Well-Being Computing Towards Health and Happiness Improvement: From Sleep Perspective

Keiki Takadama
The University of Electro-Communications, Japan
keiki@inf.uec.ac.jp

Abstract

This paper proposes the concept of *Well-being computing* which is an information technology for improving not only our *health* as physical aspect but also our *happiness* as psychological aspect, and shows its potential from the sleep perspective. Concretely, this paper introduces "our personalized sleep monitoring system" as the well-being computing technologies and shows the following implications as its effectiveness: (1) from the viewpoint of the service based on the *real-time sleep*, (1-a) good *health* is provided through a stable sleep of aged person in care house by reducing their sleep disturbance which may be occurred in diaper exchange, while *happiness* is provided by the smooth diaper exchange when aged person have a deep/light sleep; (1-b) good *health* is provided through a sufficient sleep time acquired by a fast falling asleep, while *happiness* is provided by releasing from anxiety of the insufficient sleep such as insomnia; and (2) from the viewpoint of the service based on the *long-term* sleep, (2-a) good *health* is provided through a deep sleep by continuing the daytime activities (such as a walking) which contribute to deriving a deep sleep, while *happiness* is provided by achieving a deep sleep through a change of life style; (2-b) good *health* is provided through a good sleep by keeping good bed condition (*e.g.*, a change of a pillow or mattress when cotton/spring is deteriorated), while *happiness* is provided through a discovery of suitable bedding (such as suitable pillow or bed).

1. Introduction

As IoT (Internet of Things) era arrives, a lot of vital data such as heartbeat and respiration are easily obtained from wearable sensors or ambient sensors embedded in environments such as wall or house. These data are very useful for understanding or grasping our health conditions, which promotes us to be happy when we have a healthy life. What should be noted, however, is that we cannot show that all of people will get more and more happy by obtaining their data. Some people may be busy to check such data, which is not happy for them. According to World Happiness Report 2015 by United Nations (Helliwell, Layard, & Sachs 2015), the happiness of Japan from 2012 to 2014 is 46*th* out of 158 countries including war region (the happiness of U.S.A in the same years is 15*th* as reference). More importantly, the change in happiness of Japan from 2005-2007 to 2012-2014 is 107*th* out of 125 countries (the change in happiness of U.S.A. in the same years is 95*th* as reference), both of which indicates a decrease of happiness Note that the countries which rank is 68th or below show the negative happiness growth. These results suggest that we will NOT be happy even we can obtain a lot of data including our health data.

From this fact, this paper stresses an importance of considering not only our *health* as physical aspect but also our *happiness* as psychological aspect, and proposes the concept of *Well-being computing* which is an information technology that aims to improve both aspects. We employ the word "well-being" instead of "wellness" because well-being refers to a more holistic and whole of life experience, whereas wellness refers mainly to physical health. In particular, *well-being computing* provides a way to understand how our digital experience affects our emotions and our quality of life and how to design a better well-being system.

To understand the scope of well-being computing, let's focus on the conventional healthcare systems. For example, a blood-pressure or heartrate measurement system tells us our health condition. Both healthcare systems are useful from the health viewpoint but they have limits from the happiness viewpoint (*i.e.*, the conventional healthcare systems do not mainly focus on an improving happiness). This indicates that the technology for improving not only health but also happiness is critical as the next-generation healthcare technology. As the first step towards this goal, we start to address this issue from the sleep perspective and introduce "our personalized sleep monitoring system" (Takadama 2014) as an example of well-being computing system to show its potential. We focus on sleep because many persons (even healthy persons) have some sleep troubles which may decrease their happiness (note that the total number of such peoples is approximately 24 million persons, *i.e.*, around one fifth persons in Japan (MHLW 2008)), but we believe that the *(extreme) personalized care support* to persons from the sleep viewpoint has a potential of improving their happiness (see Section 3).

This paper is organized as follows. The next section explains our personalized sleep monitoring system and its feature, and Section 3 introduces four potentials of our systems from the viewpoint of well-being computing. Finally, the conclusion is given in Section 4.

2. Personalized sleep monitoring system

Our previous research (Takadama et al. 2010) proposed the method that can estimate the sleep stage without connecting any devices to human's body as shown in Fig. 1. The upper part of Fig. 1 indicates the estimated sleep stage displayed in a potable devise such as a smart phone, tablet PC, or pad. In detail, the horizontal axis indicates the sleep time in a bed, while the vertical axis indicates the sleep stage divided into six stages, *i.e.*, the wake stage, REM sleep stage, stages 1, 2, 3, and 4 represented by W, R, 1, 2, 3, and 4, respectively. Note that the stage 4, in particular, has the deepest sleep, while the wake stage has the lightest sleep. The lower part of Fig.1, on the other hand, indicates the mattress sensor set under the bed. This mattress sensor measures the heartbeat data of a person lying down on the bed and transmits its data to a potable devise via WiFi (or the Ethernet cable) in order to estimate their sleep stage from the heartbeat.

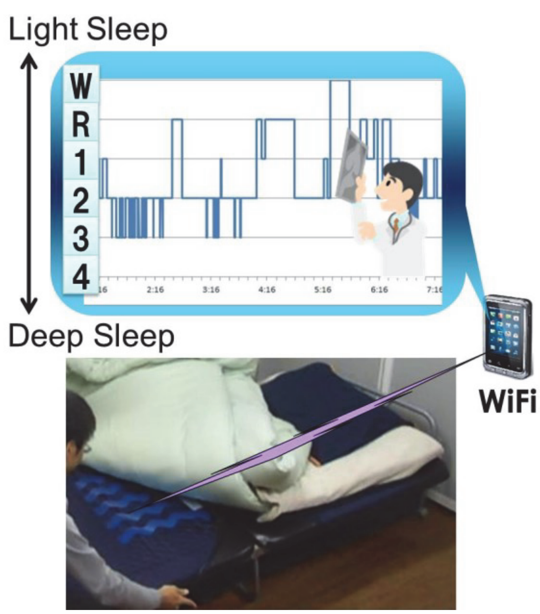

Fig 1. Personalized sleep monitoring system

Note that this method is based on the results of the several articles suggested that the heartbeat data has 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. Concretely, we employs *Emfit* sensor developed by VTT Technical Research Center of Finland as a biological sensor which can measure the heartbeat and respiration data, *i.e.*, these data are automatically measured by the piezoelectric-based mattress sensor. Since the EMFIT sensor is set under the bed, a person can stay his room as usual.

As the feature of the proposed system, the *sleep monitoring agent* is installed in a potable devise of each person to estimate his sleep stage through an adaptation to each person. Such an adaptation is essential because an appropriate frequency range of the heartbeat (which becomes a base of the sleep stage) is different among people and its appropriate range also changes as an age increases. Since our method can estimate the sleep stage by adapting to each person, it does not have to matter an age of person. What should be noted here is that *(extreme) personalized care support* can be achieved by providing agents (or systems) for each person, and such agents (or systems) should have an adaptation function to each person.

3. Potentials of well-being computing

To show the potentials of our personalized sleep monitoring system as well-being computing, the following four applications are explained as shown in Fig. 2, which are divided into the following two services based on the different sleep aspects.

Fig 2. Potentials of personalized sleep monitoring system

(1) from the service based on the *real-time* sleep
(1-a) our system can provide an appropriate time for the smooth diaper exchange according to the sleep stage;

(1-b) our system can promote a person to fall asleep quickly;

(2) from the service based on the *long-term* sleep

(2-a) our system can find an appropriate combination of daily activities which contributes to having a deep sleep as a good life style design;

(2-b) our system can discover suitable beddings which contribute to having a stable sleep.

The following subsections introduce these four potentials.

(1-a) Appropriate time of diaper exchange

Especially in the night, a time of diaper exchange in care house is very critical for both aged persons and care workers. This is because (1) aged persons generally feel bad when exchanging their diaper; and (2) in the worst case, the aged persons may become awake when care workers exchange diapers of aged persons. This is serious problem because it is generally difficult for aged persons to fall asleep once they wake up. To tackle this issue, we investigated when a diaper should be exchanged by using our personalized sleep monitoring system, and revealed the following implications: (1) a diaper should be exchanged when the aged person has a *deep* sleep if s/he does not tend to become awake in a deep sleep because s/he can continues her/his sleep, or (2) a diaper should be exchanged when the aged person has a *light* sleep if s/he easily becomes awake in a light sleep because people feel bad when waking up in a deep sleep.

To promote the above appropriate diaper exchange, our recent research (Harada et al., 2016) implemented the *real-time* sleep monitoring system for all aged persons in the same unit 1 (*i.e.*, one group of aged persons) as shown in Fig. 3. In this figure, ten rooms (from room no. 201 to 210) belong to the same unit. In these rooms, the eight persons (composed of the six persons with non-REM sleep (*i.e.*, the sleep levels from 1 to 4), one person with REM sleep, and one person with Wake stage) are in their beds, while two persons are NOT in their beds (*e.g.*, they may go to restroom or may wander from place to place).

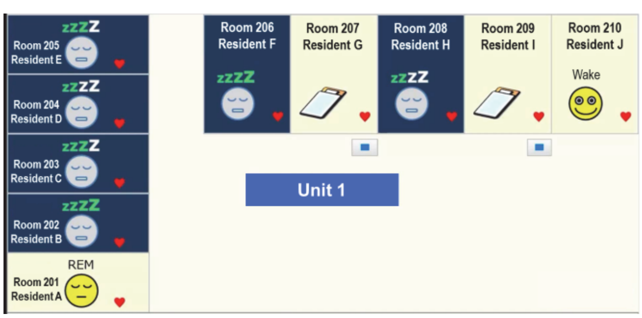

Fig 3. Real-time sleep monitoring system

Regarding the non-REM sleep, the number of the green mark "z" (the gray mark in the black/white printed version) indicates the sleep level, and the color of the room becomes dark in these sleep stages. For example, the four green marks "z" in the room no. 202 and 206 indicate that the aged persons B and F have the sleep stage 4. Regarding the REM or Wake sleep, on the other hand, the face mark without the mark "z" means to have a light sleep or wake up, and the color of the room becomes light in these sleep stages. For example, the aged person A in the room no. 201 has the REM-sleep stage, while the aged person J in the room no. 210 has the wake stage. By utilizing this kind of the sleep stage information as the service based on the real-time sleep, the care workers can determine whether diapers of aged persons should be exchanged or not according to their sleep stage. Such an appropriate timing of the diaper exchange can be found through the *personalized care support,* which contributes to improving the happiness of aged persons.

In addition to the diaper exchange, this system is also useful by utilizing the sleep stage information as follows: (1) the care workers can concentrate on the care support of aged persons who have a light sleep (*i.e.*, Wake or REM sleep stage) because they may wake up. On the contrary, the care workers do not have to prepare for the care support of aged persons who have a deep sleep (*i.e.*, from 1 to 4 sleep stage); and (2) the care workers have to search aged persons in the room no. 207 and 209 because they are not in the room.

What should be noted here is that good *health* is provided through a stable sleep of aged person by reducing their sleep disturbance during diaper exchange, while *happiness* is also provided by the smooth diaper exchange when aged person have a deep/light sleep. As claimed above, the personalized care support, which determines an appropriate timing of the diaper exchange for each person, contributes to improving the happiness of aged persons.

(1-b) Fast falling asleep

Not only aged persons in care house but also other persons have some sleep disturbances including chronic insomnia. This is very serious fact because such sleep disturbances causes several problems such as a decreases of work performance in companies and an increases of car/bus accidents due to insufficient sleep of drivers. To promote humans to have a sufficient sleep, our previous research (Takadama et al. 2015) developed the sound rhythm system that can derive a *fast falling asleep* by providing a *personally adapted sound* as shown in Fig. 4. In detail, this system focused on *heartbeat* and *respiration* because they have the strong relation to the sleep stage described in Section 2, and provided the sound adjusted to the heartbeat and respiration rates, which are automatically measured by

Emfit sensor *i.e.*, the piezoelectric-based mattress sensor without connecting any devices to human's body.

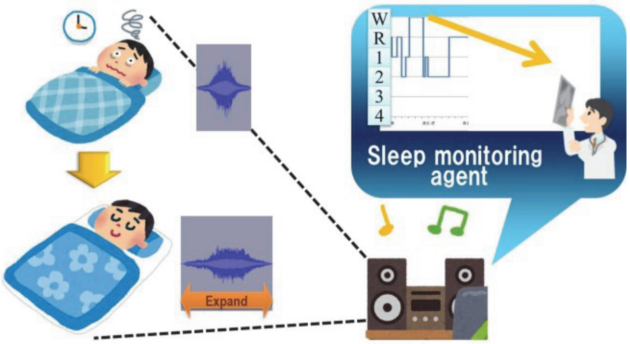

Fig 4. Sound rhythm system for fast falling asleep

As the feature of this system, the cycle of the original sound is mostly expanded (or shortened in a few case) according to the heartbeat and respiration rates to promote humans to fall asleep. Concretely, when the personalized sleep monitoring agent detects that person cannot sleep or has a light sleep from the estimated sleep stage, our system provides a little bit longer cycle of the original sound (such as the sound with the heartbeat rate × 1.05 cycle or the respiration rate × 1.05 cycle) as shown in the lower left of Fig. 4. Such a longer rhythm contributes to falling asleep or having a deep sleep, which is based on the assumption that humans tend to become sleepy as the cycle of the sound becomes long. This kind of *personally adapted sound* can be created from the viewpoint of the *personalized care support,* which contributes to improving the happiness of persons who have sleep troubles.

What should be noted here is that good *health* is provided through a sufficient sleep time acquired by a fast falling asleep, while *happiness* is also provided by releasing from anxiety of the insufficient sleep such as insomnia. This kind of service is useful when person cannot sleep or has a light sleep due to the jet lag. As claimed above, personally adapted sound as the personalized care support has a potential of providing happiness of a relief to have a sufficient sleep.

(2-a) Life style design

In care houses, most of all aged persons want to have a comfortable and healthy life. For this issue, care houses try to provide the good appetite and proper rehabilitation to aged persons for their healthy bodies, and possibly their long life. To provide such an appropriate *lifestyle design* for aged persons, our previous research (Takadama 2014) developed the *concierge-based care support system* that supports aged persons by designing their own appropriate care plans (*i.e.*, rough schedules in a day) for a comfortable and healthy life. In particular, (1) the care plan is a common for all aged persons, which means that it may not be effective for a certain person; and (2) the current one is created according to the experience of the care planner, which means that it has not yet fully optimized. This indicates that the care plan can be designed for each person as a good life style. Towards an appropriate care plan, we developed the novel data mining method (Takadama and Nakata 2015) to extract essential daily activities (*e.g.*, meal and rehabilitation) that contribute to deriving a deep/light sleep of aged persons. Note that the daily activities that derive a light sleep are also important to be specified because the possibility of having a deep sleep increases by removing the activities that derive a light sleep.

To evaluate whether the care plan provides a comfortable and healthy life to aged persons, their sleep stage is investigated from the viewpoint of the deep and stable sleep. Such an evaluation can be done by storing dairy personal data as a *big data* (*e.g.*, the heartbeat and body movement data). This indicates that the service based on the long-term sleep for better health, wellness, and well-being of aged persons is developed by utilizing the personal big data.

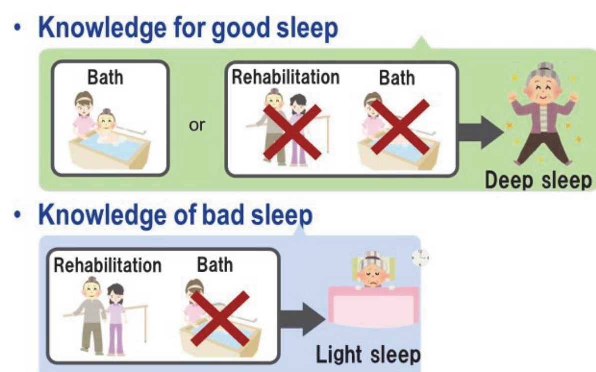

Fig 5. Knowledge for a deep and light sleep

Fig. 5 indicates some of the extracted knowledge for a deep and light sleep. This figure shows that this aged person has a good (deep) sleep when taking a bath or none of rehabilitation exercise and bath, while the same person has a bad (light) sleep when doing rehabilitation exercise without taking a bath. To understand this relationship, we interviewed the person and find that she always takes care of her body clean and she is willing to take a bath especially when doing rehabilitation exercise. From this interview, she can keep her body clean when taking a bath or not doing rehabilitation exercise, which promotes her to have a comfortable sleep. In contrast, she cannot keep her body clean when doing rehabilitation exercise, which promotes her to have an uncomfortable sleep. By utilizing such knowledge, our proposed method can design the care plan which includes the daily activities that derive a deep sleep and excludes the daily activities that derive a light sleep. This kind of individual care plan (which is not the common care plan among aged persons) is designed from the viewpoint of the *personalized care support,* which contributes to improving the happiness of aged persons.

What should be noted here is that good *health* is provided through a deep sleep by continuing the daytime activities which contribute to deriving a deep sleep, while *happiness* is also provided by achieving a deep sleep according to the appropriate life style design. This indicates that our proposed method has a potential of providing a happiness of knowing features of own sleep in addition to happiness of a feeling of an achievement of having a deep sleep.

(2-b) Suitable bedding

Most of all peoples want to find suitable bedding such as bed, pillow, or mattress in order to have their deep and stable sleep. For this purpose, they tend to purchase expensive beddings (such as products of Simmons, Serta, or Sealy) to maximize their satisfaction. In fact, expensive mattresses, for example, are designed to provide an equal distribution of body pressure in order not to press a certain part of body which may cause a lower back pain or neck hurts. However, it goes without saying that suitable bedding depends on persons which means that expensive beddings are not always provide good sleep for all of them.

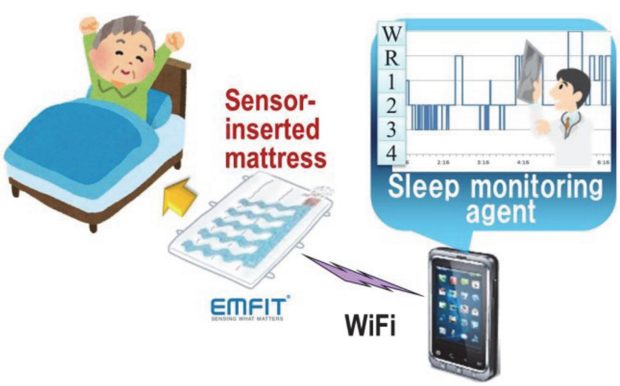

Fig 6. Sensor-inserted mattress with personalized sleep monitoring agent

In order to find suitable bedding in the true sense, we are planning to develop the sensor-inserted mattress which composed of the mattress with EMFIT sensor as shown in Fig. 6. After setting this sensor-inserted mattress in the bed, the personalized sleep monitoring agent can estimate the sleep stage automatically and can judge whether a customer has a deep and stable sleep from his sleep stage. More importantly, the agent can finally determine whether the bedding is suitable to the customer by checking a few days of his sleep stage. Finding such suitable bedding is an *extreme personalized care support,* which contributes to improving the happiness of customers.

As the new business model, we allow customers not to purchase their beddings if they do not have good sleep. This business model enables customers to purchase their beddings with high satisfaction because they can only purchase the suitable beddings which can provide good sleep. In addition to this advantage, the agent can also detect when the sleep of customers changes from good to bad by checking their sleep stages for a long-term period. Since such a change occurs when cotton/spring is deteriorated, we can tell a time for purchasing new mattress or pillow to customers. This kind of service can be done by storing personal big data as a service based on the long-term sleep.

What should be noted here is that good *health* is provided through a good sleep by keeping good bed condition (*e.g.*, a change of a pillow or mattress when cotton/spring is deteriorated), while *happiness* is also provided through a discovery of suitable bedding (such as suitable pillow or bed). In particular, such happiness cannot be acquired by the conventional business model where customers purchase their bedding according to their *subjective* evaluation (*e.g.*, a feeling of bedding) but can be acquired by the new business model where customers purchase their bedding according to their *objective* evaluation (*i.e.*, their sleep stage).

4. Conclusion

This paper proposed the concept of *Well-being computing* which is an information technology for improving not only our *health* as physical aspect but also our *happiness* as psychological aspect, and shows its potential from the sleep perspective. Concretely, this paper introduced our personalized sleep monitoring agent as the well-being computing technologies and claimed that the *(extreme) personalized care support* to persons has a potential of improving their happiness.

To shows the effectiveness of well-being computing, this paper applied our personalized sleep monitoring agent into the four applications: (1-a) diaper exchange of aged persons in care house; (1-b) fast falling asleep by the personally adapted sound; (2-a) appropriate care plan design towards a good life style with good sleep; and (2-b) a discovery of suitable bedding. From the results of these four applications, this paper revealed that the well-being computing has a great potential of providing both good *health* and *happiness*, and its effectiveness is driven from the personalized care support.

What should be noted here is that the above potentials have only been shown from only four applications. This suggests that further careful qualifications and justifications, such as employment of well-being computing technologies in other applications, are needed to increases the its potentials. Such important directions must be pursued in the near future in addition to the following future research: (1) objective evaluation of happiness (*e.g.*, by measuring Oxytocin); and (2) further increase of happiness by well-being computing technologies

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Acknowledgments

The research reported here was supported in part by a Grant-in-Aid for Scientific Research (A, No. 15H01720) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT).