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1．研究題目

Development of 3D Printed Soft Actuators for Haptics Display by Varying the Materials and Air Pressure
(材料と空気圧を変化させた触覚表示用 3D プリントソフトアクチュエータの開発)

2．研究目的

This proposal aims for development of a handheld and light weight **virtual reality (VR) controller** consists of **robotic soft actuators using multi-material 3D printable and programmable architectures controlled with air pressure**. By integrating the controller with the knowledge in Human Perception, create the computational model that take the relationship between air pressure and perceived texture, the controller could allow user (player) to perceive various haptic stimulations such as shape of complex objects, local deformation, and oscillation in VR. As shows in Figure 1, using proposed VR controller, user could perceived texture of local deformation surface in VR by accurately controlling the pressure and structure of a soft actuator. Once the soft actuator changed it shape, it rendered the different texture perception to the user's hand. The elastic force from the soft actuator further reinforce the force feedback for local deformation to **enhance 'seamless' perception of the objects in VR**. Such haptic perceptions could enable several applications, for example, to simulate complex organ perception for medical training, to enhance the telepresence system in which the remote participant could feel the same experience as the local users, and to integrating as the soft robotic grasping force feedback controller. To summarize, this proposal will contribute to the following area: 1) a novel VR controller to enhance the perceived surface texture of object using soft actuator, 2) a new soft actuator hardware with programmable architecture using multi-material 3D printer, and 3) a computational model that considering relationship between air pressure and texture perception.

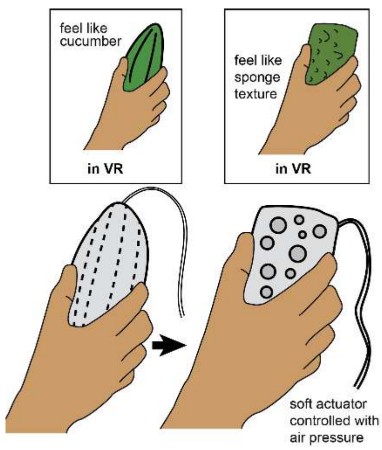

Figure 1 Proposed VR controller consists of soft actuators with programmable architectures.

3. 研究内容及び成果

<研究内容> This research seeking the VR controller that can manipulate perceived virtual objects' texture by **integrating soft actuator as the haptic display**. To adapt the soft actuator as the haptic display, I will investigate the internal structure of the soft actuation that allows for various control the shape of actuator, and to generate force feedback with the different air pressure. For example, by 3D printed the standard air tunnel that combined from **two different materials** such as Thermoplastic polyurethane (elastic material) and Polylactic acid (strength material), could allow to **adjust its shape** when different air pressure applied (Figure 2). Thus, the printed patterns and materials combination could enable different shape motion of actuator. In addition to the printed patterns, the **amount of air pressure** is indicated the haptics perception when the user interacts with actuator. Therefore, I will **conduct the perceptual experiment** that determine the amount of air pressure that change the deformation of the soft actuator in relationship with haptic rendering result.

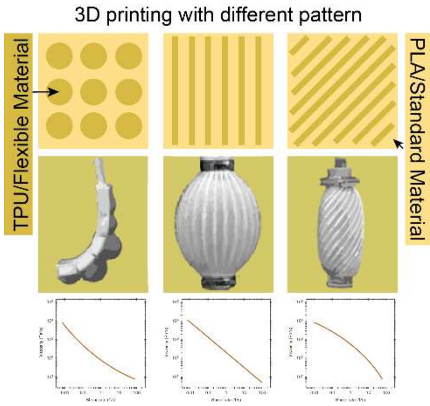

Figure 2 Illustration of 3D printed soft actuator with two materials (flexible and standard) hold the different shape characteristics depends on the printing pattern.

1. Investigating the material combination for 3D printing Soft Actuator

In the first part of this project, I have been investigated several 3D printable materials such as the Thermoplastic and Polylactic in order to fabricate a soft haptic actuator. As shown in Figure 3, the prototype system utilizing the air pressure gate to manipulate the haptic sensation and the bi-stable urethane gel to manipulate the softness when the force applying to the device. This device included the (1) coarse softness manipulation achieved by changing the temperature of a urethane gel, and (2) microstructures surface manipulation with an air based actuator. The maximum inflation of the surface is about 2.5 mm. I measured the softness characteristic of the device using type E durometer with three difference stage of urethane gel; the results shows that the measured range of softness range from 45 to 79 hardness unit (AST D2240 scale). The hardness response changed with the relationship to the time spend to heat the wax and urethane gel under the air chamber. In addition, I have found that the printed pattern of the surface also related to the expansion of the device.

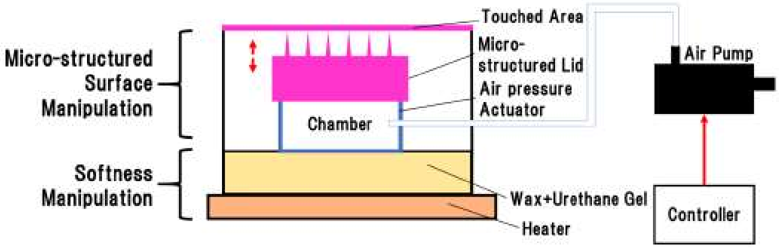

Figure 3 System diagram.

2. Modeling and simulating the deformation behavior of soft actuator

In this part of the project, I have investigated several 3D printing patterns such as dot, line and cross to create different haptic surface behavior. Combining with the bi-stable materials (e.g., wax and urethane gel), it create different characteristic when injecting with air with different pressure. As shown in Figure 4, despite the strong interfacial bonding between printed filaments, mechanical properties of the devices (i.e., soft actuators) are depends on the orientation relative to the printing direction and printing patterns. High shear stresses in the nozzle during printing are expected to align the material of the stiff polylactic along with the printing patterns. The six patterns included; (a) dot, (b) vertical line, (c) horizontal line, (d) cross 45 degree, (e) cross 60 degree, and (f) twist 45 degree. For the preliminary design, I assuming that the stiffness parallel to the printing patterns is dominated by the stiff stripes and that the soft transverse behavior is dictated only by the high compliance of the soft layer.

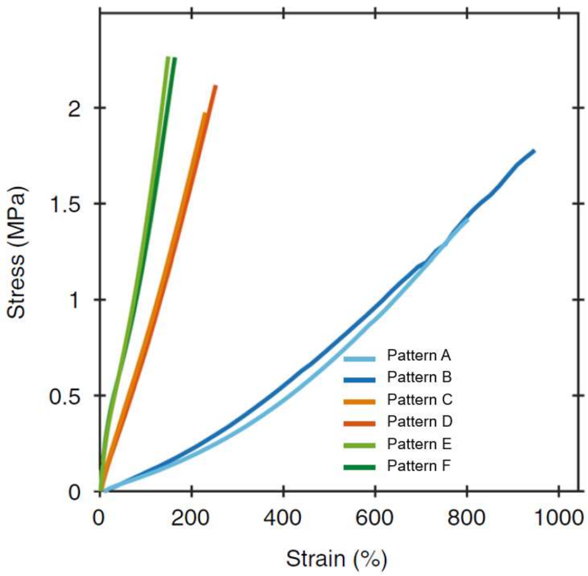

Figure 4 Mechanical behavior of printed soft actuator with different surface patterns.

3. Psychophysical experiment to compute the relationship between shape deformation and haptic rendering

I have conducted an experiments to estimate the relationship between the soft actuators and its haptic feedback. In the experiment, I have recruited 29 participants (aged 22 to 28) from a local university. All participants were right-handed. All participants also confirmed that they were not depressed or excessively tired as physical or emotional states that can alter the perception. In the experiment, I have prepared 2 samples printed with 20% infill density using dot and horizontal line patterns, respectively. The infill structure then filled with bi-stable materials (i.e., wax and urethane). During the experiment, the bi-stable materials are heated with 45C using hot air, and the air pressure injected inside the soft actuator was 0 to 6 kPA, varies using continuous time signal at 10 Hz (Figure 5). The cap on the top of soft actuator was embedded with pressure sensor to encounter the pressure state when the participant interact with the device. The pressure information, shape changing state and grasping behavior then matched with the virtual objects simulated with Unity3D orbit framework. The participants rated the 'similarity' when the pressure increase from 0 to 6 kPA using magnitude estimation. For example, they were instructed to indicate similarity value as less than 100 if they felt the stimulus was different from their experience, and vice versa. Each trial lasted about 15 minutes and included total 9 stimuli. Each participant was asked to come back to the experiment room the next day to perform a second measurement as the intervention task. The participants evaluated the horizontal line pattern with 3 to 3.5 kPa air injection perceived haptic sensation close to the visual stimulus. While for the dot pattern, the participants felt that the 4.3 to 4.9 kPa air injection perceived haptic sensation close to the visual stimulus. However, no significant different found between horizontal line pattern and dot pattern.

Figure 5 Soft actuator injected with hot air used in the experiment. (a) Horizontal line pattern, and (b) dot pattern.

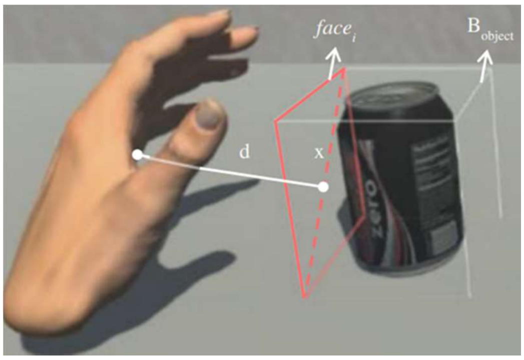

Figure 6 Sample view of grasping virtual object.

4．今後の研究の見通し

<継続研究内容に繋がる見通し> In the next step of this project, I am plan to develop a handheld and light weight VR controller that integrate the current developed soft actuator that simulate the shape and texture information, and the programmable viscosity materials that allows the user to perceive the viscosity information of the virtual contents. By integrating the knowledge in Human Perception and material control, create the computational model that take the relationship between electromagnetic and perceived viscosity, the controller could allow user (VR player) to perceive various haptic stimulations in addition to the shape of complex objects but also the weight-shifting and material properties. To do so, I will utilize the ferromagnetic material that could control its viscosity properties with magnetic field for manipulating virtual viscosity. Therefore, it would broaden the range of application with the proposed VR controller such as for virtual laboratory in which the students could learn the virtual chemistry classes or for the medical training to enhance the telepresence system in which the remote participant could feel the same experience as the local users.

5．助成研究による主な発表論文，著書名

学術論文（査読付）

- Motoki Miyoshi, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. SoftPrint: Investigating Haptic Softness Perception of 3D Printed Soft Object in FDM 3D Printers. Journal of Imaging Science and Technology (Proceedings of Printing for Fabrication 2021), Vol. 65, No. 4, pp. 40406:1-40406:8(8). July 2021.

国際会議（査読付）

- Motoki Miyoshi, Parinya Punpongsanon, Daisuke Iwai, and Kosuke Sato. *Investigation of Soft Display using Digital Fabrication and Phase-change Material*. In Proceedings of 2021 IEEE 3rd Global Conference on Life Sciences and Technologies (LifeTech), pp. 513-514. Nara, Japan, March 2021.