TACTILE DISCRIMINATION USING A 2-CHANNEL VIBRATION SYSTEM ON DIFFERENT BODY PARTS

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ABSTRACT

A multichannel tactile feedback system was developed to test human subjects' sensitivity and discrimination ability using different vibration patterns. Small vibrating motors were attached to the body, and subjects reported on their sensation comparing the left and right side of the body (arms, ankles, and wrists) in a 2-channel signal presentation. Results showed that the most sensitive spot is the wrist position, followed by the ankles. Furthermore, changes in the vibration frequency are challenging to detect; thus, using different temporal patterns of the signals is more straightforward in an actual application.

Keywords: *tactile feedback, vibrations, haptics, assistive technology*

1. INTRODUCTION

Multimodal user interfaces incorporate auditory, visual and tactile/haptic input/output devices. The visual modality is the most important during feedback, followed by audio signals [1, 2]. Both modalities can provide 2D and 3D representation of stimuli from simple desktop applications to fully immersive 360-degree augmented and virtual reality solutions. VR headsets offer real-time audio-visual rendering in gaming, exercising or in simulators. For input, keyboards, touch screens, mouse, and game controllers are the most commonly used devices however, speech recognition systems have been developed and improved for interpreting speech commands.

The tactile modality is generally reserved for feedback and has been integrated in special applications. Mobile devices (tablets, smart phones) have built-in buzzers and vibrators to alert the users to incoming calls and messages, or to give feedback during typing [3]. Sophisticated high-tech solutions, such as combat simulators, virtual realities, medical applications may use haptics to provide additional information. The more modalities are present simultaneously, the greater the cognitive load is on the user whilst dealing with the multimodal sensory information. Furthermore, the integration of all these modalities into one functioning virtual environment requires straightforward hardware and software solutions with a focus on human factors and cognitive aspects. Cognitive infocommunications and the Internet of Digital Reality (IoD) cover all these aspects [4–6].

The perception and discrimination ability of humans regarding vibrations has not been investigated in such details than it has been for vision and audio perception [7–11]. Different parts of the body show different sensitivity depending on thickness and actual moisture of the skin, body hair or layers of clothing. The term sensitivity covers both the perception accuracy of amplitude and frequency of vibrations at a given point or area of the body. Spatial accuracy means the ability to discriminate between excitation points on the skin (distance). Temporal patterns or length of the excitation signal also influence the results. Finally, the human capability to remember and recall vibrations (memory), and to process simultaneously presented excitation signals during multichannel playback is a key factor to determine how applications can embody tactile feedback.

Besides exploring human perception limits, develop-

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ments also target the creation of user friendly output devices using vibrations. Such devices have to be relatively small and of light weight, easily applied on the body and individually adjustable, durable and inexpensive. Moreover, in the case of active elements, power supply has to be warranted. Finally, as for any other sensor or actuator, the signals have to be transmitted wired and/or wireless. Wiring is a critical issue, as it can limit the scale of the movements (on arms, hands, and legs).

This paper presents a multichannel tactile feedback system [12]. Although tests were performed also using four and eight channels, a series of simplified two-channel experiments was conducted to determine usability of different body parts and signal presentation methods. The next section introduces the measurement setup, followed by the results. The results will be discussed and recommendations suggested in the conclusion.

2. MEASUREMENT SETUP

The measurement setup is based on a standard laboratory computer connected to an external sound card. Eight independent channels can be allocated to vibrating motors. Fig. 1 shows the 7.1-channel external sound card with the connectors [13]. Mono and stereo wave files were generated digitally in a multichannel wave editor. For 2-channel measurements, left and right channels were allocated to the left and right side on the body.

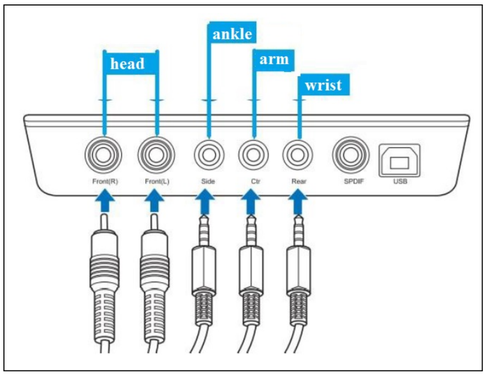

Figure 1. Connections for 8-channel playback. Different body parts can be excited in 2-channel measurements.

Fig. 2 shows a Linear Resonant Actuator (LRA) coin vibration motor. Actuators were attached to sport wristbands that could be used for ankle, arm and wrist positions left and right (Fig. 3). Based on the manufacturer's data sheet, the resonant frequency of the actuator is around 235 Hz.

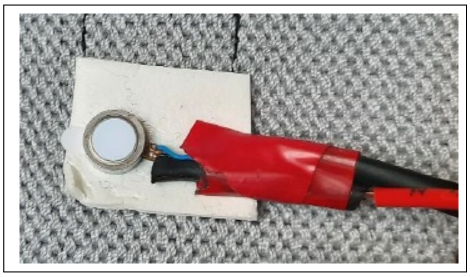

Figure 2. The LRA motor secured with double sided tape on a wristband [14].

For the experiment, 185 Hz and 300 Hz sinusoidal signals were selected for comparison to 235 Hz. Continuous signals and series of signal bursts of different lengths were presented. 27 subjects participated in the experiment (17 males, 10 females, mean age of 25.4 years). Subjects were sitting in a laboratory with the wristbands attached on the wrists, followed by ankles and arms. The first task was to detect and discriminate between different (continuous) frequencies. The second task was to detect differences between 100 ms, 250 ms and 500 ms bursts. Fig. 4 shows an example of a signal with different bursts. All signals were of 2 seconds.

3. RESULTS

The head position was insufficient for two-channel playback. Subjects could not detect the vibrations using the LRA motors fixed on a headband. Therefore, only the following excitation points were evaluated for statistical significance at the 5% level.

3.1 Wrists

Subjects could detect the vibration on both wrists using the same 235 Hz signal. Detection of differences in frequency was difficult: 18 subjects could not detect any difference neither between 185 Hz and 300 Hz nor between 185 Hz and 235 Hz. With other words, 9 out 27 were able to feel the difference between the two frequencies (p-value: 3.0E-7, z=5.19). In the case of presenting temporal differences, 500 ms ”long” bursts and 100 ms ”short” bursts were compared with 250 ms bursts. 13 out of 27 felt the shorter signal different in length (p-value: 1.67E-5, z=4.34), and 22 out of 27 the longer signal different

Figure 3. Excitation points on the arm, wrist and ankle.

(p-value: 0.02, z=2.34). Longer bursts were always easier to detect.

3.2 Ankle

Similar to the wrist position, subjects could detect the vibration of the 235 Hz continuous signal on both ankles. Having the motors higher on the lower leg resulted in decreased sensitivity. All subjects reported decreased sensitivity on the ankle compared to the wrists. One-third of the subjects felt the shorter signal different in length (p-value: 1.0E-6, z=4.95), and two-third the longer signal different (p-value: 0.012, z=3.22). Longer bursts were easier to detect than shorter.

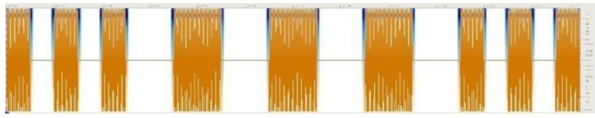

Figure 4. Example of a signal having bursts of different length.

3.3 Arms

Arms are the least sensitive spots compared to the wrists and ankles. Only 18 out of 27 subjects reported equal amplitude vibration on both arms using the 235 Hz signal (p-value: 0.001, z=3.28). Subjects reported that they had decreased sensitivity compared to the wrists. The arm is also sensitive to the placement of the transducers. Detection of differences in temporal length compared to the normal length was not significant (p-value: 0.066, z=-1.83 for shorter and p-value: 0.42, z=0.80 for longer signals). However, comparing shorter with longer, longer bursts were significantly easier to detect (p-value: 0.018, z=-2.36).

4. DISCUSSION

One of the most important application area is assistive technology. User interface design replacing or extending traditional GUIs can include haptics [15, 16]. Mobility solutions (electronic travel aids) for the visually impaired need feedback systems without headphones covering the ears. Besides bone conduction headsets, different forms of vibrations can be used for guidance [17–20]. Increasing the accessibility to the internet is very important to blind users as well, where tactile feedback could deliver additional information [21, 22].

Former experiments reported about tests using the human wrist [23–27]; hand [28, 29]; and foot [30]. These body parts are the most convenient spots for tactile feedback.

Our results support that the wrist position has the best accuracy in detecting temporal patterns and amplitude levels of vibration signals. A higher actuator position on the lower arm results in decreased sensitivity. Ankles are less sensitive than wrists, the same amplitude causes a weaker sensation. The same is true for arms in contrast to wrists. Subjects indicated almost the same sensitivity between arms and ankles, but ankles were always preferred over arms.

Amplitude compensation is needed if the excitation points have different sensitivity, or if the signals left and right are of different frequencies to avoid masking effects. Regarding frequency, only one-third of the subjects could detect any difference in the frequency compared to the nominal 235 Hz value on the most sensitive wrist spot. It is recommended to use only the resonant frequency of a given transducer and to generate alternative excitation signals based on the vibration's amplitude and temporal patterns. The output level of the external sound card set to be at maximum provided enough signal level to drive the motors and to create sensation on the skin. However, some subjects would have preferred higher amplitudes. Depending on the sensitivity of the actuators, external amplifier may be used to amplify signal amplitude. During two-channel playback, any stereo audio amplifier could be used, but overdrive can cause damage to the actuators.

Longer signals were always easier to detect in a paired comparison. Detection of the 250 ms burst was better than of the 100 ms, and the 500 ms outperformed both. Continuous signals are the most efficient, however, this limits the usability by giving up the use of temporal patterns.

Subjects reported that they can use and concentrate on 2 and even on 4 channels simultaneously. The best solution for this would be the left and right wrist and ankles. Wiring is an important issue, because the hand and arms are usually used for input commands (e.g., mouse handling, typing on the keyboard). Extended large body movements can limit the usability having too many long wires attached to the body. As most sound cards offer only stereo outputs, two-channel signal presentation on the wrists or ankles at a fixed frequency and with different temporal patterns is suggested.

5. CONCLUSION

This paper presented a multichannel tactile feedback system used for two-channel measurements on selected body parts, i.e., wrists, ankles and upper arms. Small vibrating motors were applied on adjustable wristbands on the left and right extremities. Excitation signals of different frequencies and temporal patterns were presented to 27 volunteers for comparison. Results indicate that ankle and wrist locations can be used with high accuracy, but head and arms are insufficient and inconvenient excitation points. Changes in the frequency of the vibration were easily confused; thus, changes in the temporal properties (amplitude, different patterns), and presenting signals longer than 500 ms are recommended.

6. ACKNOWLEDGMENTS

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