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A Finger-wrapping Pin-array Tactile Display for Realistic Finger Interaction in VR

Yusuke Ujitoko[1,2], Haruto Kurosawa[2], and Koichi Hirota[2]

I. Introduction

Humans obtain tactile information of objects when their skin comes into contact with the objects in daily life. When touching objects, mechanoreceptors in the skin detect and process sensory inputs such as pressure [1]. Since mechanoreceptors are distributed throughout the skin, tactile information can be obtained no matter which area of the skin makes contact with objects. This tactile information is transmitted to the brain, enabling humans to quickly and accurately perceive object properties such as texture, shape, or size [2]. The ability to recognize object properties through touch is essential for humans to understand and interact with the environment.

In recent years, Virtual Reality (VR) technologies have rapidly advanced, increasing demand for realistic touch interactions with virtual objects. However, current VR systems still face significant limitations regarding the quality of tactile feedback, making it challenging to deliver natural and detailed tactile information comparable to real-world interactions. For instance, shape recognition accuracy using conventional tactile displays in virtual environments is not typically high [3], [4], often requiring approximately one minute of exploration to recognition. This contrasts with real-world scenarios, where humans usually identify an object's shape within just a few seconds [5].

One critical limitation of existing tactile display technologies, despite advancements in higher-density arrays and faster response times [6], is that they mainly stimulate only the ventral surfaces of fingers and hands [7], [8]. Since humans naturally acquire tactile information from the entire finger surface, including the sides and dorsal surfaces, the partial stimulation to limited skin area likely restricts the accurate recognition of virtual objects in VR environments.

To address this limitation, we have developed a pin-array tactile display capable of stimulating the entire finger surface. This device incorporates a high-density pin array that wraps around the entire finger, enabling high-resolution and extensive tactile stimulation. In this work-in-progress paper, we report the characteristics of the developed tactile display. In future research, we plan to use this display to realize tactile experiences previously unattainable with existing devices and to further explore mechanisms of human tactile perception.

[1]NTT Communication Science Laboratories, 3-1 Morinosato-Wakamiya, Atsugi-shi, Kanagawa-ken 243-0198, Japan. e-mail:yusuke.ujitoko@gmail.com

[2]Graduate School of Information Systems, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan.

II. Finger-wrapping Pin-array Display System

The architecture of the tactile display system we developed is shown in Fig. 1(A). The system comprises a pin-array display, an air pressure controller, and a PC. The architecture and the air pressure controller are same as those used in our previous study [7]. By spatially separating the actuation mechanism and skin stimulation points, the flexibility in the spatial arrangement of stimulation points on the skin is improved in this architecture. Consequently, the display achieves high-density stimulation across the entire surface of the finger's skin, which was not possible with previous displays.

Fig. 1(B) shows the 3D model and the actual display. This display is designed for users to insert their index fingers. The base of the display, where the user's finger is inserted, is made of 3D-printed ABS resin. The display covers the finger up to a distance of 45 mm from the fingertip. Holes with a diameter of 1 mm are made in the ABS resin, and pins that push the skin in the normal direction are inserted into these holes. Compressed air pushes the pins, which then press against the skin. The number of stimulation points is 337, with a density of 0.13 points/mm².

One design consideration was to ensure the device fits various finger sizes. Existing displays typically cover only part of the skin surface, allowing the display's surface shape to match the user's skin shape easily. However, for a display designed as a closed surface, it is required to carefully consider how to accommodate a difference in finger sizes. Individuals with large fingers may not fit their fingers into the display. To accommodate a wider range of finger sizes, we divided the device into three parts, adjustable via screws to fit the user's finger size. This approach helps accommodate larger fingers.

Another design consideration was the layout of stimulation points on surfaces. Conventional displays typically use a grid or checkerboard pattern to arrange stimulation points, evenly spacing them to minimize spatial gaps. However, when placing stimulation points on a closed surface with a complex shape, such grid or checkerboard patterns are impossible to adopt. In this study, we adopted poisson disk sampling [9] to arrange points with a minimum distance of 2 mm between pins, achieving near-uniform spacing.

Additionally, the display used a magnetic sensor (POLHEMUS 3SPACE FASTRACK). This magnetic sensor is used to obtain fingertip position and orientation information. This information is utilized to reflect the finger's position and orientation in VR, enabling active touch interactions with

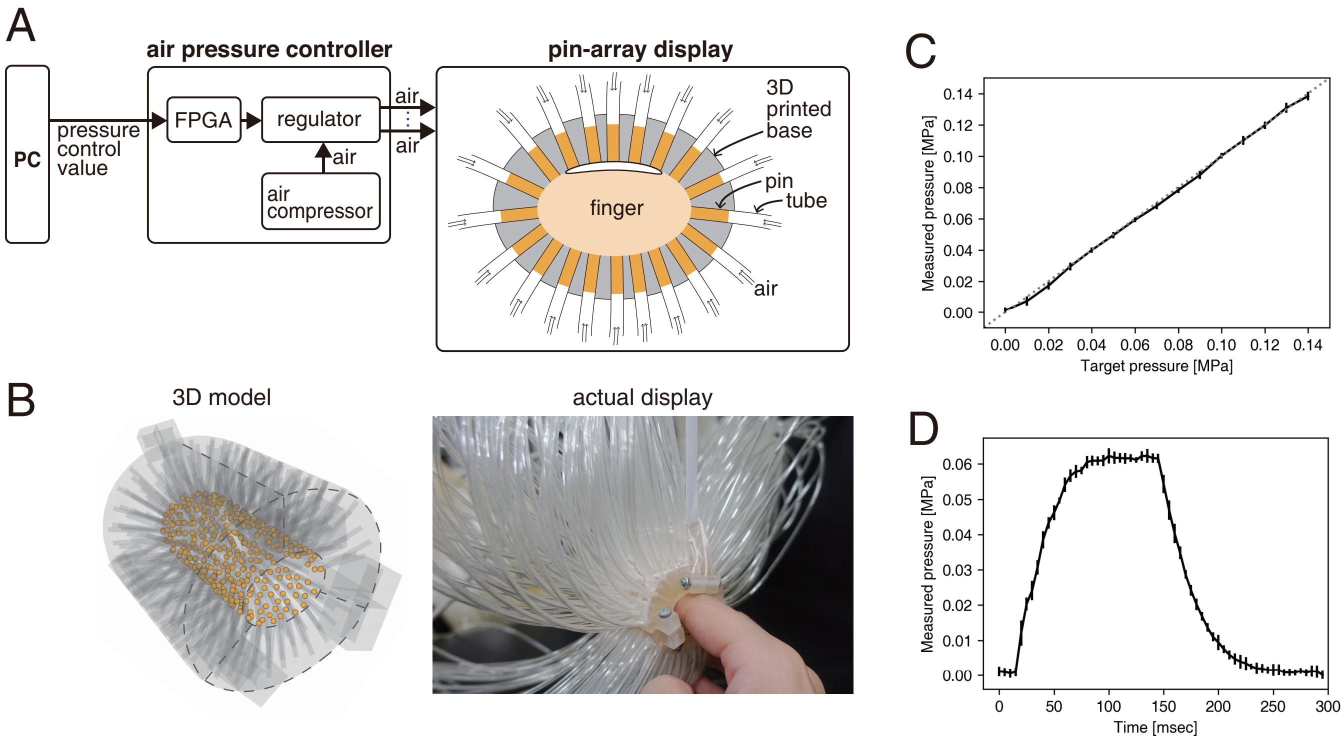

Fig. 1. Finger-wrapping pin-array display system. (A) Components of experimental system and data flow. (B) 3D model and actual device. The device is composed of three parts. (C) Target and Measured pressure after calibration. (D) Time and measured pressure when the target pressure was 0.08 MPa. Error bars denote standard deviation.

virtual objects.

III. Measurement of Pneumatic Control

To evaluate the performance of pneumatic control using the constructed display, a pressure sensor (PSE54, SMC) was mounted in a designated hole, and pressure was measured. After calibrating the system by measuring the voltage–pressure relationship, we applied voltages corresponding to target pressure values and recorded the resulting pressures. The results are shown in Fig. 1(C), where the mean ($\pm$ SD) of ten measurements is plotted for each target pressure.

A linear regression analysis was conducted between the target pressure and the measured pressure. The resulting slope was close to one (1.004), and the intercept was near zero (-0.001). The coefficient of determination (R^2) was 0.998. These results indicate that the measured pressure closely followed the intended target pressure over the entire range, confirming the accuracy of the pressure control system.

We also measured the rise time of the system. Fig. 1(D) shows the temporal profile of the pressure when the target pressure was set to 0.08 MPa. The time required to reach 90% of the target pressure was 65 milliseconds.

IV. Conclusion

we developed a pin-array tactile display capable of stimulating the entire finger surface. In future research, we plan to realize tactile experiences previously unattainable with existing devices and to further explore mechanisms of human tactile perception.

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