第 26 回日本バーチャルリアリティ学会大会論文集（2021年9 月）

Noncontact Heat Presentation for Whole Body Using High-intensity Airborne Ultrasound

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Abstract : The research aims to provide heat sensations for the whole body by irradiating high-intensity ultrasound to clothes. In this paper, we investigate the thermal effect of cloth on heat sensation by changing different clothing materials. Temperature obtained of clothing surface and human skin with each clothing material is compared.

Keyword : Mid-air haptics; Heat sensation; Whole body presentation

1. Introduction

This research aims to provide heat sensation for the whole body without wearing any special devices.

Typical methods to provide heat sensation for the whole body have been clothing with a Peltier or heater which yield motion limitation due to wiring, and the complexity of wearing. Noncontact methods can solve these problems; however, the presentation area has been limited to the hand in the existing methods [3], [4], [5], [6].

Our previous paper [6], one of the existing methods, have showed that the high-intensity airborne ultrasound on a glove with sound absorption characteristics could provide heat sensation. Based on this method, this paper proposes a noncontact method to provide heat sensation for the whole body by irradiating the high-intensity ultrasound to clothing for daily use (Fig.1). The proposed method does not require users to wear cloth with any special device because the heat source, the high-intensity ultrasound, can be generated at an arbitrary point on the cloth by adequately driving airborne ultrasound phased arrays (AUPAs).

As the first step, in this paper, we investigated suitable clothing materials for heat sensation.

2. Principle of heat sensation

When ultrasound wave strikes the surface of materials, the wave partly penetrates the material and converts into heat. Then, the heat is transferred to the contact area of skin and clothing materials to activate thermal sensations in human skin.

While ultrasound irradiation setting is same, clothing materials have different acoustic absorption coefficients. Therefore, there are differences among temperatures of materials exposed to ultrasound and the temperature that human skin perceives.

3. Experiment

We established the experiment setup to imitate the effect of human skin precepting thermal sensations created by high intensity airborne ultrasound. We measured temperature distributions of material surfaces and temperature changing patterns of silicone rubber model. The temperatures are obtained separately from thermal camera and thermal couples. All materials are exposed to the same ultrasound irradiation.

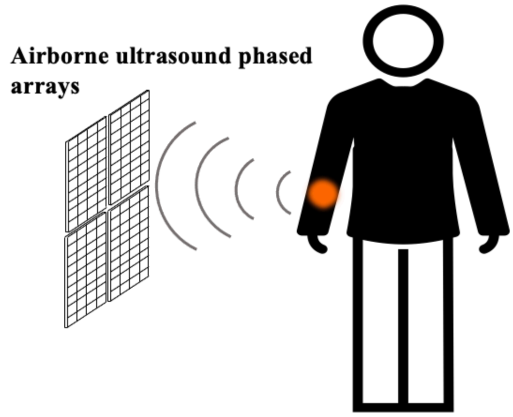

Fig. 1. Illustration of the proposed method.

3.1 Experiment setup

Fig. 2 shows the experimental setup. We used four AUPAs [1] comprising 996 transducers (TA4010A1, NIPPON CERAMIC CO., LTD.) . employed with the focal point 350 mm above the surfaces of the AUTD.

Having real arms in tests suffers from inevitable and irregular moving. To obtain stable and accurate temperature information, we designed the silicone rubber model which shares similar overall thermal properties of real skin model. In real skin models, thermal receptors are between layers of epidermis and dermis [8]. To mimic the structure, a double-layer silicone rubber model is constructed to have thermal couples set between (Fig. 3).

Around focal point, we placed several cut pieces from selected materials on a supporting plate. We used five kinds of clothing material, cotton, polyester, wool, viscous fiber, and thin linen fabric (Fig. 4). When we put silicone rubber model tightly and adhesively on fabrics, we imitate the condition in which the human body wears clothes.

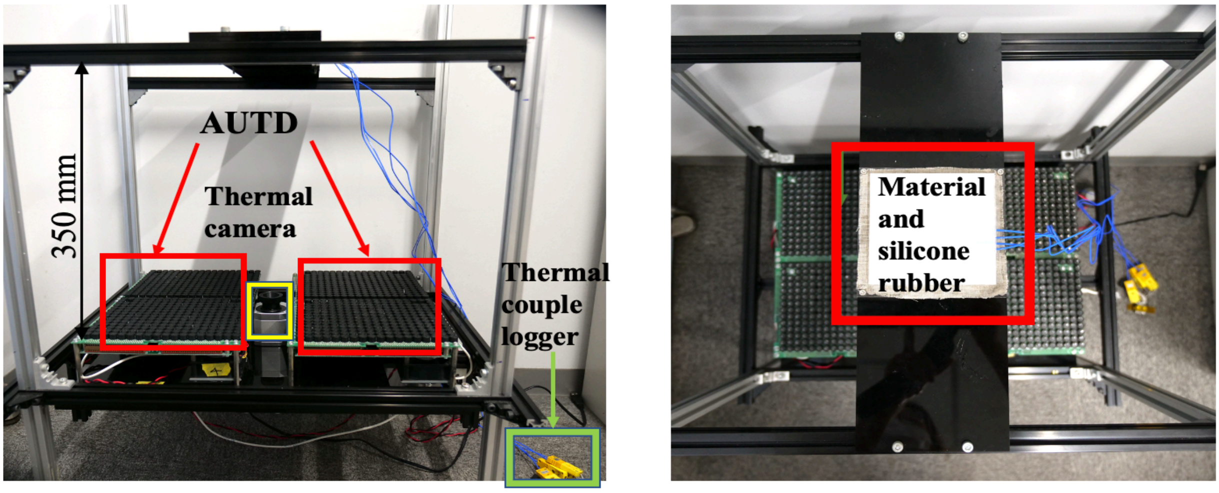

Fig. 2. Experiment Setup

	Stratum corneum	Epidermis	Dermis	Subcutaneous	Silicone rubber
Thickness[mm]	0.02	0.08	1.5	4.4	Layer 1: 0.3 Layer 2: 10
Density[kg/mm^3]	1500×10^{-9}	1190×10^{-9}	1116×10^{-9}	971×10^{-9}	1200×10^{-9}
Specific capacity [$(N\cdot mm)/(kg\cdot K)$]	3600×10^3	3600×10^3	3300×10^3	2700×10^3	1200×10^3
Conductivity[N/(s·K)]	0.235	0.235	0.445	0.185	0.2

Table. 1. Properties of skin model and silicone rubber

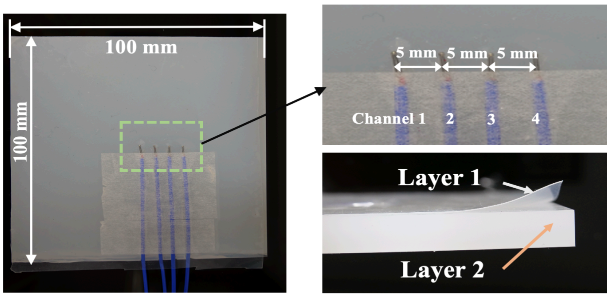

Fig. 3. Illustration of the proposed method.

Between double layers of silicone rubber, four thermocouples were arranged to measure the temperature changing pattern beneath silicone rubber model layer 1. The thermocouples were placed at 5 mm intervals, from Channel 1 to Channel 4(Fig. 3).

To collect and transmit data, we set a thermocouple data logger (SHTDL4-HiSpeed, Ymatic Inc.) at the interval duration of 100 ms.

On top of the silicone rubber model, a hot plate is set at 36 °C which is the temperature of the blood and muscle temperature of the forearm [10]. For each time measuring, the silicone rubber model was previously warmed enough by hot plate. Thermography camera (OPTPI450O29T900, Optris) was utilized to show the thermal map on the surface of the fabric irradiated by the ultrasound. For each trial, the irradiation and measuring lasts 20 seconds.

Fig. 4. Five kinds of clothing materials used in experiment

3.2 Experimental Results

Fig. 5 shows the temperature distributions on each material surface while irradiating ultrasound. Fig. 4 shows ultrasound heats locally. The temperature curves obtained from Channel 1 are seen as the representatives to be compared. Based on previous research, when temperature changing rate is within the range of 0.5 °C/s to 2°C/s, the rate of temperature change does not affect perception of warm sensations. The threshold for detecting a warm stimulus is the value of differences in temperatures. Comparing the temperatures curves of Channel 1 in Fig. 6, we can see that wool and viscose fiber responds to thermal activations most rapid. Considering the temperature difference threshold to be 1 °C , reaction time is nearly 1 s. Linen has the longest reaction time which is approximately 3 s.

4. Conclusion

We propose to create noncontact thermal sensations over the whole body utilizing high intensity airborne ultrasound. We conducted experiment to investigate appropriate materials to convey heat sensations under the same ultrasound irradiation. Based on the experiment results, we clearly see that performances differ when materials are different. Among the five materials, wool and viscose fiber

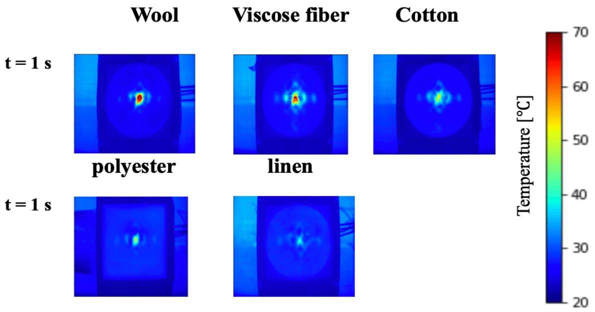

Fig. 5. Thermal distribution of surface of materials

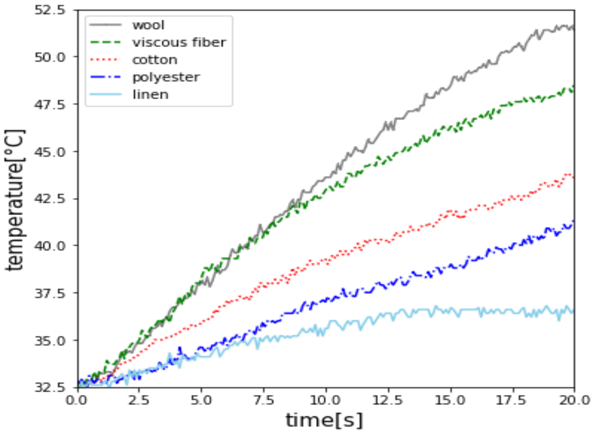

Fig. 6. Skin temperature rising curve of five materials

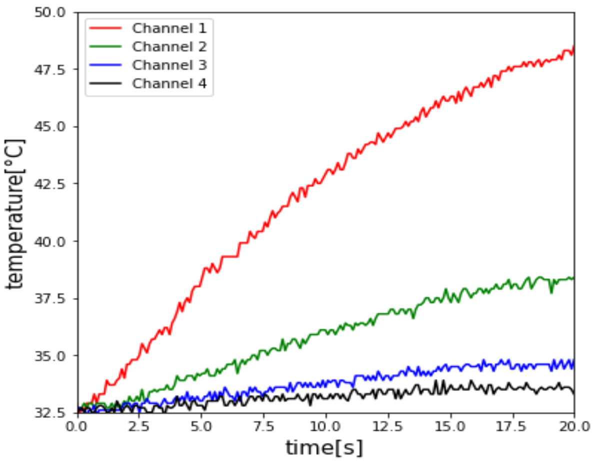

Fig. 7. Temperature rising pattern for four channels of viscose fiber

shares most rapid thermal reactions, thus people wearing wool or viscose fiber are the most sensitive to thermal sensations. For the future work, to optimize thermal sensations, we still need to further investigate properties of materials to improve the performance.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP20K19841 and JST CREST JPMJCR18A2.

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