AIR-PILLOW TELEPHONE: A PILLOW-SHAPED HAPTIC DEVICE USING A PNEUMATIC ACTUATOR

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Abstract

As a new haptic device for daily use, a pillow-shaped haptic device using a pneumatic actuator, the Air-pillow telephone, is proposed. The Air-pillow telephone allows an intimate couple at a distance to mutually share the partner's sense of touch and presence. We have developed a prototype system with an air bag driven by a piston-cylinder mechanism. The user's head motion affects the air pressure of the air bag and then its signal is bilaterally transmitted in real time via internet to actuate the partner's air pillow. Inside the pillow's subtle motion, the user can find the existence of the partner's haptic language. This paper describes the Air-pillow telephone concept and application as well as implementation of the prototype system and simulation results.

1. Introduction

In recent years there have been many studies about new communication styles employing daily commodities, such as picture frames, a bed, cushion, stuffed doll, and jacket [1-7]. Unlike ordinary everyday communication devices, such as the telephone, fax, or PC, the aim of these daily commodities is completely natural communication in which the user is not aware of the communication function inside the device. An important common point among the commodities is that the user's skin touches the device. The devices attempt to haptically transmit the intimate feeling and/or presence, which cannot be easily conveyed by conventional media: text, voice, still image and video. As one such haptic device for communication, here we propose a pillow-shaped haptic device using a pneumatic actuator: the Air-pillow telephone.

The conventional devices such as [1-7] and our Air-pillow telephone share a similar concept of the haptics in daily life. These conventional devices, however, have no function that can measure and control a user's head motion on a pillow. Therefore, with the conventional technology, it is difficult to mutually transmit subtle head motion when lying down.

2. Concept and application

Figure 1 presents a conceptual image of a communication system where an intimate couple at a distance from each other can mutually share a partner's sense of touch and presence through the pillow.

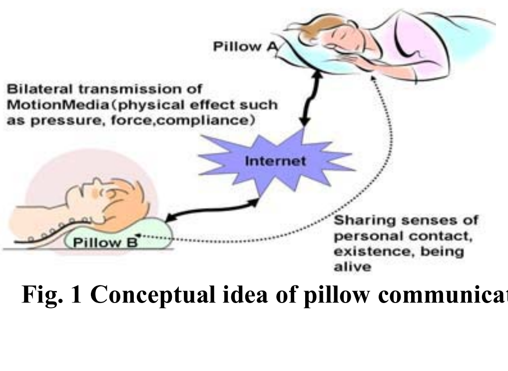

Fig. 1 Conceptual idea of pillow communication

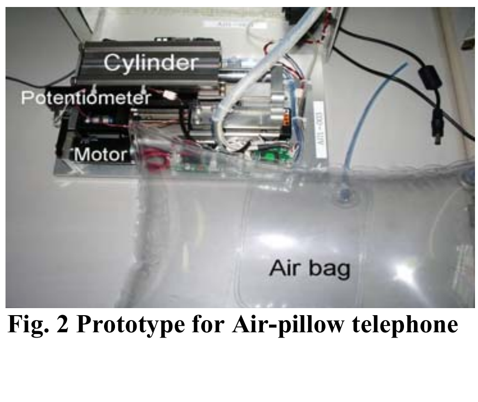

Fig. 2 Prototype for Air-pillow telephone

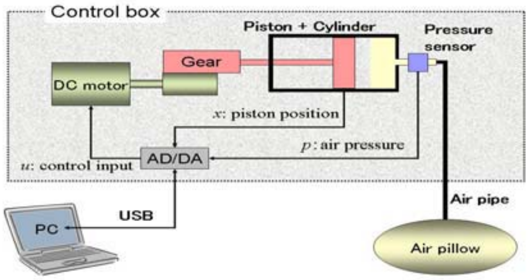

Fig. 3 Schematic drawing of the prototype system

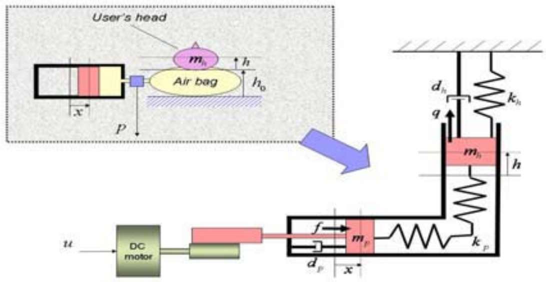

Fig. 4 Lineally approximation of the prototype

The user's head motion or pillow hugging motion affects the form of the pillow and the signal is bilaterally transmitted in real time via internet. Based on the signal, the pillow is physically affected by a certain actuator. Inside the pillow's subtle effect, the user can find the existence of the partner's haptic language. This is one of the communication services using MotionMedia [7], which has been advocated by the authors for some years.

3. A prototype system

3.1. Merits of the actuation method

Considering the concept and the application mentioned above, we have developed a prototype system with an air bag driven by a piston-cylinder mechanism. The merits of this prototype include:

- This is a very simple mechanism which can precisely control the air pressure inside the air bag. No bulky air compressor is needed.
- An air bag, in direct contact with human skin, is low noise, safe, lightweight and inexpensive. This is because it is possible to distantly separate the noisy piston-cylinder mechanism and the air bag by using just a long air tube.
- It is easy to make any form of a vinyl air bag with a laminate molding method, enabling customizing the shape for many purposes.

These three merits are available only for our method, not for the method of a built-in actuator.

3.2. Design concept

We have implemented the prototype by means of steps as follows:

- Air bag
  By testing the size and compliance of many commercially available pillows, we have determined the appropriate form and size of the air bag. For a material that will be in contact with the skin, considering the simplicity of customization and cost, vinyl was chosen.
- Piston and cylinder
  By using the above mentioned air bag and several pairs of a piston-cylinder, we have manually examined the sensitivity and sensation for users. Thus an appropriate volume of a cylinder and the required speed of a piston were determined.
- Actuator and transmission
  Taking into account the compactness of the control box involving the actuator and transmission, to satisfy the required speed and stroke of the piston, an appropriate pair for a DC motor and a transmission system (a ball bearing, a belt and a pulley) has been selected.

The final prototype system and its block diagram are shown in Fig. 2 and 3.

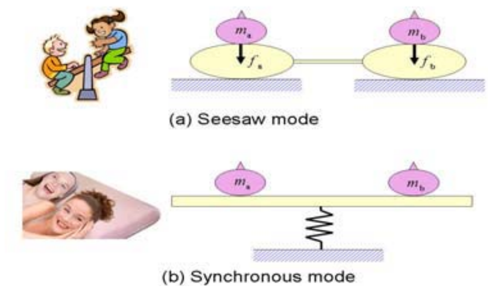

Fig. 5 Intuitive image of the two control modes

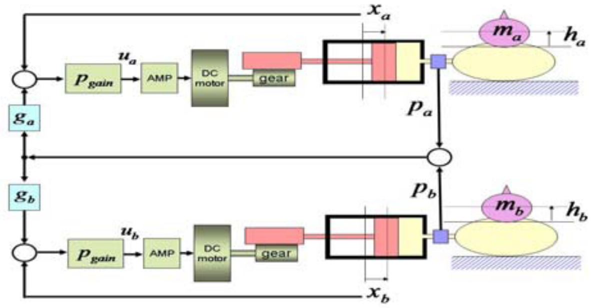

Fig. 6 Bilateral touch sense communication control

4. Dynamic modeling of the prototype system

Strictly speaking, the behavior of this air bag should be treated as a nonlinear and distributed parameter system. In this paper, however, we adopt a very simple linearly approximated model shown in Fig. 4, because high speed and accurate control will not be important for our application. The validity of this drastic approximation must be quantitatively evaluated via simulation and experimental tests.

5. Control system design

In this section, we discuss how to mutually transmit the sense of touch via internet. There are many studies about teleoperation or master-slave robot technique via internet. Their final purpose is to precisely and rapidly control the slave's position following the master operation. Therefore they are mainly focusing the control technology to ensure the robust stability and the tracking ability under an uncertain time delay due to the IP network traffic condition. In this study, however, our aim is to establish the control scheme to appropriately and mutually transmit the sense of touch for the human head. That is, the machine control is an essential mean but not our final goal. Namely our basic problem is how we can capture the human's sense and transmit it via internet and output it by means of the air bag motion. Hence we face the following problems:

(1) What is a control system structure to ensure stability under an uncertain time delay?
(2) How can we transmit head motion?

For question (1), here we propose a basic control structure such that each air pressure is exchanged via internet, while the local systems are closed by the piston position feedback to ensure the local stability regardless of the uncertainty of the internet bandwidth.
For question (2), here we propose two control modes for sense of touch transmission as follows:

5.1. Seesaw mode

In the beginning of this study, for air-pillow communication, we had a very primitive but intuitive idea inspired by the well-known *string telephone*. Namely we thought that exchanging each air pressure directly through an air pipe was the simplest and most primitive. (Fig. 5(a)) The seesaw mode is realized by substituting this passive air pipe with the active piston-cylinder mechanism and internet. Based on this primitive idea, and by using the conventional force-feedback type master-slave control technique, we design the control system shown in Fig. 6, where;

p_{gain} :a proportional feedback gain for piston position control loop,

g_a, g_b :bilateral proportional feedback gain for air pressure.

In this seesaw control mode, the control law is as follows:

$$u_a = p_{gain}\{g_a(p_a - p_b) - x_a\},\ g_a < 0, u_b = p_{gain}\{g_b(p_a - p_b) - x_b\},\ g_b > 0$$

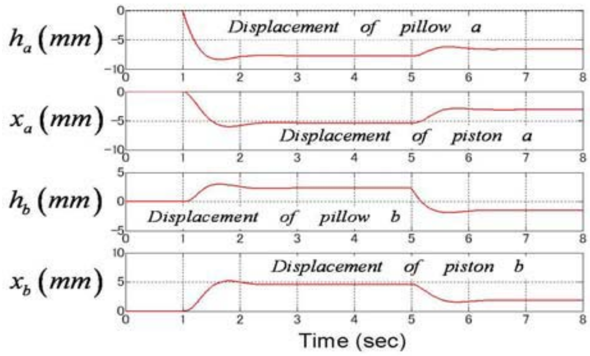

Fig.7 Simulation results (Seesaw mode)

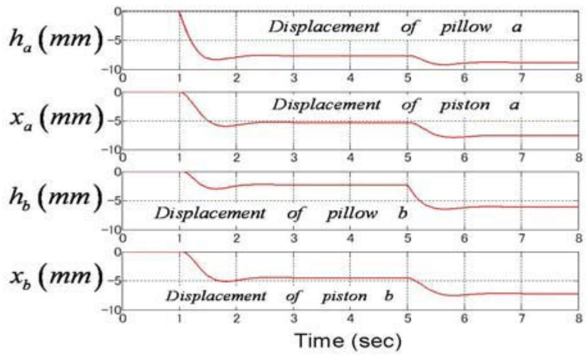

Fig.8 Simulation results (Synchronous mode)

5.2. Synchronous mode

The synchronous mode is the inverse phase of the seesaw mode motion. Synchronous is a mode where two people can share the sensation as if together they were using a big pillow as shown in Fig. 5(b).
In this synchronous mode, the control law is as follows:

$$u_a = p_{gain}\{g_a\,(p_a + p_b) - x_a\},\ g_a < 0,\ u_b = p_{gain}\{g_b\,(p_a + p_b) - x_b\},\ g_b < 0$$

Fig. 7 and 8 show simulation results when the weight of two user's head are suddenly changed under the condition of uncertain time delay over TCP/IP. And very recently we have got the similar successful experimental results. From these results, we could confirm the validity of the Air-pillow telephone hardware design and the proposed control scheme.

6. Conclusion

In this paper we describe preliminary work for the Air-pillow telephone, concentrating its mechatronics issue. In the near future we will experimentally evaluate how users can feel the sense of touch and presence of the partner. And also we will study about the haptic language as well as medical and health application. This work was partially supported by KAKENHI (19860064).

7. References

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