Creating an Impression of Virtual Liquid by Modeling Japanese Sake Bottle Vibrations

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ABSTRACT

It is known that visual, auditory, and tactile modalities affect the experiences of eating and drinking. One such example is the “glug” sound and vibration from a Japanese sake bottle when pouring liquid. Previous studies have modeled the wave of the vibration by summation of two decaying sinusoidal waves with different frequencies; we examined the validity of this model by subjective evaluation. Furthermore, to enrich expression of various types of liquid, we included two new properties of liquid: the viscosity and the residual amount of liquid, both based on recorded data.

Keywords: Haptic rendering, Pouring water, Tactile display.

Index Terms: H.5.1. [Information interfaces and presentation]: Multimedia Information System – Artificial and virtual realities

1 INTRODUCTION

It is known that when we eat and drink, the serving vessels affect the dining experience, as well as the appearance and flavor of the food. Wanshink et al. found that the size of the plates and spoons affects our perceptions of the amount of food in a dish [1]. In addition, they showed that a container affected the consumption of not only food but also drink, and people poured more juice into short, wide glasses than into tall, slender glasses [2]. They also found that larger packages encourage greater use than smaller packages [3]. Hummel et al. found that the shape of a glass influences the perception of wine aromas [4]. Not only visual but also tactile and auditory stimuli can affect impressions of food and drink. Brown reported that different packaging affected the perception of freshness [5]. Zampini et al. found that the perception of the crispness and staleness of potato chips was affected by modifying their sounds [6].

Some studies have reported that it is possible to regulate the consumption of food by changing the appearance of the container using Augmented Reality technologies. Sakurai et al. and Suzuki et al. showed that the size of a virtual dish and cup changed the perception of satiety and the amount of food or drink consumed [7] [8].

In this study, we have focused on the sound and vibration of liquid being poured from a Japanese sake bottle as an audio-haptic rendition of the liquid. Sake bottles are known for their unique “glug” sound and vibration. We believe that these sounds and vibrations affect subjective impressions of the liquid in the bottle. Previous work has shown that the wave of the vibration can be modeled by summation of two decaying sinusoidal waves with different frequency [9]. It has also been shown that the subjectively chosen amount of water to pour is affected by presenting this vibration while pouring [10]. In this paper, after examining the validity of the proposed model by subjective evaluation, we include two new properties of liquid to enrich expressions. One is viscosity, and the other is the residual amount of liquid, both based on recorded data. We anticipate that expression of these properties will enable more efficient control of user behavior; specifically, we anticipate that high viscosity will remind users of sweeter liquids and may suppress consumption, which will be our next step.

2 VIBRATION OF POURING WATER

In previous work [9], the vibration played while water was being poured from a sake bottle was modeled by the following equation consisting of two decaying sinusoidal waves with different frequencies:

$$\mathrm{Q}(\theta,t)=\sum_{n=1}^{2}A_n(\theta)\exp(-B_n(\theta)t)\sin(2\pi f_n(\theta)t) \qquad (1)$$

Here, A_1 and A_2 are the amplitude of waves, B_1 and B_2 are attenuation coefficients, f_1 and f_2 are frequencies of sinusoidal waves, and t is the duration. n = 1 is the low-frequency decaying sinusoidal waves, n = 2 is the high-frequency decaying sinusoidal waves.

A device shaped like a sake bottle was also manufactured to present the modeled vibration. The structure and appearance of the bottle-like device is shown in Figure 1. It consists of an accelerometer (KXM52-1050, Kionix), a vibrator (Haptuator Mark2, Tactile Labs Inc.), a digital audio amplifier (RASTEME SYSTEMS CO. LTD. RSDA202), a micro controller (Arduino, Arduino Duemilanova), and a PC. When a user tilts the device, a suitable vibration is generated by this device according to its tilt angle.

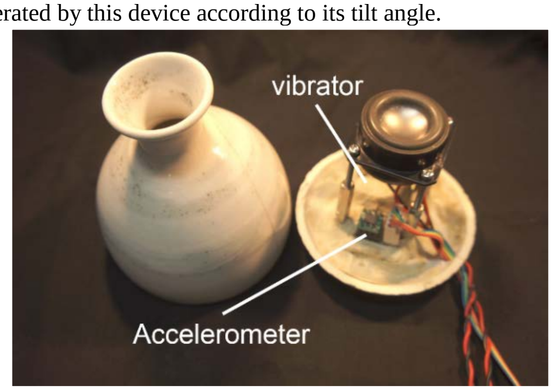

Figure 1: Sake bottle type device

3 EVALUATION OF THE EFFECTIVENESS OF THE MODEL

We evaluated validity of the proposed model. Because the model is composed of two decaying sinusoidal waves, we compared the following three waves: a decaying sinusoidal wave with lower frequency (f_1), a decaying sinusoidal wave with higher frequency (f_2), and the modeled wave (f_1 + f_2).

We recruited six people, five males and one female, aged 22 to 24, as participants.

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3.1 Procedure

First, the participants practiced tilting the sake bottle-type device several times to be able to tilt it quickly within a range of 110° to 160°. When the tilt angle was outside of that range, they were visually instructed to restore the angle.

Second, they were asked to pour water from a real sake bottle five times. The bottle was the same type used for the device, and contained 300 ml of water. The participants were instructed to empty the bottle.

Third, the participants were asked to hold the sake bottle-type device, and two out of three types of vibration were presented at random. The vibrations were presented for five seconds each, which is a typical duration for pouring 300 ml of water. After presenting two out of the three types of vibrations, the participants were asked to answer which vibration was more similar to the pouring of real water. There were six combinations (3 × 2), three trials per combination, and 18 trials in total. White noise was presented during the experiment to mask auditory cues.

3.2 Results

Table 1 shows the number of responses in the experiment. Values in the table indicate the number of responses saying that the horizontal axis conditions were closer to the feeling of real pouring water, compared to the vertical axis conditions. We calculated the scale values using Thurston's method (Figure 2). In this scale, it is obvious that the feeling of modeled waves consisting of low-frequency and high-frequency components was closer to the real sensation, compared to the single waves. There were no significant differences in the trend of the answers of each participant ($X^2(40) = 64.33$, $p < 0.01$).

Table 1. The number of responses

	Modeled wave	High-frequency wave	Low-frequency wave
Modeled wave		29	34
High-frequency wave	7		31
Low-frequency wave	2	5	

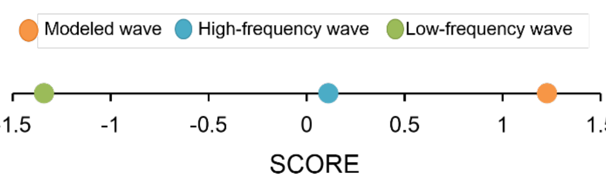

Figure 2: Score by Thurston's method

Unprompted comments after the experiment included, "The sense did really seem real" and "The vibration of the high sounds, such as the sound of water, is the most important in real cases, but the feel of the water was more natural when there was also a low vibration." These comments suggested that the wave pattern we modeled effectively reproduced the vibration, and sometimes "enhanced" the sense of pouring liquid.

4 Expression of Viscosity of Liquid

As a first step to enriching the expression of our system, we focused on viscosity. Although there are numerous types of potable liquids, there are only a limited number of words that express physical properties of liquids; words related to viscosity, such as "muddy" and "syrupy," constitute a major part of that lexicon. This implies the importance of expressing viscosity. In a practical situation, if we can add viscosity to a real fluid, it might cause users to recall "sweeter" liquids and change their behavior.

4.1 Measurement

4.1.1 Procedure

We recorded the vibration of a real bottle when pouring liquids of different viscosities. We closed the cap of a sake bottle filled with liquid, tilted it, removed the cover, and measured the vibration of the pouring liquid using an acceleration sensor attached to the center of the bottle. The sampling rate was 25 kHz. The angles of tilt were 90°, 115°, 135°, 155°, and 180°. We prepared liquids with three viscosities: 1000 mPa*s, 2000 mPa*s, and 4000 mPa*s. We used Sofutia S (NUTRI) to add viscosity to the water. The measurement was conducted 75 times (five angles, five repetitions each, with three types of liquids).

4.1.2 Results and modeling

The measured data showed repeated similar waveforms, so we extracted one of the waveforms from the measured data (Figure 3). Obviously, as the liquid viscosity increased, the overall amplitude also increased. A similar result was obtained at other angles.

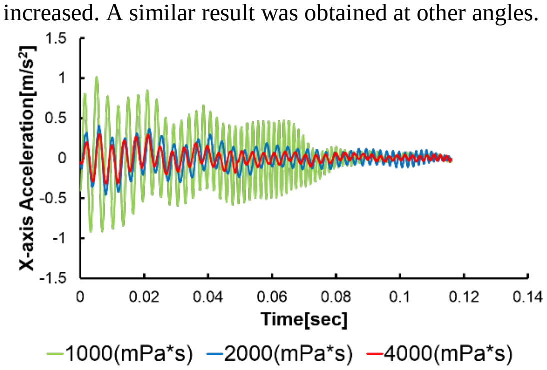

Figure 3: One wave pattern extracted by measuring the results of pouring different liquids (Bottle angle 135°)

We performed a Fourier transform (Figure 4). Two peaks appeared, regardless of viscosity. However, comparing the ratio of high-frequency peaks to low-frequency peaks, the ratio became smaller with larger viscosities, i.e. the more viscous liquid had a relatively lower sound.

Based on these observations, we considered two methods for reproducing the feel of viscous liquid. One was to lower the amplitude of the whole wave pattern, and the other was to change the amplitude ratio of low-frequency and high-frequency waves.

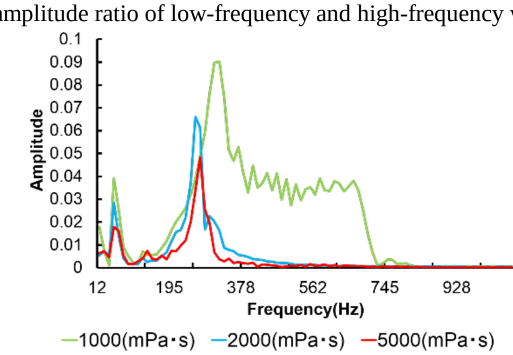

Figure 4: Frequency components of vibration of different liquids (Bottle angle 135°)

4.2 Subjective evaluation

4.2.1 Procedure

To determine which contributes most to the perception of viscosity, we conducted a subjective evaluation. We recruited a group of five naïve participants, two males and three females, 21 to 22 years of age. White noise was presented to the participants by headphones throughout the experiment to mask audio cues.

In the first set, the model simulating the vibration of normal water (the basic model), and the model that reduced the amplitude of the entire waveform (the amplitude model), were each presented alternately. Subjects were asked to freely describe the difference between the two

In the second set, the basic model and the model that changed the ratio of low-frequency and high-frequency amplitude (the frequency model) were presented alternately. Again, subjects were asked to freely describe the difference between the two. The total amplitude ($A_1 + A_2$ in equation (1)) was kept constant in the frequency model. The order of the two sets was randomized among participants.

4.2.2 Results and discussion

When the amplitude model was presented, the participants described it as "light" or "smooth" compared to the basic model. This means that the amplitude model did not express the increased viscosity. On the other hand, when the frequency model was presented, the participants commented that "the bubble seems to become small" and “Liquid viscosity becomes higher and it flows slowly.” This result suggested that the frequency model, in which the ratio of low-frequency and high-frequency components changes, is effective in expressing viscosity.

4.3 Reproduction of viscous liquid vibration

We found that the frequency model is effective in expressing different liquid viscosities. The amplitude is dependent on the tilt angle and the viscosity of liquid, but we observed that the ratio between A_1 and A_2 is constant. Thus, A_1, A_2 is represented by the following equation:

$$A_1 = cA_{sum}(\theta), A_2 = (1-c)A_{sum}(\theta) \qquad (2)$$

Where A_{sum} is the sum of two amplitude and c is the ratio of the two decaying sinusoidal wave amplitudes determined by the viscosity of the liquid, which is 0.33 in the case of water.

4.4 Threshold of subjective viscosity

We conducted an experiment to verify that the subjective viscosity is altered by changing the ratio of high- and low-frequency components. We also measured the threshold of the viscous sensation. We recruited three people, two male and one female, aged 21 to 22, as participants.

4.4.1 Experimental environment and procedure

Participants were asked to compare the subjective feeling of the liquid viscosity of the comparison stimulus versus a standard stimulus. As the standard stimulus, we presented $c = 0.33$ in equation (2), which is close to the vibration of water. We prepared nine kinds of vibration: $c = 0.18$, 0.22, 0.26, 0.29, 0.33, 0.37, 0.41, 0.45, and 0.49 as the comparison stimuli. The maximum amplitude of the wave was adjusted to be the same.

The participants held the device at a fixed 90° angle and were presented the two stimuli. White noise was presented during the experiment to mask auditory cues. Participants were asked to answer which vibration had a greater viscosity.

There were 10 repetitions for each combination, and 90 repetitions in total.

4.4.2 Results and discussion

The results and the logistic curve fitting are shown in Figure 5. As we expected, the large c (ratio of the two decaying sinusoidal waves) clearly gave the sensation of larger viscosity. The 25%-75% thresholds were at c = 0.29 and c = 0.42. After the experiment, a participant commented that making the judgment was easy, which implies that our method of presenting viscosity is quite robust.

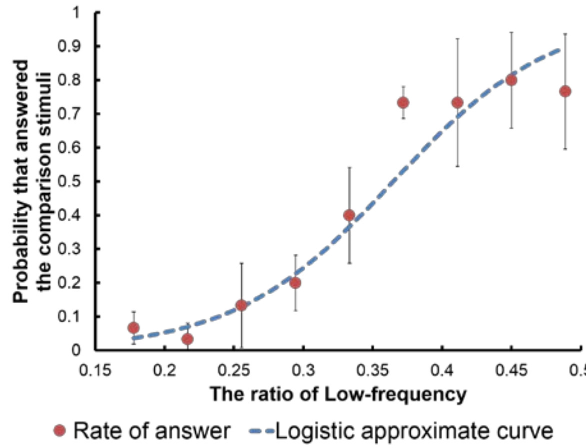

Figure 5: Probability that the comparison stimulus is chosen

5 Modeling the vibration as a function of the residual quantity

As a second step to enrich the expression of our system, we modeled vibration as a function of the residual amount in a sake bottle. This is considered important for future application, because one example of a planned future application is to affect users' consumption of liquid.

5.1 Measurement

5.1.1 Measurement system

The measurement system consists of a computer, an accelerometer (KXM52-1050, Kionix), an electric scale (EK-6100i, A&D), and a sake bottle that is the same as the device. Capacity of the sake bottle was 300 ml. The sake bottle was placed on an electronic scale with a stand that supported the bottle. The vibration of pouring water was recorded as acceleration data at a sampling rate of 25 kHz, and the residual quantity in the sake bottle was recorded as weight data at a sampling rate of 5 Hz.

5.1.2 Procedure

The sake bottle was fixed to the stand. We filled the bottle with water, covered its mouth, and tilted it. The tiling angles were 90° (horizontal), 115°, 135°, 155°, and180° (upside-down). We started the measurement upon removing the cover. The measurement was conducted five times for each angle, for 25 total trials.

5.1.3 Results

Figure 6 shows a representative graph of the recorded data with different tilt angles. Although the outflow speeds and the amount of water remaining after the measurement were different across different tilting angles, the outflow speed was almost constant regardless of time.

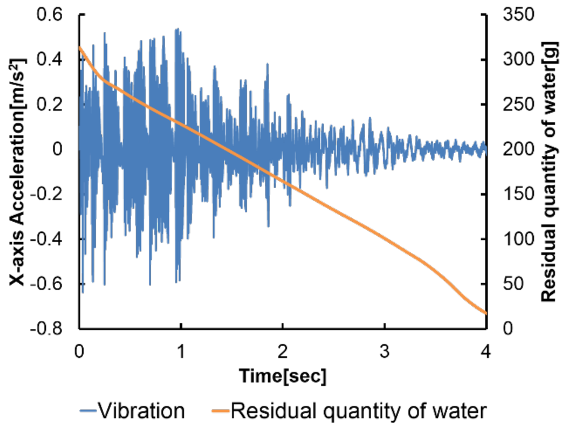

Figure 6: Vibration and quantity of water being poured

(Bottle angle 135°)

5.2 Modeling

5.2.1 The residual quantity

The measured data show that the residual quantity of water decreases as a linear function of time, which was observed for all measured angles. We modeled the residual quantity of water in accordance with the changing angle, as follows:

$$V(\theta,t)=V_0-\int k(\theta)tdt \qquad (3)$$

where V_0 is the initial quantity of water, $k(\theta)$ is the decreasing rate of water that is equivalent to the tilt angle, and t is time.

5.2.2 Change in the maximum amplitude

As we mentioned in section 2, the recorded data are considered as a train of waves, each wave consisting of two decaying sinusoids. We modeled each wave unit using equation (1), and observed that B_1 and B_2 were almost random, f_1 and f_2 were almost constant, whereas A_1 and A_2 decreased with time, but the ratio of A_1 and A_2 did not change with time or with the angle of the bottle. Therefore, we plotted the sum of the amplitude (A_1+A_2) as a function of the residual quantity of water, as shown in Figure 7. We observed that the sum of the amplitude can be fitted to a linear function of residual quantity ($y = 0.0027x-0.2277$; $R^2 = 0.6358$). By predicting the residual amount using equation (3), and calculating amplitudes using expressions (1) and (2), we can model the vibration waves in real time no matter how the tilt angle changes.

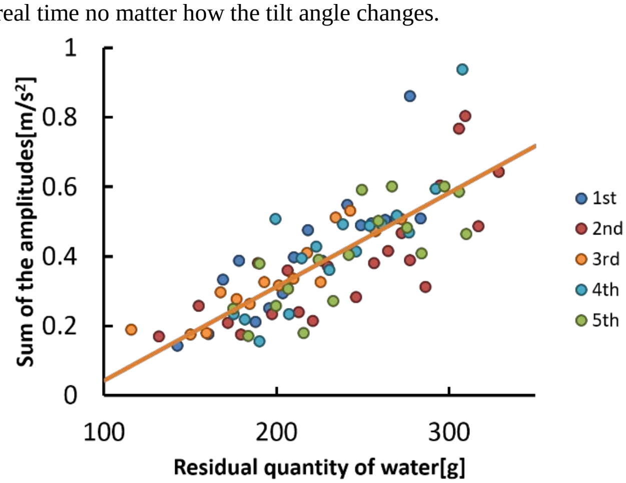

Figure 7: Plot of the amplitude (Bottle angle 135°)

5.3 Reproduction of vibration

We used a sake bottle type device to observe the appropriateness of our model. In our preliminary evaluation with participants who participated in the previous evaluations, the participants mostly commented that the sensation became much more natural than in the previous model, and they could easily estimate the residual quantity of water. They typically tried to adjust the tilt angle of the device while pouring, and found that the "glug" vibration changed naturally with both tilt angle and time. On the other hand, they also commented that they felt as if the amount of water was less than they initially expected. This may be because we presented a stronger than natural vibration that gave the impression of a larger amount of water.

6 Conclusion

The purpose of this project is to add haptic rendition to our daily drinking experience, particularly focusing on the "glug" feeling of a Japanese sake bottle. In this study, after examining the validity of the previously proposed model of vibration by subjective evaluation, we included two new properties of liquids to enrich expression. One is viscosity and the other is the residual amount of liquid, both based on recorded data.

Although we are currently using a bottle-type device that cannot be used for real drinking, we have already made a type of attachment that can be used with a real bottle. Our next step is to attempt rendition of real liquid using our findings, such as the idea that high viscosity reminds users of sweeter liquids and may suppress consumption.

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