Development of a Pen-Type Device for SPIDAR-Tablet that Presents Force and Thermal Sensations

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Abstract. The quality of education can be improved by combining information and communication technology (ICT) education using personal computers (PCs) and tablets, which have gained considerable popularity over the last few years with virtual reality (VR) technology. Many students have difficulty in comprehending various physical and mathematical phenomena intuitively even if they can be expressed in mathematical formulae. Sensitization (visualization, auralization, and tactileization) could help enhance the understanding of these phenomena. In this study, to increase the understanding of thermodynamic phenomena via force and thermal sensations, we used a tablet-type thermodynamics learning support system. In a previous study, a piston was displayed in a VR space on a tablet, and the pressure changes were presented as force sensation using a force feedback device and a SPIDAR-tablet. Using a pen-type thermal feedback device, the temperature changes were presented as thermal sensation; however, the current SPIDAR-tablet presents two issues: i) the force control unit and thermal control unit are separated during the development stage, and ii) the presented force is weak because the motor power is small; therefore, it is difficult to feel force changes. In this study, to solve these limitations, we first integrated the force and temperature control circuit, and then enhanced the presented force by changing the motor and fabricating a new frame. Then, we assessed and confirmed the improvement of the force that was presented.

Keywords: VR learning system · Force feedback · Thermal feedback

1 Introduction

Online connection and use of information and communication technology (ICT) devices such as personal computers (PCs) and tablets are currently used in education to enhance its quality [1]. Building an environment where people can learn independently, effectively, and without losing interest would promote the use of ICT in education [2].

The use of learning support systems based on VR technology is expected to help in devising effective learning programs. Such systems should allow learners to proactively participate [3].

C. Stephanidis et al. (Eds.): HCII 2021, LNCS 13095, pp. 96–105, 2021.
https://doi.org/10.1007/978-3-030-90963-5_8

In this study, we focus on haptic presentation in learning with tablet devices. Using tablets, which are extensively used in education, and extending the VR function with haptic presentation devices, we expect to reduce the cost of introducing a VR learning environment. In our previous study, we developed a device that can present force sensation for use in tablet operations [4]. Furthermore, the pen-type thermal sensation presentation device was added to the SPIDAR-tablet, and the force and thermal sensations were simultaneously presented to the tablet [5]. The issues that require to be addressed are the weakness of the presented force and circuit integration [5]. In this study, we fabricated the circuit board and frame for a new SPIDAR-tablet to improve the force sensation and integrate the force and thermal sensation circuits. Then, we conducted a quantitative evaluation of the force.

2 Previous Research

2.1 SPIDAR-Tablet

SPIDAR-tablet is a device that presents a force sense to the touch panel of a tablet. The string tension is controlled by motors attached to four corners of the frame, and a ring connected to the string can be attached to the finger to present the force sensation. Figure 1 shows the SPIDAR-tablet for iPad Pro [5].

This SPIDAR-tablet has a small circuit board and uses small motors; therefore, the frame is extremely compact and portable. However, the output is small and cannot present sufficient force sensation.

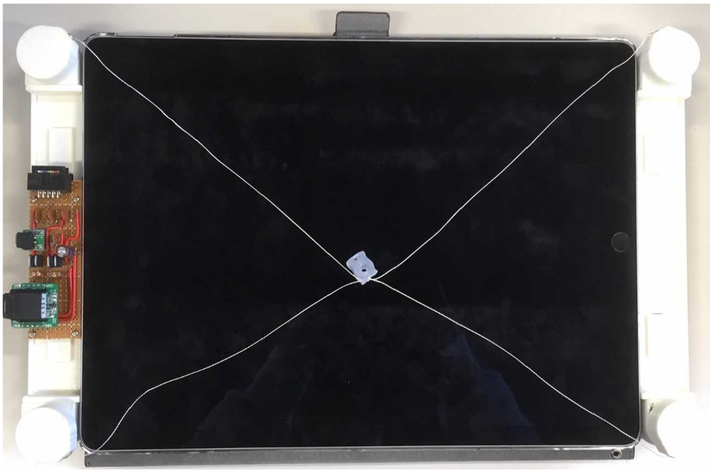

Fig. 1. SPIDAR-tablet for iPad [5]

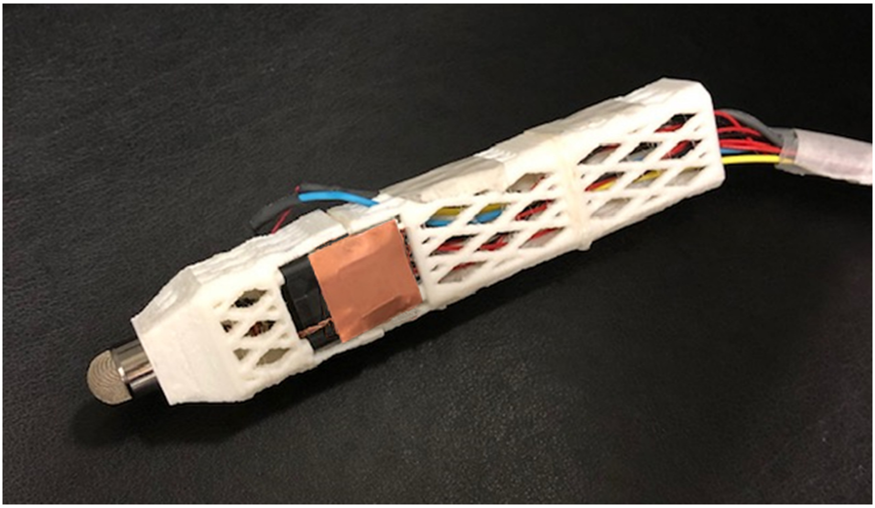

Fig. 2. Pen-type thermal sensation presentation device [5]

2.2 Pen-type Thermal Sensation Presentation Device

The pen-type thermal sensation presentation device shown in Fig. 2 adds thermal sensation to the user's fingertip. This device has a heat sink and fan in a frame produced using a 3D printer, a Peltier device, and a Cu plate to enable thermal sensation to the fingertip [5].

As shown in Fig. 3, by attaching SPIDAR-tablet strings to the pen tip, it can be used to present force and thermal sensations simultaneously. However, the limitation is that both force and thermal sensation control circuits are separated, and the wiring is complicated.

2.3 Thermodynamic Learning Support Application

We developed an application to assist students in learning thermodynamics using this device [5]. The virtual space was developed using Unity [6]. Figure 4 shows an example of the developed virtual space.

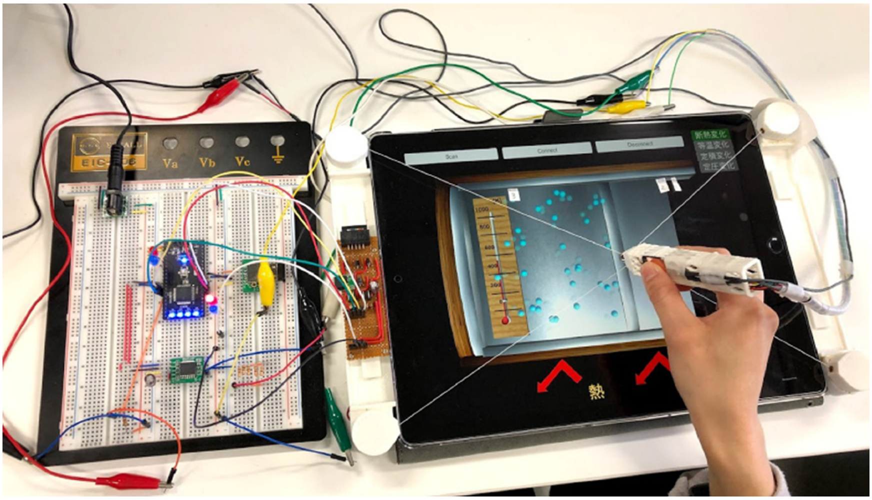

Fig.3. Combined use of pen-type thermal presentation device and SPIDAR-tablet [5]

For this application, the device shows the gas pressure and temperature in the cylinder as force and thermal sensation, respectively, and visually shows the movement and temperature change of the particles. After selecting one of the four thermodynamic state changes in the tablet menu, i.e. adiabatic, constant pressure, constant volume, and isothermal changes, when the learner moves the piston via tablet, the particle velocity and the indicated thermometer value changes.

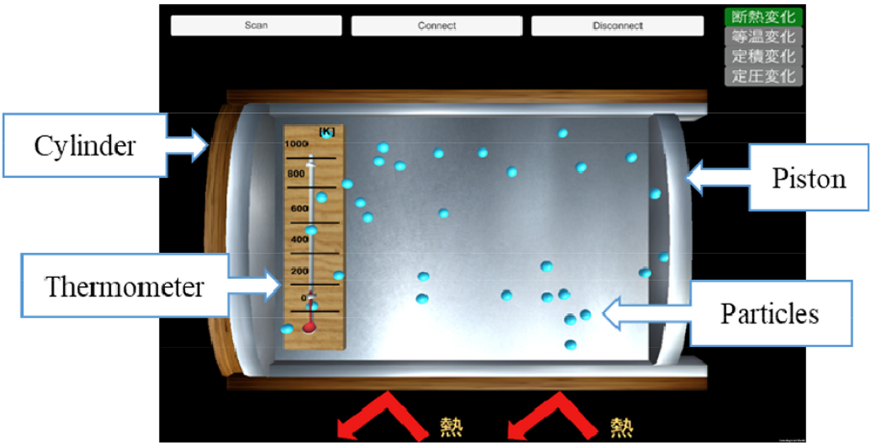

Fig. 4. Virtual space

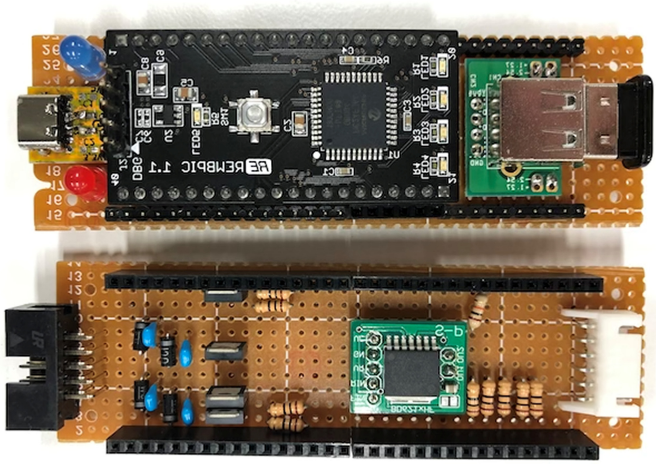

Fig. 5. Circuit boards that integrates force and thermal sense presentation

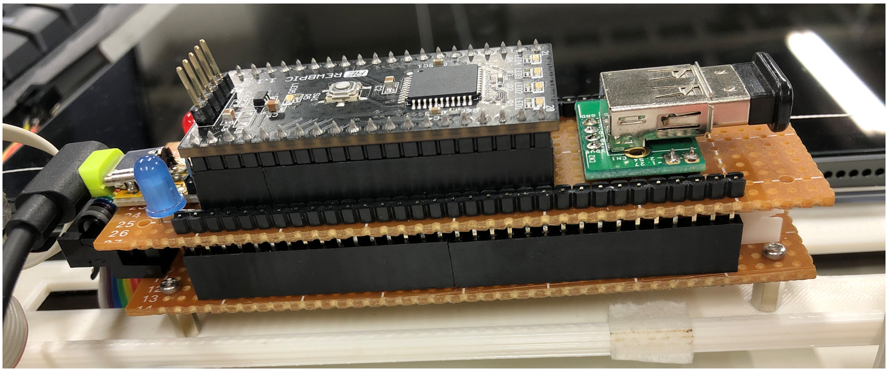

Fig. 6. Combined the integrate circuit

3 Device Fabrication

3.1 Integrated Circuit

Figure 3 shows the integrated circuit of force and thermal control was fabricated. The PIC board used was a REWBPIC (Running Electronics LLC.) with PIC24FJ64GB004 (Microchip Technology Inc.). Figure 5 shows the integrated circuit board. As shown in Fig. 6, the circuit board was divided into two parts and configured in two stages. While installing the circuit board on the one side of the frame, we made it compact using a two-stage configuration just as we did with the conventional frame shown in Fig. 1. The connection between the circuit board and the pen is shown in Fig. 7. The pen is connected with a connector so that it can be removed when not in use.

3.2 System Configuration

Figure 8 shows the configuration of the force and thermal presentation system. First, the force and temperature values are calculated from the tablet via simulations. Then, these values are sent to the central processing unit (CPU) using Bluetooth Low Energy communication. In terms of the force sense, the CPU generates pulse-width modulation (PWM) signals, with the duty cycle corresponding to the received values and feed them to the motor drivers to control the torques of the motors. This allows to control string tension and demonstrates a force sense to the user. As for thermal senses, the CPU compares the target temperature with the temperature of the Peltier device and determines the PWM duty cycle using PID control. Consequently, the heat transfer of the Peltier element can be controlled and the user can get a thermal sensation.

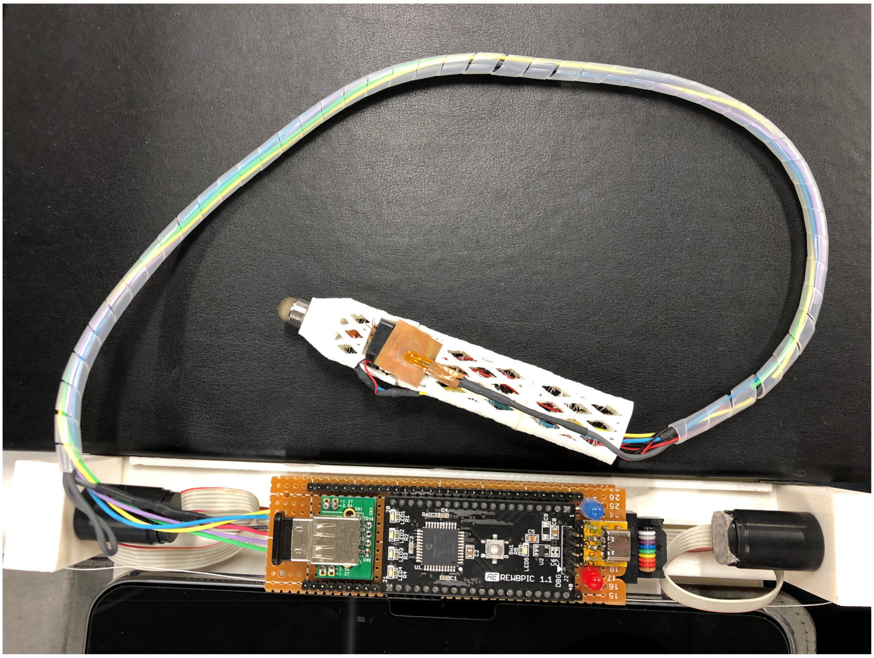

Fig. 7. The integrate circuit with the pen-type thermal presentation device

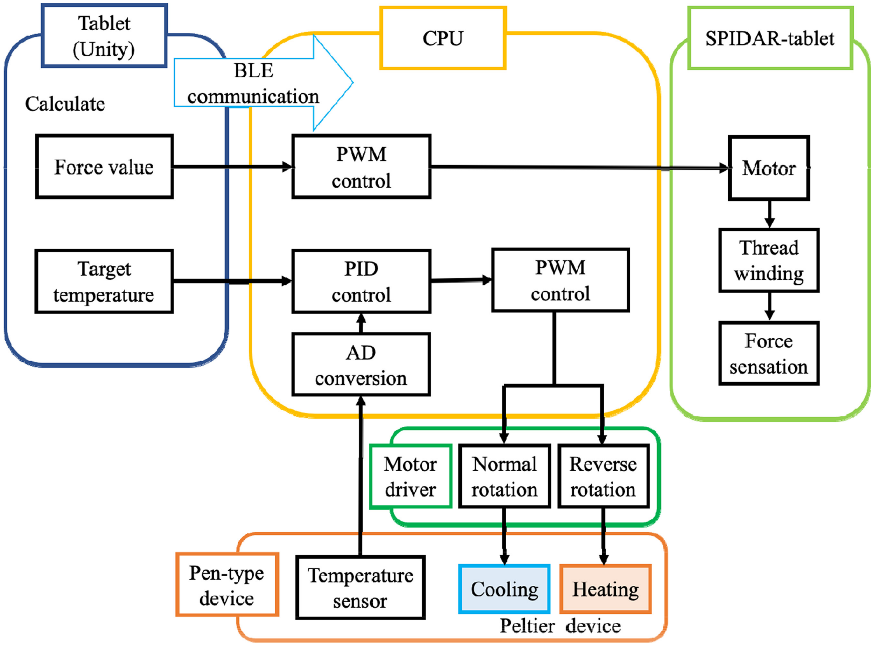

Fig. 8. The system configuration diagram

3.3 New Frame of SPIDAR-Tablet

Because of the motor performance, the magnitude of the force of conventional SPIDAR-tablet was weak, making it slightly difficult for the user to clearly perceive the force sensation changes. Therefore, we circumvented this limitation by changing the motor with a higher performance one.

In this study, the frame of the SPIDAR-tablet fabricated is described. Figure 9 shows the overall view of the newly fabricated force-enhanced frame. We designed the frame by adjusting its height, width, and the outlet height of the string from the pulley cover because the motor is larger than that used in the conventional frame.

First, for the conventional SPIDAR-tablet frame, the DC motor RF-300FA-12350 (Mabuchi Motor Co., Ltd.) was used; however, as mentioned above, because the force that can be presented is less, we used the DC motor 1724T006SR (FAULHABER Co., Ltd.). Table 1 lists a comparison of DC motor specifications.

Table 1. DC motor specifications

	RF-300FA-12350	1724T006SR
Rated voltage [V]	3	6
Rated torque [mNm]	0.48	4.2
Stop torque [mNm]	2.51	11.5
Weight [g]	22	27

Next, we described the change of the motor mounting method. For the conventional frame, the motor is vertically mounted to the tablet. For the new frame, the motor was horizontally mounted to the tablet, as shown in Fig. 10. The reason is that the outlet position of the string is considered. Because of the large axial length of the motor, if it is vertically installed as in the past, the outlet position of the string will be high. Therefore, by laying motor and pulley sideways, the height of the outlet is adjusted.

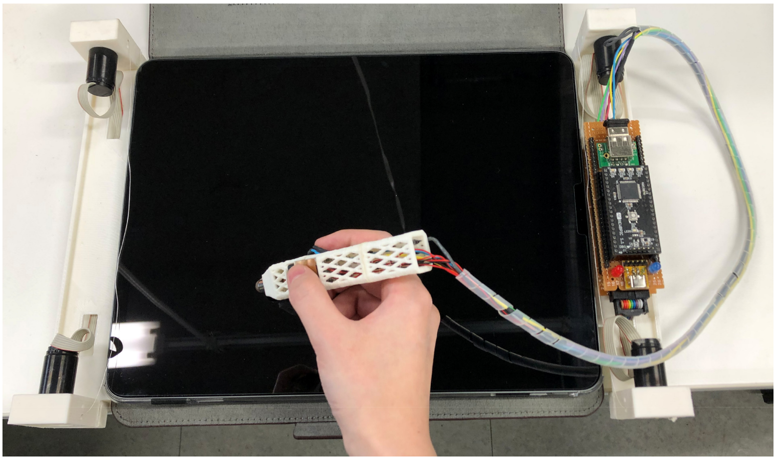

Fig. 9. The overall view of the force-enhanced frame

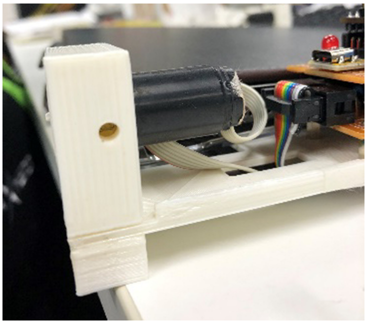

Fig. 10. A part of frame with motor installed

4 Evaluation Experiment

In this experiment, we evaluated the improvement of the magnitude of the presented force sensation, which has been a previously problem, by comparing the change in the string tension against the duty cycle of PWM control between conventional and new frame.

4.1 Experimental Method

In this experiment, we compared the string tension in the conventional frame and the new frame of the SPIDAR-tablet. The duty cycle of the PWM control was varied between 0% and 100%, and the string tension was measured at each point. The horizontal force was then measured against the string outlet of one motor.

4.2 Experimental Results and Discussions

Figure 11 shows that, for both conventional and new frames, the tension was linearly proportional to the duty cycle. Furthermore, the maximum force of the new frame was twice as large as that of the conventional frame. This indicates that we have achieved our aim of improving the force perception.

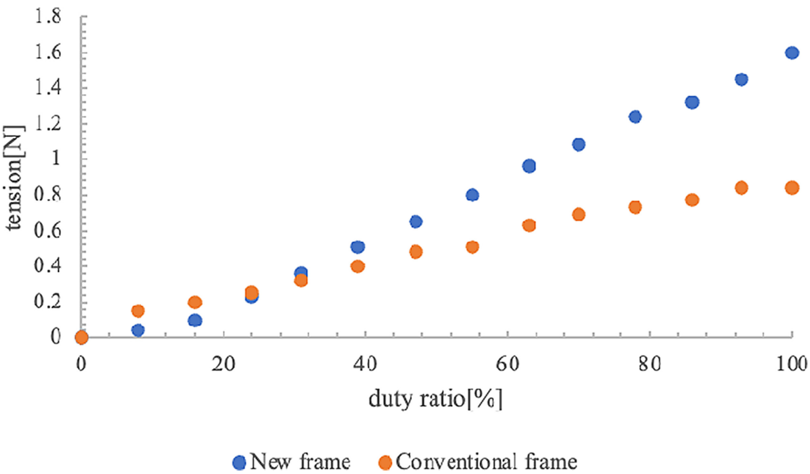

Fig. 11. The results of the string tension in the conventional and new frames of the SPIDAR-tablet

5 Conclusions and Future Prospect

In this study, we first integrated the circuits in a SIPDAR tablet and pen-type thermal presentation device. Consequently, we reduced the complexity of the connection between the SPIDAR-tablet and pen-type thermal presentation device and made the structure compact. Next, we replaced the motor of the SPIDAR-tablet and we designed a new frame to enhance the presentation force. By quantitatively evaluating the string tension in both old and new devices, we improved the presenting force.

As a future prospect, it is necessary to conduct the same experiment using the new device and evaluate performance as the previous study demonstrated that it was difficult to feel the force when the force and temperature were simultaneously presented [5]. Moreover, we will try to improve the thermal sensation presentation by enhancing the device structure and temperature control system. In addition, we aim to apply the system to the contents in wide areas using visual, force, and thermal sensation presentation as well as thermodynamics.

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