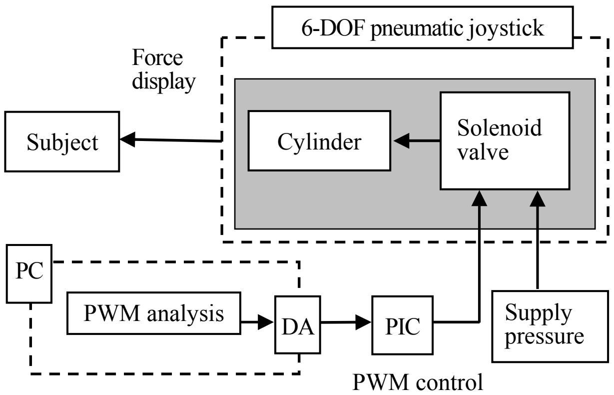
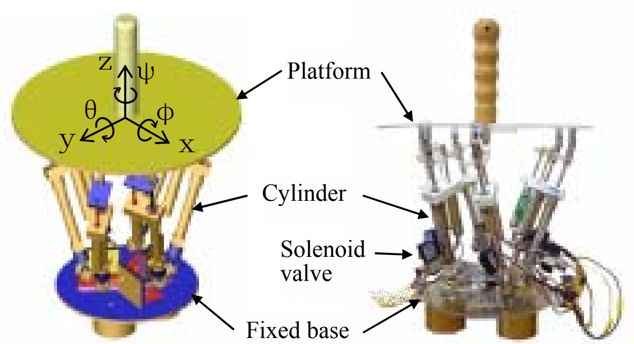


Fig.2 System configuration

Fig.3 (a) shows design model by three-dimensional CAD. Fig.3 (b) shows the pneumatic joystick test structure. The joystick consists of platform, pneumatic cylinder, solenoid valve, and fixed base.



(a) CAD modeling (b) Test structure

Fig.3 Pneumatic joystick system

Working range is calculated from this joystick by the reverse-movement study analysis in consideration of the geometrical restraint condition by the amount of expansion and contraction of the cylinder. Table 1 shows the working range of six degree of freedom.

Table 1 Working range

Translation (mm)	x	−30.7～41.9
	y	−32.6～32.6
	z	−16.6～16.3
Rotation (degree)	φ	−9.1～9.1
	θ	−8.9～9.2
	ψ	−41.8～41.8

2.3 PWM control that uses PIC

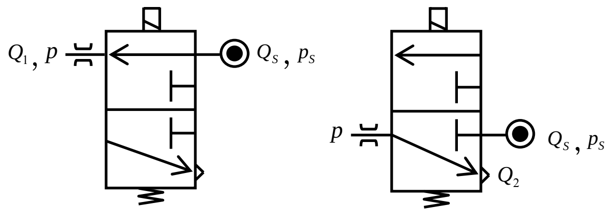
PIC is a kind of the microcomputer that the microchip technology company developed. It controls connected part of the computer and peripherals, and 35 instruction words are used.

PIC16F877 is used to provide the PWM output function and the AD output function.

The PWM control is a method to change the turning on time to the pulse wave at a constant cycle, and the modulation rate τ is the ratio of the on time in a constant cycle.

2.4 Control of thrust force of cylinder

The PWM control of the solenoid valve is used to control the thrust force of the pneumatic cylinder. Fig.4 (a) and (b) show respectively turn on and off of three-way solenoid valve [4].



(a) ON (b) OFF

Fig.4 Three-way solenoid valve

Moreover, the driving circuit of pneumatic cylinder is shown in Fig.5. The τ decided with PC is converted in DA, the solenoid valve is controlled by PWM control based on τ by PIC, and the thrust force of the cylinder is controlled[4].

The relation between the average control pressure at this time and the modulation rate τ of PWM becomes expression (1). Here, Ps is supply pressure.

Thrust force F of the cylinder is given from expression (1) by expression (2).

$$p = p_s \frac{\tau^2}{\tau^2 + (1-\tau)^2} \quad \cdots(1)$$

$$F = \eta A p_s \frac{\tau^2}{\tau^2 + (1-\tau)^2} \quad \cdots(2)$$

Here, A is an area of the pushing side of the cylinder, η is a load factor.

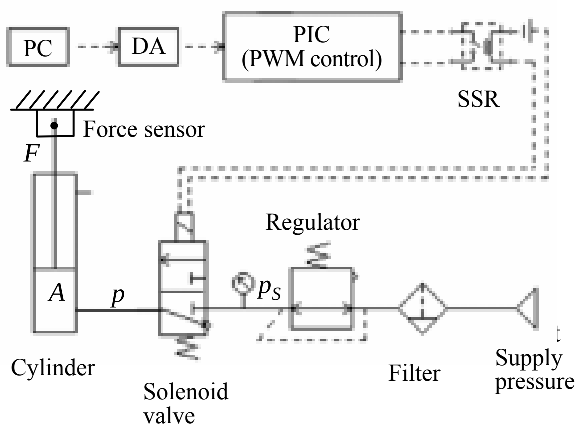


Fig.5 Driving circuit of pneumatic cylinder

3 Experimental result

3.1 Characteristics of pneumatic cylinder

We experimented with a single cylinder. The load cell is set up between a fixed wall and the cylinder to measure the thrust force of the cylinder as shown in Fig.6. The supply pressure is adjusted to 0.15MPa. In three conditions (2, 15, and 27mm) with different amount of the cylinder expansion and contraction (min 0, max 30mm), the thrust force of the cylinder for the change in the modulation rate τ is measured. The measurements and predictions by expression (2) are shown in Fig. 7 (a). When the amount of the cylinder expansion and contraction is small, difference of the characteristic of the thrust force by prediction and experiments exists.

Then, the different capacity of the accumulator of three conditions (314, 942, and 1570mm^3) is set between the solenoid valve and the cylinder, and the results of the thrust force of the cylinder in each case are shown in Fig.7 (b). Here, the supply pressure is adjusted and 0.15MPa and the amount of the cylinder expansion and contraction are adjusted to be 2mm.

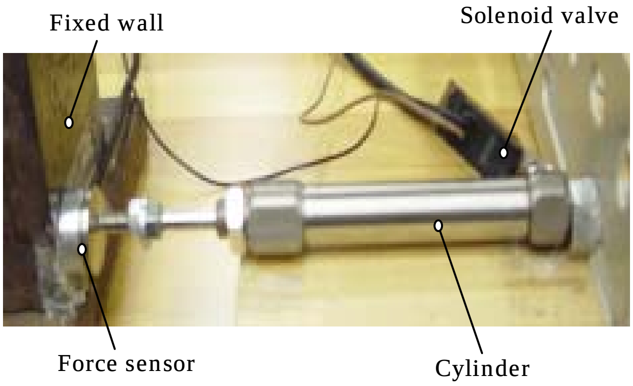
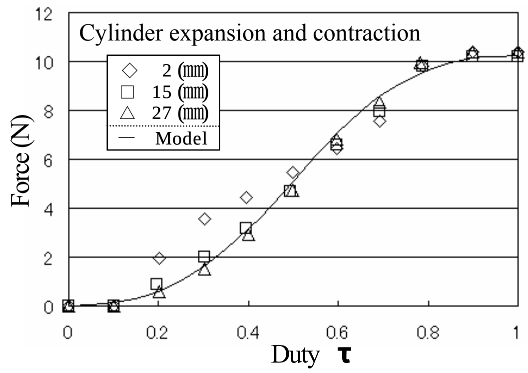


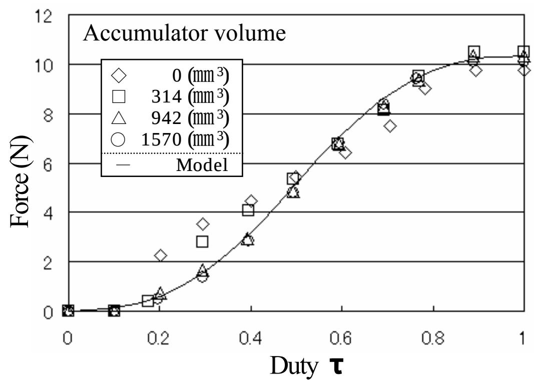
Fig.6 Experiments with a single cylinder

The experiment value has been improved by greatly taking the capacity of the accumulator.

From the result, when the amount of the cylinder expansion and contraction is small, that is, when the volume between the solenoid valve and the cylinder is small, the compressibility of air influences the pressure characteristic. And it is understood that the force characteristic is depend on the capacity of the accumulator.



(a) Without accumulator



(b) With accumulator

Fig.7 Cylinder force

3.2 Characteristics of pneumatic joystick

The thrust force of the pneumatic cylinder is controlled, and it supplies the force control of the pneumatic joystick shown in Fig.1. The force sensor (0~100N) consists of the strain gauge, and the force in z-direction is measured. The same modulation rate is given for six cylinders, and the force of z-axis is measured. Fig.8 shows results of experiment, when the posture is adjusted to be neutral position (cylinder expansion and contraction 15mm) and the supply pressure is 0.15Mpa.

The calculated value is summation of each thrust force of 6 cylinders in vertical direction obtained from expression (2).

The prediction agrees well with the measurements, and the z-axis force control is possible. A force of approximate 53N is generated when the supply pressure is 0.15Mpa, and it has been understood that enough forces experienced by man is generated.

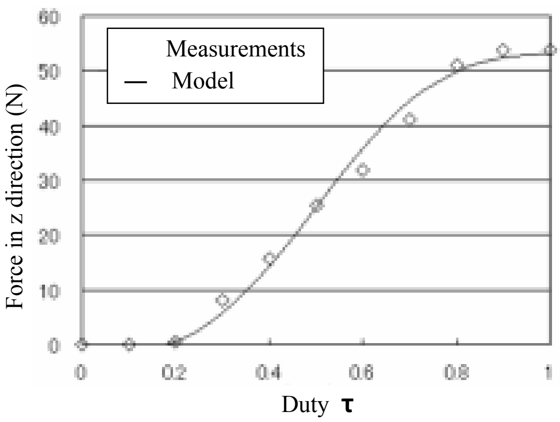


Fig.8 Force control of joystick

4 Summary

The pneumatic joystick has been developed, and the six-degree of freedom force control was achieved.
The conclusion is shown below.

(1) The thrust force of the cylinder is generated by the PWM control of the solenoid valve. And the control characteristic of the thrust force of the cylinder was confirmed by the change in the amount of the cylinder expansion and contraction
(2) The compressibility of air can be compensated with accumulator, and the control characteristic of the thrust force of the cylinder has been improved.
(3) The pneumatic 6-DOF parallel mechanism type joystick was developed. The z-axis force control was evaluated by the experiment, and the force control by the PWM control is possible.

References

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