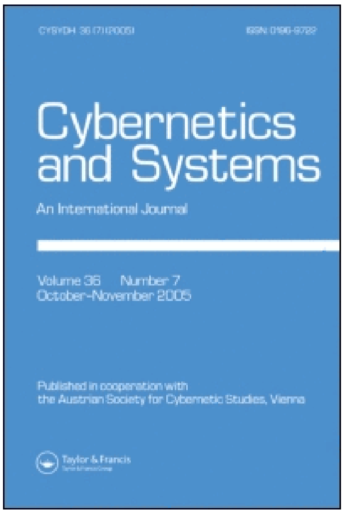

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DAILY PHYSIOLOGICAL SIGNAL MONITORING SYSTEM FOR FOSTERING SOCIAL WELL-BEING IN SMART SPACES

Ahyoung Choi [a];Woontack Woo [a]
[a] GIST U-VR Lab., Oryong-dong, Buk-gu, Gwangju, S. Korea

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Daily Physiological Signal Monitoring System for Fostering Social Well-Being in Smart Spaces

AHYOUNG CHOI and WOONTACK WOO
GIST U-VR Lab., Oryong-dong, Buk-gu, Gwangju, S. Korea

We propose socially acceptable physiological signal monitoring system consisting of a natural sensing interface and an intuitive information display. The natural sensing interface, BioPebble, is a simple, natural, and enjoyable stone-type interface embedded in daily objects such as remote controllers or mobile devices. The intuitive information display, Rainbow display, represents physiological signal information using an intuitive information visualization method for novice users. The information is transferred to the mobile personal station wirelessly and visualized using an appropriate mapping strategy considering the differences of individual users. From the experiment, we found that the sensing interface is more comfortable and involves more aesthetic feeling compared to disposable wired interfaces while retaining effectiveness in monitoring physiological signals regularly during a short period of time. In addition, visualized information in a rainbow-shaped display is easily understood by novice users but not by professionals and caregivers. From these observations, we expect that this monitoring system enables users to monitor their physiological status easily with the proposed interface and display. As a result, this system accelerates social well-being by helping users to regularly check their physiological status for precaution of abnormal condition.

KEYWORDS rainbow-shaped display, social well-being care applications, stone-type physiological sensing interface

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Address correspondence to Ahyoung Choi and Woontack Woo, GIST U-VR Lab, Oryong-dong, Buk-gu, Gwangju 500-712, S. Korea. E-mail: achoi@gist.ac.kr; wwoo@gist.ac.kr

INTRODUCTION

Clinical equipment with wired sensors in a home environment has been reported these days. However, typical equipment for physiological monitoring in the home is usually used by professional physicians (Eysenbach 2001). Wired sensors are complex to use and obstructive in daily work. In addition, results from typical equipment are displayed for professional physicians and are decided by professional prescription. However, the increasing requirements for usability and availability of health information challenge traditional approaches to daily health monitoring (Baek et al. 2005; Korhonen et al. 2003). In order to reduce complex usability and low availability of information for novice users, a wrist-type or band-type monitoring interface with a small display has been proposed.

Previous research studying monitoring interfaces, including glove-type, wrist-type, armband-type, ring-type, and embedded unconstrained-type sensing devices had the following problems (Picard et al. 2001; Ryoo and Bae 2007; Kao et al. 2005; Matthews et al. 2007; Sung and Marci 2005; Tamura et al. 1998). Glove-type sensing devices cause users to feel discomfort due to the increased weight of the device and due to perspiration. In the case of wrist-type sensing devices, signals are easily corrupted because of changes in the sensing position and situations where there is a significant amount of user movement (Rhee and Asada 2001; Hayes and Smith 1998). Band-type sensing devices resolve such problems by sensing position change because they can be more firmly attached to the user's body; however, the band pressure and weight often mean that the user may become tired during long-term monitoring (Anliker et al. 2004). An additional problem is that previous monitoring systems typically show the measured results in a display and then send the measurements to the professional's site. These systems usually provide the information from the viewpoint of the service provider; that is, the information is managed, collected, and regulated by the service provider. As such, most users cannot understand their specific situation without obtaining professional advice. To solve this problem, researchers have explored methods for presenting user activity information using ambient and mobile displays as potential monitoring systems. For instance, Consolvo et al. (2008) presented a way to increase the awareness of human beings in daily activity monitoring systems (Sukeda et al. 2006). In addition, there is some previous literature on social awareness technology for aging people (Mynatt et al. 2004). In this work, they represent various kinds of context such as activity, physiological signal information to digital portrait for supporting social awareness among extended family members.

To address these issues, we propose a socially acceptable health monitoring system to foster social well-being by designing a natural sensing interface and an intuitive information display. For natural sensing interface, this work utilizes a user-centered design process, referred to as a stepwise design process. The shape of this interface links social cues of health with a stone-shaped interface. For intuitive information display, we propose a user-adaptive display to represent physiological signal. This display has the ability to recognize individual users personally with contextual information and then it visualizes adaptively according to the recognized user's context. In the experiment conducted, we observed significant benefits for users of sensing interface and its visualization via a natural and interactive physiological signal monitoring system. We discuss how this system fosters social well-being through this monitoring application.

The proposed monitoring system has the following advantages. First, the sensing interface satisfies the need for simplicity, natural use, enjoyment, aesthetic value, and comfort as well as functional aspects. Normal users access the sensing interface in a natural manner without being concerned about the details of the measurement procedures or complex guidelines. Second, a dynamic mapping strategy of information visualization for novice users guarantees better understanding in interpreting the information naturally without background expert knowledge of physiology and medical science. Therefore, the proposed monitoring system allows users to interact the same way as they do with other simple and intuitive interfaces and to benefit from an interaction metaphor. From these observations, we expect that this monitoring system enables users to monitor their physiological status easily with a comfortable and aesthetic interface and with an intuitive display. Thus, it accelerates social well-being by helping users regularly check of their physiological status for precaution of disease.

The outline of the remainder of this article is as follows. In the following section, we provide details of the proposed sensing interface and visualization method with respect to hedonic and ergonomic characteristics: simplicity, natural use, enjoyment, aesthetic value, comfort, and so on. Then we describe the implementation results and the experimental setup and analyses are discussed. We conclude the article and suggest possible directions for future work.

DAILY PHYSIOLOGICAL SIGNAL MONITORING SYSTEM FOR SOCIAL WELL-BEING

In this article, we present a daily physiological monitoring system for social well-being. To foster social well-being, we propose a pervasive sensing device that has a socially acceptable shape and intuitive information display, which empower family members' social awareness. We adopt the definition of *socially acceptable user interface* by referencing previous literature (Healey et al. 1998). We define *socially acceptable sensing device* as an interface that enables the user to employ the full power of the health monitoring system in a daily life while being socially unobtrusive. For the social acceptance test, we evaluate how inconspicuous the device is to use, how easy it is to control, and how attractive it is to use. In addition, we refer "social interface" in robotics as a natural interface that uses social cues of human communication (Fong and Dautenhahn 2003). In this case, the term *natural* conceptually implies that users can use the devices seamlessly and interface without consciousness and that these interfaces follow social cues such as being enjoyable.

In addition, the information obtained from the sensing interface is consumed directly by users with readable cues and can be interpreted by users without knowledge of background information. The key technologies of the proposed system include two phases. The first phase acquires a user's sensed physiological information using a sensing interface. In the second phase the processed information is presented on a rainbow-shaped ambient display with an adaptive information mapping strategy.

Stone-Type Natural Sensing Interface

In this section, we provide details of the stone-type natural sensing interface. In general, it is necessary for sensing devices to meet users' requirements during monitoring, with particular attention being paid to such aspects as design and usability, as well as the essential sensor functions (Gemperle et al. 1998). The concept of physiological sensors for use in daily life should thus be concerned with comfort and aesthetic shape in order to improve upon current physiological signal monitoring and prevention services. To this end, prior to designing the shape of the sensing interface, we observed commonly used mobile and wearable apparatuses such as mobile phones, MP3 players, computer mouse devices, and so on. We analyzed the common features of referencing devices with respect to their whole form, including left- and right-side views, decorations, materials, color, and accessories. The forms of these devices are considered preferable because (1) they are streamlined and (2) they have a size that can be fully covered by a user's hand. In addition, we designed our sensor based on the metaphor of a stone, because in the health care industry, natural stone has a conceptual accordance with health and well-being.

After the initial construction of the whole form of the sensing interface, we then designed the details of stone-type interface with a repetitive and stepwise process. We applied the user-centered design (UCD) process in greater detail to ensure the development of a comfortable and usable physiological sensor (Norman and Draper 1986). The basic procedure of UCD is as follows: specify the goals and task, specify requirements, produce design condition, evaluate designs, and finalize when the system meet the requirements. During the initial development of the sensing interface, we collected feedback from users and then concretized the details in each step as seen in Figure 1.

We then built prototype of sensing interface using a 3D modeling program and we implemented hardware with three types of sensors: a photoplethysmography (PPG) sensor, a galvanic skin response (GSR)

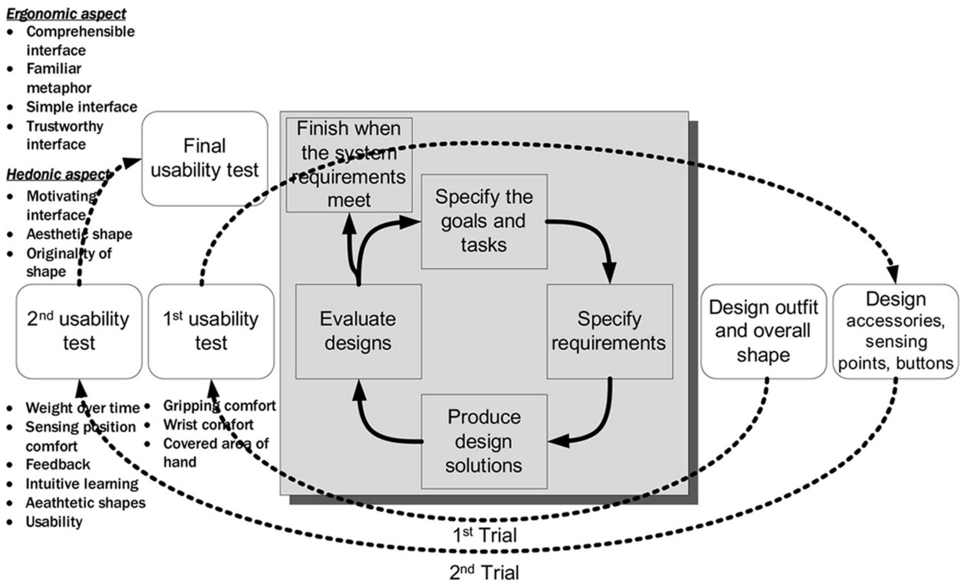


FIGURE 1 User-centered design process of stone-type physiological sensing device.

sensor, and a skin temperature (SKT) sensor. The sensing positions of these separate sensor points on sensing the interface were determined by emperical experiment whether the signal is uncorrupted or not. Therefore, we put the PPG sensor point at the thumb position to check the changes of heart clearly and to minimize the problem of differences in finger lengths among potential users. The skin conductance and skin temperature sensor points are located under the palm.

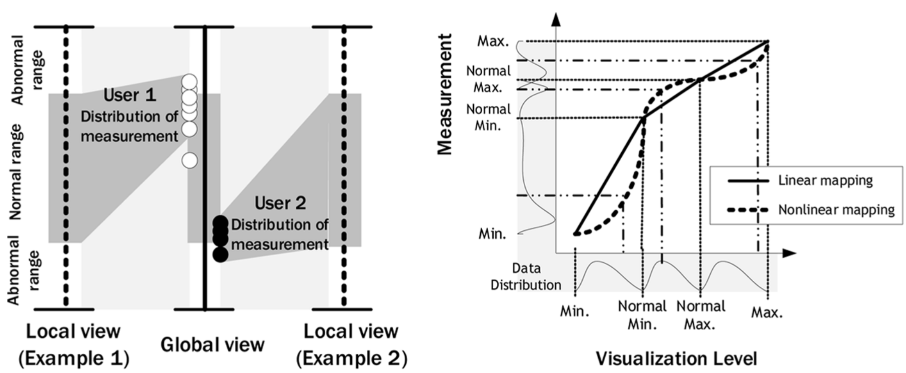
Rainbow-Shaped Intuitive Information Visualization

In this section, we explain a user-adaptive display to represent the physiological signal. This system monitors at most eight users simultaneously since we used Bluetooth technology. Note, however, that each selected device by a user displays only the user's information. For adaptive visualization, this system captures signal range of at most eight users' physiological signals at the same time. Then it recognizes individual users personally with contextual information and then it visualizes adaptively according to the recognized user's context. This proposed visualization method enables the device to record the range that is most commonly observed during the monitoring period and then maximize the presentation of this range. The mapping strategy is not deterministic but flexible and randomly changed according to the user's situation. In order to magnify the results of a certain range, mapping functions were subsequently applied, enabling the device to measure the range that is most commonly observed during the monitoring period and then maximize the presentation of this range. This mapping follows guidelines established by previous literature pertaining to the distribution of human physiological signal characteristics, which indicates that individual users have different ranges of distribution. Therefore, we propose that the device should be able to check the details of a certain range and monitor any variation in this range; this mapping strategy can change according to the historical changes and experiences of a particular user as shown in Figure 2(a). Figure 2(b) illustrates the differences of mapping functions. We fix each minimum and maximum point of measurement axis and display axis. Normal range of individual users and display window are also computed as index points. According to the mapping strategy of each range, we find appropriate mapping function such as logistic function, exponential function, first- or second-order differential equations, and so on.

For applying a mapping strategy, we define representation type of physiological signal. Physiological signals can be expressed as an N-dimensional array, $1 \times N$. We have three different types of arrays to map.

$$\begin{aligned} \text{Individual physiological signal measurements: } X &= \{x_1, x_2, x_3, x_4, \ldots, x_k\} \\ \text{Standard physiological signal measurements (or range): } S &= \{s_1, s_2, s_3, s_4, \ldots, s_k\} \\ \text{Display levels: } P &= \{p_1, p_2, p_3, p_4, \ldots, p_v\} \end{aligned} \tag{1}$$

where k has maximum range of observation and v means display resolution. For regulating each different level of scale, we set important points to generate mapping function. $O_{min}(Source, State)$ indicates minimum value of observed physiological signal obtained from individual user, source, in a certain specific condition, state. For example, $O_{min}(User1, Normal)$ means the minimum value of the first user who is in a normal physiological



(a) (b)

FIGURE 2 Socially interactive visualization method: (a) conceptual mapping strategy and (b) user-adaptive mapping function.

condition. Similarly, O_{max}(*Source*, *State*) shows the maximum value of observed physiological signal of current normal (or abnormal) state user. D_{min}(*State*) and D_{max}(*State*) illustrate the minimum and maximum values of display where state indicates normal state, abnormal state, and initial state. If we map the global measurements, we obtain the position of distributed signal with global view point; if not, we acquire the signal from the local view from the different display.

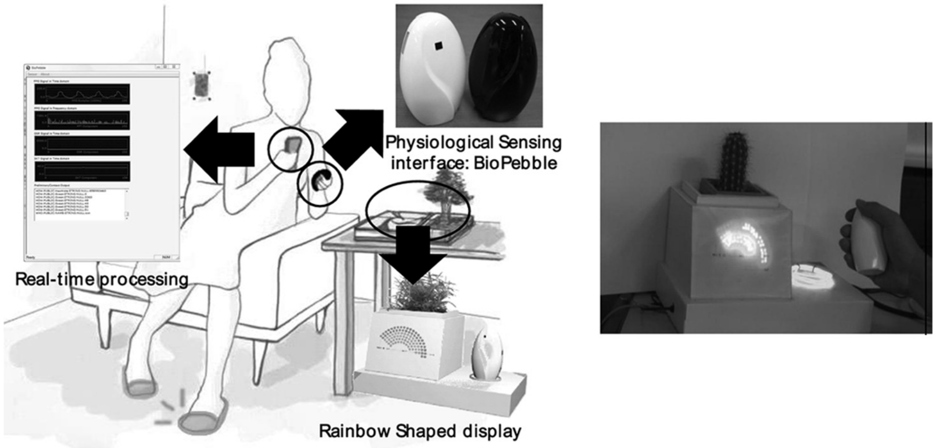
For display measurement coordination, we employ transformation function, F, where F_1 is for linear mapping and F_2 is for nonlinear mapping. A typical mapping strategy is based on linear mapping. However, in this work, we suggest a nonlinear mapping method that takes into account the user's distribution of measurement in the information visualization step. To determine the mapping function we compute the gradient considering the frequency of measurements. For magnifying the signal over the normal range, we apply a log scale function as a mapping function. Otherwise, the signals below the normal range can be emphasized by exponential function. The relationship between measurement and display level is depicted in Eq. (2).

$$\begin{aligned} &P(x) = F[X(t)] \\ &P(x) = \{p(x), p(x+\tau), p(x+2\tau), p(x+3\tau), \ldots, p[x+(v-1)\tau]\}, \text{ where,} \\ &\quad \tau = (\delta/v - 1) \end{aligned} \tag{2}$$

The mapping of the processed physiological signals from the sensing interface to this rainbow-shaped ambient display is suitable to illustrate the steps needed to present the digital information in different colors and levels. Ambient displays are useful and simple interfaces to obtain digital information, engage human senses, and present information by using an object that can be processed in the background of awareness (Wisneski et al. 1998). In this work, we represent the user-adaptive information via ambient interface for engaging human senses and for enhancing the readability of physiological information.

IMPLEMENTATION

In this section, we describe the implementation of our monitoring system. This monitoring system includes a stone-type natural sensing interface and ambient display to visualize information socially natural manner. First we developed a stone-type sensing interface, as a result of several rounds of modeling, preusability tests, and prousability tests. For the first round, we designed the overall shape of the proposed sensing interface. In this step, we evaluated different types of gripping method such as computer mouse-type device, joy stick-type device, bar-type device, and stone-type device.



(a) (b)

FIGURE 3 Overview of the health monitoring system: (a) system concept and (b) implementation results.

From the first usability, we concluded that the stone-type device showed most simple and intuitive to grab the sensor and comfortable to monitor for a long time. In the second round, we specified the sensing position, button position, switch metaphor, and feedback design in terms of operation step, communication step, and activation step. Figure 3 illustrates the overall health monitoring system and its implementation results of proposed natural sensing interface embedded with three different kinds of sensors: PPG, GSR, SKT. The sensed information was transferred to mobile devices using a wireless communication method.

The implementation details of the proposed monitoring system are shown in Figure 4. In Figure 4, the main processing module (figure in center)

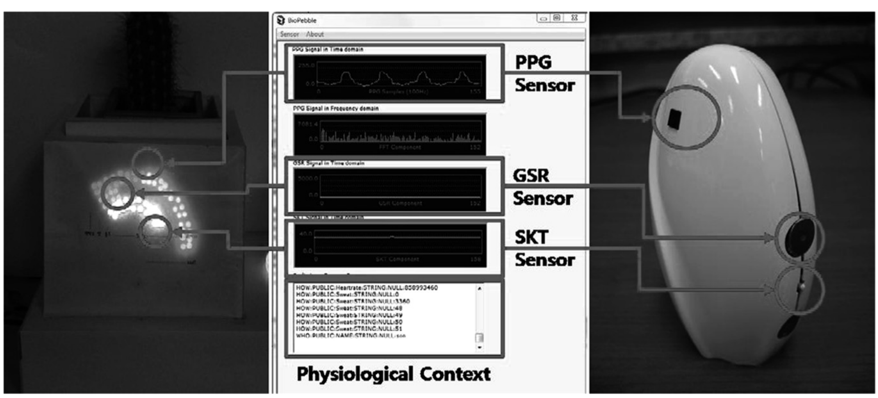


FIGURE 4 Implementation details (left: display, center: processing unit, right: sensing interface).

can receive and send contextual information because it was developed on a unified context aware application model (UCAM) framework (Oh and Woo 2007). Thus, this system recognizes contextual information such as overall body condition of the individual user, number of users, profile of multiple users, and so on.

This sensing device transmits the signal wirelessly—in this case, using a Bluetooth connection—at a sampling rate of 100 Hz, which meets the Nyquist sampling rate of heart rate variables. The sequence of the transmitted signals included a carriage return value (1 byte), a GSR value (2 bytes), a heart rate value (2 bytes), and a temperature value (2 bytes). Power was controlled by a tag switch that supplied power only when the sensor was held. The distance from display to sensing devices did not matter in practice. However, the distance from display to mobile device (or from sensing device to mobile device) should be less than 100 m because Bluetooth technology covers ranges within 100 m.

In addition, we developed a rainbow-shaped display, where each line of the rainbow represents a measured signal. We applied red for heart rate measurement, amber for GSR measurement, and green for temperature measurement because we used the concept of a rainbow in the proposed display. We mapped the longest line to the heart rate because heart rate showed large changes during one minute of monitoring compared to hand temperature. Hand temperature rarely changed its value. In addition, we applied Oriental science theory, five elements theory, which indicates the relationship between color and organs of the body (Veith and Rose 2002). Figure 5 shows the visualization result of the rainbow display. The left figure represents the normal condition of the user and the center and right figures express the abnormal condition of the user, especially in skin conductance.

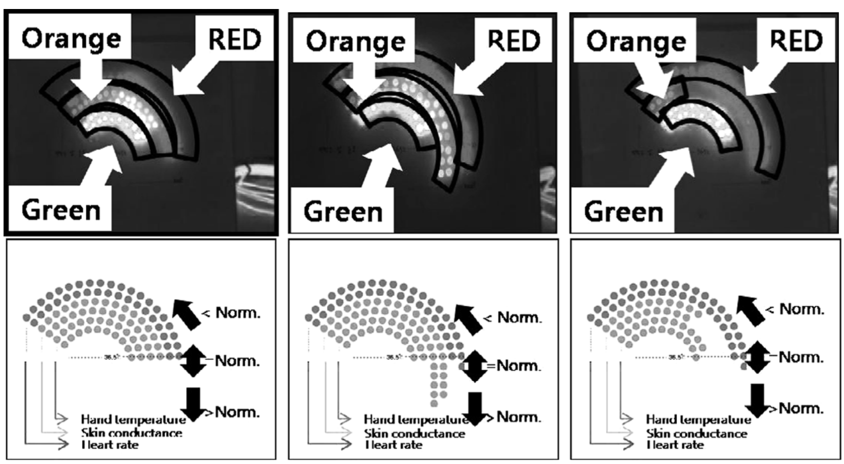


FIGURE 5 Rainbow display (left: an example of normal condition, center/right: examples of abnormal condition).

EXPERIMENTAL ANALYSIS

In this section, we evaluate the proposed simple, natural, and enjoyable sensing interface and intuitive information visualization method for novice users. We evaluate how this system supports social well-being. We observed how many normal users would accept this sensing concept and how much they were satisfied with this sensing interface and method. In this experiment, we compared the shapes of different sensing interfaces in terms of aesthetic appeal, comfort of grip, simplicity of use, and other hedonic and ergonomic factors. Hedonic and ergonomic aspects are important factors because users' cognitive concerns during monitoring have an influence on the measurement results (Hassenzahl et al. 2000). In addition, access time was computed to confirm how easy the sensing interface was to use. In the experiment about display, interactive information visualization was evaluated using an observation method. In this experiment, we verified whether the proposed visualization method was sufficiently readable for a novice user. Furthermore, we tested whether the information visualization with an adaptive mapping strategy adaptively supported a wide range of individual users.

In the stage of designing experiment, we recruited 12 people of different ages who had different academic backgrounds; for example, electronic engineering, computer science, art, etc. Six were from electronic engineering and computer science departments, three had an art background, and the rest had no particular academic background. They all were visitors or researchers at Gwangju Institute of Science and Technology. Of the 12 subjects who participated in the user study, 5 were female and 7 were male. Overall demographics of participants are shown in Table 1. As a prestudy, we collected basic profile information from each user, including gender, age, profession, and previous experience of computer or handheld devices. We analyzed the

TABLE 1 Descriptions of the Participants.

Age	Gender	Occupation	Average usage time of computer per day	Average usage time of handheld devices per day	Mental status	Physical status
28	Female	Student	Less than 10 h	Less than 3 min	Good	Neutral
28	Female	Administrator	More than 10 h	Less than 30 min	Neutral	Neutral
27	Male	Student	Less than 10 h	Less than 10 min	Neutral	Very bad
58	Male	Officer	Less than 5 h	Less than 10 min	Good	Good
55	Female	Housewife	Less than 1 h	Less than 10 min	Good	Good
28	Male	Student	Less than 10 h	Less than 3 min	Neutral	Neutral
28	Male	Student	Less than 10 h	Less than 10 min	Neutral	Neutral
32	Male	Student	Less than 10 h	Less than 3 min	Neutral	Good
29	Male	Student	Less than 10 h	Less than 10 min	Neutral	Good
41	Female	Artist	Less than 5 h	Less than 30 min	Neutral	Neutral
28	Female	Artist	More than 10 h	Less than 10 min	Neutral	Neutral
32	Male	Artist	Less than 10 h	Less than 3 min	Good	Good

(a) (b)

FIGURE 6 Physiological signal sensing interface used for experiments: (a) stone-type and (b) disposable wired-type.

subjective questionnaire filled out by users after testing each type of sensing device; in analyzing the questionnaires, we applied a method for determining semantic differences in each user's subjective feedback.

In this experiment, we compared only two sensing interfaces, a stone-type and a disposable wired-type as shown in Figure 6. Various types of sensing devices can be used to monitor physiological signals in the home environment. Note, however, that we selected the wired-type sensing interface because it is a standard interface used in daily health monitoring in the home environment. The stone-type physiological sensor detects three physiological signals: pulse, hand temperature, and hand GSR. In order to reduce novelty effect, we repeated evaluations with three different groups of people who had different academic background during 4 days. In addition, we recorded how much users were accustomed to computer or handheld devices and time dependency of measurements. Once a user evaluated device A after device B, the user did the same experiment in reverse order.

In our previous work, we investigated user satisfaction according to different sensing interfaces. Based on previous observations, we evaluated user satisfaction levels pertaining to the shapes of different sensing interfaces. The subjects compared each sensing interface and recorded their level of satisfaction about the aesthetic appearance on a 5-point Likert scale (e.g., from 1, strongly disagree to 5, strongly agree). This experiment showed that the overall satisfaction ratio of the stone-type sensing interface yielded better results than the wrist-type sensing interface. The average satisfaction of the stone-type and wrist-type interfaces was 3.83 and 3.33, respectively, and showed significant differences when we applied an ANOVA test ($p = 0.039 < 0.05$). From these observations, we concluded that a stone-type physiological sensing device offered a better grip, comfort, and effective sensing stability (Choi et al. 2008). In this section, we extended this subjective evaluation to clarify dominant factors that defined this satisfaction. Hassenzahl et al. (2000) presented a usability test for hedonic and ergonomic aspects. To analyze the proposed sensing device, we then expanded the dimensions of the questionnaire from a 5-point Likert scale to a 7-point Likert scale.

For further analysis, we allowed the subjects to experience each type of sensing device and then asked them to respond to a questionnaire. In this questionnaire, each rating was expressed through the use of bipolar verbal scale anchors, where extreme case words were described at the end of the rating scale. Subjects were asked to select their degree of satisfaction between the anchors; we referred to the bipolar anchors stated in a previous work (Hassenzahl et al. 2000), though some of the factors did not meet the same criteria for evaluating the physiological monitoring system. As such, we selected the following criteria to evaluate the appearance and usability of the proposed pervasive sensing device, as illustrated in Table 2.

From the subsequent analyses, we observed factors affecting user acceptance and satisfaction of physiological monitoring, as seen in Figure 7. The index items "comprehensible," "simple," "trustworthy," and "familiar" indicated ergonomic aspects, and the others addressed hedonic aspects. With respect to the ergonomic ratio, the stone-type interface had the highest score on the simple-to-use index, original-to-use index, aesthetic appeal index, and comprehensible-to-use index but was deemed less trustworthy compared to the disposable wired-type interface. In case of the hedonic ratio, we observed that the stone-type interface had more hedonic aspects than the disposable wired-type interface. Thus, in this experiment we found that whereas the subject felt that the stone-type sensing interface was more novel and simpler to use, it was less trustworthy than the disposable wired-type interface.

In Figure 7, we can see changes in satisfaction in terms of experience time. In the case of the stone-type interface, the familiar and trustworthy factors drastically increased as the experience time increased. However, as the users became more accustomed to the stone-type sensing interface, their satisfaction in terms of comprehensible and aesthetic feelings were reduced; the disposable wired-type interface had the lowest score for simple, though it

TABLE 2 Items for the Subjective Questionnaire.

Keywords	Description
Comprehensible	Did you understand the sensing procedure and method without referring to the manual?
Simple	Is the sensing method simple and unobtrusive?
Trustworthy	Is the sensing method trustworthy?
Familiar	Does the sensing method become more familiar with time?
Original	Is the sensing method original?
Aesthetic	Is the shape of the sensing device aesthetic?
Motivating	Are you motivated by the sensing interface?

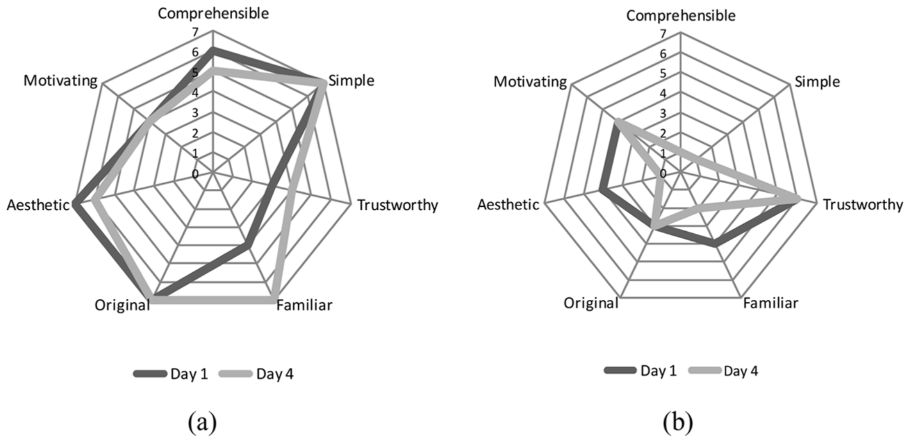


FIGURE 7 Satisfaction in terms of monitoring time for (a) stone-type and (b) disposable wired-type interface.

became notably more familiar and aesthetic after subjects experienced the interface for 4 days. From this evaluation, we confirmed that the stone-type sensing interface had a simple and aesthetic design and thus was deemed appropriate for use in monitoring physiological signals in a natural manner in a home environment.

For the second part of our evaluation, we observed the minimum time required to obtain reliable results by considering three signal ranges: transition range, reliable range, and error range; the definition of each range is illustrated in Figure 8. To determine an appropriate monitoring time, we monitored each physiological signal for 30s, 1 min, and 5 min, depending on the ranges. In Figure 8, the time of saturation for each range was approximately 30s, 1 min, and 5 min, respectively. Although errors were accumulated when the monitoring time increased, we observed a larger reliable signal range, as in the 5-min monitoring case. For the user feedback on different

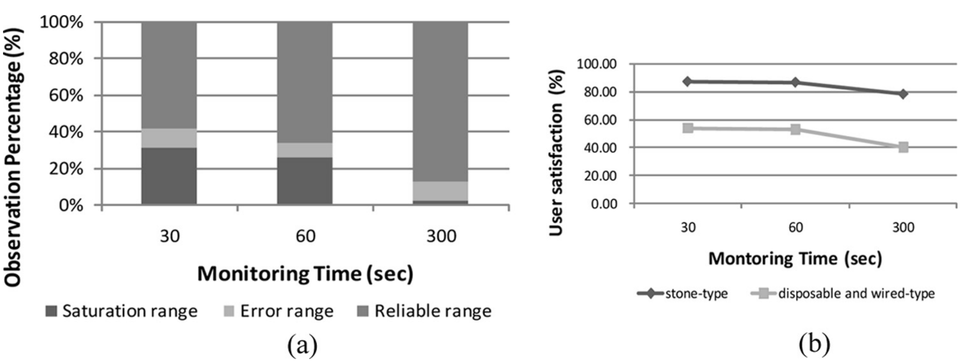


FIGURE 8 Monitoring time dependency: (a) signal aspect and (b) user aspect.

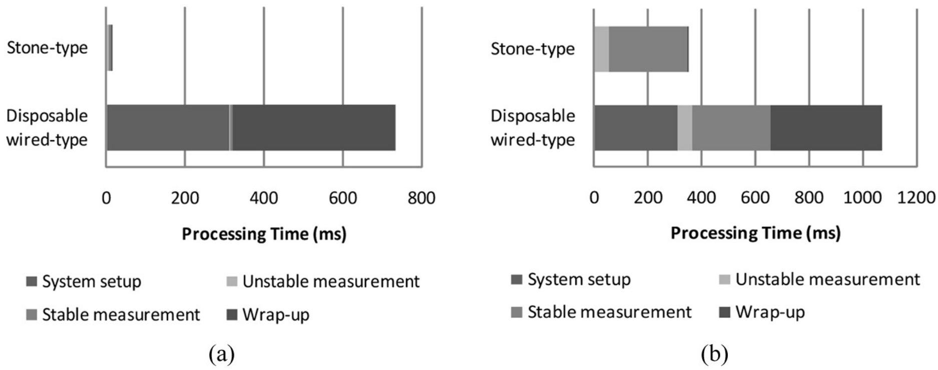


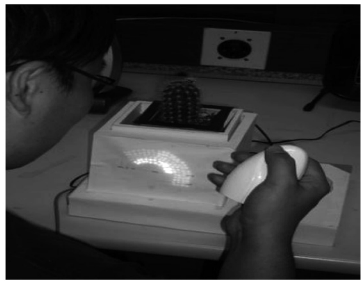
FIGURE 9 Processing time for monitoring with the proposed interface: (a) 1-min monitoring case and (b) 5-min monitoring case.

monitoring times, we received the result in Figure 8. Overall satisfaction was decreased as monitoring time was increased. From this observation, we obtained up to 80% satisfaction when we monitored physiological signal during 5 min.

As an extension of the above experiment, we measured the time for the entire process, from the preparation step to the wrap-up step; for example, turning on a measurement device, attaching sensors to the body, turning off the measurement device, and illuminating the sensors, as shown in Figure 9. Here, we compared two different sensing interfaces, a stone-type (i.e., the proposed sensing interface without wires) and an attached-type (i.e., typical sensing equipment with wires or electrodes). As a result, we observed that the stone-type sensing interface required a shorter access time for monitoring the physiological conditions.

For the third evaluation, we verified whether the proposed visualization method sufficiently supports readable social cues for a novice user. Furthermore, we confirmed whether the information visualization with an adaptive mapping strategy adaptively supports a wide range of individual users. For assessing user satisfaction with the rainbow display, we tested the different kinds of information visualization methods during monitoring as seen in Figure 10. We got some feedback from the subjects after they watched different kinds of display during 5 min. For the evaluation, we measured the time how long it took to understand the displayed physiological signal and asked them the meaning of displayed information. In this observation, about 66.67% subjects understood the meaning of rainbow display within 5 min. And we also checked that displayed information was coherent between changes of physiological signal and displayed information and which display was the easiest display to understand the physiological status. From this observation, we found that most participants preferred the rainbow display over the graph-type display. They checked the changes of physiological

(a)



(b)

FIGURE 10 Usability of different display type: (a) typical graph-type display and (b) proposed rainbow-type display.

signal by increased movement, such as running and jumping, and reported that both displayed response coherently. However, some users who had experience on physiological monitoring would like to know the changes and history of their recordings.

For evaluation of effect on social awareness, we allowed multiple subjects to monitor their physiological signals simultaneously with the proposed monitoring system. Each subject could see his or her physiological condition as well as other subjects' physiological conditions through two kinds of display; one was rainbow-shaped display and the other was stripe-type display as shown in Figure 11. In this experiment, we observed the response of subjects if the physiological condition of his or her confederates were odd or strange. If the confederates condition was odd, subjects started to worry about the confederate's condition as well as their own. In some cases, the displayed result was not accepted by others. From this observation, we found that physiological signal information empowers people's social awareness.

FIGURE 11 Social awareness evaluation among multiple subjects.

From the studies, we found that the proposed sensing interface was beneficial to monitor regularly during short-term in a home environment. In addition, the simple and intuitive display supported social awareness among extended family members. Normally, participants showed interest in other participants they looked odd. However, this monitoring system had the following limitations. First, the sensing interface required the attention of the user during signal monitoring. The sensing information was also sensitive to users' motion artifacts and sensing condition. Second, satisfaction of sensing interface was decreased as monitoring time was increased. In long-term monitoring, a wired sensing device might be more beneficial because this sensing device required little attention from the users. Third, the rainbow shape was not quite intuitive enough for users to understood at first sight. They were not quickly able to understand the meaning of each color and their current physiological condition. In addition, some people got tired of the LED lights after 5 min of monitoring.

CONCLUSION

In this work, we propose a socially acceptable natural sensing interface and intuitive information display. From our evaluations, we concluded that a socially acceptable sensing device, BioPebble, was inconspicuous to use, easy to control, and attractive to use, which was verified by a high score on the simple-to-use index, original-to-use index, aesthetic appeal index, and comprehensible-to-use index. These cognitive concerns about the sensing device employed the full power of the health monitoring system in a daily life while being socially unobtrusive. In addition, the intuitive information display, Rainbow display, supported peoples awareness of their confederates' physiological conditions and resulted in promoting social awareness of people. In addition, the dynamic information visualization display, which changed according to individual user's measurements, was more effective to convey physiological status to novice users. As a future work, we will further evaluate with a larger group during a longer time for reliable analysis. In addition, we will test an effect of different kinds of display and sensing devices reported on to date.

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