The 33rd Annual Conference of the Japanese Society for Artificial Intelligence, 2019

Vibrational Artificial Subtle Expressions to Convey System's Confidence Level to Users

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Artificial subtle expressions (ASEs) are machine-like expressions used to convey a system's confidence level to users intuitively. So far, auditory ASEs using beep sounds, visual ASEs using LEDs, and motion ASEs using robot movements have been implemented and shown to be effective. In this paper, we propose a novel type of ASE that uses vibration (vibrational ASEs). We implemented the vibrational ASEs on a smartphone and conducted experiments to confirm whether they can convey a system's confidence level to users in the same way as the other types of ASEs. The results clearly showed that vibrational ASEs were able to accurately and intuitively convey the designed confidence level to participants, demonstrating that ASEs can be applied in a variety of applications in real environments.

1. Introduction

Many studies in human-computer interaction have tried to use vibrational information as a communication channel with users based on the perceptual features of haptic sense [Ryu 2008]. Specifically, vibrational information was utilized to notify the user of the progress of the system's functions [Cauchard 2016], urgent information for pedestrians [Saket 2013] or tactile icons for blind people [Qian 2011]. This vibrational information was also utilized to represent the system's emotional states to users [Mathew 2005]. However, so far, there have been no studies that use vibrational information for conveying the system's confidence level to users in a complementary manner.

In terms of conveying system's confidence level, Komatsu et al. [2010] already proposed using artificial subtle expressions (ASEs) as machine-like expressions used to convey a system's confidence level to users intuitively in a complementary manner. Specifically, they proposed two simple beeping sounds used as "auditory ASEs": a flat sound (flat auditory ASE) and a sound with a decreasing pitch (decreasing auditory ASE). These auditory ASEs were added after the system's verbal suggestions. They then showed that suggestions followed by decreasing auditory ASEs intuitively conveyed a low system confidence level to users (Figure 1).

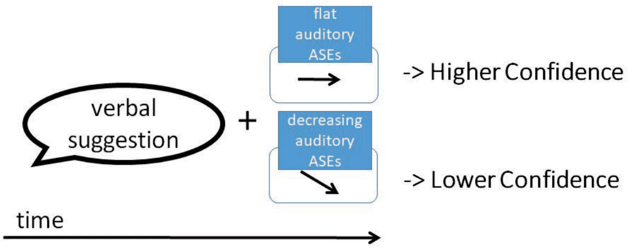

Figure 1. Auditory artificial subtle expressions (ASEs)

The purpose of this study is to propose "vibrational ASEs" based on our knowledge of "auditory ASEs." In this paper, we first describe the design of vibrational ASEs and then describe experiments done to confirm whether vibrational ASEs can convey a system's confidence level to users in the same way as auditory ASEs. Finally, we discuss the pros and cons of vibrational ASEs on the basis of the results of our experiments.

2. Design of Vibrational ASEs

We think that vibrational ASEs should be added after a system's verbal suggestions to convey a higher or lower confidence level to users like auditory ASEs. In the case of auditory ASEs, a flat sound (a flat auditory ASE) conveys a higher confidence level, and a sound with a decreasing pitch (decreasing auditory ASE) conveys a lower confidence level to users. We thus prepared two vibration patterns used as vibrational ASEs: one to convey a system's higher confidence level, and the other, a lower confidence level. We assumed that vibrations with a fixed frequency (flat vibrational ASE) would convey a higher confidence level and that vibrations with a continuously or gradually decreasing frequency (decreasing vibrational ASE) would convey a lower confidence level; that is, the time variation pattern of the frequency of vibrations was almost the same as that of auditory ASEs (Figure 2).

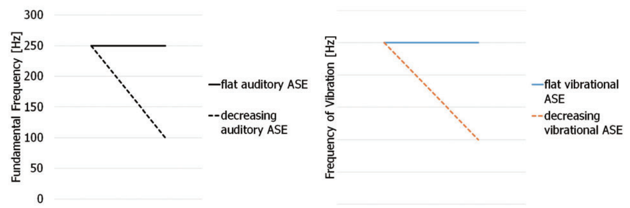

Figure 2. (left) Auditory ASEs and (right) vibrational ASEs at beginning

However, we cannot control the degree of frequency of the vibration motors on a smartphone because the vibration API of smartphones does not provide a method for controlling the frequency of the motors. It only provides a method for controlling the on/off statuses on the basis of vibration patterns.

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Therefore, we prepared the following two patterns for flat and decreasing vibrational ASEs (Figure 3).

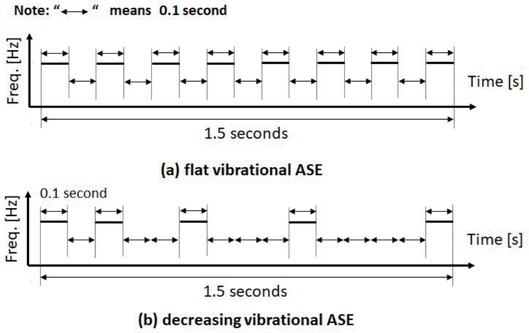

Figure 3. Vibrational ASEs. (a) Flat vibrational ASE and (b) decreasing vibrational ASE.

- Flat vibrational ASE: eight 0.1-second long vibrations with 0.1-second long intervals [Figure 3(a)].
- Decreasing vibrational ASE: five 0.1-second long vibrations. Lengths of intervals are 0.1, 0.2, 0.3, and 0.4 seconds [Figure 3(b)].

We preliminarily confirmed that gradually lengthening the intervals between vibrations made users feel the sensation of deceleration or decreasing velocity, while a fixed length of vibration intervals made users feel the sensation of a constant velocity. The total durations of flat and decreasing vibrational ASEs were both 1.5 seconds.

3. Experiment

3.1 Overview

We conducted an experiment to investigate whether the proposed vibrational ASEs were able to convey a system's confidence level to users accurately and intuitively; that is, whether the flat vibrational ASE conveys a higher confidence level and the decreasing vibrational ASE a lower confidence level.

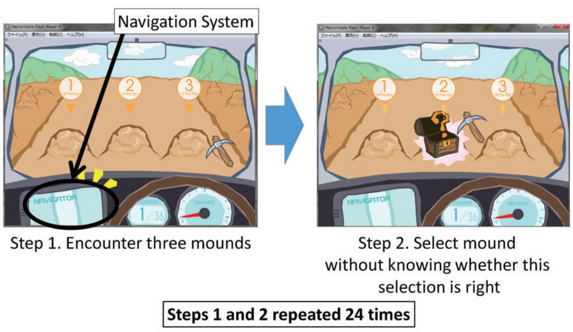

Figure 4. Driving treasure hunting video game

As an experimental setting, we used a "driving treasure hunting" video game (Figure 4). In this game, the game image scrolls forward on a straight road as if the participant is driving a car with a navigation system and with small three mounds of dirt appearing along the way. A coin is inside one of the three mounds, while the other two mounds contain nothing. The game ends after the participant encounters 24 sets of mounds (24 trials).

The purpose for each participant is to get as many coins as possible. Which of the three mounds has the coin is randomly assigned. In each trial, the navigation system to the left of the driver seat (circled in the left image of Figure 4) told them in which mound it expected the coin to be by using a verbal suggestion followed by a vibrational ASE. The participant could freely accept or reject the navigation system's suggestions. In each trial, even after the participant selected one mound among the three, he/she was not told whether the selected mound had the coin or not (only a question mark appeared from the opened treasure box, as shown in the right image of Figure 4). The participants were then informed of their total numbers of coins only after they finished all 24 trials. It took about three minutes to complete this game. This game setting was commonly used in most former studies on ASEs, and the design in this study is fairly standard in human factor literature; it is a variation of a lane change task, which is a ISO-standardized driving task (ISO 17387:2008).

3.2 Stimuli

In this experiment, the navigation system used Japanese speech to suggest to the participants the expected location of the coin, that is, "ichi-ban (no. 1)," "ni-ban (no. 2)," or "san-ban (no. 3)." These speech sounds were created by adding robotic-voice effects to the recorded speech of one of the authors. The duration of these three sounds was 0.5 seconds.

One of two vibrational ASEs was played immediately after the verbal suggestion (Figure 5). These two ASEs were the flat vibrational ASE or decreasing vibrational ASE. The suggestions followed by decreasing vibrational ASEs were designed to inform users of the system's lower level of confidence in its suggestions, while those with flat vibrational ASEs were to inform them of a higher level of confidence.

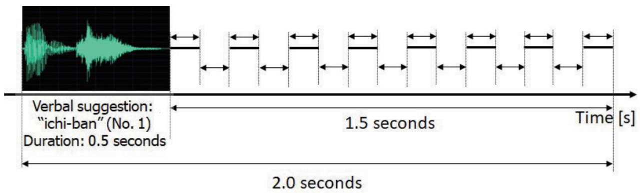

Figure 5. Speech waveform of suggestion "ichi-ban" with flat vibrational ASE

Here, the total length of a suggestion and a vibrational ASE was exactly 2.0 seconds (suggestion: 0.5 seconds, vibrational ASE: 1.5 seconds, and no interval between them). There were 6 variations of stimulus (3 suggestions × 2 ASEs). Among 24 trials of mound selection, each of these 6 variations was presented to the participants 4 times in a random order.

While the participants' played the game, we measured the response time, which was defined as the duration between the onset of the verbal suggestions and the participants' mound selection, and this was automatically measured by the experimental system implemented in the game environment. After playing the game, the participants were asked to answer the following two questions.

Q1: "Did you feel the vibrations during this game?"

Q2: "How many patterns of vibration did you notice?"

3.3 Participants

20 Japanese undergrads and graduate students participated (15 males and 5 females; 19 – 24 years old). These participants voluntarily responded to a call for participants from the authors. The participants were asked to be seated at a table, and an experimenter passed out a consent form with instructions on the experiment. These instructions and the experimenter never mentioned or explained the vibrational ASEs given after suggestions made to the participants. Afterward, a smartphone (Arrows M03, Fujitsu Limited, OS: Android 6.0.1) was passed to the participants, and they were asked to start the video game while holding the smartphone in their hands (Figure 6). The game was implemented in a web browser (Google Chrome: 60.0.3112.116) with JavaScript and the PixiJS library.

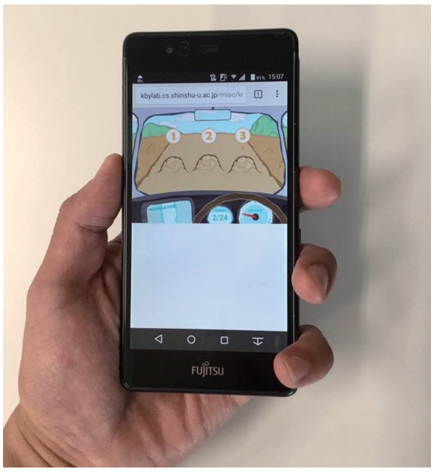

Figure 6. Smartphone and driving treasure hunting video game

3.4 Results

To investigate whether the vibrational ASEs could convey the designed confidence level to the participants or not, we calculated the rejection count, which indicates how many system suggestions were rejected by the participants (maximum rejection count: 12 times for each confidence level). For all 20 participants, the average rejection count of the 12 flat vibrational ASEs was 1.55 (SD = 1.99), while that of the 12 decreasing vibrational ASEs was 4.60 (SD = 4.13, Table 1).

Table 1. Average rejection counts for flat and decreasing vibrational ASEs

Type of vibrational ASE	Average rejection count
Flat	1.55 (SD = 1.99)
Decreasing	4.60 (SD = 4.13)

The rejection counts were analyzed with a dependent t-test (independent variable: flat/decreasing vibrational ASEs, dependent variable: rejection counts). The results showed significant differences between these two ASEs [$t(19) = 2.62$, $p = .017$, Glass' delta = 1.53], so we observed that suggestions with decreasing vibrational ASEs showed higher rejection counts compared with those with flat vibrational ASEs. Consequently, we confirmed that vibrational ASEs can convey the designed confidence level to the participants in the same way as auditory ASEs.

From the participants' answers to the two questions, Q1 and Q2, presented after the experiment, we found that all 20 participants felt vibrations during the game, but only 8 participants answered that there were two vibration patterns. We then compared the average rejection counts of the participants who were unaware that there were two vibrations with those of the other participants who were aware of this fact (Table 2). A 2 × 2 mixed ANOVA [within independent variable: vibration patterns (flat/dec.), between independent variable: awareness of two vibrations (Yes/No), dependent variable: rejection counts] showed that there were no significant differences in the interaction effects [$F(1,39) = 0.23$, n.s., effect size $f = 0.11$] and in the main effect of the between independent variable [$F(1,39) = 2.12$, n.s., effect size $f = 0.34$], but there was a significant difference in the main effect of the within independent variable [$F(1,39) = 6.82$, $p < .05$, effect size $f = 0.62$]. These results showed that all participants responded to the given stimuli in a similar way regardless of their awareness of the vibration patterns. This result clearly indicates that the participants responded to these vibrations intuitively without deeply considering what these patterns meant.

Table 2. Average rejection counts for two vibrational ASEs in terms of the participants' awareness of vibration patterns

Participants who noticed two types of vibrations	Average Rejection count for Flat ASE	Average Rejection count for Dec. ASE
Yes: 8 participants	2.00 (SD = 2.50)	5.75 (SD = 3.93)
No: 12 participants	1.25 (SD = 1.48)	3.83 (SD = 4.07)

3.5 Additional Experiment

We thus conducted a consecutive experiment to investigate whether simultaneously presenting verbal suggestions and the proposed vibrational ASEs could convey a system's confidence level to users accurately and intuitively. The experimental setting and procedure was completely the same as that of experiment 1 except for the timing at which the verbal suggestions and vibrational ASEs were presented.

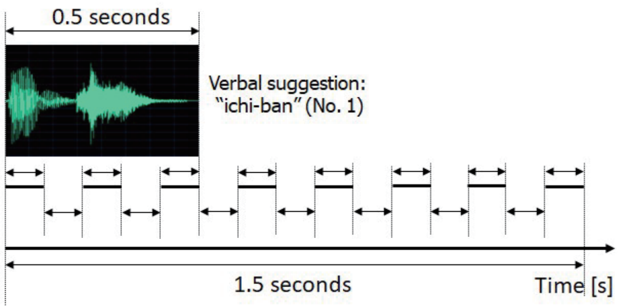

Figure 7. Speech waveform of suggestion "ichi-ban" and flat vibrational ASE in experiment 2

In this experiment, the vibrational ASEs were presented simultaneously with the verbal suggestions (Figure 7). The length of the suggestions with vibrational ASEs was exactly 1.5 seconds (suggestions: 0.5 seconds, vibrational ASEs: 1.5 seconds).

20 Japanese undergrads and graduate students participated (14 males and 6 females; 20 – 23 years old). These participants

voluntarily responded to a call for participants, and they did not participate in the former experiment.

To investigate whether vibrational ASEs presented simultaneously with verbal suggestions can convey the designed confidence level to the participants or not, we calculated the rejection counts. For all 20 participants, the average rejection count of the 12 flat vibrational ASEs was 1.65 (SD = 2.01), while that of the 12 decreasing vibrational ASEs was 5.30 (SD = 3.58, Table 3).

Table 3. Average rejection counts for flat and decreasing vibrational ASEs in experiment 2

Type of vibrational ASE	Average rejection count
flat	1.65 (SD = 2.01)
decreasing	5.30 (SD = 3.58)

The rejection counts were analyzed with a dependent t-test (independent variable: flat/decreasing vibrational ASEs, dependent variable: rejection counts). The results showed significant differences between the two ASEs [$t(19) = 3.92$, $p = .001$, Glass' delta = 1.82], so we confirmed that suggestions with decreasing vibrational ASEs showed a higher rejection count compared with those with flat vibrational ASEs, the same as in experiment 1. Therefore, we confirmed that vibrational ASEs presented simultaneously with verbal suggestions also could convey the designed confidence level to the participants.

Table 4. Average rejection counts for two vibrational ASEs in terms of the participants' awareness of vibration patterns

Participants who noticed two types of vibrations	Average Rejection count for Flat ASE	Average Rejection count for Dec. ASE
Yes: 11 participants	1.45 (SD = 2.06)	5.18 (SD = 3.90)
No: 9 participants	1.89 (SD = 1.91)	5.44 (SD = 3.13)

From the participants' answers for the two questions, Q1 and Q2, presented after the experiment, we found that all 20 participants had noticed that they felt vibrations during the game, and 11 participants answered that there were two vibration patterns. We then compared the average rejection counts of the participants who were unaware or aware of the two vibrations (Table 4). A 2 × 2 mixed ANOVA [within independent variable: vibration patterns (flat/dec.), between independent variable: awareness of two vibrations (Yes/No), dependent variable: rejection counts] showed that there were no significant differences in the interaction effects [$F(1,39) = 0.01$, n.s., effect size $f = 0.02$] and in the main effect of the between independent variable [$F(1,39) = 0.13$, n.s., effect size $f = 0.08$], but there was a significant difference in the main effect of the within independent variable [$F(1,39) = 14.39$, $p < .01$, effect size $f = 0.89$]. These results also clearly indicate that the participants still responded to these vibrations intuitively, the same as in the former experiment.

4. Discussions and Conclusions

We tested the template in the following versions. In this paper, we proposed a novel type of ASE that uses vibration, called vibrational ASEs. We implemented the vibrational ASEs on a smartphone and conducted experiments to confirm whether they can convey a system's confidence level to users in the same way as the other types of ASEs. The results clearly showed that vibrational ASEs were able to accurately and intuitively convey the designed confidence level to the participants.

One of the noteworthy achievements of this study was that it was found that vibration information can be utilized as ASEs in the same way as auditory, visual (LED-based), and motion ASEs. As already mentioned, most smart devices are equipped with vibration motors, so the results of this study will drastically increase the applicability of the ASEs into various kinds of devices. The other noteworthy achievement was that simultaneous usage of vibrational ASEs and verbal suggestions was shown to be possible. If the modalities of the main protocol and complementary protocol were the same, simultaneous usage would be difficult; for example, if verbal suggestions and auditory ASEs were presented simultaneously, the verbal suggestions would mask or overlap the auditory ASEs, and vice versa, so eventually, the main protocol and complementary protocol would interfere with each other. However, the results of this study clearly showed that it is possible to present the main protocol and complementary protocol simultaneously in the case that the modalities of these protocols are different. This finding would contribute to expanding the variety of stimuli for users and also to shortening the length of the stimuli.

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