Dynamic Force Display in Virtual World by Fluid Power Glove

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ABSTRACT

This paper describes the development of a dynamic force display device using pneumatic bellows actuators to display dynamic force sensation for the operating human being from real or virtual environment. Static characteristics of the pneumatic bellows actuator are experimentally and theoretically investigated. It is also experimentally investigated that the force sensation is applied on the operator's fingers by the prototype of the dynamic force display device using the four pneumatic bellows actuators. We demonstrate the dynamic force feedback system for grasping virtual solid objects in a virtual environment of 3D computer graphics. The operator can interactively communicate the virtual object in the computer world.

KEY WORDS

Virtual Reality, Pneumatic Bellows, Fluid Power Glove, Force Display, Grasp

INTRODUCTION

Technical innovation in virtual reality technology is very important on human-machine interface in robotics, mechatronics, computer networks, medicine, or every engineering field. Human being can feel like realistic information in a virtual environment for the virtual reality technology. Especially, a force and tactile sensation to operator's hand in dexterous teleoperated manipulations is one of the important human-machine interfaces. Recently, many researchers have been developed the force and tactile display systems [1][2]. Tanie and Kotoku [8] have developed an electrical actuated master arm designed specifically for virtual reality simulations. Iwata [7] has developed a force-

feedback platform (The HapticMaster; Nissho Electronics Co.) that controls forces to the operator's hand. The user's hand needs to be kept on the platform so the master is not fully portable. Burdea, et al. [4] have developed a portable master (The Rutgers Master) designed to retrofit a sensing glove using four pneumatic micro-cylinders placed in the palm of a glove on a small L-shaped platform. This glove is not allowed the simulation of virtual object weight as no wrist feedback is provided. A portable hand master with more degrees of freedom has been developed by Bouzit, et al. [5]. The hand master provides force feedback to 14 finger segments for the grasping motion. The motion control of actuators is done through pulleys and micro cables. Kramer [6] has patented a "Force feedback and texture simulation

interface device" that is modified a sensing glove and added to force and touch feedback. Force feedback is provided by multiple plastic cables that are routed from the wrist mount to the fingertips. The CyberGgrasp (Virtual Technologies, Inc.) using Kramer's patent is commercially available for force feedback by a human hand. Micro air pockets placed in a glove are used to provide pneumatic touch feedback [9]. Each air pocket has two micro-capillary tubes and air pressure is regulated by an electro-pneumatic valve. The use of pneumatic drive simplifies the design and reduces the feedback structure weight.

In our previous study [3], a dynamic force display device using flexible pneumatic actuators to display dynamic force sensation for the operating human being from real or virtual environment has been developed. We call this device "Fluid Power Glove". The flexible pneumatic actuator was made of an ethylene-propylene flexible tube. When a compressed air is supplied to the flexible tube, the bending stiffness and compliance of the tube is changed and flexion and extension forces are generated to a bending direction.

This paper describes the development of a new prototype of the Fluid Power Glove using pneumatic bellows actuators for displaying force to the operator's fingers. We demonstrate the dynamic force feedback system for grasping virtual solid objects in a virtual environment of 3D computer graphics. The computer graphics display motion pictures of the virtual objects and the operator's hand model according to the actual motion of the operator's hand and the object. The operator can interactively communicate the virtual object in the computer world.

FLUID POWER GLOVE

In some applications of virtual reality, it is necessary that operators sense the contact force when a virtual object is grasped. Although the user gets an impression that a solid object is touched, it is possible to penetrate the virtual object. The effect is quite unnatural and affect the user's performance. The way to overcome this feature is to employ a dynamic force display system that prevents a virtual object from being penetrated. In the dynamic force display system, it is necessary to provide sufficient force while keeping the feedback hardware light and portable. Pneumatic actuators are cheap, clean, light and inherently safe due to air compliance.

In our previous study [3], the dynamic force display device "Fluid Power Glove" using flexible pneumatic actuators has been developed. The flexible pneumatic actuator was made of the flexible air tube. In our previous Fluid Power Glove, we have some problem for configuration, rigidity and deformation of the flexible pneumatic actuator. There was a case in which it was accompanied for the sense presentation by some discomforts of displaying the dynamic force sensation for

Figure1 Bellows Type Fluid Power Glove

Figure2 Photo of Fluid Power Glove

the operating human being from real or virtual environment.

In this paper, we describes the development of a new prototype of the Fluid Power Glove using pneumatic bellows actuators for displaying force to the operator's fingers in the next generation. A new prototype of the developed Fluid Power Glove is illustrated in Fig.1 and a photo is shown in Fig.2. The prototype of the Fluid Power Glove consists of four pneumatic bellows actuators in which air pressure is regulated by a pneumatic pressure control valve, and a fitting glove for the operator's hand. The pneumatic bellows actuators are fixed in palm of the hand side of the fitting glove. Each bellows actuator allows both flexion and extension of the fingers when the compressed air is not supplied to these actuators. When the operator's hand in the virtual world grasps objects such as a virtual rubber ball or solid ball,

Figure 3 Pneumatic Bellows

Figure 4 Relationship between Internal Pressure and Expansion for Pneumatic Bellows

the compressed air is supplied to the pneumatic bellows actuators and the operator can feel dynamic contact forces on his fingers. The contact force depends on the dimension of the object deformation as well as its modeled compliance.

The Fluid Power Glove is very light and wearable for operator's hand. As a result, the operator can be easily and unconsciously fitted to the Fluid Power Glove for dynamic and interacted force feedback from the working equipment in real or virtual environments. The Fluid Power Glove has the advantages of a low cost, a compact and lightweight structure, and is a clean and safety device.

PNEUMATIC BELLOWS ACTUATOR

Generally, the pneumatic bellows actuators are used for the linear motion actuators. In this study, however, the characteristics are utilized by the attention to the flexibility of bending direction of the pneumatic bellows actuator. The possibility mounting for operator's hand as an actuator for the resistance force generation should be investigated. In this section fundamental characteristics

of the pneumatic bellows actuator are discussed.

Figure 3 shows a structure schematic drawing of the pneumatic bellows actuator used in this study. The forming bellows is made of the beryllium that has a thickness of 0.09 mm. The bellows has an inside diameter of 7.5 mm and an outer diameter of 12 mm. A nominal spring constant of the bellows is 1.96 N/mm, and an effective sectional area is 0.77 cm². A part of the bellows is closed, and other end is connected with a piping joint for air supply.

The extension force of the bellows axially arises and total length of the bellows is axially extended, when the bellows pressurizes the inside. It returns to the free initial length according to the spring effect of the bellows itself, when the bellows is decompressed the inside. It is assumed that the bellows actuator is a linear spring, a dimensionless elongation L_B is given as follows;

$$L_B = \frac{A}{kL} p \quad (1)$$

where A is the effective sectional area, k is the nominal spring constant, L is a free initial length of the bellows and p is the internal air pressure, respectively.

Figure 4 shows the static characteristics of the pneumatic bellows for the elongation versus the internal pressures. The pneumatic bellows used in this study is extended about 25% of the free initial length and has no hysteresis for expansion and shrink. The continuous line in this figure is a calculation result of the linear spring characteristics given as the Eq.(1). With the increase in the internal pressure, the expansion of the bellows decreases in comparison with the linear spring, and it is found that the bellows have a nonlinear spring property.

The bellows is originally used as an axial motion actuator. However, it is also used for the restraint for the bending direction of the finger as resistance force generation actuator for the Fluid Power Glove. The flexural property of bellows is investigated in the mind in respect of such structural characteristics.

By modeling the bellows as a general coiled spring in the concentrated load affected the tip, the relation between a restoration torque T_B and a bending angle θ is modeled as a following equation [10].

$$T_B = \frac{\pi G d^4}{l \left(1 + \frac{2G}{E} \right)} \theta \quad (2)$$

where d is the material thickness, E is the modulus of longitudinal elasticity, G is the modulus of transverse elasticity, and l is the effective length of the bellows, respectively.

Figure 5 shows both experimental results of the static characteristics of restoration torque versus the internal pressure with the bending angles and calculation results

Figure 5 Relationship between Bending Angle and Restoration Torque for Pneumatic Bellows

of the coiled spring characteristics. The experiments on case of the non-pressurization condition and case of the pressurization condition in bellows are carried out. It is clear that more large restoration torque of the pressurization has been obtained in generating restoration torque characteristic. The continuous line in Fig.5 is calculation result of coiled spring characteristics given in the Eq.(2). The result in non-pressurization agrees well with the result of the Eq.(2). In the pressurization, it seems to generate more large restoration torque for the bending direction, because the rigidity of the bellows changes. Especially, it is experimentally confirmed that this tendency remarkably appeared in the pressure over 0.2 MPa. It is a result of having to some extent flexibility further than the pressurization in non-pressurization. Therefore, it can be said that the pneumatic bellows is suitable for the installed actuator for the Fluid Power Glove.

DYNAMIC FORCE DISPLAY SYSTEM

In this section, it is experimentally investigated that the force sensation is applied to the operator's fingers by the prototype of the Fluid Power Glove using the four pneumatic bellows actuators. Figure 6 shows the configuration of the dynamic force display system using the Fluid Power Glove. Compressed air is supplied and regulated from an air compressor to the Fluid Power Glove by the electro-pneumatic pressure control valve. The air pressure value is measured at the inlet of the pneumatic bellows actuator with a semiconductor type pressure transducer and directly fed back to the reference command path. The reference command for the air pressure to the electro-pneumatic pressure control valve is adjusted at a suitable value according to the interacted forces for virtual grasping objects. The microcomputer

Figure 6 System Configuration

Figure 7 Computer Graphics of Hand and Object in Virtual World

commands to operate the pressure control valve according to the dimensions and compliance of the grasped object and the bend of each fingers. The bend of fingers is measured by a thin electrical strain gauge stuck on the surface of the fitting glove. Each joint of flexing finger angle is measured indirectly by a change of resistance of the strain gauge. The change in resistance produces a change in voltage on a Wheatstone bridge. The measured bending data are stored in a personal computer PC through A/D converter. The output data of the bend sensor is calibrated by grasping a standard object. The calibration has been done to be repeated every time the Fluid Power Glove is put on at the start of a grasping session for the operator.

Figure 8 Experimental Result for Grasping of Virtual Solid Ball with Diameter of 20 mm

Figure 9 Experimental Result for Grasping of Virtual Solid Ball with Diameter of 50 mm

The shape of a virtual object and a human hand for visual sensation in virtual space have been created by a 3D computer graphics using 3D surface model graphics libraries "Method3D" based on some standard polyhedrons [3]. The 3D display of visual sensation for the operator's hand and the object in the virtual world is presented in Fig.7. The computer graphics display motion pictures of the virtual objects and the operator's hand model according to the actual motion of the operator's hand and the object. The operator can interactively communicate the virtual object in the computer world.

EXPERIMENTAL RESULTS

In our experiments we image to grasp three kind of solid balls in the virtual environment. Figure 8 shows a typical experimental result of the bending angle of finger and supplied air pressure change for grasping a virtual small solid ball that has an outer diameter of 20 mm. There are a series of two times of the grasping operation. In the case of grasping the virtual solid ball, a constant value of regulated air pressure (0.2 MPa) is momentarily supplied to the pneumatic bellows actuators and the dynamic contact force displays to the operator's fingers at a virtual contact point shown as an arrow in Fig.8. When the constant value of compressed pressure is momentarily supplied to the Fluid Power Glove, the operator's finger is restricted to the flexion and the bending angle of the finger is nearly kept at a constant value according to the dimension of the small ball. The operator can feel like grasping the solid object.

Experimental results of grasping another dimensions of the virtual solid balls are also demonstrated in Fig.9 and Fig.10. The outer diameter of the virtual solid balls have 50 mm in Fig.9 and 80 mm in Fig.10, respectively. The

Figure 10 Experimental Result for Grasping of Virtual Solid Ball with Diameter of 80 mm

effect of displaying the force sensation of the different type of virtual solid balls to the actual operator's hand is experimentally confirmed by using the Fluid Power Glove.

CONCLUSIONS

The dynamic force display device using the pneumatic bellows and the virtual contact force feedback system has been developed for virtual reality applications and the performance of the system has been experimentally investigated. The effect of displaying the dynamic force sensation for the different type of the virtual solid balls to the operator's hand is experimentally confirmed by the dynamic force feedback system. The dynamic force sensation is applied on the operator's hand by the Fluid

Power Glove. The operator can interactively communicate the virtual object in the computer world. The Fluid Power Glove is portable, light weight and safety device in virtual reality applications.

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