Somewhat Strange Feeling of Touching, Lifting, and Swinging in Mixed-Reality Space - Psychophysical Analysis of Haptic Illusion Caused by Visual Superimposition -

Yuta Kataoka
Ritsumeikan University
1-1-1 Noji Higashi, Kusatsu,
Shiga 525-0058, Japan
y_katao@rm.is.ritsumei.ac.jp

Abstract
Mixed Reality (MR) is technology that can combine the real world and virtual world in real time. It realizes an interactive operation with real objects and virtual objects. In MR space, the appearance of a real object can be changed by superimposing a virtual object. It is possible to create different situations between haptic and visual information by utilizing the features of MR. The theme of the author's research is the examination of how human perception is changed by visual influences, and analysis of the conditions under which change occurs. Until now, it has been confirmed that the weight perception and volume perception are changed by superimposing virtual liquid objects over the real objects to alter liquid movement or liquid volume. This paper outlines current research and prospects.

ISS '18 Companion, November 25–28, 2018, Tokyo, Japan

ACM ISBN 978-1-4503-6010-4/18/11.
https://doi.org/10.1145/3280295.3281634

CCS Concepts
• **Human-centered computing** → **Mixed / augmented reality**;
• **Computing methodologies** → **Perception**;

Author Keywords
Mixed Reality; Haptic Display; Pseudo-Haptics; Weight Perception; Volume Perception

Introduction

Mixed reality (MR) seamlessly combines the real world and virtual world in real time, and as an advanced system of virtual reality (VR) it is attracting more and more attention. It is possible to electronically merge the information that we want to superimpose over the real object in MR space. For example, by superimposing various interior and exterior virtual objects on automobile mock-ups, we can interact with and touch the changed equipment [1].

Furthermore, MR technology can create situations that do not occur in the real world where visual and haptic information are different. Humans perceive information from the real world through various sensory modalities such as visual, haptic, and auditory. Each modality does not perceive information independently but interacts with the others to perceive it. Visual information particularly and strongly influences human perception, so perception can be modified by creating a different situation between body movement and its visual information.

We have confirmed that various changes occur in haptic perception by differentiating between haptic and visual information in MR space. For example, we have confirmed that the center of gravity perception is modified by superimposing differently sized virtual objects over real objects [2]. In the process of researching, a question arose regarding how humans are perceived when an object imitating the dynamic movement inside a real object, like water, is superimposed. Then, we confirmed that weight perception is changed by superimposing a virtual liquid object over the real object through preliminary experimentation. However, the influence of this phenomenon's condition and the parameters of real and virtual objects have not been clarified. To address this problem, we aim to analyze how influence affects perception by superimposing a virtual liquid object over the real object and changing each parameter (Figure 1).

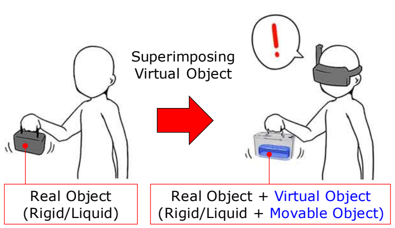

Figure 1. Research concept.

Related Work

Humans can perceive object features such as length, weight, and shape by holding or touching an object [3, 4]. Additionally, object features are perceived by complementary work through somatic sense and special sense. As an example of this interaction, pseudo-haptics are a well-known form of illusion. It is a phenomenon in which a pseudo-haptic is perceived without requiring physical haptic presentation by differentiating between visual information and body movement. This phenomenon is expected to be applied to various interface developments because it can easily produce haptic sensation (without using a haptic device) by using visual information.

Furthermore, human perception is based on the reliability of information received by various sensory modalities [5]. The influence of visual modality is enormous, so perception tends to be strongly affected by visual information [6]. It is possible to perceive a change of sensation based on visual information by changing the appearance of the real object. Nakahara *et al.* reported that shape perception can be altered by superimposing an angular or rounded virtual object on the real object [7]. It has also been reported that various sensations, such as hardness and material, are affected by visual information [8, 9]. However, most of the research concerning the effects of visual information on haptic sensation focuses on static information such as object texture and appearance.

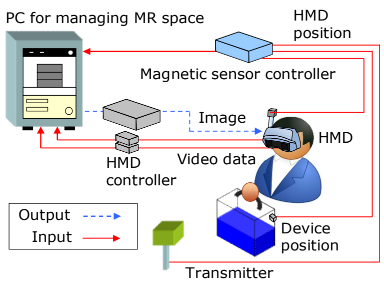

Figure 2. System configuration to construct MR environment.

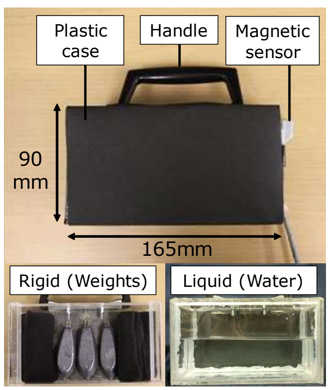

Figure 3. Real object used in experiment.

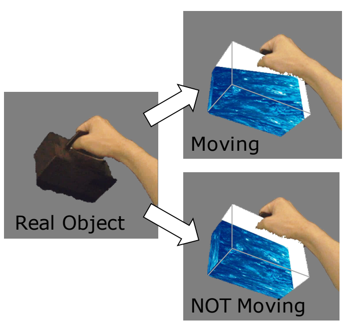

Figure 4. Virtual object used in experiment.

Several studies have been proposed to perceive the dynamic movement inside a real object. Minamizawa *et al.* propose a method of presenting the movement of a ball inside a virtual container using a fingertip-mounted haptic device [10]. *Yao et al.* propose a method of presenting the rolling of a ball in an empty cylinder by recording and presenting the vibration of the ball as it rolls [11]. These studies use the haptic device or haptic stimuli to perceive the internal dynamics of an object. In contrast, our study analyzes what kinds of changes occur in human perception when modifying the internal dynamics of a real object by exclusively presenting visual information. The author's research objective is to systematically analyze the influence on perception by superimposing a virtual object imitating water over a real object, and to broaden the range of haptic presentation techniques in MR. It is necessary to organize the conditions of an experiment because various conditions must be considered for the parameters of real and virtual objects. For this reason, the research is divided into two approaches:

Research Approach

In approach 1, we analyze the influence on weight perception by superimposing virtual liquid over the real object through psychological experimentation and measurement of muscle activity. In approach 2, we analyze the influence on volume perception by superimposing different volumes of liquid over the real object that encloses water.

Both approaches aim to clarify human perceptual characteristics when presenting internal dynamics or various volumes of virtual liquid. Current research works are described in the following chapters.

Weight Perception [12]

Purpose

The weight perception is changed by superimposing a virtual liquid object imitating the movement of water on the real object. In this study, we analyze in detail what kind of real and virtual object conditions affect weight perception.

Environment

A video see-through-type HMD and the MR Platform System (Canon, VH-2002) is used to construct the MR environment (Figure 2). The position/attitude information for the participant's head and the real object is acquired using magnetic sensors (POLHEMUS, 3SPACE FASTRAK).

An acrylic case with dimensions of 165 mm width x 80 mm depth x 90 mm height, and with a handle attached, is used for the real object grasped by the participant. Two types of real objects are prepared with fixed weights (rigid condition) or water at 45 mm height (liquid condition) and both objects weigh 750 g (Figure 3). The presented virtual container contains the same dimensions as the real object: 165 mm width x 80 mm depth x 90 mm height. The liquid volume within the virtual container has a height of 45 mm. In the experiment, the participant swings the real object left and right with presenting the virtual liquid.

Furthermore, a simple model is set to imitate the movement of water. This model omits detailed expressions such as wave and splash, and it expresses simple approximation of the liquid surface to a straight line. We additionally set the condition that liquid does not move against the swing of the real object to analyze the influence of the liquid movement (Figure 4).

	Real object	Superimposed virtual object
P1	Rigid (Weights)	None (watch a black case)
P2		Not moving
P3		Moving
P4	Liquid (Water)	None (water is not visible)
P5		Not moving
P6		Moving
P7		None (water is visible)

Table 1. Experimental patterns to analyze the visual influence on weight perception.

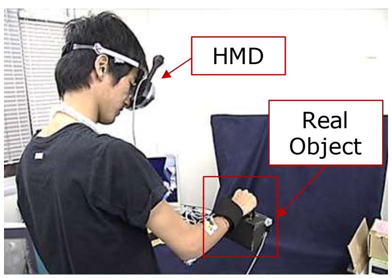

Figure 5. Experimental scene.

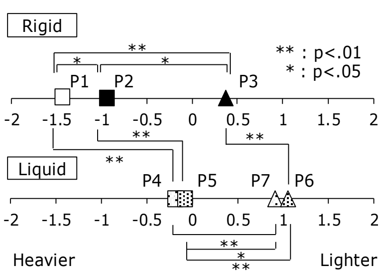

Figure 6. Result of experiment on weight perception.

Method

The subjective experiment is conducted based on Thurstone's pair comparison to analyze the influence on weight perception by the combination of real objects and virtual objects. There are seven patterns of P1 to P7 combining the condition of real and virtual objects (Table 1). If the weight perception is affected by visual information, a bias of psychological scale should be observed. The number of trials is ${}_7C_2$ = 21 times per person, and there are 11 participants. The posture of the participant requires grasping the real object from a standing position with the elbow bent at a 90-degree angle (Figure 5). The experimental procedure is as follows:

1. The participant wears the HMD.
2. Two types are selected at random from the seven types of patterns (Table 1).
3. One of the two types of patterns chosen in 2. Is presented to the participant.
4. The participant grasps the real object and swings the object left and right (100 BPM, 3 seconds).
5. 3. and 4. are repeated in the same way for the other pattern chosen in 2.
6. Ask the participant to answer which pattern feels heavier.
7. Repeat 2. to 6. for remaining combinations.

Result

The two lines in Figure 6 show the psychological scale on the perceived weight. As the numerical value increases, it indicates that participants perceive the real object more lightly. Furthermore, a sign test is conducted to determine whether there are significant differences on weight perception depending on certain conditions. The following results can be seen from the experiment:

(i) The real object is lightly perceived by watching the movement of the virtual liquid object under both rigid and liquid conditions. In the rigid condition, it was lightly perceived in the order of P1, P2, and P3; P4, P5, and P6 under the liquid condition have the same trend.

(ii) The P7 condition of watching the movement of actual water is perceived more lightly than the P4 condition, which does not see the movement of actual water. Therefore, it is important to watch the movement of water and swing the real object to perceive the weight as light.

From (i) and (ii), it is found that weight perception can be affected without changing the physical properties of the real object by presenting the movement of water. In addition to this experiment, the quantitative experiment is conducted to measure muscle activity during the swing. See [12] for details.

Volume Perception [13]

Purpose

In the previous chapter confirms that weight perception is affected by presenting the movement of liquid. As a next step, a virtual object with different volumes of liquid is superimposed over the real object that encloses water. Thereby, we confirm whether participants perceive liquid volume depending on virtual liquid volume.

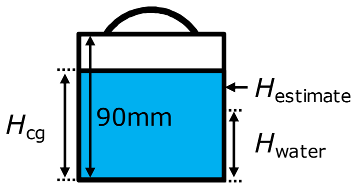

Figure 7. Relationship between actual water volume (H_{water}), virtual liquid volume (H_{cg}), and estimated volume ($H_{estimate}$).

	Water height of real object (H_{water})	Water height of virtual object (H_{cg})
V1	22.5 mm	45 mm
V2		67.5 mm
V3	45 mm	22.5 mm
V4		67.5 mm
V5	67.5 mm	22.5 mm
V6		45 mm

Table 2. Experimental patterns to analyze the visual influence on volume perception.

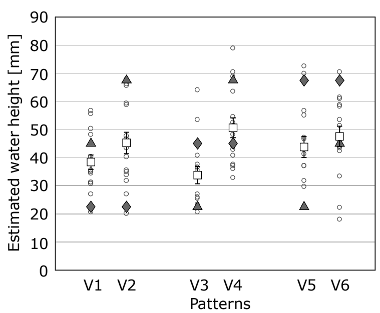

Figure 8. Result of experiment on volume perception.

Environment

The MR system, container of the real object, and liquid model of the virtual object used in the experiment are the same as the previous chapter. Three real objects are prepared at 500 g, 750 g, and 1000 g of the weight, and the heights of water are 22.5 mm, 45 mm, and 67.5 mm respectively. In addition, three types of virtual liquid are prepared with heights of 22.5 mm, 45 mm, and 67.5 mm respectively. Moreover, the participant uses sealed headphones (Peltor, Htm79a) to block external sounds and white noise.

Method

The subjective experiment is conducted to analyze the influence on volume perception by superimposing various virtual liquid volumes. There are six patterns of V1 to V6 combining the conditions of real objects and virtual objects (Figure 7, Table 2). If the volume perception is affected by visual information, a bias of estimated value should be seen. The number of trials is ${}_6C_1$ = 6 times per person, and there are 15 participants. The posture of the participant is the same as the previous chapter. The experimental procedure is as follows.

1. The participant wears the HMD and the headphones.
2. One type is selected at random from the six types of patterns (Table 2).
3. The participant grasps the real object and swings the object left and right (for any length of time).
4. The participant indicates the estimated water volume.
5. Repeat 1. to 4. for remaining patterns.

Result

The results of the experiment are shown in Figure 8. Within the markers plotted in the figure, □ shows the average value of the participant's estimated volume, ○ shows individual estimated volume ($H_{estimate}$), ◆ shows water volume inside the real object (H_{water}), and ▲ shows liquid volume of the virtual object (H_{cg}). If the average value of the estimated volume is closer to the virtual liquid volume, it means that volume estimation is influenced by visual information. The following results can be observed from the experiment.

(i) The estimated value is influenced by the virtual liquid volume under all conditions. In particular, the average value of V1 and V6 conditions show approximately the same estimated value that the virtual liquid volume does.

(ii) The influence of visual information decreases as the difference between the volume of the real object and virtual object enlarges. The average value of V2 and V5 conditions show the influence of visual information is decreased, because the difference in liquid volume has enlarged (45 mm) between the real object and virtual object.

From (i) and (ii), it is found that volume perception can be affected by altering the appearance of liquid volume. Furthermore, human perception is determined based on the reliability of the sensory modalities, and the experimental results can confirm the same trend as in the previous study [5]. Please refer to the literature [13] for details.

Conclusion and Future Works

We analyze the influence of virtual liquid movement and liquid volume, and result show that weight perception and volume perception are changed accordingly. Moving forward, we plan to analyze the perception mechanism in above-described researches. Both researches confirm that human perception is modified by visual information. However, it has not been analyzed to discern why perception is changing. We intend to clarify the perceptual mechanism by kinematic and neuroscience analysis.

Acknowledgements

I would like to thank my supervisor, Prof. Asako Kimura, for her useful comments and on-going support. This work was supported in part by a Grant-in-Aid for Scientific Research (B) Grant Number 16H02861.

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