Changing Perception of Physical Properties using Multimodal Augmented Reality: Position Paper

Geert Lugtenberg
Utrecht University
The Netherlands
g.lugtenberg@students.uu.nl

Christian Sandor
Nara Institute of Science and Technology, Japan
sandor@is.naist.jp

Wolfgang Hürst
Utrecht University
The Netherlands
huerst@uu.nl

Alexander Plopski
Nara Institute of Science and Technology, Japan
plopski@is.naist.jp

Takafumi Taketomi
Nara Institute of Science and Technology, Japan
takafumi-t@is.naist.jp

Hirokazu Kato
Nara Institute of Science and Technology, Japan
kato@is.naist.jp

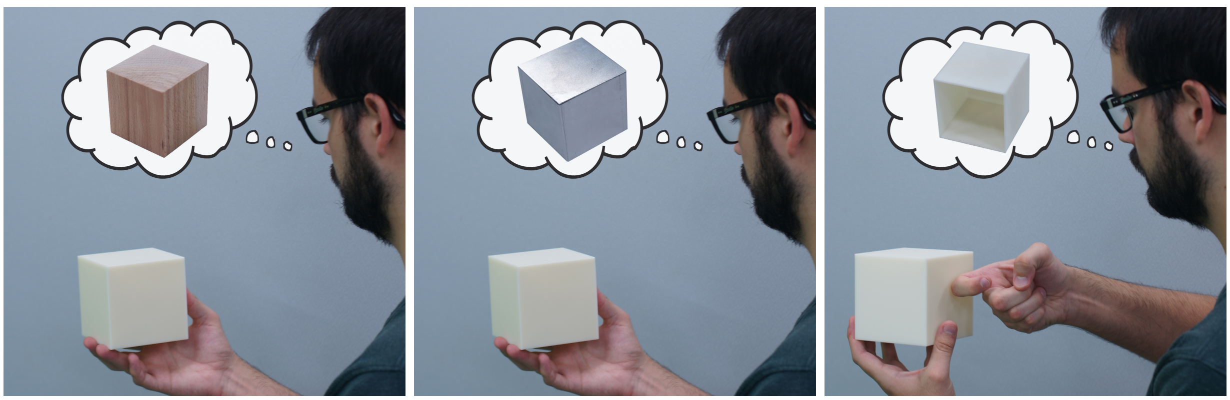

Figure 1: In the ultimate AR system, perception of physical properties, such as material and object density, can be changed as desired.

ABSTRACT

By means of augmented reality (AR) systems it has become increasingly easy to manipulate our perception of real objects. In this position paper we review existing work that changes physical property perception, and propose methods for changing perceived object density during haptic interaction. Our goal is to modulate the sound emitted by an object when touched. We hypothesize that augmented sound can make people think that an object is hollow or solid regardless of its actual object density. We describe an experiment to validate this hypothesis. Participants tap a hollow or solid cube and are asked to determine if it is hollow or solid, based on the multimodal feedback.

This research is a first step towards an AR system that can alter multimodal perception of object physical properties, and open doors for related research.

CCS Concepts

•Human-centered computing → Mixed / augmented reality;

Keywords

augmented reality; multimodality; physical property perception; object density; audio feedback; haptic interaction

1. INTRODUCTION

A large number of applications in AR to date focus on realistic visual rendering of virtual objects, and changing how real objects are visually perceived. Comparable work in other modalities is relatively lacking. Achieving consistent realism in other modalities, e.g. touch [2], sound [10], smell and taste [7], is still challenging as augmenting a new virtual object into the environment often requires additional hardware (e.g. haptic machinery) and physics simulation. But if an existing object is used, often we can achieve our goal by only manipulating the object's physical properties instead of creating a new object. Figure 1(a,b) shows a visual manipulation of an object's material, and (d) auditory manipulation of an object's density. Depending on the application, only perception of some properties of the object need to be changed, e.g. hardness, color, density, to appear realistic. The ultimate goal of this research is the creation of an AR system that can change perception of object physical properties, in order to simulate desired material and object-density.

With the increased accessibility of 3D printing, studies aimed towards perception of physical properties can contribute to using 3D printed objects as 'templates'. Perception of more and more physical properties of these template objects could be altered as desired. In this position paper we review existing work aimed at changing physical property perception and evaluate what is missing to reach the ultimate goal. Finally, we propose a research plan to study object density perception.

2. RELATED WORK

We review previous work on modifying perception of physical properties of rigid objects. The ultimate AR system could ideally alter perception of all physical characteristics of objects, however characteristics that humans cannot perceive without instruments are of far less interest. We are concerned with perception of physical properties that play a role when haptically interacting with objects. In particular, we focus on stiffness, mass (weight), roughness and hardness.

2.1 Stiffness

Stiffness is the ability of an object to resist deformation in response to force. It is perceived by multiple sensory systems, in particular audition and tacticion. DiFranco et al. [2] explore the influence of sound on the haptic perception of stiffness in a virtual environment. They use a haptic device to simulate feedback from a surface with varying stiffness. Upon contact with the surfaces, impact sounds are generated. They found that audio cues affected the stiffness perception, even when the haptic feedback remained the same. Hachisu et al. [3] created a haptic device that, upon impacting a real object, adds or subtracts vibrations to the resulting surface vibration. They found that this changed the perceived stiffness of the material and created the illusion that the real object was made of a different material.

2.2 Weight

The 'Size-Weight illusion' is a famous illusion of perceived weight [1]. It states that when holding objects of the same weight but different size, the bigger object is perceived to be lighter than expected. R-V Dynamics [4] created an illusion that changes weight perception of a real object. They superimposed computer-generated imagery (CGI) representing inertial force of movable objects in an AR environment. They found that with CGI of moving (dynamic) volumes, objects are perceived to be lighter. Visual stimuli can also affect perceived vibrotactile intensity [9]. Vibrations are perceived 'lighter' when visual cues suggest a larger or heavier object. These works suggest that discrepant perceived weight accompanying a change in perceived density could be countered with visual stimuli.

MVAR'16, November 16 2016, Tokyo, Japan

DOI: http://dx.doi.org/10.1145/3001959.3001968

2.3 Surface roughness

Kagimoto et al. [6] analyze the perceived 'roughness' of a real surface with visual and audio stimuli. They superimpose a material on a surface, and play augmented audio stimuli when the user touches the surface. They found that when two objects have identical roughness, visual and audio stimulation can change perception of haptic roughness between the two. In this research, the roughness of the physical object remains the same and thus visual and auditory cues could be utilized to make the user perceive a rougher or less rough surface.

2.4 Hardness

Perception of hardness is not only a tactile experience but can also be influenced by visual stimulation [5]. In SoftAR [8] the haptic experience of softness is influenced by visual stimulation of the surface that is interacted with. Deformation of the surface of an object is experienced haptically, but also visually. This knowledge is used to project an exaggerated deformed image onto a surface on touch, to simulate increased softness. This technique can be used when simulating material that is softer than the physical material (e.g. perceiving wood or plastic to be styrofoam).

3. PROPOSED RESEARCH

From the previous section we notice a lack in the literature of object density perception. We propose a research plan on changing perceived object density.

3.1 Problem

Density is a material property that represents mass per unit volume. We define *object density* as mass per apparent object volume, i.e. a hollow object has a lower object density than a solid object of the same apparent volume. Object density is perceived by integration of multimodal cues. Applying a force impulse (e.g. tapping the object, scratching the object) causes the object to vibrate. This can be an indicator for density by means of haptic feedback. Less dense objects vibrate more powerfully because there is less mass to displace. These vibrations are perceived not only haptically, but also aurally. Based on this, we hypothesize that augmenting interaction sound feedback can change the perception of object density.

This research focuses on how to manipulate perceived object density. We approach this problem by augmenting the sound heard when tapping on an object (see Figure 2). We further investigate what effect discrepant audio feedback has when discriminating between a hollow and a solid object by asking the following research questions:

RQ 1 *How does auditory feedback influence our multimodal perception of object density?*

RQ 2 *Can we achieve a different perception of object density (solid or hollow) by modifying auditory feedback during tapping, but keeping the object's physical properties fixed?*

3.2 Methodology

We investigate three possible methods to augment real contact sound to simulate object density (Figure 3). In all cases there is an offline phase. The methods are evaluated by their expected performance, realism and implementation difficulty.

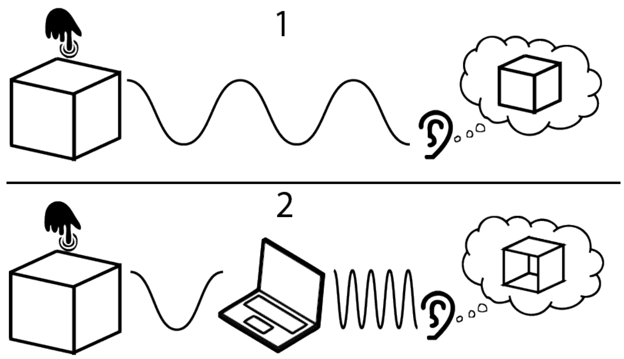

Figure 2: Our approach to modify perceived object density. Haptic interaction with a solid cube produces sound. (1) The cube is perceived as being solid. (2) The sound is modified so that the cube is perceived as hollow.

3.2.1 Pre-record audio samples

The simplest way to simulate object density with augmented contact audio is to play back the pre-recorded audio samples. In the offline phase, sound emitted by tapping a hollow and solid cube is recorded. At run-time, when the target object is touched the user hears the recorded sound. Sounds are cued by a Wizard of Oz style presentation where the supervisor initiates the playback.

Although this method is easiest to implement, we expect that audio will not have a high level of realism, because of variable force used when tapping and temporal discrepancies between moment of impact and audio sample being played.

3.2.2 Morph captured interaction sound

The second approach is to modify pre-recorded audio samples to captured impact duration and velocity. The preparation phase is the same as for the first method: record tapping and scratching sounds coming from interaction with cubes. A microphone captures vibrations that occur in the object when there is haptic interaction. Based on frequency analysis of the input, sound is morphed to more closely resemble the desired sound.

This method presents a good trade-off between implementation difficulty, run-time performance and realism. We expect it to perform better than playback of pre-recorded audio samples.

3.2.3 Deep learning of interaction audio/video

We plan to develop a deep learning algorithm that takes a video sequence as input and can predict corresponding sound features with a trained neural network. The sound features are then matched to a database of impact sounds features, and the best matches are stitched together and played back to the user.

We expect this method to be difficult to implement, but yield realistic results and easier to generalize to different interactions with objects.

3.3 Experiment

We propose a psychophysical experiment to evaluate the following hypotheses:

Hypothesis 1 *With varying object density and matching (real) sound, object density will be determined correctly (i.e., correctness will not significantly differ from 100%).*

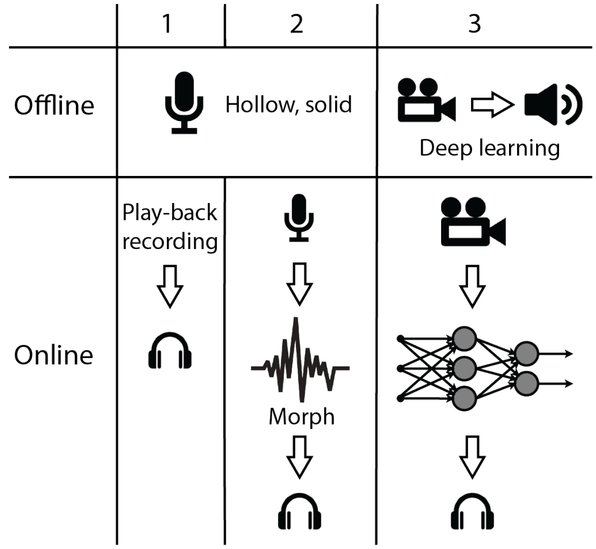

Figure 3: Schema of three methods that augment contact sounds: (1) Pre-record audio, (2) Morph real audio, and (3) Deep learning of interaction A/V. Every method has an offline and an online phase.

Hypothesis 2 *With varying object density and fixed neutral sound (white noise), object density has to be guessed (i.e., correctness will not significantly differ from 50%).*

Hypothesis 3 *With fixed object density and varying (pre-recorded) sounds, object density will be determined based on the sound, independent of the actual density.*

The platform to be used will consist of real 3D printed cubes of solid and hollow density firmly attached to the surface of a desk. There is no visual indication that the cubes are any different. A piezoelectric microphone is attached to the side of the cube, and the user wears external sound damping headphones. The dependent variable is *Perceived density* and can be either hollow or solid. Independent variables are *Cube density* (hollow or solid) that is changed throughout every iteration of the experiment, and *Interaction audio* which can be real sound, fixed sound (static noise), augmented hollow sound or augmented solid sound.

Procedure

A cube of variable density is placed in a holder on a table surface. Participants sit in front of the cube and can see it throughout the experiment. Participants are asked to only tap the cube on the top side, with their index finger. They are asked to decide whether the cube is hollow or solid, and until they do they can tap as many times as desired. After the participant decides this, the cube is changed with a cube with different object density (solid or hollow). Participants will not hear or see this exchange. In a first condition, verifying Hypothesis 1, participants hear real sound emitted by the cube. In a second condition, verifying Hypothesis 2, participants wear headphones that also cancel external sounds and hear fixed audio (static noise). In a third condition, verifying Hypothesis 3, participants wear headphones and hear augmented contact sound generated by our system. The augmented sound resembles either hollow or solid audio, and varies throughout every iteration of the procedure.

4. CONCLUSION

In this position paper we discussed an AR system that can manipulate perceived object physical properties. Three methods are proposed to simulate object density by augmenting interaction audio.

We expect that the findings of this research give insight into the effect of audio cues on our multimodal perception of object density of real objects. Furthermore the methods described can be used to simulate density of real objects, to an extent. 3D printed objects can be perceived as having a desired range of densities, without having to change the actual model or material, saving both time and material costs. Furthermore, this research contributes towards the ultimate goal of changing perception of physical properties to simulate all possible real objects.

Finally, for future work we introduce visual cues of object density to the AR system. We then explore the effect of augmented interaction sound on users' ability to discriminate between hollow and solid objects.

5. ADDITIONAL AUTHORS

Additional authors: Nina Rosa (Utrecht University, email: n.e.rosa@uu.nl).

6. REFERENCES

[1] A. Charpentier. Experimental Study of Some Aspects of Weight Perception. *Archives de Physiologie Normales Pathologiques*, 3:122–135, 1981.

[2] D. E. DiFranco, G. L. Beauregard, and M. A. Srinivasan. The Effect of Auditory Cues on the Haptic Perception of Stiffness in Virtual Environments. In *Proceedings of the ASME Dynamic Systems and Control Division*, volume 61, pages 17–22, 1997.

[3] T. Hachisu, M. Sato, S. Fukushima, and H. Kajimoto. Augmentation of Material Property by Modulating Vibration Resulting from Tapping. In *Proceedings of the International Conference on Human Haptic Sensing and Touch Enabled Computer Applications*, pages 173–180, 2012.

[4] S. Hashiguchi, Y. Sano, F. Shibata, and A. Kimura. RV Dynamics Illusion: Psychophysical Influence on Sense of Weight by Mixed-Reality Visual Stimulation of Moving Objects. In *Proceedings of the International Conference on Virtual, Augmented and Mixed Reality*, pages 55–64, 2014.

[5] Y. Hirano, A. Kimura, F. Shibata, and H. Tamura. Psychophysical Influence of Mixed-Reality Visual Stimulation on Sense of Hardness. In *Proceedings of IEEE Virtual Reality*, pages 51–54, 2011.

[6] M. Kagimoto, A. Kimura, F. Shibata, and H. Tamura. Analysis of Tactual Impression by Audio and Visual Stimulation for User Interface Design in Mixed Reality Environment. In *Proceedings of the International Conference on Virtual and Mixed Reality*, pages 326–335, 2009.

[7] T. Narumi, S. Nishizaka, T. Kajinami, T. Tanikawa, and M. Hirose. Augmented Reality Flavors: Gustatory Display Based on Edible Marker and Cross-modal Interaction. In *Proceedings of Human Factors in Computing Systems*, pages 93–102. ACM, 2011.

[8] P. Punpongsanon, D. Iwai, and K. Sato. SoftAR: Visually Manipulating Haptic Softness Perception in Spatial Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics*, 21(11):1279–1288, 2015.

[9] N. Rosa, W. Hürst, W. Vos, and P. Werkhoven. The Influence of Visual Cues on Passive Tactile Sensations in a Multimodal Immersive Virtual Environment. In *Proceedings of the ACM International Conference on Multimodal Interaction*, pages 327–334, 2015.

[10] K. Van Den Doel, P. G. Kry, and D. K. Pai. FoleyAutomatic: Physically-based Sound Effects for Interactive Simulation and Animation. In *Proceedings of ACM Computer Graphics and Interactive Techniques*, pages 537–544, 2001.