

Towards Ambient Intelligence System for Good Sleep By Sound Adjusted to Heartbeat and Respiration

Keiki Takadama^{*1}, Yuusuke Tajima^{*1}, Tomohiro Harada^{*1},
Atsushi Ishihara^{*2}, Morito Morishima^{*2}

^{*1} The University of Electro-Communications, Japan
{keiki@inf, y_tajima@cas.hc, harada@cas.hc}.uec.ac.jp

^{*2} Yamaha Corporation, Japan
{atsushi.ishihara morito.morishima}@music.yamaha.com

Abstract

This paper aims at developing the *ambient intelligence* sleep system that can derive a *good sleep* by providing a *personally adapted sound*. For this purpose, this paper explores the sounds that have a potential of deriving a good sleep and investigates their effect from the several viewpoints (e.g., the sleep latent time). To promote a good sleep, this paper focuses on *heartbeat* and *respiration* which are related to a sleep (i.e., its rate decreases as falling asleep) and proposes the ambient intelligent sleep system that provides the sound adjusted to the heartbeat and/or respiration rates, which are automatically measured by the piezoelectric-based mattress sensor without connecting any devices to human's body. The human subjective experiments of the six subjects for a nap case and the seven subjects for a night sleep case have revealed the following implications: (1) the new wave sound adjusted to both the heartbeat rate (x 1.05) and respiration rate (x 1.05) can shorten the *sleep latent time* in a nap case in comparison with no sound or the other four types of the sounds; (2) the combination of the two sound sources (adjusted by the heartbeat and respiration rates) contributes to shortening the sleep latent time in comparison with one sound source; (3) the new wave sound can shorten not only the sleep latent time but also the *Non-REM3 latent time* in a night sleep case in comparison with no sound; and (4) the new wave sound can keep not only an appropriate sleep cycle but also the very similar sleep cycle from the Non-REM to the next one in a night sleep case in comparison with no sound.

1. Introduction

Recently, around one fifth persons in Japan (i.e., approximately 24 million persons) have some sleep disturbances including chronic insomnia (MHLW 2008). This is very serious fact because such sleep disturbances

causes several problems such as an increase of a number of wandering at midnight or a decrease of an appetite of aged persons from the viewpoint of care support and an increase of a number of car/bus accidents from the viewpoint of taxi and bus companies.

To promote humans to have a *good sleep* (e.g., a fast sleep latent time, a deep and stable sleep, or keeping the same sleep rhythm), this paper aims at developing an *ambient intelligence* sleep system (Zelkha & Epstein 1998; Aarts, Harwig & Schuurmans 2001) that can derive a *good sleep* by providing a *personally adapted sound*. For this purpose, this paper focuses on *heartbeat* and *respiration* which are related to a sleep (i.e., its rate decreases as falling asleep) and proposes the sleep system that provides the sound adjusted to the heartbeat and respiration rates, which are automatically measured by the piezoelectric-based mattress sensor without connecting any devices to human's body.

This paper is organized as follows. The next section briefly explains the concept of ambient intelligence and its sleep system. The human subject experiment is conducted in Section 3, and the proposed sleep system is discussed from the viewpoint of ambient intelligence in Section 4. Finally, the conclusion is given in Section 5.

2. Ambient intelligence and its sleep system

Ambient intelligence

Ambient intelligence (i.e., intelligence embedded in environment) is an information technology that can provide useful information by adapting to human activities in living environment. The characteristics of ambient intelligence are summarized as follows (Zelkha & Epstein 1998; Aarts, Harwig & Schuurmans 2001):

- (1) Information technology in ambient intelligence is embedded into the environment;
- (2) It can recognize the situational context of subject;
- (3) It can be personalized to subject;
- (4) It can change in response to subject; and
- (5) It can anticipate desires of subject.

Ambient intelligence sleep system

Following the above concept of ambient intelligence, we developed the preliminary version of the *ambient intelligence* sleep system that can derive a *good sleep* by providing a *personally adapted sound* as shown in the upper part of Fig. 1. In detail, this system employs *Max/MSP* (developed by Cycling '74) installed in the tablet PC (Windows 8) as a sound source, Relit LSX-700 (developed by Yamaha) as a speaker, and *Emfit* sensor (developed by VTT Technical Research Center of Finland) as a biological sensor which can measure the heartbeat and respiration data by just laying in bed, *i.e.*, these data are automatically measured by the piezoelectric-based mattress sensor without connecting any devices to human's body. Since the EMFIT sensor is set under the bed, a person can stay his room as usual.

The lower part of Fig. 1 indicates the procedure of our sleep system, which is summarized as follows: (i) the biological sensor measures the heartbeat and respiration rates of a human, (ii) the personally adapted sound as the sound source is created according to these two rates, and (iii) the personally adapted sound is produced to a human via the speaker. Note that the falling asleep time can be roughly estimated by the heartbeat and respiration rates.

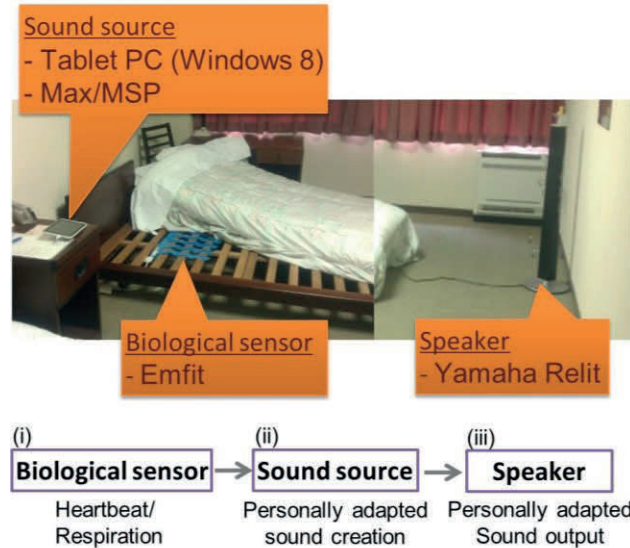


Fig. 1 Ambient intelligence sleep system (composed of Sound source (Max/MSP), Biological sensor (Emfit), and Speaker (Yamaha Relit))

Algorithm for personal adapted sound

As the important characteristics of our sleep system, Fig. 2 shows how the personally adapted sound is created according to the heartbeat and respiration rates. Concretely, the figures in the upper, middle, and lower parts indicate the original sound, the modified sound (*i.e.*, the personally adapted sound), and the heartbeat and respiration rate transition. The basic idea of our sleep system is to provide the sound based on the heartbeat and respiration rates. This is because they have the strong relation to the sleep stage (Harper et al. 1987) (Otsuka et al. 1991) (Shimohira et al. 1998), *e.g.*, its rate decreases when falling asleep while it increases when becoming to wake up. Focusing on this characteristic, the cycle of the original sound is expanded (or shortened as contrast) to promote humans to fall asleep. Concretely, our sleep system provides a little bit longer cycle of the original sound (such as the sound with the heartbeat rate $\times 1.05$ cycle or the respiration rate $\times 1.05$ cycle). This is based on the assumption that humans tend to become sleepy as the cycle of the sound becomes long.

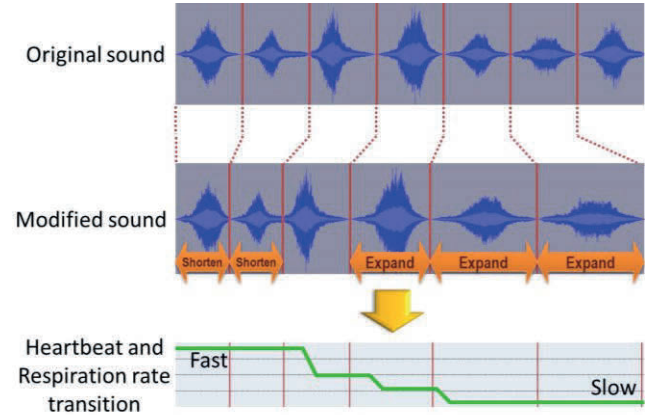


Fig. 2 Personally adapted sound creation

3. Human subject experiment

Cases

To investigate the effectiveness of our ambient intelligence sleep system, we conduct the following human subject experiments by dividing two cases. Note that all human subjects in the experiments are persons without any disability. The room shown in the upper part of Fig. 1 is used for both cases in the experiments.

● Case 1: A nap

The six male subjects (whose averaged ages are 50.3 ± 12.2) take their naps from 30 to 45 minutes in the afternoon. The sleep latent time of the subjects are

compared with no sound and the five types of the sounds as shown in Table 1.

● Case 2: A night sleep

The seven male subjects (whose averaged ages are 42.8 ± 7.46) take their sleeps whole a night. The sleep latent time, the Non-REM3 latent time, and the sleep cycle from the Non-REM to the next one of the subjects are compared with no sound and the best sound found in case 1.

Sound types

All types of the sounds are summarized as shown in Table 1. In detail, the No. 1 sound does not produce any sound (*i.e.*, no sound), the No. 2 sound is composed of both the long synthetic sound (with the respiration rate $\times 1.05$ cycle) and the short synthetic sound (with the heartbeat $\times 1.05$ cycle), the No. 3 sound is composed of both the new wave (with the respiration rate $\times 1.05$ cycle) and the short synthetic sound (with the heartbeat $\times 1.05$ cycle), the No. 4 sound is the MIDI music (with the heartbeat $\times 1.05$ cycle), the No. 5 sound is the wave sound (with the respiration rate $\times 1.05$ cycle), and the No. 6 sound is the wave sound (with the respiration rate $\times 0.95$ cycle).

Table 1 Sound types

No.1	No sound	
No.2	Synthetic	Respiration $\times 1.05$, Heartbeat $\times 1.05$
No.3	New wave	Respiration $\times 1.05$, Heartbeat $\times 1.05$
No.4	MIDI	Heartbeat $\times 1.05$
No.5	Wave	Respiration $\times 1.05$
No.6	Wave	Respiration $\times 0.95$

To understand the sounds employed in this experiment, the details are summarized as follows: (1) the *synthetic sound* created by the synthesizer is the artificial sound for a good sleep, and the *MIDI music* is also created as the electronic sound for a good sleep. In contrast, the (*normal*) *wave* and *new wave* are similar to a wave in sea to promote humans to become sleepy. Note that the new wave is arranged to improve the quality of sound more naturally than the normal one; (2) the loudness of all sound types is normalized to 40 dB SPL; (3) the sound adjusted to the heartbeat is designed to have the cycle from 60 to 70 per minutes, while the sound adjusted to the respiration is designed to have the cycle from 15 to 20 per minutes. The number of the sounds that our sleep system produces is determined according to the heartbeat and respiration rates. Note that one unit of these sound is created slightly different, which are selected at random to provide the

variety of the sounds; and (4) the No. 2 and 3 sounds have the two sound sources (*i.e.*, the heartbeat- and respiration-based sounds), while the No. 4, 5, and 6 sounds only has the one sound source (*i.e.*, either the heartbeat- or respiration-based sounds).

Experimental results

● Case 1: A nap

Fig. 3 shows the results of the six male subjects who took their naps from 30 to 45 minutes in the afternoon. In detail, the vertical axis indicates the *sleep latent time* (in second), while the horizontal axis indicates the five types of the sound with no sound. Note that the thin bar shown in each sound type indicates the standard deviation of the sleep latent time.

From this figure, the new wave sound adjusted to the heartbeat rate $\times 1.05$ cycle and respiration rate $\times 1.05$ cycle can shorten the *sleep latent time* in comparison with no sound and the other four types of the sounds. In contrast, the wave with the respiration rate $\times 1.05$ cycle and the wave with the respiration rate $\times 0.95$ cycle clearly provide the big standard deviation of the sleep latent time. This result suggests that the new wave sound can provide a fast falling asleep, while No. 5 and 6 sounds are hard to achieve it. Considering the fact the synthetic sound can also show the good results, which also suggests that the combination of the two sound sources (related to the heartbeat and respiration rates) contributes to shortening the sleep latent time in comparison with one sound source (related to either the heartbeat or respiration rate). Since the heartbeat rate (*i.e.*, 60 to 70 per minutes) differs from the respiration rate (*i.e.*, 15 to 30 per minutes), in particular, the integration of such different sounds increases the possibility for the short sleep latent time.

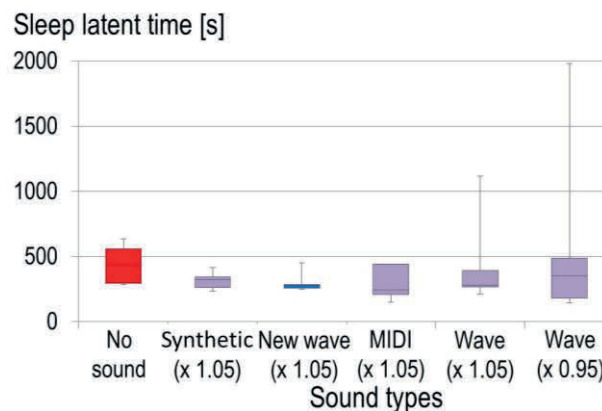


Fig. 3 Sleep latent time (case 1: A nap)

● Case 2: A night sleep

Figs. 4, 5 and 6 show the results of the seven male subjects who took their sleeps whole a night. In detail, the vertical axes in Figs. 4, 5 and 6 indicate the *sleep latent time* (in second), the *Non-REM3 latent time* (in second), the number of the REM stage, respectively. The horizontal axes in Figs. 4, 5 and 6, on the other hand, indicate the two sound types, *i.e.*, the no sound and the new wave sound. Note that the thin bar shown in each sound type indicates the standard deviation of the sleep latent time, the Non-REM3 latent time, and the number of REM stage.

From Figs. 4 and 5, the new wave sound can shorten not only the sleep latent time but also the *Non-REM3 latent time* in comparison with no sound. This result suggests that the new wave sound can derive a deep sleep fast. As another feature of the new wave, the standard deviation of the sleep latent time in the case of the new wave is shorter than that in the case of no sound, which suggests that the new wave has the stable sleep latent time.

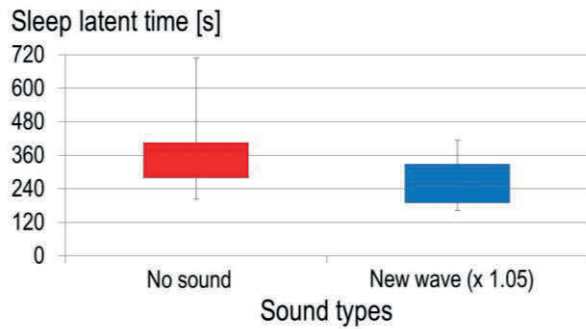


Fig. 4 Sleep latent time (case 2: A night sleep)

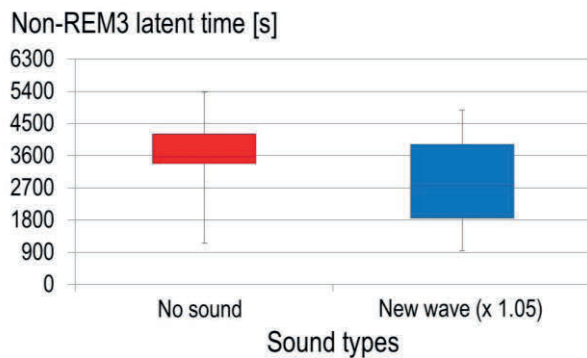


Fig. 5 Non-REM3 latent time (case 2: A night sleep)

From Fig. 6, the new wave sound can keep the very similar sleep cycle from the Non-REM to the next one in comparison with no sound. This can be easily understood by the very small standard deviation of the number of REM stage in the case of the new wave while

the large standard deviation in the case of no sound. In other words, the subjects in the case of the new wave can have a regular sleep with around 90 minutes cycle of REM stage, while the subjects in the case of no sound have a non-regular sleep with from 50 to 180 minutes cycle of REM stage. This result suggests that the new wave sound can keep the stable and appropriate sleep rhythm.

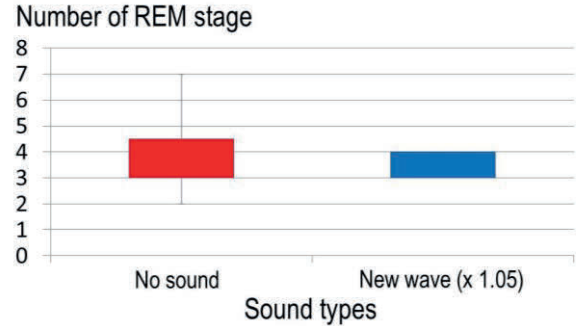


Fig. 6 Number of REM stage (case 2: A night sleep)

4. Discussion

Relationship between ambient intelligence and sleep system

From the viewpoint of the concept of ambient intelligence described in Section 2, the proposed technology in our sleep system has the following relationship to ambient intelligence:

- (1) **Embedded into environment:** The proposed technology in our sleep system is embedded into a bed and speaker (which corresponds to an environment), meaning that its technology is embedded into the environment.
- (2) **Recognition of situational context of subject:** Our sleep system can judge whether a person is almost falling asleep from his heartbeat and respiration rates, meaning that the proposed technology can recognize the situational context (*e.g.*, falling asleep) of subject.
- (3) **Personalization to subject:** Our sleep system can provide a sound adjusted to the heartbeat and respiration rates of subject, meaning that the proposed technology can personalize the sound to subject.
- (4) **Change in response to subject:** Our sleep system changes the sound cycle when a subject is hard to fall asleep, meaning that the proposed technology can change the sound cycle in response to subject situation.
- (5) **Anticipation of desires of subject:** Our sleep system can anticipate the appropriate sound cycle for a good sleep, meaning that the proposed technology can

anticipate the target sound cycle from the heartbeat and respiration rates (which can be regarded as the desire of subject from the viewpoint of a good sleep). Other desires of subject include a fast sleep latent time, a deep and stable sleep, or keeping the same sleep rhythm.

As described above, the proposed technology in our sleep system satisfies all of five characteristics of ambient intelligence. This suggests that our sleep system is based on ambient intelligence.

5. Conclusion

This paper focused on the heartbeat and respiration which are related to a sleep (*i.e.*, its rate decreases as falling asleep) and developed the preliminary version of the *ambient intelligence* sleep system that can derive a good sleep by providing a *personally adapted sound* adjusted to the heartbeat and respiration rates of humans. To promote a good sleep, this paper explored five types of the sounds that have a potential of deriving a good sleep and investigates their effect from the several viewpoints (*e.g.*, the sleep latent time) through a comparison with all types of the sounds including no sound.

The human subjective experiments of the six subjects for a nap case and the seven subjects for night sleep case have revealed the following implications: (1) the new wave sound (*i.e.*, the No.3 sound) adjusted to both the heartbeat rate ($\times 1.05$) and respiration rate ($\times 1.05$) can shorten the *sleep latent time* in a nap case in comparison with no sound or the other four types of the sounds, which means that its sound can provide a fast falling asleep; (2) the combination of the two sound sources (related to both the heartbeat and respiration rates) contributes to shortening the sleep latent time in comparison with one sound source (related to either the heartbeat or respiration rate); (3) the new wave sound can shorten not only the sleep latent time but also the *Non-REM3 latent time* in a night sleep case in comparison with no sound, which means that its sound can derive a deep sleep fast; and (4) the new wave sound can keep not only an appropriate sleep cycle but also the very similar sleep cycle from the Non-REM to the next one in a night sleep case in comparison with no sound, which means that its sound can keep the stable and appropriate sleep rhythm.

What should be noted here is that the above implications have only been obtained from data of a small number of the subjects. This suggests that further careful qualifications and justifications by increasing the number of the subjects are needed to generalize our results. Such important directions must be pursued in the near future in addition to the following future research: (1) an investigation of the effectiveness of other types of the sounds because the five types of the sounds are not enough

to cover other potential sounds; (2) the human subject experiments with not only woman subjects but also aged persons whose ages are older than the subjects in our experiment; and (3) a personalization of the content of the sounds such as favorite sounds instead of the wave sound employed in our experiment.

References

- Aarts, E., Harwig, R., and Schuurmans, M.: "Ambient Intelligence" in *The Invisible Future: The Seamless Integration Of Technology Into Everyday Life*, McGraw-Hill Companies, 2001
- Harper, R.M., Schechman, V.L. and Kluge, K.A.: "Machine Classification of Infant Sleep State Using Cardiorespiratory Measures", *Electro-encephalogr: Clinic Neurophysiology*, No. 67, pp. 379-387, 1987.
- Ministry of Health, Labour, and Wellness (MHLW): *National Health and Nutrition Examination Survey*, 2008.
- Otsuka, K., Ichimaru, Y. and Yanaga, T.: "Studies of Arrhythmias by 24-hour Polygraphic Records. II. Relationship between Heart Rate and Sleep Stages", *Fukuoka Acta. Med.*, Vol. 72, No. 10, pp. 589-596, 1991.
- Shimohira, M., Shiiki, T., Sugimoto, J., Ohsawa, Y., Fukumizu, M., Hasegawa, T., Iwakawa, Y., Nomura, Y., and Segawa, M.: "Video Analysis of Gross Body Movements During Sleep", *Psychiatry Clinic Neuroscience*, Vol. 52, No. 2, pp. 176-177, 1998.
- Zelkha, E., Epstein, B., Birrell, S., and Dodsworth, C.: From Devices to "Ambient Intelligence", *Digital Living Room Conference*, 1998