Stone-Type Physiological Sensing Device for Daily Monitoring in an Ambient Intelligence Environment*

Ahyoung Choi[1], Yoosoo Oh[1], Goeun Park[2], and Woontack Woo[1,2]

[1] GIST U-VR Lab.,Gwangju 500-712, S. Korea
[2] GIST CTI, Gwangju 500-712, S. Korea
{achoi,yoh}@gist.ac.kr, ge9156@hotmail.com, wwoo@gist.ac.kr

Abstract. Recently there has been increasing research into mobile physiological sensing devices to explore the benefits in the areas of monitoring health and well-being. However, previous works have mainly focused on functionality, and less so on affective shape, comfort use, and stable sensing. In this work, we propose a stone-type physiological sensing device for general users, rather than professional experts. We found that our device was comfortable, stable and had aesthetic appeal for users during monitoring. To develop an affective shape, and to increase comfort, we applied a user-centered design process. We also used context-based physiological signal analysis to obtain stable analysis results according to individual users. As an application, we developed a rainbow ambient display to give visual feedback to users. We expect that this product can be applied in various healthcare applications.

Keywords: Physiological sensing device, Real-time physiological signal analysis, Context awareness, Daily health monitoring.

1 Introduction

Currently there has been increased research interest in physiological sensing devices for use in daily life [1-3]. For developing sensing devices in Ambient Intelligence (AmI) environments, AmI technology is of interest because people normally do not carry their belongings and any portable devices. The following issues need to be considered: unobtrusive monitoring of physiological status with embedded sensors, intelligent analysis methods for health monitoring, and appropriate altering of the ambient display [4-5]. With the advent of wireless communication technology, light-weight Micro-electromechanical Systems (MEMS) technology, and greater computing power on mobile computing devices, various kinds of physiological sensing devices have been developed [6-7]. These include glove-type, wrist-type, armband-type, ring-type and embedded unconstrained-type sensing devices, all of which can be equipped in beds or bathrooms [8-11]. Glove-type sensing devices can conceal sensing lines and therefore have better aesthetics compared to the wrist-type and band-type sensing devices. In the case of wrist-type sensing devices, uncorrupted

* This research is supported by Foundation of UCN Project, the MKE 21st Century Frontier R&D Program in Korea and is a result of subproject UCN 08B3-O1-20S.

E. Aarts et al. (Eds.): AmI 2008, LNCS 5355, pp. 343–359, 2008.

signals can be reliably detected in the static condition. In addition, this type of device does not interfere with the user's work. In the case of band-type sensing devices, these can resolve the problem of movement in the sensing positions, because they can be more firmly attached to the body of the user.

However, most previous work developed sensing devices and analysis which supported light-weight wireless communication, multiple signals sensing and processing. Sensing devices in the AmI environment need to be comfortable to handle and need to capture the variations in sensing signals. In addition, most mobile devices are sensitive to environmental noise and motion. Therefore, a monitoring system that is both comfortable and stable is required. Some users of glove-type sensing devices report discomfort from increased weight and perspiration over a period of time. In the case of wrist-type sensing devices, in situations where there is a significant amount of movement by the user, signals can be corrupted because of changes in the sensing position [12]. In addition, band pressure and weight often mean that the user may become tired or uncomfortable during long term monitoring [13]. In terms of signal analysis, previous devices provided wireless and stable analysis results under experimental conditions. Employing these devices in daily life, some researchers proposed a pattern classification method for collecting activity information [14]. Activity information from the inference engine is used for ECG sensor activation, with a Bayesian classifier to remove activity noise.

To address these issues, we propose a stone-type mobile physiological sensing device, BioPebble. It provides an effective gripping sensation, aesthetic appeal and stable analysis of multiple context information. To maximize the aesthetic appeal of BioPebble, our research utilized a two axes positioning map with cool-warm and soft-hard axes. In order to develop the most effective gripping sensation, we applied a user-centered design process, which is a stepwise design process. In addition, BioPebble supports real-time wireless and multiple signal processing and adaptive analysis with context awareness technology. Context information is obtained from heterogeneous sensory inputs from multiple sensors and services.

As a result of these improvements, we have been able to derive significant benefits for users of the BioPebble, stone-type sensing devices and its analysis. These advantages include stable sensing, repeatability, and reproducibility of measurements in daily monitoring. In addition, BioPebble is comfortable to use and maximizes the aesthetic appreciation applicable to the AmI environment. From the usability test, BioPebble shows an example of appropriate physiological sensing devices in the future AmI environments. Some level of intention from users to monitor their physiological status, is beneficial not only usability but also stable sensing. It means that semi-automatic method combining cognitive aspect is more appropriate to check rough health status.

The outline of this paper is as follows. In Section 2, we explain the details of BioPebble with respect to three characteristics: aesthetic appeal, comfort, and stable sensing. Section 3 describes the implementation details. The experimental setup and analyses are discussed in Section 4. Section 5 illustrates the ambient display of BioPebble in future AmI environments. We conclude in Section 6, and suggest possible directions for future work.

2 BioPebble: Stone-Type Physiological Sensor

It is necessary for sensing devices to meet users' requirements during monitoring with particular attention to such aspects as design, usability, as well as the essential sensor functions. The concept of physiological sensors for use in daily life should therefore be concerned about comfort, aesthetic shape and stable sensing in order to provide better health monitoring and prevention services. In this section, we describe BioPebble, a stone-type grippable physiological sensing device which has been designed with three key words in mind: "Human, Well-being, and Simple User Interface."

2.1 User-Centric Physiological Sensor Design

In order to construct the shape of the first prototype of BioPebble, we observed commonly used mobile apparatus such as cellular phones, MP3 players, the computer mouse and so on. These commercial products were categorized according to two criteria: the sense of touch and the degree of warmth. Based on these axes, we constructed a sample BioPebble with a positioning map. The commercial products were divided into 4 groups, Groups A, B, C and D according to their place on the positioning map as described in Table 1.

Table 1. Description of Positioning Map

Group	Features	Key words
Group A	Soft-Warm	Soft, Simple, Feminine, Comfortable
Group B	Soft-Cool	Sweet, Fun, Clean, Cheerful
Group C	Hard-Warm	Dynamic, Strong, Intensive, Bold
Group D	Hard-Cool	Masterful, Gentle, Solid, Heavy

We designed BioPebble by reference to Group A's device because users felt most comfortable while using this particular device. The form of Group A is preferable because it is streamlined, and its size is designed to be fully covered by the hand. These two features mean that the area which is directly in contact the user's hand is larger than that of the other groups' designs. We analyzed Group A's common features with respect to the whole form, including the left and right side view, decorations, materials, color, and accessories. In BioPebble, in order to maximize the area which is covered by the hand, we designed a bulged center. Accessories such as wheels, displays, buttons and so on, are also made in a similar smooth circular shape. In addition, we designed our sensor based on the metaphor of a stone, because in the healthcare industry, natural stone has conceptual accordance with health and well-being.

After building the basic form of BioPebble, we designed BioPebble in greater detail with the user-centered design (UCD) process for comfort and usable physiological sensor development [15]. UCD is a repetitive and stepwise process. Users first work with a prototype, and from this, developers and designers obtain necessary feedback. During the initial development of BioPebble we collected feedback from the subjects and concretize the details in each step as shown in Fig. 1.

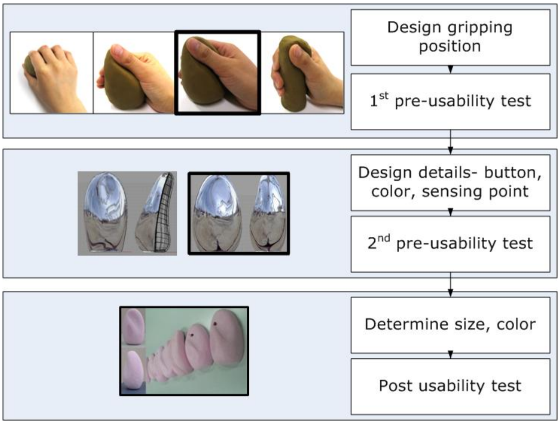


Fig. 1. BioPebble design process

After selecting the shape of our sensor, we sketched details using a 3D modeling program and made prototypes. For the 2nd usability test, we observed the users over a period of about ten to fifteen minutes in order to collect subjective data, as described in Table 2.

Table 2. Requirement for Mobile Physiological Sensor Design

Problem	Requirement
Increased weight over time	Use light weight materials
Increased perspiration during long-term monitoring	Use anti-sweat materials
Sensor positions (especially, temperature sensors) can cause discomfort or pain	Minimize the projection of sensors
Difficulty in maintaining finger attachment during long term monitoring	Attach to the palm for greater stability
Difficulty in establishing common standards for sensor lines and length	Sensor position should avoid individual body characteristic and should be general
Ability to easily change batteries	Place the battery cover on reverse side of sensor
Users are unaware if the device is activated	Simple displays such as LEDs should be able to provide this information
Inconvenience in activating the sensor	Power begins automatically when users hold the sensor
Learning to use the device	The sensing interface and method should be intuitive and easy to understand
Difficulty in maintaining static sensing conditions	Sensors should support wireless technology to allow the user more freedom to measure
Should be pleasant	Gentle curves and lines should be used

From this, we were able to collect feedback from multiple users for further design modifications to the BioPebble design referenced by the previous work [16].

2.2 Real-Time Physiological Signal Processing

BioPebble is equipped with three kinds of sensors, photoplethysmography (PPG) sensor, galvanic skin response (GSR) sensor and skin temperature (SKT) sensor. These three sensory inputs are delivered by Bluetooth communication from BioPebble to a mobile device. In this way, BioPebble can give real time and multiple physiological sensing. In addition, we carefully selected the sensing methods and points. The essential features of any sensing device are the individual sensor points. The position of these separate sensor points on BioPebble is determined according to the range of corrupted signal. For example, a PPG sensor point is located at the thumb position because that position minimizes the problem of differences in finger length among people. In addition, we can obtain the PPG signal clearly on the peripheral. A skin conductance sensor point and a skin temperature sensor point are located under the palm because this type of bio-data is most accurately collected through the palm. Of these sensors, it was decided that the PPG sensor should be located on the periphery but the other sensors (GSR, SKT) do not need to be limited in terms of their sensing position. Based on this theory, we selected the sensing points for stable analysis.

For physiological signal analysis, we apply the following processing steps, as shown in Fig.3. First, three kinds of signal are retrieved from the sensor, and then we remove the baseline of the sensed signal with a band-pass filter. Signal tendency information is gathered after low-pass filtering, and high frequency noise is also removed. For regulating the size of sensed data, down-sampling is then processed. In addition, calibrating the sensory information is done in a modification step. If the sensory data is not sufficient, an interpolation is activated. Second, a feature extraction step is processed. In this step, we utilize the features from the time-domain and frequency-domain. In the case of pulse signals, frequency domain analysis is required. From this step, we compute the basic feature values such as peak to peak intervals, intensity, differences and slopes, and frequency.

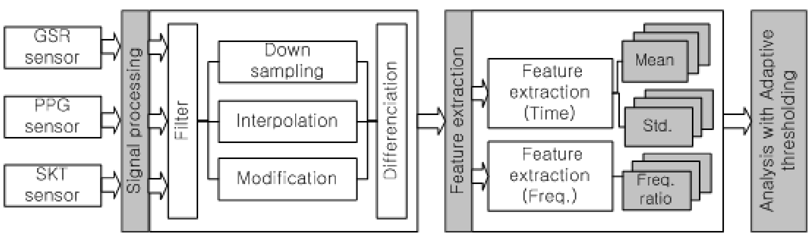


Fig. 3. Steps for Physiological signal processing of BioPebble

In the physiological signal analysis step, finally, we proposed the adaptive physiological signal analysis method. Physiological signals obtained from devices such as mobile phones can have significant variations according to prevailing environmental conditions and any movement of the user. Therefore, if the measurements are taken within a certain time period, they may provide unstable results due to these variations. Also the heart can be sensitive to other conditions, such as outdoor temperatures, the weather, caffeine, and even the mood of the user.

In previous work, it has been reported that thermal stress is influenced by personality, and that gender has an effect on the heart rate [17-18]. Therefore, an integrated analysis considering the user`s condition and context is crucial in physiological signal analysis.

In this section, we applied context awareness technology on a framework for decision making, which provided seamless communication between sensors and services [19]. This framework includes the functions of context integration, inference and decision making, and therefore can easily obtain multiple sensory contexts from sensors in the framework. This multiple contextual information is utilized in the decision making step. In order to get the distribution of data, we collected the data for a week and modeled it using a non-parametric method. The modeled physiological signal was then interpreted by the weighted values which describe the amount of excessive range. We divided the user's condition into two cases: normal and abnormal, and then computed the distribution of each status. The outliers were eliminated from the measurement set.

3 Implementation

In this section, we explain the implementation of BioPebble. We developed BioPebble in several steps of modeling, pre-usability test and pro-usability test. In the first step, we devised several different gripping shapes: a computer mouse, a joystick, a stone and a bar. These are shown in Fig. 4.

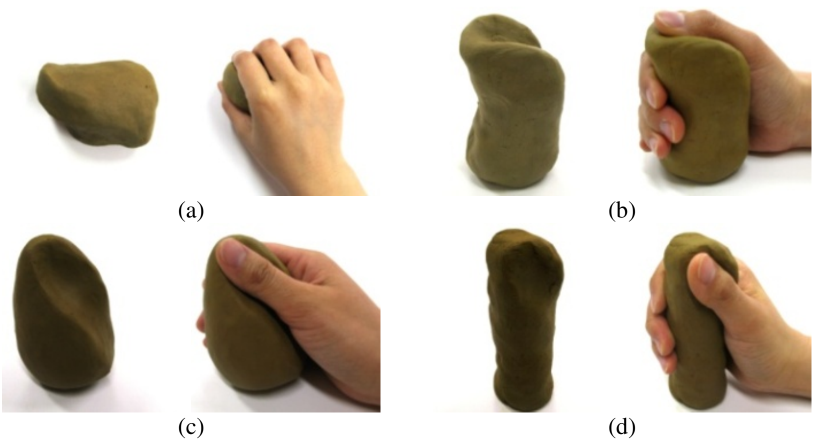


Fig. 4. Grip design: (a) mouse-type (b) joystick-type (c) stone-type (d) bar-type

From this usability test, we eliminated the designs which did not meet our themes of design, aesthetics, comfort, and stable sensing. The mouse-type prototype met the criteria for comfort to be covered by the hand. However its shape was a little unfamiliar to users. In the case of the joystick sensing device, most users also felt comfortable while gripping it. However, the overall shape did not adequately satisfy the criteria of warmth and softness. The bar-type sensing device was also somewhat comfortable, but there was some space between the user's palm and the device's body. Therefore, this type was not appropriate for measuring signals in a stable manner. From among the four types, we concluded that the stone-type sensing device was the most effective with respect to size, shape and sensation when measuring physiological signals. At the same time, the stone-type sensor was found to be aesthetically pleasing for users. For the pretest, we constructed a prototype of BioPebble, as illustrated in Fig. 5.

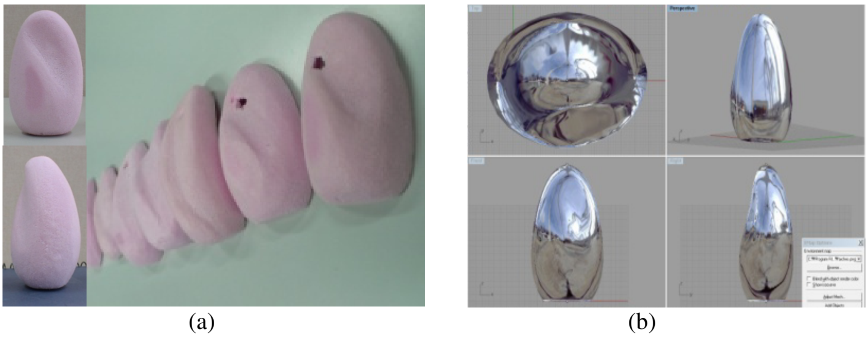


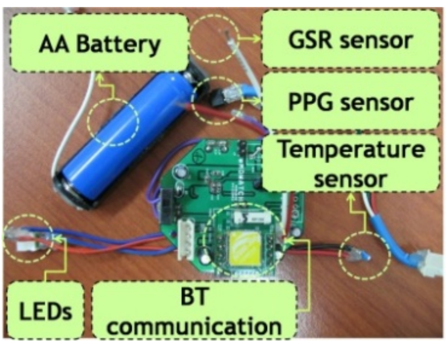
Fig. 5. BioPebble prototype (a) mock-up (b) 3D model

We built a 3D model of BioPebble according to the measurement of a mock-up using a CAD program. This modeling data was then used to make the prototype. We obtained the final application with rapid prototyping equipment. From the user survey and data analysis of BioPebble, we obtained the final design given in Fig. 6, which illustrates the front, back, side and top views.

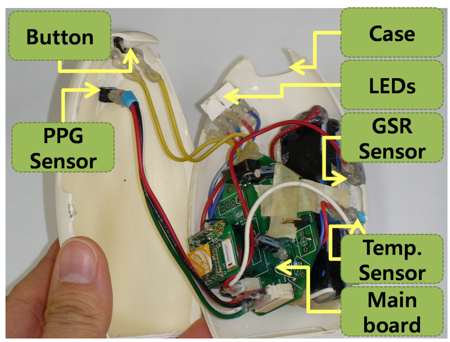
Fig. 6. Detailed description of sensor positions and size in BioPebble

A detailed description of BioPebble is provided in Fig. 6. BioPebble is 6 centimeters long, 4 centimeters wide and 10 centimeters high. It is divided into two pieces: an upper section and a lower section. The battery cover is located on the lower section, and the on/off button is on the top. A PPG sensor is located at the thumb position. GSR and SKT sensors are placed at the side of the sensor, in the palm. For the on/off button, we use a tag switch, which activates only if the tag button is pushed by the index finger. Two LEDs show the status of power and wireless Bluetooth network connection. The final design of our stone-type sensing device has a streamlined shape and all sensor points and lines have a round shape. The materials of BioPebble include a plastic coating cover with a glossy finish to protect against heat and sweat. For a more light-weight sensing device we use a plastic cover to reduce weight.

BioPebble has three kinds of physiological sensor points: GSR, PPG and SKT sensors. It transmits its signal via Bluetooth. The sampling rate of BioPebble is 100Hz which meets the Nyquist sampling rate of heart rate variables. The sensed signal is transferred with a header. The sequence of transmitted signals includes carriage return value, GSR value, PPG value and SKT value. The composition of BioPebble hardware is shown in Fig. 7(a), and the hardware located within the BioPebble prototype is shown in Fig. 7(b).



(a)



(b)

Fig. 7. BioPebble hardware: (a) Hardware component (b) Inside view

For adaptive analysis, we developed BioPebble analysis software which captures, stores and analyzes signals over a certain period of time. We constructed the user model from the stored data set. The standard value initialized the threshold at the first step, and then an adaptive analyzer updated the threshold referenced by the user model.

4 Experimental Analysis

We believe our proposed BioPebble can provide users with a measurably better affect, a more comfortable grip, and stable signal analysis with adaptive threshold. In order to verify this, we conducted three experiments. For the aesthetic appreciation

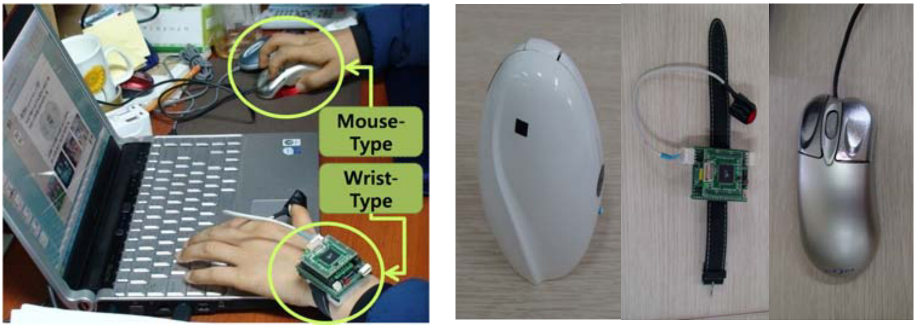


Fig. 8. Usability test with several types of physiological sensing devices (Left: BioPebble, Center: wrist-type device, Right: mouse-type device)

evaluation and satisfaction with sensor positions, we undertook a usability test with 12 subjects, as shown in Fig. 8, and took subjective measures, such as questionnaires, while the subjects were using BioPebble.

The independent variables of this experiment were the type of physiological sensing device: a wrist-type, a mouse-type, or a stone-type device. We chose these devices for evaluating the appropriateness of monitoring devices in the AmI environment. A mouse-type device can monitor the physiological signal while users are working. A wrist-type device can unobtrusively measure changes in physiological status. In this experiment, we used for comparison with BioPebble has been in use since 2004. Dependent variables were error rate, sensing accuracy. We kept the dependent variables constant. Of the 12 subjects, 5 of them were female and 7 were male. 6 of the subjects had engineering backgrounds, 3 were majors in art, and the remainder had no academic background. The average age of participants was 34.5 years old. First we surveyed user profiles, looking at such things as age, gender, occupation and basic background, all of which can have an effect on physiological signal sensing. Basic background information included the length of time on computers, whether subjects normally wear wrist watches, and the usage time of cellular phones. After this basic survey, we allowed the participants to make use of each device sequentially over both long term (over 15 minutes) and short term (within 5 minutes). Finally, we conducted usability test for feedback. In this experiment, we also recorded the degree of the satisfaction about the questionnaire.

4.1 Aesthetic Shape

For aesthetic appreciation, we asked the participants to grade the various devices in terms of attractiveness. The grading rate was from 1 for least attractive, to 5 for most attractive. Fig. 9 shows the results of the aesthetic satisfaction of BioPebble.

Compared to other sensing devices, BioPebble gave the best satisfaction. The average degree of satisfaction was 3.9, while the wrist-type sensing device and the mouse-type sensing device had 3.4 and 2.9 on aesthetic satisfaction, respectively. For

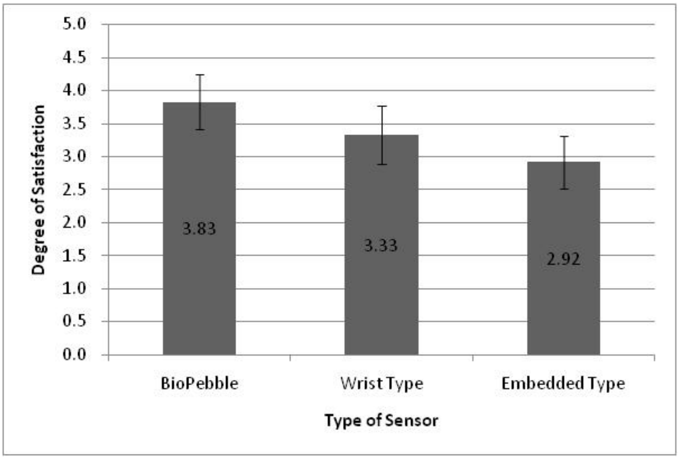


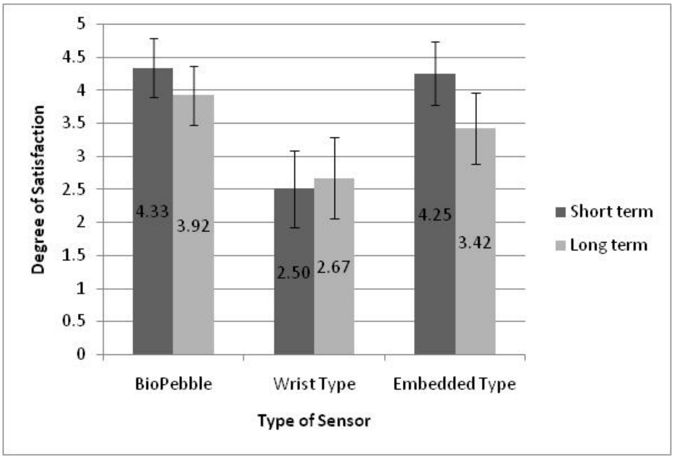
Fig. 9. Aesthetic satisfaction according to the type of sensing device (Degree of satisfaction)

statistical analysis, we used the ANOVA and Tukey's post analysis. There are significant differences among the different types of sensing devices ($p=0.039<0.05$), in terms of aesthetic satisfaction.

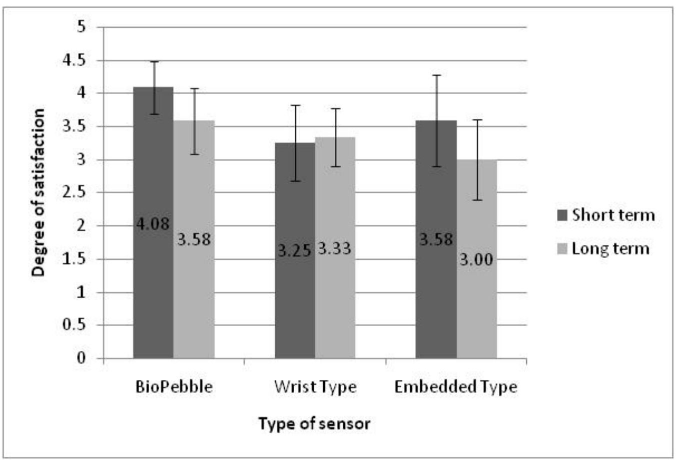
4.2 Comfort Grip

In the second experiment, we surveyed satisfaction in terms of the position of the three sensor points by varying the measurement time. In this investigation, we questioned the participants about their satisfaction degree on these sensor positions and handling comfort.

In the case of sensor position intervention, BioPebble and the mouse-type device were more satisfactory than the wrist-type device. However, the satisfaction decreased in long term monitoring. Normally, the wrist-type device rated better in long term measuring even if the absolute grade record was the lowest among the tested devices. Therefore we concluded that BioPebble had little intervention in long term and short term monitoring compared to the other types of sensors. In the second survey, we observed that BioPebble was the most comfortable for short term monitoring. However the degree of satisfaction also largely diminished when data collection occurred over a longer period of time, for example, 15 minutes. We also did statistical analysis using post analysis method such as ANOVA tests and Tukey tests. In the case of sensor point position comfort, we observed that there were significant differences among the different devices ($p=0.026<0.05$). In the test for handling comfort, there were significant differences ($p=0.0<0.05$). BioPebble and the mouse-type device showed the most significant differences. Participants informally provided the following information. BioPebble is designed to be used by just one hand, but participants suggested a sensor that could be used with both hands. Also participants noticed that BioPebble interferes with normal work. Also, in long term monitoring, participants noted increased discomfort in two areas: on the finger tips which measure heart beat, and from slippery surfaces caused by hand perspiration.



(a)



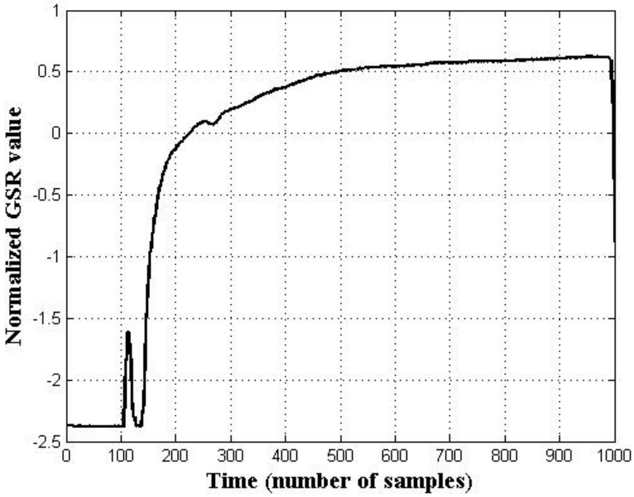
(b)

Fig. 10. Satisfaction in long term and short term monitoring (a) about sensor position (b) about gripping comfort

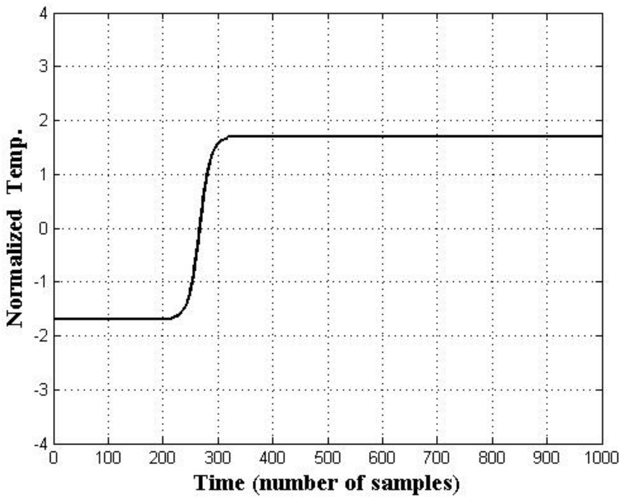
4.3 Stable Sensing

In this section, we evaluated the performance of the sensors. To do this, we collected signals from the three sensors, GSR, PPG, and SKT over a period of one minute using BioPebble. We analyzed 100 measurements and measured the average response time and response intensity. All results were processed through a normalization function, shown in Fig. 11.

In this experiment, we observed how BioPebble reacts to stimuli. We gave the subjects certain stimulus such as striking, a fright, noisy music and so on. According



(a)



(b)

Fig. 11. Distribution of measurements of BioPebble: (a) Normalized GSR (b) Normalized hand temperature

to the type of stimuli, the response time and response intensity can be quite different. However, we selected the average value, excluding the outliers. The responses of BioPebble are summarized in Table 3.

In order to evaluate the stability of BioPebble in sensing capability, we compared the analysis results in the situation where a subject moves during monitoring. Using BioPebble, we collected data when the subject was in the normal body condition.

Table 3. Responses of BioPebble

Sensor type	Response Time (Second)	Response Magnitude (Norm. Value)
GSR	2.35	3
Temp.	2.10	4

From this experiment, we observed that BioPebble gave better stability and more stable results compared to commercial equipment. Analysis results of commercial equipment showed them to be more greatly influenced by the motion artifact.

In addition, we observed the stable sensing had an effect on cognitive aspects of users, such as the intention to measure the physiological status, and agreement to monitor their physiological status. BioPebble reflects some level of cognitive intentions of users because most users agree to measure and monitor the physiological signal before gripping the BioPebble. Comparing to the other devices, BioPebble showed stable sensing results because it supported explicit measures of physiological status. Even though the mouse-type and the wrist-type devices sense signals in a seamless manner, a mouse-type device is sensitive to movement, and a wrist-type device is harder to fix in the sensing position. From this observation, we conclude that for better stable sensing, users need to follow instructions.

5 Ambient Display with Rainbow Shape

Ambient displays use the physical environment as an interface to obtain digital information, engage human senses, and present information by using an object which can be processed in the background of awareness [21]. In an ambient intelligence environment, ambient displays are more useful than conventional displays such as monitors for the engagement of our senses. In previous works, intelligent furniture had been devised in order to display daily information [22]. However, there is no research about physiological information visualization. We developed the physiological signal display taking into account that the end user would be a non-specialist, i.e., one who has no specialized academic background in human physiology. In order to make this signal more understandable for these users, we visualized information through every-day objects such as pots, tangible bars and so on, as in Fig. 12. Some of these objects were used as display tools.

The simple scenario in an AmI environment is as follows. The user holds the BioPebble with one hand, and data is transferred to a mobile PC and LEDs in smart pots and objects. The user can see the information from both the mobile PC and the LEDs of the smart pots and trees. This information enables the user to understand their entire body condition from the ambient display embedded in the background. In one of the applications, we implemented a pot with a display of a rainbow shape, as seen in Fig.13. The mapping of the processed physiological signals from BioPebble to this ambient display in a rainbow shape is suitable for showing the steps of digital information through different colors and levels.

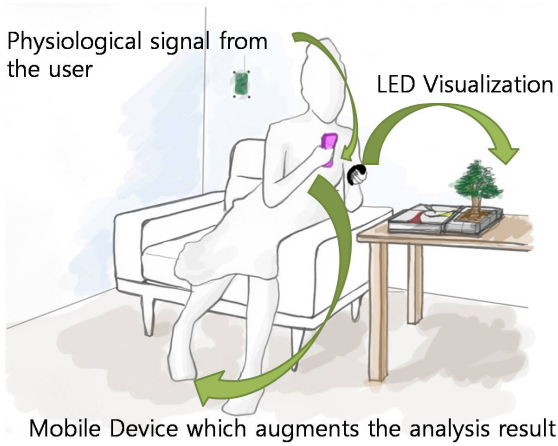


Fig. 12. Application scenario in a smart home environment with BioPebble and ambient display

Fig. 13. Implementation of rainbow/stripe visualization with a pot

Each line of the rainbow represents a measured signal. A red line indicates the pulse signal of the heart and the orange line shows skin conductance. The green line indicates hand temperature. Each sensing signal is mapped in each line of the rainbow. The mapping from BioPebble to rainbow display linearly represents the step of sensed values by referencing the threshold value. The stripe display also represents data linearly. The sensed values are divided into abnormal and normal condition. Table 4 shows how normal and abnormal conditions are identified. Each level is decided by the size of LEDs in the rainbow display. The division of conditions is referenced by each value of the sensed signals. If the user's sensed values are abnormal, the rainbow display will show an irregular shape, as shown in Fig.14 (b).

This application was demonstrated at the Korean HCI conference (Feb. 13~15, 2008). During the exhibition in the KHCI conference, we had the opportunity to do field tests of BioPebble. Most users showed interest in the system of BioPebble and the rainbow display. According to individual interests and academic background,

Table 4. The identification of normal/abnormal conditions

Conditions	Body Temperature		Skin Conductance		Heart rate	
	Level(8)	Values	Level(14)	Values	Level(16)	Values
Abnormal	1-4,6-8	otherwise	1-9, 11-14	otherwise	1-11,13-16	otherwise
Normal	5	29-31	10	1700 ~ 1800	12	80~90

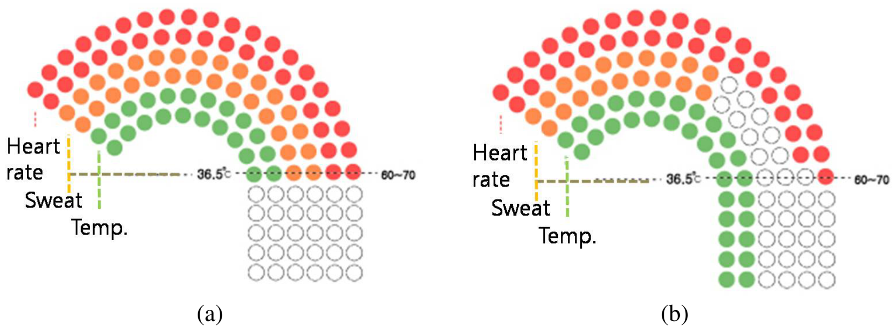


Fig. 14. Physiological information visualization with Rainbow Display (a) normal condition (b) abnormal condition

responses were quite different. Participants who have interests in sensor development expressed curiosity about the sensing positions and sensing methods. They agreed that BioPebble is satisfactory in terms of stable and comfortable sensing. Participants used increased movement, such as running and jumping in order to check and evaluate analysis results. Most of them felt that the measurements and analysis results seemed accurate. Participants from design backgrounds focused on the meaning of the stone-type sensor and well-being care applications. They said that the pot with the rainbow display and BioPebble was consistent with the concept of well-being. In addition, after simple observation, they were quickly able to understand how to grip BioPebble, thus confirming our claim that BioPebble is intuitively usable. From these field tests, we believe that BioPebble can be readily used as a physiological sensing device applicable in a daily life.

6 Conclusion

In this work, we propose a stone-type physiological sensing device, BioPebble, which maximizes the gripping sensation from the user and increases the aesthetic appreciation in short and long term monitoring. We compared BioPebble's performance in these areas with wrist-type and mouse-type sensing devices. BioPebble supports real-time, wireless and multiple signal sensing and provides adaptive analysis based on contextual information. In future work, we will evaluate the BioPebble focusing on hedonic and ergonomic qualities [23], and elaborate the design to allow users greater comfort in long term monitoring situations. We will also develop a computational model for context based physiological signal analysis. We will apply this model with a basic standard data set and evaluate the user model with scientific theory. The proposed sensing and analysis method could be applied to hand phones or mobile PCs. Our goal would be to reduce user awareness of the health monitoring process.

References

1. Ilkka, K., Juha, P., Mark, V.G.: Health monitoring in the home of the future. IEEE Eng. Med. Biol. Mag. 22, 66–73 (2003)
2. WenChung, K., WeiHsin, C., ChunKuo, Y., ChinMing, H., ShengYuan, L.: Portable Real-Time Homecare System Design with Digital Camera Platform. IEEE Trans. Consumer Electron. 51, 1035–1041 (2005)
3. Marketta, N., Rafael, G.F., Eija, K., Jorge, L.G.: Supporting Independent Living of the Elderly with Mobile-Centric Ambient Intelligence: User Evaluation of Three Scenarios. In: Schiele, B., Dey, A.K., Gellersen, H., de Ruyter, B., Tscheligi, M., Wichert, R., Aarts, E., Buchmann, A. (eds.) AmI 2007. LNCS, vol. 4794, pp. 91–107. Springer, Heidelberg (2007)
4. Emmanuel, M.T., Stephen, I., Kent, L.: Portable Wireless Sensors for Object Usage Sensing in the Home: Challenges and Practicalities. In: Schiele, B., Dey, A.K., Gellersen, H., de Ruyter, B., Tscheligi, M., Wichert, R., Aarts, E., Buchmann, A. (eds.) AmI 2007. LNCS, vol. 4794, pp. 19–37. Springer, Heidelberg (2007)
5. Erik, G., Luca, P., Alessandro, P., Alessia, R., Giuseppe, A.: Assemblies of Heterogeneous Technologies at the Neonatal Intensive Care Unit. In: Schiele, B., Dey, A.K., Gellersen, H., de Ruyter, B., Tscheligi, M., Wichert, R., Aarts, E., Buchmann, A. (eds.) AmI 2007. LNCS, vol. 4794, pp. 340–357. Springer, Heidelberg (2007)
6. DongWan, R., Changseok, B.: Design of The Wearable Gadgets for Life-Log Services based on UTC. IEEE Trans. Consumer Electron. 53, 1477–1482 (2007)
7. Robert, M., Neil, J.M., Paul, H., Peter, J.T., Martin, A.S.: A Wearable Physiological Sensor Suite for Unobtrusive Monitoring of Physiological and Cognitive State. In: 29th Annual International Conference of the IEEE EMBS, pp. 5276–5281. IEEE Press, New York (2007)
8. Rosalind, W.P., Jocelyn, S.: The Galvactivator: a glove that senses and communicates skin conductivity. In: 9th International Conference on Human-Computer Interaction (2001)
9. Sokwoo, R., BooHo, Y., Haruhiko, H.A.: Artifact-Resistant Power-Efficient Design of Finger-Ring Plethysmographic Sensors. IEEE Trans. Biomed. Eng. 48, 795–805 (2001)
10. Urs, A., Jamie, A.W., Paul, L., Gerhard, T., François, D., Michel, B., Fatou, K., Eran, B.S., Fabrizio, C., Luca, C., Andrea, B., Dror, S., Menachem, A., Etienne, H., Rolf, S., Milica, V.: AMON: A Wearable Multi parameter Medical Monitoring and Alert System. IEEE T. Inf. Technol. Biomed. 8, 415–427 (2004)
11. Toshiyo, T., Tatsuo, T., Mitsuhiro, O., Mikiko, Y.: Fully automated health monitoring system in the home. Med. Eng. Phys. 20, 573–579 (1998)
12. Matthew, J.H., Peter, R.S.: Artifact reduction in photoplethysmography. Appl. Optics 37, 7437–7446 (1998)
13. Michael, S., Carl, M., Alex, P.: Wearable feedback systems for rehabilitation. Journal of NeuroEngineering and Rehabilitation 2, 17 (2005)
14. Winston, H., Wu, M.A., Batalin, L.K., Au, A.A., Bui, T., William, J.K.: Context-aware Sensing of Physiological Signals. In: 29th Annual International Conference of the IEEE EMBS, pp. 5271–5275. IEEE Press, New York (2007)

15. Donald, A.N., Stephen, W.D.: User Centered System Design. Lawrence Erlbaum Associates, Mahwah (1986)
16. Francine, G., Chris, K., John, S., Malcolm, B., Richard, M.: Design for Wearability. In: 2nd International Symposium of Wearable Computers, pp. 116–122. IEEE CS Press, Los Alamitos (1998)
17. LeBlanc, J., Ducharme, M.B., Pasto, L., Thompson, M.: Response to thermal stress and personality. Physiol. Behav. 80, 69–74 (2003)
18. Rod, K.D., Yoshio, N., Melissa, E.G., Ray, W.T., Andrea, L.D., Steven, N.B.: Heart rate variability, trait anxiety, and perceived stress among physically fit men and women. International Journal of Psychophysiology 37, 121–133 (2000)
19. Dongpyo, H., Youngjung, S., Ahyoung, C., Umar, R., Woontack, W.: wear-UCAM: A Toolkit for Mobile User Interactions in Smart Environments. In: Sha, E., Han, S.-K., Xu, C.-Z., Kim, M.-H., Yang, L.T., Xiao, B. (eds.) EUC 2006. LNCS, vol. 4096, pp. 1047–1057. Springer, Heidelberg (2006)
20. Yoosoo, O., Woontack, W.: A Unified Application Service Model for ubiHome by Exploiting Intelligent Context-Awareness. In: Murakami, H., Nakashima, H., Tokuda, H., Yasumura, M. (eds.) UCS 2004. LNCS, vol. 3598, pp. 192–202. Springer, Heidelberg (2005)
21. Wisneski, C., Ishii, H., Dahley, A., Gorbet, M., Brave, S., Ullmer, B., Yarin, P.: Ambient Displays: Turning Architectual Space into an Interface between People and Digital Information. In: Streitz, N.A., Konomi, S., Burkhardt, H.-J. (eds.) CoBuild 1998. LNCS, vol. 1370, pp. 22–32. Springer, Heidelberg (1998)
22. Hiroko, S., Youichi, H., Yukinobu, M., Takeshi, H.: Information-Accessing Furniture to Make Our Everyday Lives More Comfortable. IEEE Trans. Consumer Electron. 52, 173–178 (2006)
23. Hassenzahl, M., Platz, A., Burmester, M., Lehner, K.: Hedonic and Ergonomic Quality Aspects Determine a Software's Appeal. In: CHI Letters 2, 1, pp. 201–208. ACM Press, New York (2000)