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Haptic Interaction

Perception, Devices and Algorithms

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Preface

Welcome to the proceedings of the third international conference, AsiaHaptics 2018, held in Incheon, Korea, during 14–16 November.

AsiaHaptics is a new type of international conference for the haptics fields, featuring interactive presentations with demos. The conference became the place to experience more than 90 demonstrations of haptics research.

While the haptics-related research field is huge, this book divided into six parts.

Part 1 is composed of eight chapters, treating perception and psychophysics of haptics. They are undoubtedly the basis of the haptics research.

Part 2 is composed of nine chapters, treating rendering methods. They treat important steps toward practical application of haptics, such as how to convert recorded vibration, force, and thermal information for haptic display.

Part 3 is composed of 12 chapters, treating haptic technology. These are somewhat in-between science and application, giving novel schemes to convey haptic information.

Part 4 is composed of 28 chapters, treating novel devices. Haptics is still an immature and rapidly growing field, and intensive research is required for device development.

Part 5 is composed of 13 chapters, treating haptic application, especially focusing on real-world interaction, such as controlling robots, e-commerce, and welfare.

Part 6 is composed of seven chapters, treating application of haptics to virtual reality, which is an intensively studied area of haptics.

This book helps not only active haptic researchers, but also general readers to understand what is going on in this interdisciplinary area of science and technology. All papers have accompanied videos available online. Therefore, readers can easily understand the concept of the work with the supplemental videos.

November 2018

Sang-Youn Kim
Masashi Konyo
Ki-Uk Kyung
Hiroyuki Kajimoto
Dongjun Lee

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Correction to: LinkGlide: A Wearable Haptic Display with Inverted Five-Bar Linkages for Delivering Multi-contact and Multi-modal Tactile Stimuli C1
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Haptic Perception and Science

Midair Ultrasound Haptic Display with Large Workspace

Shun Suzuki(✉), Masahiro Fujiwara, Yasutoshi Makino, and Hiroyuki Shinoda

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Abstract. Midair haptic display using airborne ultrasound enables to give tactile feedback to a human body without wearing any devices. In the conventional ultrasound midair haptics system, the workspace was limited to the space of about 30 cm cube. In this paper, we integrate multiple ultrasound display units to achieve a large workspace. Our prototype system enables visuo-tactile interaction with AR images in a space of about 2 m cube.

Keywords: Midair haptics · Visuo-haptic interaction · Mixed reality

1 Introduction

The Airborne Ultrasound Tactile Display (AUTD) originating from the study by Iwamoto et al. [1] enabled non-contact haptic feedback to the human body surface. Such midair haptic display devices have been studied to provide haptic feedback in a VR, AR and MR environment. The advantage of midair haptics is that the user does not have to wear any devices and the movement of the user is not limited. However, in the conventional midair haptic system using ultrasound such as HaptoMime [2] and HaptoClone [3], the workspace is limited to a space of 30 cm cube at most, and the movement of the user is limited to this space. This is because ultrasonic waves are highly attenuated in the air.

To obtain the desired convergence of ultrasound in a large workspace, the workspace should be surrounded by many transducers. The problem is to digitize the position and posture of these transducers. The practical way is to surround the workspace with multiple phased array units (AUTD units) with a convenient size. By arranging multiple AUTD Unit, we can design a large workspace flexibly.

In this paper, we achieve a system that enables visuo-haptic interaction in a space of 2 m cube, where the user can freely move both hands while standing. Figure 1 shows a picture of the proposed system. The system monitors the motion of user by depth sensors and displays visual and haptic feedback when the user touches a 3D image.

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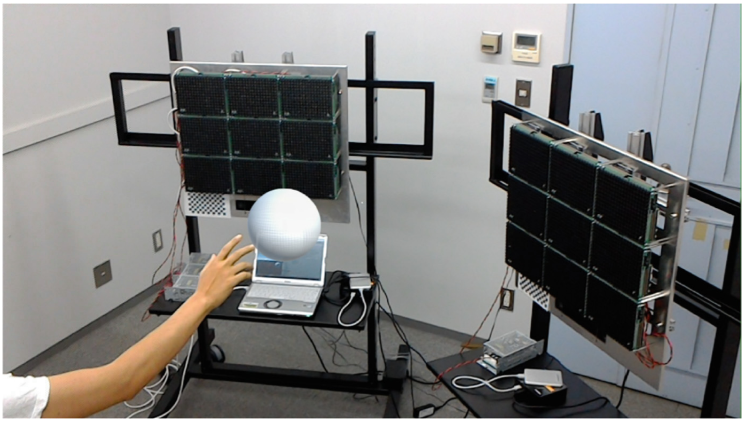

Fig. 1. Multiple phased array system. A user can touch and interact with an AR image.

2 Prototype System

The system configuration used in this study is shown in Fig. 2. Each AUTD unit has a depth sensor (Kinect v2, Microsoft Corp.) for three-dimensional measurement, a slave PC and nine AUTD subunits. The slave PC is connected to the master PC via the LAN. All units are synchronized, three-dimensional measurement is performed simultaneously and point cloud data is transmitted to the master PC. The master PC obtain the position and posture of the AUTD units and controls the AUTD units based on the information from the depth sensor.

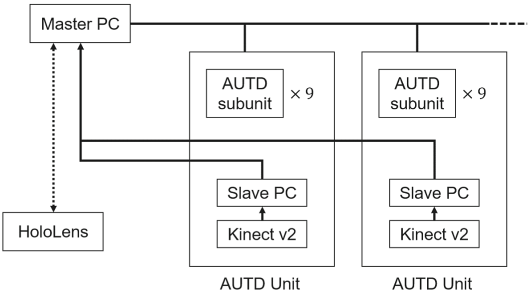

Fig. 2. Proposed system configuration.

The appearance of the AUTD unit is shown in Fig. 3. Nine AUTD subunits are fixed to the aluminum frame. One AUTD subunit has 249 ultrasonic transducers and the AUTD unit has 2241 transducers in total. The depth sensor is also fixed to the frame. The positional relationship between the AUTD subunit and the depth sensor is measured in advance.

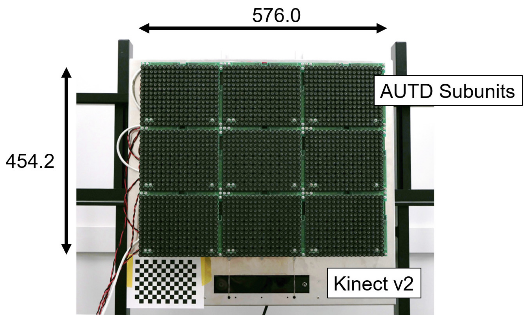

Fig. 3. Photograph of AUTD Unit. Dimensions are in mm.

Stereoscopic 3D image is drawn by MR device (HoloLens, Microsoft Corp.). Calibration between MR device and AUTD unit is performed by using calibration pattern attached to AUTD unit. Since HoloLens has a self-position estimating function, calibration is performed only once at the beginning. Calibrations of multiple AUTD Units are also performed by using this function.

3 Conclusion

In this paper, we proposed a visuo-haptic interactive system, whose workspace is over 2 m cube. In the proposed system, a standing user can move hands freely and interact with a 3D image with tactile feedback. The system configuration of the prototype was shown. The objective evaluation of the effect of midair haptics in such large space remains as a future study.

Acknowledgement. This work was supported in part by JSPS Grant-in-Aid for Scientific Research 16H06303 and JST ACCEL Embodied Media Project.

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Efficiency of Haptic Search Facilitated by the Scale Division

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Abstract. An experiment was conducted to reveal the efficiency of haptic search facilitated by the division of the searchable area. Tactile maps with five different numbers of divisions were presented to 16 blind participants and they were instructed to find the target. The results show that the search time became minimal at the 4×5 condition, but there was no significant difference between any pair of conditions.

Keywords: Haptic search · Scale division · Search time · Tactile map · Blind people

1 Introduction

Scales provided around tactile maps can shorten the search time for tactile symbols on the map [1]. However, the optimum number of divisions has not been found yet. In our prior study, an experiment was conducted in which tactile maps with five different numbers of divisions were presented to blindfolded sighted participants, and the results indicate that scales with 3×4 divisions minimize the search time [2]. In the current study, the same protocol as in the prior study was applied to blind participants.

2 Experiment

The tactile maps consisted of B4 sized swell paper with scales, roads (1 mm solid lines), and target stimuli (a circle of 9 mm). Scales with a line length of 5 mm and a width of 1 mm were added around the map, so as not to be confused with the lines of the streets (see Fig. 1). The number of divisions of the length and width were changed through the experiment, 2×3, 3×4, 4×5, 5×6, respectively (length $\times$ width). Maps without scales were prepared as a comparison.

Sixteen early blind people (9 male and 7 female, with a mean age of 28.7 years) participated in the experiment. They were informed of the divided area that contained the target before each trial. In addition, the number of divisions for the next trial was explained before starting the search. The participants used both hands for the searching task. All five conditions were shown to each of the participants in a different order of the stimuli. Ten tactile maps were used for one condition, which is one set, and the map was shown randomly. The participant's searching time was recorded by a stopwatch and the finger motion was recorded by a motion capture system (OptiTrack, V120: Trio).

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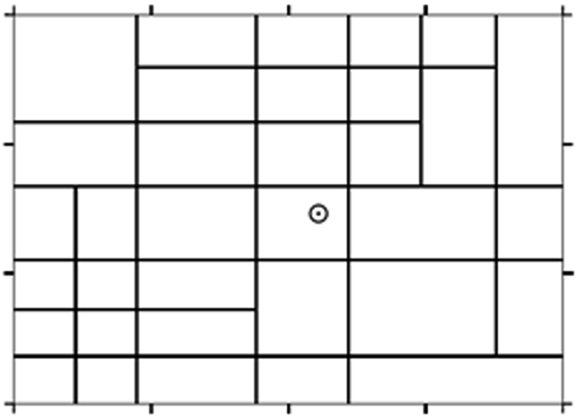

Fig. 1. An example of the target on the map with 3 × 4 divisions (the target was placed in the 2–3 area).

The study protocol was reviewed and approved by the institutional review boards of the University of Niigata.

3 Results

Figure 2 shows the relationship between the number of divisions and search time. The search time became minimal at the 4 × 5 condition. On the other hand, some trials that involved searching failures and the starting over of scale-counting took extremely long times at the 2 × 3 and 5 × 6 conditions. In comparison with blindfolded sighted participants, the search times became shorter at all conditions, and the entire search time was halved [2].

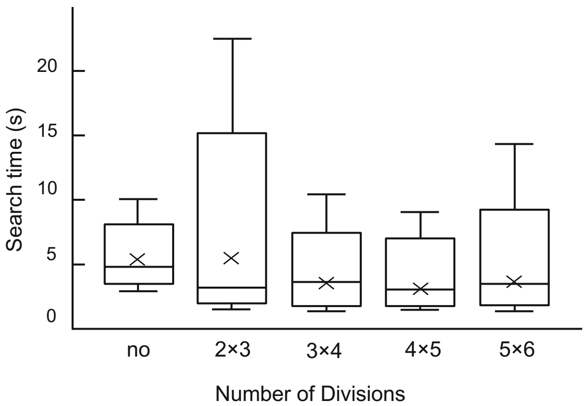

Fig. 2. Quantiles of the search time by the number of divisions. X-marks represent the average.

A Friedman test showed a significant difference among the five conditions (χ^2 (4) = 12.25, $p < .05$). However, multiple comparison using the Ryan's procedure showed no significant difference between any pair of conditions ($p > .05$).

4 Conclusion

In this study, the haptic search experiment using a tactile map with five different scale conditions was conducted in order to reveal the efficacy of the divided area. The results indicate the 4 × 5 divisions minimize the search time, and the relationship between the number of divisions and search time was not monotonic. Contrary to the hypothesis, the search time in the 2 × 3 condition was longer than in the non-scale condition. This could be the participants searched the entire map carefully in the non-scale condition and that led to short search times, on the other hand they searched only the divided area that had the target in the 2 × 3 condition but failed. Then they had to start over the search and that led to long search times. In contrast, the median searching time over the 3 × 4 and 5 × 6 conditions had no large difference. It is assumed that the effect of the divided area on efficiency of the haptic searching has a limitation from a certain size. Therefore, for the future prospect, we should conduct a study of the different sizes of tactile maps in order to reveal the relationship between search time and the size of the map.

This finding should be utilized for the optimization of automated tactile map creation system.

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Body-Ownership Illusion by Gazing at a Blurred Fake Hand Image

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Abstract. Feeling body ownership over a fake body image in video games or virtual environments may enhance the immersion and feeling of presence in them. In these situation, the sharpness of the image may influence the induction of the body-ownership illusion. In this study, we investigated the effect of blurring the image on the rubber hand illusion experience under seven levels of blur intensity. The results showed that blurring the image within the limits of hand recognizability may induce stronger body ownership of the fake hand but may not influence agency. This indicates that body ownership of a body image can be controlled by the sharpness of the presented image.

Keywords: Body ownership · Agency · Rubber hand illusion · Blurred image

1 Introduction

The induction of feeling as if a body image on a computer screen is part of one's own body is expected to provide greater immersion and presence in the virtual environments or video games. The feeling of a part of one's body (body ownership) and the sense of authorship of body motion (body agency) [1,2] have been investigated in the rubber hand illusion (RHI) paradigm [3]. The RHI is an illusory experience one feels body ownership over a fake hand while gazing at it being exposed to spatially and temporally congruent visuohaptic stimuli.

Many studies have attempted to induce the RHI through a computer screen [4–7]. For instance, one study found that, when screen projection of the camera image of the hand was delayed by more than 300 ms, the RHI becomes weaker [4]. However, the conditions for inducing a body-ownership illusion has not been investigated thoroughly. In this study, we focused on the sharpness of the body image captured by a camera and projected on a computer screen, which

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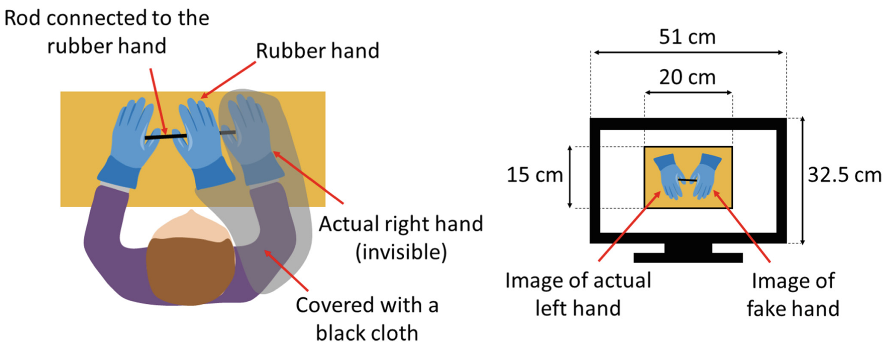

Fig. 1. Left: top view of the apparatus for inducing an active RHI. The right hand is covered with a black cloth. The movements of the actual and fake hands are synchronized by the rod. Right: specification of the screen and image used in the experiment.

is often restricted by the specification or performance of the camera, monitor, computer, and communication environment used. Determining the influence of image sharpness on the RHI contributes to the development of video games and virtual reality environments that employ the body-ownership illusion.

The influence of image sharpness on the RHI has not previously been investigated. Therefore, we investigated it in an RHI experiment where participants gaze at a fake hand image. Participants moved their own hand and the fake hand synchronously while gazing at seven images (each with a different level of blur) in a random order. Then, they answered to a questionnaire related to body ownership and agency. The results of this study are beneficial for controlling the body ownership of a fake body image on a computer screen.

2 Materials and Methods

2.1 Participants

Five university students (all right handed males aged between 21 and 23) who had no experience of the RHI participated in the experiment with informed consent. This experiment was approved by the ethical committee of the School of Engineering, Nagoya University (#17–12).

2.2 Experimental Setup for Inducing the RHI Through a Screen

Rubber gloves, an acrylic rod for synchronizing the hand motion, and a black cloth for covering the actual right hand and arm were used for inducing the RHI (Fig. 1 (left)). This apparatus was also used in [8]. Participants wore the rubber gloves and moved their hands synchronously with the fake hand by softly grasping the acrylic rod fixed to the fake hand.

The motion of the actual and fake hands was captured by a camera (HD WEBCAM C270, Logicool), and the camera image (15 cm × 20 cm, 408 × 544 pixel) was

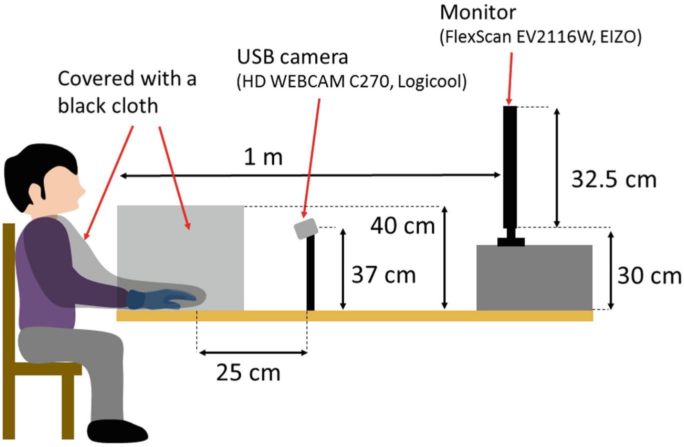

Fig. 2. Side view of the experimental setup for inducing RHI through a screen.

projected on a monitor (FlexScan EV2116W, EIZO) with a refresh rate of 59–61 Hz (Fig. 1 (right)). The captured image was flipped horizontally to give a mirror image [2]. The camera and monitor were located in front of the participant as shown in Fig. 2, and the captured image of their hands was shown on the monitor. The monitor height was same as the participant's eye level. The fake and actual hands were hidden by a frame covered with black cloth in order to prevent a direct view.

2.3 Methods

The camera images were blurred by an average filter. The blur levels were changed by the filter size, which had seven levels that range from not blurred (filter size: 0) to blurred beyond hand recognition (filter size: 75×75 pixel) in a geometrical series. The seven levels of blurred image are shown in Fig. 3.

2.4 Task

Before the experiment, participants tapped or rubbed the table with them on and experienced the RHI by gazing at the fake hand as shown in Fig. 1 (left), such that they could familiarize themselves with the rubber gloves. Then, participants experienced the RHI at seven levels of blurred image projected in a random order. The first four trials were used for practice. Then, 14 trials were conducted (each of the seven levels of blur was shown twice). Participants experienced the stimulus for one minute in each trail.

The magnitudes of body ownership and agency over the fake hand are rated by the questionnaire [1–3]. The questionnaire shown in Table 1 was a modified version of the one used by Botvinick and Cohen [3]. Q1 and Q2 are related to body ownership and agency, respectively, and the others are control items.

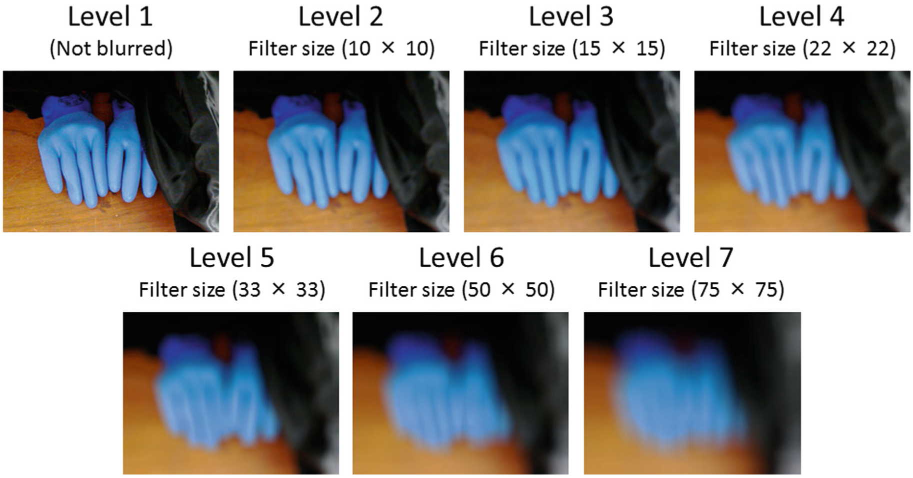

Fig. 3. Seven levels of blurred image used in the experiment. For the image of level 1, no filtering effect was applied. For levels 2–7, average filters of different sizes were applied.

Table 1. Questionnaire for evaluation of the RHI intensity

Q1	I felt as if the rubber hand was my own hand
Q2	It seemed like I was directly moving the rubber hand
Q3	It seemed as if I might have more than one right hand or arm
Q4	It felt as if my (real) hand was turning "rubbery"
Q5	It appeared (visually) as if the rubber hand was drifting towards the right (towards my real hand)
Q6	The rubber hand began to resemble my own (real) hand in terms of shape, size, or some other visual feature
Q7	I felt as if my (real) hand was drifting towards the left (towards the rubber hand)

Participants gave each question a score on a seven-level scale for each trial (-3 for strongly disagree up to $+3$ for strongly agree). A positive answer score indicates that the participant agreed with the question.

3 Results

The answer scores from each participant were averaged in each stimulus condition. Figure 4 shows the means and standard errors of the answer scores for each question and each blur level. The answer scores against Q3–Q7 (control items) were equally negative under all conditions, which denied the suggestibility of the setting. We applied a one-way ANOVA to the answer scores against Q1 and Q2, which are related to the RHI, by considering the blur levels as the factor to investigate the effect of blur process.

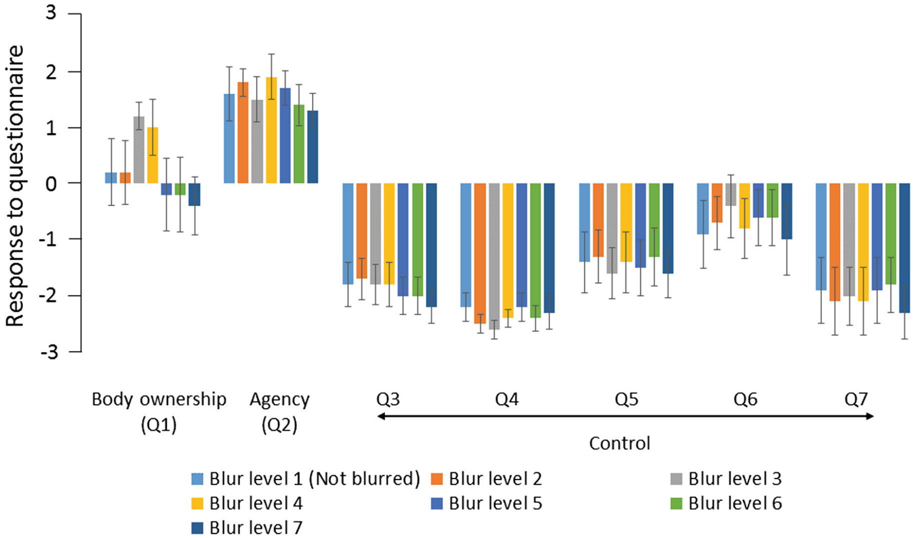

Fig. 4. The means and standard errors of the RHI questionnaire scores for each blur level.

The answer scores against Q1 (body ownership) were positive values for blur levels 1–4 and were negative values under stronger blurring conditions. Furthermore, they peak between blur levels 3 and 4. However, these were not significant results ($F(6, 63) = 1.27$, $p = 0.29$). The answer scores against Q2 (agency) were positive values under all blurring conditions and there was no significant difference among any conditions ($F(6, 63) = 0.35$, $p = 0.91$).

4 Discussion

Body ownership was reported in slightly blurred conditions (blur levels 3 and 4), but not in intensive blurring conditions where the hands become unrecognizable. Moreover, the answer scores against body ownership under blurring conditions within the limits of hands being recognizable (i.e., blur levels 3 and 4) were higher than under the unblurred condition. This result can be explained by the inverse effect [9], where the illusion, which is a multisensory integration of visuohaptic cues, might have been strengthened by degradation in the reliability of visual cues. Also, slightly blurred conditions (blur levels 3 and 4) may masked the visual difference between the fake and actual hands, and might have resulted in intensive illusions. However, given the limited number of participants, we could not achieve significant results and further investigation is required.

Although agency was reported regardless of the blurring intensity, the types of it differed between blur levels. Under blur levels 3 and 4, body agency may be induced since body ownership was also reported. On the other hand, under stronger blurring conditions (blur levels 5–7), external agency [1] may be induced in the same way as when you use a tool or manipulate an object.

In this way, using an unclear image within the limits of hand recognizability may be effective for inducing body ownership on the fake hand image while remaining agency.

5 Conclusion

In this study, we investigated the effect of blurring a fake hand image on the RHI experience. Camera images of participants' hands were blurred to seven different extents and projected on a monitor in front of them. Participants answered a questionnaire related to illusion after moving their actual and fake hands synchronously while gazing at the blurred image. The results showed that blurring the image within the limits of hand recognizability induced stronger body ownership than under unblurred conditions. However, agency was induced equally under all blurring conditions. We suggest that the blurring process within the limits of hand recognizability may be effective for inducing body-ownership illusion with a fake hand image on a screen.

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A Soft Tactile Display Using Dielectric Elastomer Actuator for Fingertip Interaction

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Abstract. In this paper, we demonstrate a soft tactile display composed of a thin dielectric elastomer (DE) actuator coupled with silicone gel in a bubble shape, which can provide tactile stimulation to the skin. The design of the tactile display is referred from hydrostatically coupled DEA structures. We could observe the maximum force of the tactile actuator as 378 mN. In addition, the actuating module could provide exerting force higher than 250 mN in overall range of perceivable frequencies.

Keywords: Dielectric elastomer actuator · Soft · Tactile display · Haptic · HC-DEA

1 Introduction

So far, tactile feedback has been achieved through vibration or shape transformation [1, 2]. Nonetheless, more research needs to be done in order to create a thin, flexible, and safe tactile display.

Electro-active polymer (EAP) actuators, especially dielectric elastomer actuators (DEA), are emerging soft actuators that are characterized by its large area strain, fast response, high specific energy density, light weight, low cost and low power consumption [3, 4]. However, DEA still have challenges in producing sufficient amount of output force for using in tactile displays. Several researchers have tried to overcome this issue through hydrostatic coupling (0.8 N) [5, 6], and multi-layering (255 mN) [1].

In this demonstration, we implement a soft actuator for tactile display composed of DEA layers coupled with silicone gel in a bubble shape, which has been proposed as HC-DEA (Hydrostatically Coupled Dielectric Elastomer Actuator) [5, 6]. In order to verify applicability of the soft actuating mechanism as a tactile display in human perceivable range, we have conducted measurement of exerting force in accordance with frequency variation. The soft tactile actuator shows fast response, and sufficiently large output force (output force: >250 mN in frequency range: 0–300 Hz).

2 Experimental

2.1 Fabrication

The soft tactile display is composed of dielectric elastomer (DE) layers coupled with silicone gel. In this structure, the ball-shaped silicone gel lies within dielectric elastomer and passive layers. The dielectric elastomer membrane is made of 0.5 mm thick

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3M VHB 4905 film, pre-stretched by a ratio of three. The active layer's diameter is 10 mm, and the frame's diameter is 18 mm. The working principle of the tactile actuator is as follows. First, voltage is input to the device. Then, due to induced electrical potential, the dielectric elastomer membrane (lower layer) undergoes expansion [3]. As a result, the DE membrane buckles and the ball-shaped silicone gel moves perpendicularly down. On the other hand, when voltage is turned off, the membrane contracts and the silicone gel moves up (Fig. 1).

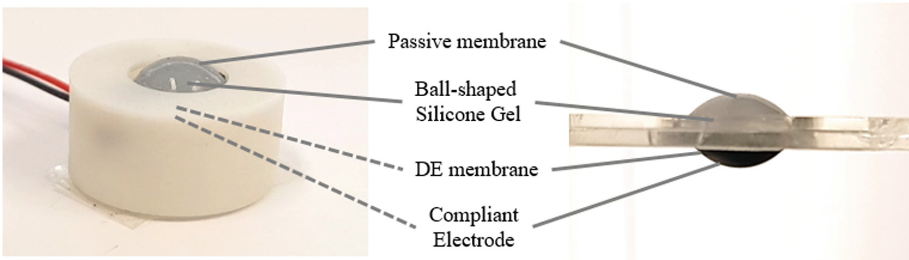

Fig. 1. Fabricated soft tactile display

2.2 Actuation Performance Test

The performance of soft tactile display is evaluated by measuring its output force. The load cell is made contact with the actuator's passive layer for an accurate force measurement. For the measurement, square waves of 4 kV amplitude at 0–300 Hz frequency are input to the display. Figure 2 shows the output force as a function of frequency.

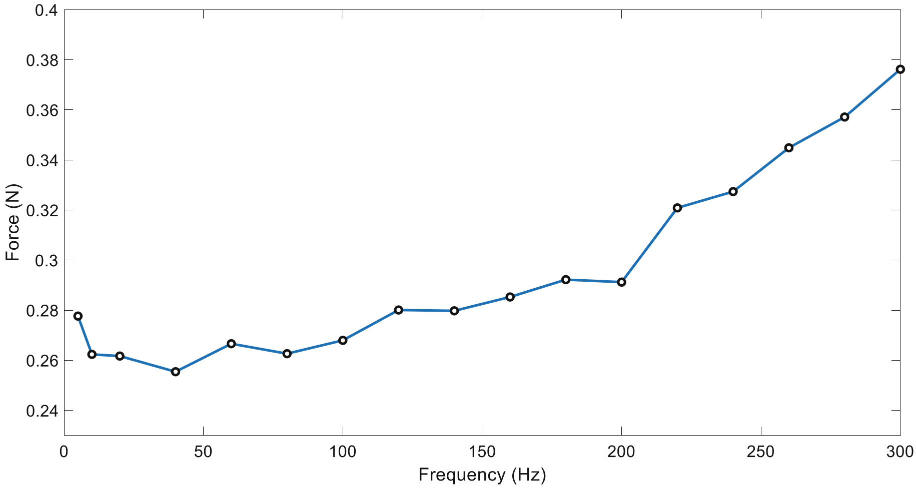

Fig. 2. Performance test of DEA under loading condition with input frequency sweep at 4 kV

The measured output force of soft tactile display is higher than 250 mN at all operating frequencies. The highest output force is measured as 378 mN at 300 Hz. As force perception threshold at fingertip is reported to be 1.7 mN in 320 Hz [7], the fabricated soft tactile display proves to be appropriate for human-machine applications.

3 Conclusion and Future Work

In this paper, the soft tactile display based on DEA coupled with silicone gel in a bubble shape has been demonstrated. The actuator recorded a maximum force of 378 mN at 300 Hz. In the low frequency zone, around 5 Hz, the output force is measured as 279 mN.

In the future, we will consider fabricating actuator applicable to wearable interfaces, such as fingertip tactile glove and forearm vibro-tactile band. Since the threshold of force perception in forearm is much higher than the fingertip, providing not only contact force, but also vibro-tactile stimulus to the skin is considered.

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Haptic Texture Authoring: A Demonstration

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Abstract. We present a haptic texture authoring algorithm for synthesizing new virtual textures by manipulating affective properties of existing real textures. Two different spaces are established: "affective space" built from a series of psychophysical experiments and "haptic model space" built on features from tool-surface contact vibrations. Another space, called "authoring space" is formed by merging the two spaces, whereby, features of model space that were highly correlated with affective space become axes of the space. Thus, new texture signal corresponding to any point in authoring space can be synthesized by weighted interpolation of nearest real surfaces in perceptually correct manner.

Keywords: Haptic texture · Interpolation · Texture perception · Texture rendering · Psychophysics

1 Introduction

In the field of texture perception, the relationship between visual perception and physical characteristics of surfaces has received a high level of interest from the research community, while, on the other hand, the relationship between tactile perception and physical characteristics is a less trodden path. This can be accredited to the difficulty in finding specific factors and characteristics of tactile perception which can be controlled and manipulated independently. It is a well known fact that vibrations originating from interaction with different surfaces play a vital role in texture perception and identification. Various researchers have successfully rendered virtual tactile sensations by reproducing vibrations encountered during tactile interactions [3]. However, such studies did not succeed in pointing out definitive characteristics that can be used to directly manipulate the perception or affective properties of textures. The process of directly manipulating the affective properties is called as haptic texture authoring.

The main aim of haptic texture authoring is to provide a system where the affective properties of textures are readily manipulated. This can be achieved if a relationship is established between the physical properties of textures and its affective properties. In this study, the physical properties are modelled using the algorithm presented by Abdulali et al. in [1], whereas, the affective properties

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