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Posture Feedback System with Wearable Speaker

Arinobu Niijima[1]

***Abstract*— Maintaining good posture when using a laptop or a smartphone can prevent computer vision syndrome and text neck syndrome. However, it is difficult to remain aware of posture during an activity. Thus, wearable systems with posture feedback can help maintain good posture during daily activities. In this paper, we propose a posture feedback system that uses a commercial wearable speaker, which has been used for music and video conferencing when working from home. To judge a user's posture as good or poor, we focus on estimating the distance between the user's eyes and the screen when using a laptop and the neck tilt when using a smartphone. To estimate the distance, we use an active sensing method with ultrasound sent from a wearable speaker to a microphone on a laptop or a smartphone. The sound pressure of ultrasound changes depending on the distance between the wearable speaker and the microphone. In addition, an active sensing method can be used to estimate neck tilt because the sound pressure changes depending on the angle between the wearable speaker and the microphone. When the system judges the user's posture as poor, it will provide auditory feedback by applying digital audio effects to audible sounds (i.e., audio being listened to). Audio signal processing is implemented as a web application so users can use our system easily and immediately. We conducted three experiments to verify the feasibility of our proposed method. The sound pressure changed depending on the distance and angle between a wearable speaker and a microphone, and the system could judge posture as good or poor at almost 100 % under the experimental conditions.**

I. INTRODUCTION

As people spend more time using laptops and smartphones to work from home, computer vision syndrome and text neck syndrome are becoming serious problems [1], [2], [3], [4], [5]. Previous studies indicated that appropriate head posture and neck posture are necessary to prevent them. For example, when using a laptop, the distance from the screen should be more than 50–60 cm. When using a smartphone, the neck should not be tilted. Poor posture leads to conditions such as eyestrain, dry eyes, low back pain, and neck pain. Though maintaining good posture is important, it is difficult to remain aware of posture during an activity. Therefore, a posture feedback system can help maintain good posture. Previous studies proposed posture feedback systems that used dedicated wearable devices [6], [7], [8], [9].

In this paper, we propose a novel wearable system that uses a commercial wearable speaker, which has been used for music and video conferencing when working from home (overview shown in Figure 1). To judge posture as good or poor, we focus on estimating the user's distance from the screen when using a laptop and the user's neck tilt when using a smartphone. To estimate the distance, we used an active sensing method with ultrasound [10], [11] sent from a wearable speaker to a microphone on a laptop or a smartphone. The sound pressure of ultrasound changes depending on the distance between the speaker and the microphone that is approximate to the distance between the user's eyes and the screen. In addition, we use the active sensing method to estimate neck tilt because the sound pressure changes depending on the angle between the wearable speaker and the smartphone due to the directivity of ultrasound and the microphone. When our system judges a user's posture as poor based on the estimated distance or neck tilt, it provides auditory feedback through digital audio effects to audible sounds (e.g., adding white noise or distortion to music being listened to).

[1]NTT Human Informatics Laboratories, NTT Corporation, Kanagawa, Japan. e-mail: arinobu.niijima.hw@hco.ntt.co.jp

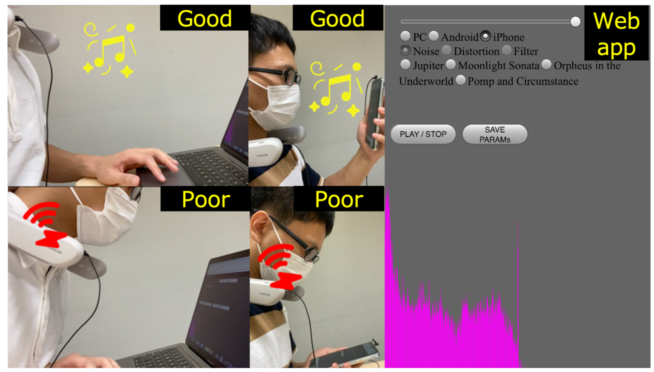

Fig. 1. Posture feedback system with a wearable speaker. Active sensing with ultrasound sent from the wearable speaker to the microphone on their laptop or smartphone estimates the user's posture. When the user's posture becomes poor, they are alerted with auditory feedback from digital audio effects. Audio signal processing is implemented as a web application.

II. RELATED WORK

Previous studies proposed estimating user posture with wearable sensors or with sensors embedded in a chair. Wang et al. developed a wearable intelligent system with an accelerometer embedded in a headband to monitor cervical postures [6]. Smart Rehabilitation Garment is a wearable system for posture monitoring that combines a number of inertial measurement units controlled by a microcomputer [7]. Fragkiadakis et al. presented a sitting posture recognition system that acquires the pressure distribution of a sitting person with 13 piezoresistive sensors placed on a seat [12]. Unlike previous studies that employed dedicated sensors for posture monitoring, we use a wearable speaker that is not only for posture monitoring but also for listening to music, increasing the motivation to use it during daily activities.

Methods of feedback in posture feedback systems are visual, auditory, and tactile feedback. NeckGraffe is a postural awareness system that gives a visual data analysis of the amount of time a user maintains an unhealthy neck posture and provides feedback to alert them to assume a healthy posture [8]. Tiger is a pair of wearable glasses that monitors a user's screen-viewing activities and provides real-time feedback with light and vibration to help users follow the 20-20-20 rule [9]. Backtive is an interactive office chair that improves posture and sitting behavior through tactile and visual feedback [13]. To avoid irritating feedback like pop-ups [14], we used auditory feedback that would be seamless by changing sound quality.

III. Proposed Method

To estimate a user's posture, we use an active sensing method with a wearable speaker and a microphone on a laptop or a smartphone. To make users aware of poor posture, the system provides auditory feedback by applying digital audio effects to audible sounds (audio being listened to).

A. Hardware

In this paper, we use a commercial wearable speaker, SRS-WS1 (SONY). It is worn on the user's shoulders, and both ends have a speaker with a vertical slit. The speakers can provide sounds from audible range to non-audible range.

B. Software

Audio signal processing is implemented as a web application using Web Audio API. The procedure is as follows:

1) A wearable speaker sends audible sounds and ultrasound at 20 kHz simultaneously.
2) A microphone on a laptop or a smartphone receives the sounds.
3) The system computes the fast Fourier transform (FFT) with 1024 samples.
4) The peak power around 20 kHz is recorded.
5) The system judges whether the user's posture is good or poor based on the recorded power.
6) If the posture is judged as poor, the system provides auditory feedback by applying digital audio effects to audible sounds.

Some smartphone microphones have a low pass filter that cut off 20 kHz. However, shadow noise is in the audible range [15]. Therefore, we can estimate the power of ultrasound by recording the peak power of shadow noise even if there is a low pass filter.

C. Algorithm

Our hypotheses about the relationship between the sound pressure of ultrasound and the user's posture are as follows:

- When using a laptop, the closer the distance between the speaker and the microphone is, the higher the sound pressure is.
- When using a smartphone, the larger the neck tilt angle is, the higher the sound pressure is. The reason is the wearable speaker has a vertical slit on each end that sends sounds, so the sound pressure will be higher when a smartphone is under the slits. Figure 2 shows the relative positional relationship of horizontal and vertical positions.

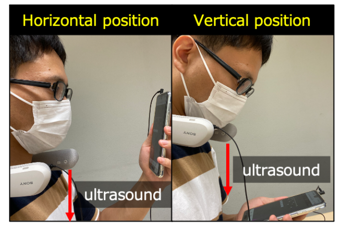

Fig. 2. Relative positional relationship of wearable speaker and smartphone. The direction of ultrasound is vertical, so the sound pressure will be higher under the vertical position.

The sound pressure of ultrasound will be higher when the user's posture gets worse, indicated when the distance between the user's eyes and the screen is too close while using a laptop or when the user's neck is tilted while using a smartphone. Therefore, the system can judge the user's posture as good or poor by comparing the current sound pressure and the threshold preset based on three-sigma limits (mean + three-sigma) calculated from sound pressure data when good posture is maintained.

IV. Experiments

We conducted three experiments to verify whether our method can judge a user's posture as good or poor when using a laptop or a smartphone. In Experiment 1, we investigated mapping the sound pressure and the distance between the wearable speaker and a laptop microphone. In Experiment 2, we investigated differences in the sound pressure depending on the angle between the wearable speaker and the smartphone. In Experiment 3, we evaluated the accuracy of judging good or poor posture when using a laptop or a smartphone. The Institution's Ethical Review Board approved all experimental procedures involving human subjects.

A. Experiment 1: Mapping sound pressure and distance between wearable speaker and laptop microphone

1) Procedure: We measured the sound pressure of ultrasound while changing the distance between a wearable speaker (SONY, SRS-WS1) and a microphone on a laptop (Apple, MacBook Pro). We set both the horizontal and the vertical distances at 0, 20, 40, and 60 cm, respectively, and there were 16 conditions. The wearable speaker sent ultrasound of 20 kHz. The microphone received the ultrasound, and the laptop computed the FFT with 1024 samples and recorded the A/D value (0–255) of the maximum peak power between 19.5–20.5 kHz 500 times under each distance condition.

2) Results: Figure 3 shows the average A/D value of the ultrasound measured 500 times under each distance condition. The farther the distance gets, the smaller the value is. We conducted an unpaired t-test between good posture (the distance is more than 50 cm) and poor posture

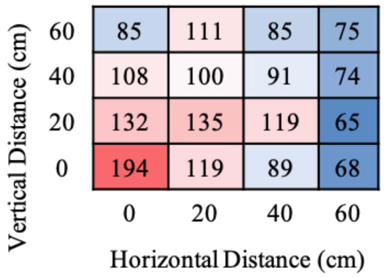

Fig. 3. Mapping of sound pressure and distance between the wearable speaker and the laptop microphone. Each value represents an average A/D value (0–255) of the sound pressure of ultrasound measured 500 times.

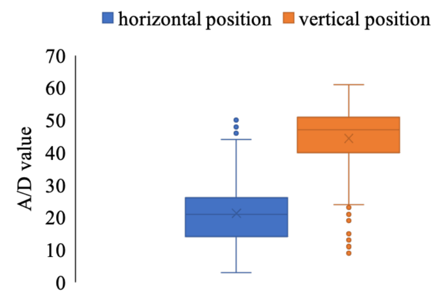

Fig. 4. Box plots represent A/D values (0–255) of shadow noise caused by ultrasound measured 500 times under each condition. Under the horizontal positional condition, the smartphone was in front of the wearable speaker. Under the vertical positional condition, the smartphone was under the wearable speaker.

(the distance is less than 50 cm); the result indicates that there was a significant difference ($t = 67, p < 0.01$). The distance between the wearable speaker and the microphone is approximate to the distance between a user's eyes and a screen of a laptop. Therefore, the experimental results suggest that our method can estimate the distance from the sound pressure and judge if a user's posture is good or poor.

B. Experiment 2: Differences in sound pressure depending on angle between wearable speaker and smartphone

1) Procedure: We measured the sound pressure of ultrasound under the horizontal and vertical positional conditions of a smartphone. These positional conditions represent the presence (with) or absence (without) of the user's neck tilt while using the smartphone. With neck tilt, the smartphone is under the ends of the wearable speaker in the vertical positional condition under which the angle is large. Without neck tilt, the smartphone is in front of the wearable speaker in the horizontal positional condition under which the angle between the wearable speaker and the smartphone is small. We measured the sound pressure of ultrasound with the microphone on the smartphone (Apple, iPhone 11 Pro) 500 times under the horizontal and vertical relative position. The distance between the wearable speaker and the smartphone was set to 20 cm, which is the average viewing distance [16]. We recorded the maximum power between 11–13kHz, which is shadow noise [15] because iPhone's microphone has a low pass filter. The audio signal processing was the same as that in Experiment 1.

2) Results: Figure 4 shows the box plots representing the A/D values (0–255) of shadow noise caused by ultrasound under each condition. Under the horizontal positional condition, the average A/D value was 21. Under the vertical positional condition, the average A/D value was 44. We conducted an unpaired t-test; the result indicates that there was a significant difference ($t = -36, p < 0.01$). These results suggest that the sound pressure changed depending on the angle between the wearable speaker and the smartphone, so the system could estimate the neck tilt. The system can judge the user's posture as poor based on the sound pressure being higher because it increases under both conditions of the distance from the screen being close and of the user tilting their neck.

C. Experiment 3: Accuracy evaluation of judging posture

1) Procedure: We calculated the accuracy of judging a user's posture as good or poor when using a laptop or a smartphone. First, we measured the accuracy when using a laptop. A participant (male, 35 years old) wore a wearable speaker and set the web application for measuring the sound pressure of ultrasound. The procedure was as follows:

1) We measured 1000 samples of the sound pressure of ultrasound when the distance between the eyes and the screen was 50–60 cm to set the threshold for judging posture as good or poor.
2) We calculated three-sigma limits of the measured 1000 samples to set it as the threshold.
3) We measured 1000 samples of the sound pressure when the distance was 50–60 cm to collect test data of good posture.
4) We measured 1000 samples of the sound pressure when the distance was 20–30 cm to collect test data of poor posture.
5) We labeled samples as good posture when the sound pressure was lower than the threshold; we labeled samples as poor posture when the sound pressure was higher than the threshold.
6) We calculated the accuracy from the predicted labels and the correct labels.

Next, we measured the accuracy when using a smartphone. The participant wore the wearable speaker upside down (Figure 2) so the lower slits would not be covered by their shoulders. The procedure was the same as the above procedure. The distance was set to 20 cm as in Experiment 2. When the participant used the smartphone without tilting their neck, the smartphone was in front of the wearable speaker, and we labeled it as good posture. When the participant tilted their neck while using the smartphone, the smartphone was under the tips of the wearable speaker, and we labeled it as poor posture. We calculated accuracy from the predicted labels and the correct labels.

2) Results: Table I shows the accuracy was 100 % when using the laptop. Table II shows the accuracy was 99.5 % when using a smartphone. These results suggest that our

TABLE I
ACCURACY EVALUATION WHEN USING A LAPTOP

		Predicted label	
		good posture	poor posture
Correct label	good posture	1000	0
	poor posture	0	1000

TABLE II
ACCURACY EVALUATION WHEN USING A SMARTPHONE

		Predicted label	
		good posture	poor posture
Correct label	good posture	1000	0
	poor posture	10	990

system can judge a user's posture based on the sound pressure of ultrasound.

V. DISCUSSION

Our experimental results proved that the active sensing method can be used to judge a user's posture as good or poor when they are using a laptop or a smartphone. The sound pressure of ultrasound changes significantly depending on the distance between the wearable speaker and the microphone, and it changes depending on the angle between the wearable speaker and the microphone due to the directivity of ultrasound.

We have used this system working from home for a pilot study, we confirmed it works properly while playing music: When our posture became poor, the system responded with audio effects such as white noise, bandpass filter, or distortion. Because our system consists of a commercial wearable speaker and a web application that can be used easily and immediately, our system can be used continuously during daily activities.

However, the limitations are as follows. First, our method cannot work with headphones or earbuds. To use our system with them, an additional speaker is necessary to send ultrasound to the microphone on a laptop or a smartphone. Second, the threshold has to be calibrated before using the system and recalibrated when changing environments because the sound pressure of ultrasound changes depending on the environment. Third, we should conduct accuracy evaluation with more participants to procedure credible results.

VI. CONCLUSION

We proposed a posture feedback system that utilizes a commercial wearable speaker. We use an active sensing method with ultrasound to judge whether a user's posture is good or poor when using a laptop or a smartphone. When their posture is poor (e.g., by the user closing the distance between their eyes and the screen or by tilting their neck), the sound pressure of the ultrasound will be higher than when their posture is good. We use auditory feedback such as digital audio effects to make users aware of their poor posture. We conducted three experiments to determine whether our method can judge a user's posture as good or poor. The experimental results showed that the sound pressure of the ultrasound changed significantly depending on the distance and the angle between the wearable speaker and the microphone, and the accuracy in judging posture while using a laptop or a smartphone was almost 100 %. Next, we will investigate if our system will help maintain good posture at work for long periods. Therefore, in future work, we will recruit participants who can work with our system for long periods.

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