Whole-body tactile sensing technique using force sensors fixed at supporting points

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***Abstract*— This study reports the development of a force-sensing device for converting a cover for robots or electrical appliances into an interface by mounting the device on the supports or legs of these objects. The device is composed of a force sensor with a clamp. A demonstration using a desk shows that ready-made products can be easily turned into a tactile interface by simply fixing the device on the leg or supporting points. The contact force and its position on a regular desk can be estimated from the response of four force sensors fixed on the legs. Application programs using this interface are introduced.**

I. INTRODUCTION

This study deals with a technology for converting a cover for robots or electrical appliances into an interface by installing force sensors on their legs. Many studies have focused on the principles of identifying tactile sensing information using force sensors. Tactile sensing information, in the context of this study, refers to the locations of force application points and their vectors. Bicchi indicated that this concept can be extended to elastic body links [1]. Iwata *et al.* developed a whole-body sensing interface by applying the concept to human-assisting robots [2]. The interface offers the advantage of accurately detecting the sum of external forces acting on the link, but it could still be improved by reducing wiring and sensors, since additional touch sensors are used to determine the contact surfaces [3]. The author developed a whole-body-type tactile sensor, haptic armor, and demonstrated that sensors and wiring are not required for obtaining tactile information, even when the external shell shapes were discontinuous [4]. This concept was extended to a non-convex shape [5] and soft material [6]. The technique was also extended to force-based gesture input for robots [7]. In addition to being applied as a cover for a robot, it was also applied as a desk equipped with force sensors, the haptic desk [8], [9]. FuwaFuwa [10] is an interface with similar effects, but it has a restriction that the interface material must be pliable. This paper summarizes the studies in [3]–[9] and demonstrates the potential of force sensors for use as a device for a tactile interface with robots or electrical appliances. The greatest advantage of the method is that sensor devices do not have to be located around the surface.

II. CONFIGURATION OF DEVELOPED SYSTEM

A. Mechanism

This device is composed of four force sensors and a PC to process the sensing information. The structure of the device is such that it can be fitted on the supports or legs of desks. The application of the haptic armor concept [8] makes it possible to detect external force application points even if no tactile sensors are installed on the surface skin of objects. In the mechanism developed in this research, force sensors are installed on the supports of objects subject to conversion into interfaces. A mechanism with a fixture attached to a force sensor was developed. The setup is shown in Fig. 1. The end effector of the force sensor was secured to a leg using a clamp mechanism tightened by rotating the grip. A six-axis force sensor (CFS034CA301U, Leptrino) was used as the force sensor. These sensors could be replaced by three-axis force sensors, since six-axis force/torque information can be integrated from multiple three-axis force sensors.

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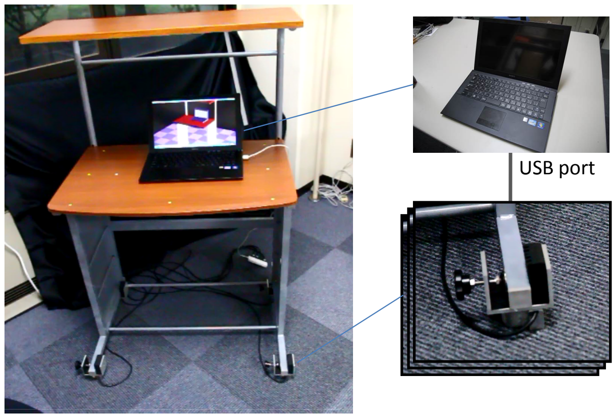

Fig. 1. Force-sensing device with mounting mechanism

B. System Configuration

The right side of the Fig. 1 shows the system configuration. The objects that were converted into interfaces were not included in the basic configuration, since this research was an attempt to convert a regular desk into an interface. This system comprised force sensors installed on the legs of objects as well as a USB hub and a laptop PC. The concept in this paper can be applied so long as the force and the resultant force of moments of the six axes can be derived, even if the number of sensors is decreased. The information from the force sensors is sent to the laptop PC, and the external forces as well as their application points are identified by a software process running on the PC. The objects can be used as interfaces for the PC by sending the information to the mouse driver or software.

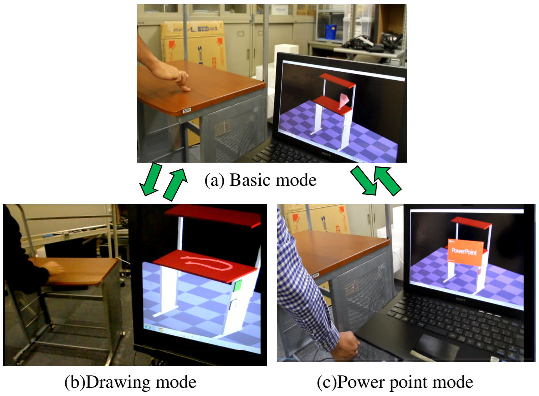

Fig. 2. Three modes switched by virtual button

C. Entry of Geometrical Shapes of Interfaces

The basic principle of contact location calculation is shown in [3]. In addition to the response values obtained from the force sensors, the geometrical shape of the object should be known. Inputting the geometrical shape is generally a tedious task. However, if only objects with simple shapes, such as a desk, are considered, and if a model is prepared in advance, the geometrical shape can be input by simply entering the dimensions. Hence, in this study, a simple rectangular desk was selected as the object, and its model was input into the program in advance. A variety of desks can be considered simply by entering three parameters: the length, width, and height.

D. Haptic Desk Application Program

As shown in Fig. 2, the haptic desk application program has three modes: (a) basic mode, (b) drawing mode, and (c) PowerPoint mode. Additionally, object recognition based on loads can be performed regardless of the currently executed mode. (a) The basic mode displays the contact points and external force vectors. (b) The drawing mode allows the continuous drawing of contact points and the retention of these drawing strokes. The thickness of the drawing strokes can be controlled according to the sizes of the external force vectors. (c) In the PowerPoint mode, PowerPoint is manipulated by pressing virtual switches. Six operations are set with separate switches.The switches on the top board and the side frame were located within a square domain with sides of 0.1 m.

E. Setting of virtual switches

The equilibrium of moment for an acting external force is expressed by (1).

$$F^e \times (P^e - P^o) + \sum_{i=1}^{n} (F_i^s \times (P_i^s - P^o)) = 0 \qquad (1)$$

where P^e is the point of application, P^o is the position of the reference coordinates, and P_i^s is the position of the th sensor, as determined from the reference coordinates. P^o and P_i^s are known values that are structurally determined, whereas F_i^s can be measured by using a force sensor.

The feature to detect the position of a contact point is utilized to establish virtual switches on the desk. Suppose switches are set on the lth surface of the desk, positions for setting switches are determined by (2).

$$f_l(P_j^{switch}) = 0 \qquad (2)$$

where P_j^{switch} is the central position of the jth switch. The domain of the switches is set by referring to the central position of the switches. The switch state numbers of the switches, indicated by (3), vary based on the positional information of contact points and on the force information acquired from force sensors.

$$S_j = g(P^e, F^e, t) \qquad (3)$$

Simple switches operate by the contact point P^e and external force F^e, changing the value of the switch state number S.

III. Conclusion

This paper described the development of a force-sensing device for converting a desk into an interface by mounting the device on the supports or legs of the desk. A variety of shapes must be acceptable to the program if the device is to be mounted on regular desks. If a geometric model of the desk is given in advance, the external forces and their application points can be identified by simply entering their dimensions. Application programs using the properties of the proposed interface were developed. The activated programs are selected by virtual buttons created on the regular desk. This kind of technique to simplified sensing mechanism is a good candidate for robots, which has strong needs for simplified sensing mechanism.

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