Sensorized Environment for Self-communication Based on Observation of Daily Human Behavior

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Abstract

This paper describes an intelligent environmental system, SELF (Sensorized Environment for LiFe), that enables a person to maintain his or her health through "self-communication." The system externalizes a "self" by storing personal data such as physiological status, analyzing it, and reporting useful information to assist the person in maintaining his or her health. To establish the methodology to create such a system, this study analyzes and re-defines the self as an object of information processing. Self-communication is nothing but understanding ourselves objectively. It is not easy to put into practice because it requires a visualized or numerized representation of oneself. As an example of an externalized self, this study focused on the physiological status of a person. The physiological status is obtained as follows: SELF observes the person's behavior with distributed sensors invisibly embedded in the daily environment, extracts physiological parameters from it, analyzes the parameters, and accumulates the results. The accumulated results are used for reporting useful information to maintain the person's health. The authors constructed a model room for SELF consisted of a bed with pressure sensor array, a ceiling lighting dome with a microphone, and a washstand with a display. Fundamental results of self-externalization using SELF are presented.

1 Introduction

Human beings can think about themselves. They can understand their present condition and decide what to do in the future based on the their present condition. However, like other abilities such as memory, calculation, and vision, the ability of thinking about oneself also has limits. It is difficult for humans to understand their condition objectively because their judgment depends largely on their feeling and knowledge. As an example, let us consider the status of our physiological selves, namely the condition of our health. Most people cannot notice a change in their condition without a medical monitor.

It is not until a phenomenon is broken down and represented as objective data that a person can grasp the phenomenon, ponder it, share it with other people precisely, and discuss it with them. This is true of self-data. Externalizing the self as objective data enables the person to gain a deeper insight into himself or herself.

This study addressed problems in an intelligent system which enables a person to understand himself or herself objectively by externalizing the self as objective data. Specifically, this study focused on the problems for a method of externalizing the self from the person to the intelligent system in order to objectify the self, and a method for recombining his or her externalized self with the person to guarantee the person's accessibility to the externalized self.

To solve these problems, this study was based on the following : Human behavior is communication media that enables the person to convey self-data naturally. A daily environment with sensors and computer is a new approach to deal with the person's daily behavior as an object of information processing. Namely, an environmental computer with sensors can automatically observe daily behavior, extract the self-data from the observed behavior, and represent the result.

Research on an environmental computer has been reported. The concept of ubiquitous computing[1] was presented and opened the way for research on supporting human activities in a daily environment with ubiquitous computing devices. For example, the the DigitalDesk[2], Smart Room[3], Robotic Room[4], Intelligent Room[5], and Intelligent Space[6] have been proposed. These research studies show the possibility of providing information at home input through natural human gestures without the use of keyboards, mice, and other special input devices. In particular, the Robotic Room provides not only information services but also mechanical services using robotic elements by understanding human natural behavior. An invisible computer[7] symbolizes the direction of these technologies. It is the concept of enabling a person to concentrate on his or her activity itself by hiding the computer and thus removing it from the person's

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consciousness.

This paper describes the concept of self-communication which enables a person to understand himself or herself objectively and continuously by observing the person's daily behavior with invisible computer technology that analyzes and represents the observed behavior, and reports useful information for ther person's daily life. This paper also describes the method for creating such a system and reports on a healthcare support system (SELF; Sensorized Environment for LiFe) which was constructed to demonstrate the proposed concept.

This paper is organized as follows: The next section describes the proposed concept of self-communication. The authors identify the necessary functions for realizing the self-communication and describe the method of realizing the functions. The effectiveness of the self-communication system constructed by integrating these functions is also discussed. In section 3, the authors report on the healthcare support system. Conclusions are presented in section 4.

2 Self-communication based on Human Daily Behavior

2.1 Concept of Self-communication System

This section describes the drawbacks in thinking about ourselves to clarify what we need to compensate for by externalizing ourselves. In this study a "self" is defined as a representation which we can use for analyzing ourselves (self-analysis), evaluating ourselves (self-evaluation), improving ourselves (self-improvement) and realizing desirable conditions for ourselves (self-fulfillment).

The drawbacks in thiking about ourselves are shown as follows.

Drawbacks in thinking about ourselves

1. Uncontrollability
   When and where a person should access and remember self-data and how important this task is cannot be controlled. Such a task tends to be uncertain and contingent.

2. Subjectivity
   Self-data is not based on objectivity. It tends to be subjective and inaccurate.

3. Knowledge dependency
   Self-data is generated only by the knowledge system the person has. No matter how important a signal is, the signal may be processed inadequately or ignored as being insignificant if the person has limited knowledge.

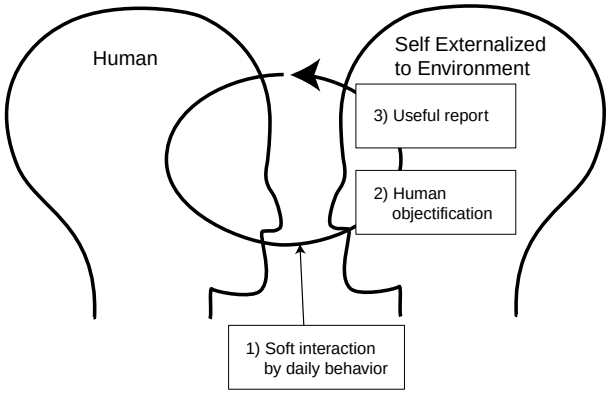

Fig. 1: Concept of self-communication system

Based on our analysis, we propose a concept of "self-communication."

Self-communication is communication via an intelligent environmental system which can 1) externalize the self from the person to the system by observing the person's daily behavior in order to objectify the self, and 2) recombine the externalized self with the person to guarantee the person's accessibility to the self based on the person's daily behavior.

Figure 1 shows a conceptual diagram of a self-communication system we propose. The system consists of the functions of 1) soft interaction by human daily behavior, 2) human objectification, and 3) useful report. Each function is described in detail in the following.

Soft interaction by human daily behavior In view of interaction, we describe the appropriate interaction for self-communication. Interaction can be categorized into hard interaction and soft interaction.

Hard interaction puts an emphasis on the quick response of the system. Conventional computers are used only for hard interaction. Hard interaction is appropriate for a task where we process data which already exists. Let us consider preparing documents. As long as we use the computer, while sitting at the computer, we don't have to walk around to gather necessary information. However, conversely a computer where the input/output devices and processors are concentrated in one place requires us to be near it. It is not suitable for dealing with typical events in our daily lives because most people's daily lives don't occur near the computer nor around the computer, much less on the computer.

On the other hand, soft interaction puts an emphasis on the sustainable usage of the system over a long term. To this end, daily behavior is utilized as information media.

Daily behavior has the following features. 1) Time regularity; the behavior tends to occur regularly be-

cause of the physiological needs of the body. 2) Spatial regularity; the behavior also tends to occur in special places where the necessary tools are located because the tools cannot be moved freely. Figure 2 shows an example of some daily behaviors. This daily behavior loop consists of waking up in the morning, going to a washstand to make up or wash the face, and going to a bed to sleep at night. Thus there are daily behavior loops in our daily lives because of time-space regularities.

Taking such features of daily behavior into consideration, by embedding sensors into the furnishings necessary for daily behavior and observing the behavior with the embedded sensors, we can have the system input self-data periodically. Similarly, by embedding output devices into tools or furniture, we can have the system provide some information to the person naturally when he or she uses the furniture. The function of soft interaction through daily behavior enables the sustainable usage of the system over a long term because the input/output of the system is integrated with daily behavior and that there is no concept of operation or working space.

In terms of the drawbacks in thinking about ourselves, the function of soft interaction by human daily behavior compensates for drawback (1) controllability. Since output devices are installed in places where the person is conscious of information, the person can get the information certainly and periodically.

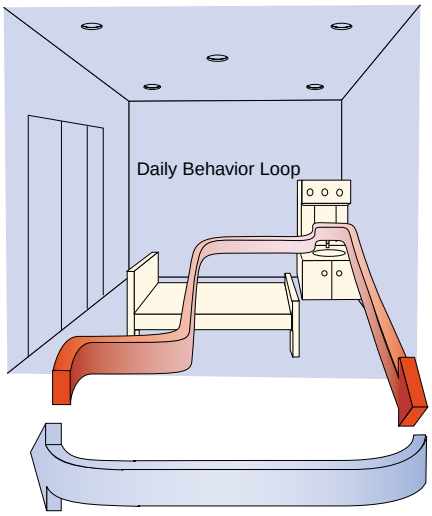

Fig. 2: Human daily behavior

Human objectification The function of human objectification compensates for drawback (2) subjectivity, and drawback (3) knowledge dependency.

Without any criteria, a person's judgment depends largely on feelings and tends to be inaccurate. Inaccurate data prevent us from examining it by comparing it with other data or past data. Therefore, our insight into ourselves is limited considerably. To go beyond the limits, we must objectify ourselves based on constant criteria.

Objective data based on constant criteria enables us to perceive our differences compared with others and differences compared with our past condition precisely and to use the objective data in order to evaluate and improve ourselves. Moreover, if the objective data is extracted as scientific variables, we can utilize the knowledge of that science to amplify our ability to interpret the data.

Useful report To make the generated objective data significant to the person, the system must extract significant facts and report them. Let us consider the physiological self again. When the person shares the self-data with a doctor, the doctor wants to know the physiological parameters of the self-data. On the other hand, the person wants to understand the self-data more intelligibly and focuses on only any changes from the past condition of the self in daily life. This function enables the person to know what he or she needs to know and what he or she wants to know.

2.2 Realization Scheme for Self-communication System

Figure 3 depicts a scheme of the self-communication system. The system consists of 1) a sensorized environment for soft interaction, 2) a human model for human objectification, and 3) a part for creating a useful report. In this study, sensorization means making the room itself a sensor for inputting human daily behavior by embedding sensors into the room invisibly to keep the room's appearance natural. The data flows in the system as follows: In the sensorized environment, the system observes the human's daily behavior and sends the observed data to the human model. The human model consists of an environmental model, a human behavior model, and a human scientific model. The environmental model is used for observing human behavior with the environmental sensors. The human behavior model is used for extracting objective variables from the observed behavior data. The human scientific model consists of knowledge to extract meaning from the fundamental data which is extracted by the human behavior model. If this knowledge is already available, we can create the human scientific model using the knowledge. Finally, the system creates a report by analyzing the self-data and informs the person using the sensorized environment.

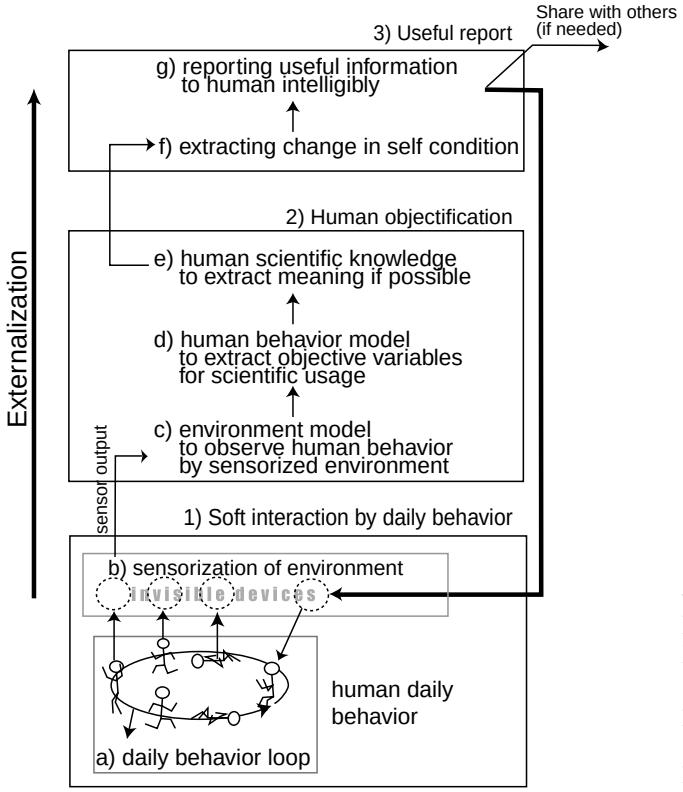

Fig. 3: Scheme of self-communication system

2.3 Advantages of Self-communication System

The advantages of using the self-communication system compared with thinking about ourselves without the self-communication system are 1), 2) and 3) (a), and the advantages compared with a conventional computing system, which has only the capability for the hard interaction, are 3) (a) and (b).

1. Objectivity of data
   By externalizing the self as objective representation based on constant criteria such as scientific facts, we can refer to the self-data objectively, recognize change in the self-data, and improve ourselves by evaluating the change.

2. Amplification of interpretation capability
   Even if we lack the necessary knowledge, the system can extract an important meaning from our data using a human model for human objectification.

3. Sustainability of system usage

   (a) Certainty of data input/output
   The function of soft interaction guarantees the input of data with certainty because the input and output of human behavior data is performed utilizing human daily behavior which is repeated accompanying daily life activity irrespective of the system's existence.

   (b) Automatism of data update
   Since regular periodic input of human behavior data is guaranteed, the data the system processes and reports to us are guaranteed to be the latest.

3 Healthcare Support by Self–communication

3.1 Healthcare Support

Healthcare is an issue of communication between a person and his or her physiological system. The viewpoint of communication with the self is important. It is necessary for the person to maintain his or her health by grasping the physiological self objectively and continuously by communicating with the person's physiological self.

Sleep is one of the most familiar problems for most people. Respiratory disorders during sleep, including sleep apnea syndrome and snoring, prevent the person from gaining the benefits of proper sleep. Because such disorders cause increased respiratory work and hypoventilation[1], which create various adverse effects on sleep and daytime activities.

From this perspective, of the many functions a healthcare support system should have, this study focuses on the SELF healthcare support system with its function of monitoring of the respiratory system's condition, storing and analyzing it, and reporting useful information to the person.

3.2 System Architecture of SELF

Figure 4 outlines the architecture of SELF in terms of soft interaction by daily behavior, human objectification, and useful report. SELF consists of 1) a sensorized environment for the soft interaction, 2)a human physiological model for human objectification, and 3) a part for creating a useful report. The data flows in SELF as follows: In the sensorized environment, SELF observes daily human behavior and sends the observed data to the human model. The human model consists of an environmental model, a human physical model, and a human physiological model. Finally, SELF creates a report using the physiological data of the person and informs the person using the sensorized environment.

[1] A state in which tidal volume is small and a person has a shortage of oxygen.

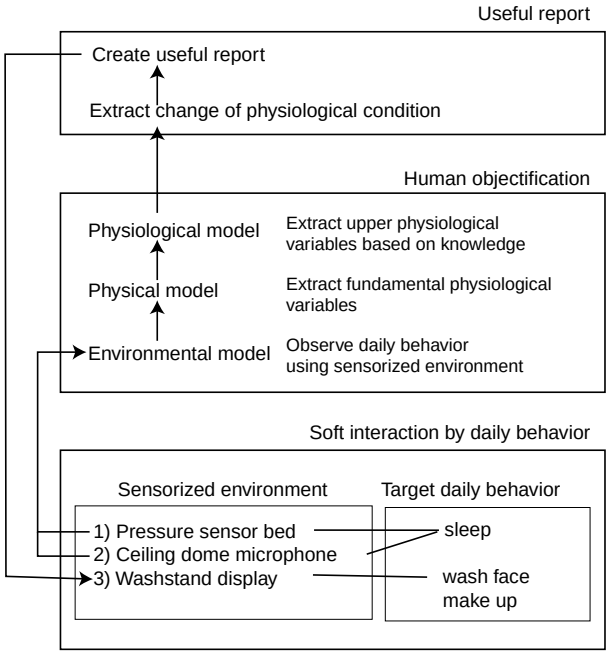

Fig. 4: Architecture of SELF

3.3 Soft Interaction: Sensorized Environment

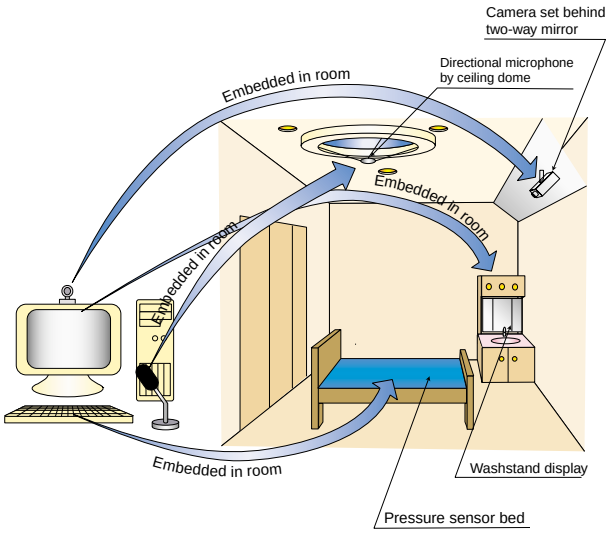

Fig. 5: Sensorization

The room is sensorized as shown in Fig. 5. A keyboard, which is a kind of touch sensor, becomes a bed-shaped touch sensor. A microphone is embedded into a lighting fixture. A display is embedded into a washstand. Figure 6 shows the photograph of the constructed bed room.

Fig. 6: Photograph of bed room

In SELF, soft interaction is realized as follows: 1) SELF observes a person using the pressure sensor bed and the ceiling dome microphone when he or she goes to bed and sleeps, 2) SELF reports useful information to the person using the washstand display when he or she goes to the washstand to wash his or her face or make up after waking up.

These devices are explained in detail in the followings.

3.3.1 Pressure Sensor Bed

The pressure sensor bed consists of a pressure distribution sensor array, a controller, and a bed[8, 9]. Figure 7 shows a photograph of the bed. Figure 8 shows an example of output from the pressure sensor bed. The pressure distribution sensor has 210 Force Sensing Resistors (FSRs) which are set at 7[cm] intervals. An FSR is a thin film sensor made from piezoresistive polymer. The sampling frequency of the pressure image is 20 [Hz]. The measuring range of each pressure sensor is 0 to 1[kg]. The pressure sensor bed is used for monitoring the breath curve, oxygen desaturation, posture, and body movement. These parameters will be explained later.

3.3.2 Ceiling Dome Microphone

The authors invented the ceiling dome microphone which consists of a ceiling dome, a lighting fixture, and a omnidirectional microphone. Figure 9 shows a photograph of the ceiling dome microphone. This device has two functions: indirect lighting and gathering sound. The ceiling dome is used to reflect both light and sound. A microphone is set at the focal point of the reflector. The device enables detection not only snoring sounds but also normal breathing sounds with high sensitivity while keeping the room's appearance natural. It is positioned above the bed. The gain ob-

Fig. 7: Pressure sensor bed

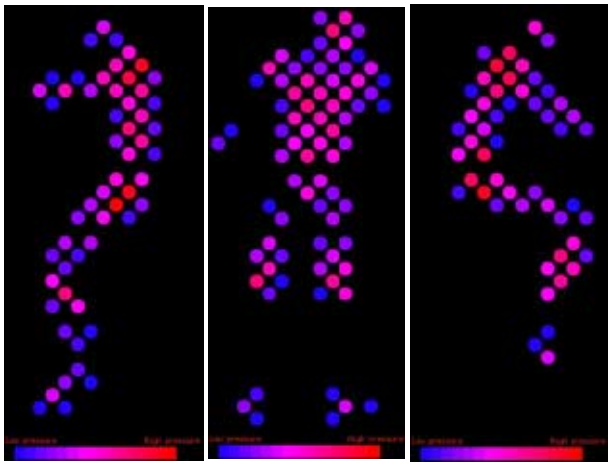

Fig. 8: Example of output of pressure sensor bed

tained by the ceiling dome ranges from -18 to 31 [dB] depending on the frequency of the sound. Figure 10 shows the gain obtained by the ceiling dome. The gain is maintained at more than 20[dB] for high frequency sounds of more than 6[kHz]. Since the frequency of normal breathing sounds ranges from 5 to 15 [kHz], this device can be used to detect breathing sounds, i.e., air flow at the mouth and nose. The diameter of the dome is 900[mm]. Figure 11 shows an example of breathing sounds detection using the filter and the ceiling dome microphone. Room's background noise includes such noises as those of an air conditioner and a computer. The figure shows that both the inhalation and exhalation component of the breath cycle are detected quite clearly.

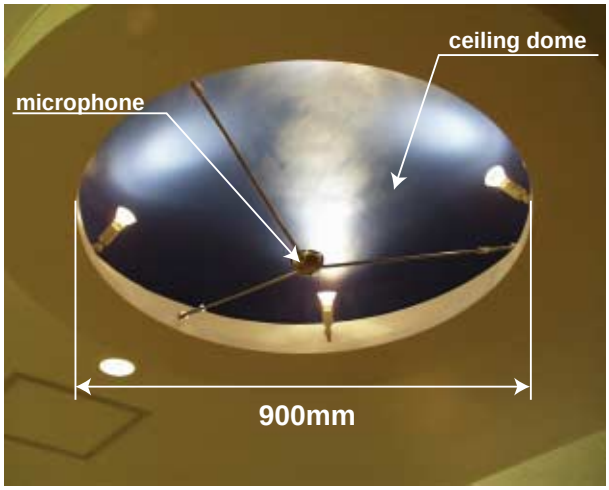

Fig. 9: Ceiling Dome Microphone

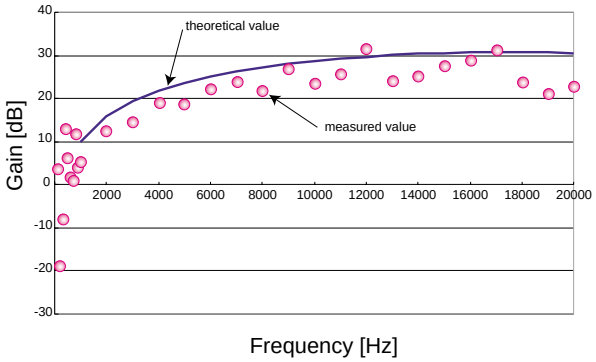

Fig. 10: Gain obtained by ceiling dome microphone

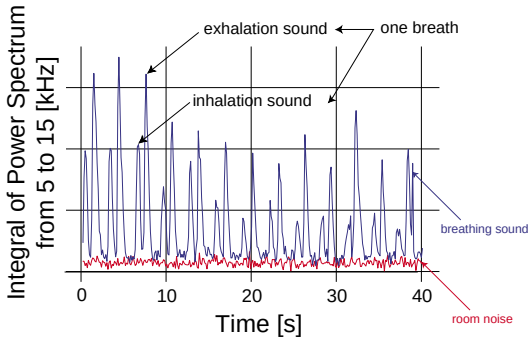

Fig. 11: Detection of normal breathing sounds by ceiling dome microphone

3.3.3 Washstand Display

The washstand display consists of cameras, a monitor, and a two-way mirror. It can reflect the person's face while superimposing health information around the face. It can also zoom in on a part of the face. It works not only as an excellent mirror but also as a display of the healthcare support system. Figure 12 shows a prototype of the washstand display. Figure 13 explains its structure. Currently the prototype has only the mirror part of the washstand. Other parts of the washstand will be added later.

Fig. 12: Prototype of washstand display

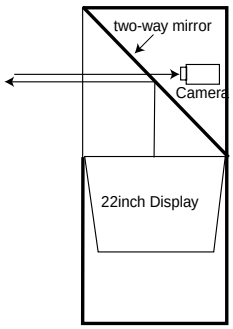

Fig. 13: Structure of washstand display

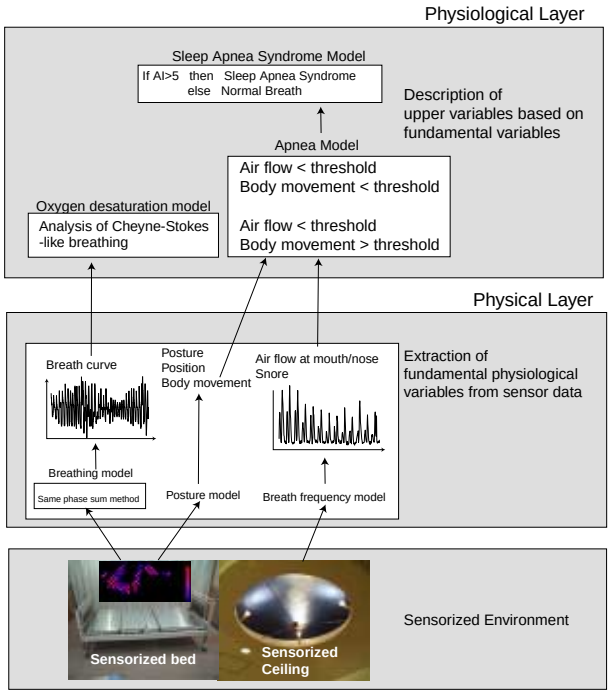

Fig. 14: Human model for understanding physiological meaning

3.4 Human Objectification: Human Physiological Model

3.4.1 Human model

The human model maps human daily behavior into a physiological meaning space. Figure 14 shows the human model we created. It consists of a physical and physiological layer hierarchy. The physical layer infers fundamental physiological values (e.g., breath curve and air flow at mouth/nose) from sensor signals, and the physiological layer consists of a description of physiological knowledge and infers upper physiological values (e.g., values relating to apnea, Cheyne-Stokes-like breathing, and oxygen desaturation in blood) from the fundamental physiological values based on the physiological knowledge. Details on the physiological values the human model can infer are described in the following. Note that all physiological values are obtained by unrestricted monitoring.

3.4.2 Physiological values detected using human model

1. Posture, body movement
   Posture is recognized by analyzing pressure sensor signals based on a posture model. Body movement is calculated by detecting changes in

pressure sensor output[8].

2. Breath curve
   Breath curve is calculated by the "same phase sum method" which is a method for appropriately summing the control offset considering the phase difference in the output change in the pressure sensor[8].
3. Oxygen desaturation in blood
   Oxygen desaturation is detected by detecting Cheyne-Stokes-like breathing from the calculated breath curve. The principle is that Cheyne-Stokes-like breathing occurs with high probability when oxygen desaturation appears. This method can detect only the frequency of oxygen desaturation, not absolute values of oxygen desaturation[10].
4. Air flow at mouth and nose
   Air flow at the mouth and nose is detected using the ceiling dome microphone.
5. Apnea
   Apnea is identified when air flow does not occur for more than 10 minutes.

3.5 Useful Report

Figure 15 is an example of a useful report displayed on the washstand display. The report consists of weekly and daily information on the changes in health condition and is expressed with bar graphs and text. Changes to be notified to the person are determined based on the average condition of the person and of other people. For the basis of information on the average condition of people, we used a medical textbook.

Figure 16 shows an example of a report for a doctor. If the person wants to share the health data with a doctor, the report is output in a format we defined by asking several doctors.

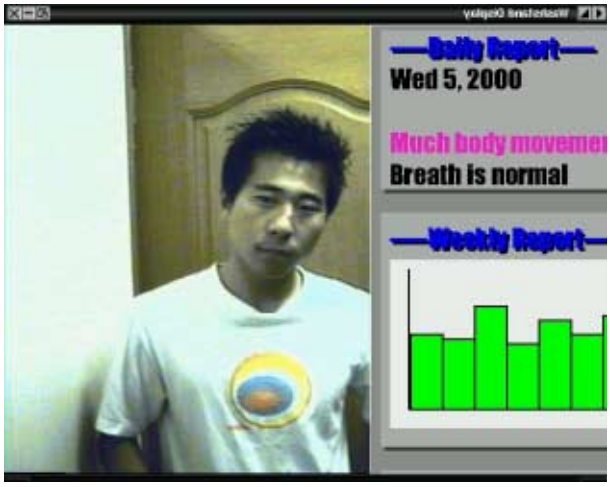

Fig. 15: Example of daily output of washstand display

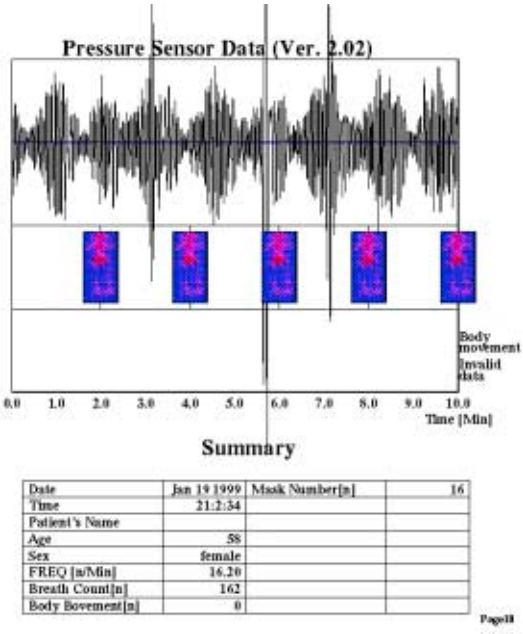

Fig. 16: Example of report for doctor

4 Conclusion

This paper proposed the concept of "self-communication" via an intelligent environmental system which can 1) externalize the self from a person to the system by observing the person's daily behavior in order to objectify the self and 2) recombine the externalized self with the person in order to guarantee the person's accessibility to the self based on the person's daily behavior.

This study clarified the method for realizing self-communication. Self-communication consists of 1) soft interaction by daily behavior, 2) human objectification, and 3) useful report. Personal data is acquired through the soft interaction and is stored. By human objectification, the personal data is mapped into objective data. The objective data is reported to the person intelligibly using the soft interaction again.

The advantages of self-communication are a) objectivity of data, b) amplification of interpretation capability, and c) sustainability of system usage. This paper also reported on an application system of self-communication to healthcare support called SELF (Sensorized Environment for LiFe). SELF stores the physiological condition of the person, analyzes it, and reports useful information to help the person maintain his or her health based on the person's daily behavior. The SELF sensorized environment consists of a bed with a pressure sensor array, a ceiling dome lighting fixture with a microphone, and a washstand with a display. The fundamental results of the functions of SELF were presented.

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