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

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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 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 46th out of 158 countries including war region (the happiness of U.S.A in the same years is 15th as reference). More importantly, the change in happiness of Japan from 2005-2007 to 2012-2014 is 107th out of 125 countries (the change in happiness of U.S.A. in the same years is 95th 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 portable 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 portable devise via WiFi (or the Ethernet cable) in order to estimate their sleep stage from the heartbeat.

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 portable 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.

(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;

(2) from the service based on the long-term sleep (2-a) our system can provide an appropriate life style design according to the next day 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 work-
ers. 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 diap ers 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 investi-
gated 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 contin-
ues her/his sleep, or (2) a diaper should be exchanged
when the aged person has a light sleep if s/he easily be-
comes 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
(compo sed 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).

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 be-
comes 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 diap ers
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 sup-
port, 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 sup-
port 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 provid-
ed 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 per-
sonalized 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 per-
formance in companies and an increases of car/bus acci-
dents due to insufficient sleep of drivers. To promote hu-
mans to have a sufficient sleep, our previous research
(Takadama et al. 2015) developed the sound rhythm sys-
tem that can derive a fast falling asleep by providing a per-
sonally 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 Sec-
tion 2, and provided the sound adjusted to the heartbeat
and respiration rates, which are automatically measured by

Fig 3. Real-time sleep monitoring system
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 daily 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.

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 custom-er 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 justifica-
tions, 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.

References


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