2022 年度　永守財団　研究助成　研究報告書

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1．研究題目

Development of Haptic Thermal Perception Device for VR Controller using Flexible Thermoelectric Material
(柔軟な熱電材料を用いた VR コントローラ用触覚熱知覚デバイスの開発)

2．研究目的

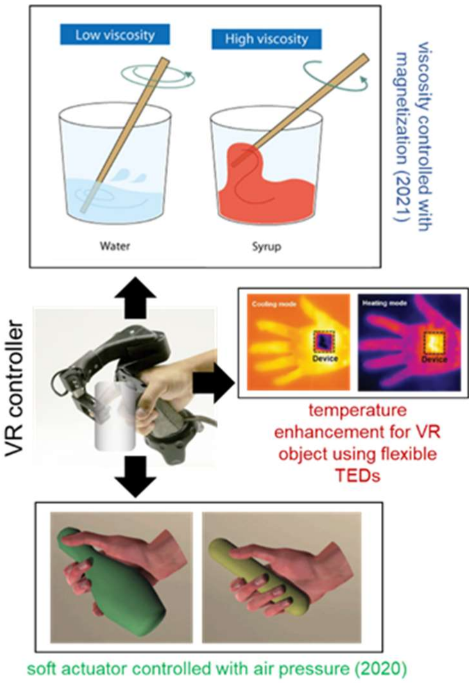

Figure 1 Proposed VR controller that can simulate the different haptic thermal properties for VR object (red) in addition to shape (green) and viscosity properties (blue).

This research proposal aims for development of a handheld and lightweight virtual reality (VR) controller consists of robotic soft actuator (presented previously in FY2020), electromagnet (presented previously in FY2021), and programmable perceived temperature using thermoelectric devices (TEDs). Continue from the previous research proposals proposed in the Nagamori FY2020/2021, this research project is aims to add an additional haptic perception to VR/AR users by integrating the temperature illusion of touching object together with the shape and viscosity perception. By integrating the knowledge in human perception and materials manipulation, create the computational model that take the relationship between TEDs and perceived temperature. This method could allow the user (VR player) to perceive various haptic stimulation not only to the shape and viscosity properties of the touched complex objects, but also the apparent temperature of such virtual objects. As shown in Figure 1, this proposal will contribute on the previous works (Nagamori FY2020/FY2021) by carrying the VR controller with shape, texture and its elastic properties, and adding the temperature perception with TEDs. Therefore, by the end of the research period, this system could fulfill the VR experience not only for entertainment but also the educational and training aspect. To summarize, this proposal will contribute to the following area: 1) a novel controller to enhance both perceived shape, textures, viscosity and temperature of the target virtual objects, 2) a computational model that considering the relationship between temperature rendering and apparent temperature through the visualization and tactile perception.

3. 研究内容及び成果

The goal of this research is to provide the sense of temperature integrated with viscosity perception and sense of soft interaction. Our team developed the following prototype and conducted experiments to verify the usability and the system limitation.

1. Fabrication of thermal display on VR controller

We develop a prototype of the thermal display using flexible TEDs embedded directly with user fingers, and therefore, it is possible to attach with the VR controller. We mold the flexible silicone to mounted the flexible piezoelectric and electrical sensitive materials together as the form of the device. The materials connect to an electric wire to transmit its voltage output. The prototype is shown in Figure 2.

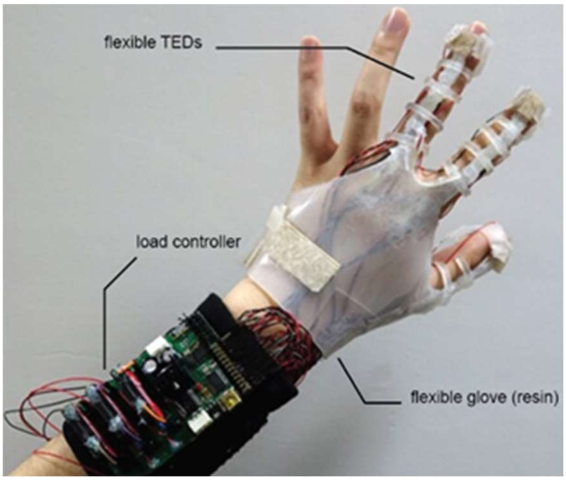

Figure 2 Prototype of Flexible TEDs

2. Parameterize the voltage input and optimize the thermal output

We conducted the experiment to measure the flexural durability of the TEDs and make sure that the emit temperature is stable. Therefore, we utilized the thermal camera to detect the apparent thermal through the device. The experiment reaches by adding the voltage to the TEDs between 5V (i.e., minimum voltage input requirement) to 15V (i.e., maximum voltage requirement). For each time, the thermal measurement stops when the temperature is stable around 1 minute. As shown in Figure 3, we found that the device can express the temperature around 15C to 35C with the stable temperature around 33C (Figure 3E) at the voltage of 15V, the similar behavior has been observed with the input voltage of 10V but it required additional time to TEDs reach the stable temperature stage. The accumulation time that is required for stable temperature is around 20 to 30 seconds.

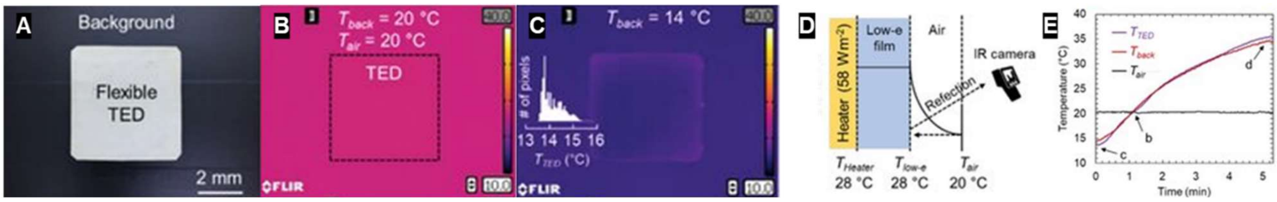

Figure 3 The parameterization experiment: (A, D) flexible TED attached on the black background and the setup with thermal (IR) camera, (B) the TEDs at average environment temperature (20C), (C), the lowest temperature measured by thermal camera, and (E) the experimental results when input 15V voltage to reach stable stage.

We conducted another experiment to optimize the accumulation speed by attaching a small phase change material (PCM) and conductive surface between flexible TEDs. Since the PCM could gain the temperature faster than TEDs, we accelerate the temperature perceived by users using PCM. Once the TEDs reach the optimal stage, we then release the PCM operation (Figure 4(Left)). As shown in Figure 4(Right), the PCM layer absorbed or released heat to maintain a comfort skin, and to manipulate the acceleration of temperature depends on the target application. While the PCM itself is

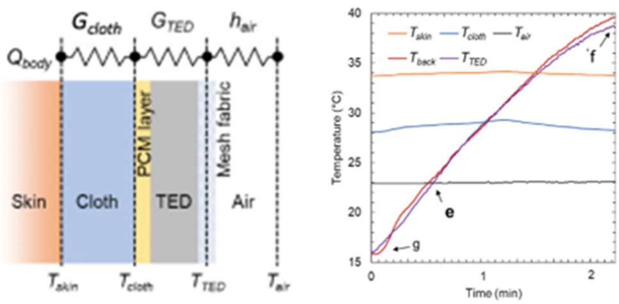

Figure 4 The schematics of TEDs embedded with conductive surface and phase change material (Left), and the experimental results (Right).

difficult to control the stable temperature (i.e., the heat can accumulate over time), it is possible to increase the temperature change process of flexible TEDs. Our experimental results found that the temperature reach to 39C takes around 2 seconds, which means that by providing 3V voltage, it is possible to provide the immediate temperature around 30C to the users, while wait for the flexible TEDs to maintain its heating process. We then utilized this method for our future final prototype.

3. Subjective Experiments

We are conducting the experiment to understand the relationship between voltage input and the perceived thermal output with and without visual stimulus (i.e., the virtual objects provided on the HMD). To verify the quality of the thermal information, our experiment included the thermal sensitivity with virtual objects between with color information and without color information. While we cannot conclude the experimental results at the moment of this report, we owing to the advantages of our device to improve user immersion in the VR environment.

4. 今後の研究の見通し

We submitted the results of our experiments from our current system (flexible TEDs with PCM) to the Journal of Advanced Function Materials, which is currently under review by the external experts in the field. The subjective evaluation through our current systems is planned for submit as a work-in-progress paper to IEEE Haptics Symposium 2024.

As we mentioned in previous section, we cannot develop our final design that embeds the flexible TEDs with previously developed VR controller. Therefore, after we conducted the subjective experiments. We plan to integrate our device with the VR controller so that it can offer the temperature of virtual object together with other material properties (with bare hand). The main challenge is the weight and the flexibility limitation of each component. Once we can integrate all components together, we plan to conduct further experiments to verify the usability of our method in VR environments.

5. 助成研究による主な発表論文，著書名

学術論文(査読付)

1. Thammathip Piumsomboon, Youngho Lee, and Parinya Punpongsanon. Editorial: Supernatural enhancements of perception, interaction, and collaboration in mixed reality. Frontiers in Virtual Reality(Section Augmented Reality), Vol 4, No. 2023, pp. 1-3. February 2023.
2. Shengze Zhong, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. Estimation of Fused-Filament-Fabrication Structural Vibro-Acoustic Performance by Modal Impact Sound. Elsevier Computers & Graphics (Special Issues on Computer-Aided Design and Computer Graphics 2023). (In press)
3. Liyuan Lin, and Parinya Punpongsanon. Exploration of Affective Thermal Perception through Flexible TEDs. Advanced Functional Materials. (Under Review)

国内会議(査読付)

1. Zhong Shengze，プンポンサノン・パリンヤ，岩井大輔，佐藤宏介. Structure Design with Text-Guided Stylization. 第 67 回システム制御情報学会研究発表講演会，p.202-203， 2023 年 5 月.