Hassle-free Sensing Technologies for Monitoring Daily Health Changes

● Akihiro Inomata ● Yoshinori Yaginuma

In an aging society beset with a multitude of social problems, there are growing expectations for technologies to support elderly people and patients in maintaining and increasing the "things that I can do for myself." Such expectations can be met by expanding the use of advanced mobile devices in diverse scenarios, by developing wearable sensors, and by using numerous sensors embedded in the environment. These actions will enable widespread extensive use of mechanisms for supporting human activities and health in everyday life. An important technological element for achieving such mechanisms is the ability to continually sense the state of the individual and the surrounding environment. This means first and foremost that sensors must be able to capture essential information as a performance requirement. It also means that sensing must be convenient for the user; i.e., the difficulty or bother of operating sensors must be eliminated, and the continuous collection of information must be hassle-free. Under the theme of "health support in daily life," this paper describes detection of a person's pulse through facial imaging and in-home monitoring using compact, light, and multi-functional wearable sensors as sensing technologies for hassle-free understanding of an individual's behavior and health. It also introduces joint research on assisted independent living for smart house residents.

1. Introduction

As the need grows for maintaining and improving the health of the elderly and of those people still working in order to achieve a healthy, long-life society, there is much anticipation about new mechanisms that will make it easy for people to determine and manage the state of their health in harmony with their individual lifestyles.[1–3]

Fujitsu is working on a variety of mechanisms for recording and collecting health status data on individual users via smartphones and sensors, for aggregating and storing these data in the cloud, and for visualizing those data from the cloud. These mechanisms will make it possible to quantitatively determine the state of one's health using familiar measuring devices such as a pedometer and a blood glucose meter and will enable users to upload a description of their daily diet and receive advice from a remote specialist. They will improve health literacy through online education and enable sharing of information with family members and friends via social networks. These mechanisms will further support health improvement by linking up with information related to health and medical care in the workplace or local community.

In terms of "preventive health improvement," such mechanisms will motivate and support people by enabling them to quantitatively determine their health status on their own. At the same time, support should be given to maintaining and increasing the "things that I can do for myself" after something has happened such as the onset of a disease. We define this field as "prognostic wellness"; it encompasses such activities as supporting self-help efforts in the home and workplace, easing the burden on the family, and reducing health maintenance and recovery costs at home and at work.

In both of the above areas, the concern is not simply to examine and diagnose a person at the time of some event such as the onset or recurrence of a disease. There is also a need for sensing technologies to enable the continuous and real-time collection of information within a person's everyday life—including the time before and after the occurrence of some event—so that the health of that person can be monitored continuously for the benefit of that person, the person's family, and healthcare support specialists.

Such sensing technologies must, of course, enable the collection of necessary information on an ongoing basis, while making user operation straightforward and hassle-free. Since the composite collection of various types of information can increase the amount of knowledge gained, there is a need for smart devices comprising advanced technologies, sensors that attach to one's body (wearable sensors), and sensors installed in a smart house that can capture events in the form of diverse signals not normally picked up by the five human senses. There is also a need for the ability to convert those signals into information from various perspectives. Support must also be provided to make the above mechanisms easy to use.

In this paper, under the banner of "health support in daily life," we discuss Fujitsu's development of sensing technologies for hassle-free gathering of information on a person's behavior and health and the surrounding environment. It describes, in particular, technology for detecting and measuring a person's pulse through facial imaging,[4] in-home monitoring using compact and light, multi-functional wearable sensors, and joint research on assisted independent living for smart house residents (**Figure 1**).

2. Pulse detection and measurement through facial imaging

We first introduce technology for detecting and measuring the pulse in real time through facial imaging as an example of a sensing technology for determining a person's behavior and state of health in an easy, hassle-free manner.

In managing one's health, a mechanism that can make it easy to capture daily trends and detect slight changes in those trends is desirable. In general, however, it has been necessary to use specialized instruments to measure the state of one's health, which means attaching and operating them. The trouble of doing so has made it easy for people to neglect or forget to take measurements. In this regard, the pulse rate is a basic index representing a person's state of health. However, to facilitate its continuous measurement, bothersome restrictions such as attaching and operating an instrument and staying still while taking measurements need to be reduced, and the process needs to be automated as much as possible.

Against the above background, we have developed technology for detecting a person's pulse rate that makes use of the fact that hemoglobin in the blood absorbs green light. This technology captures changes in brightness on the surface of a person's face[5] arising

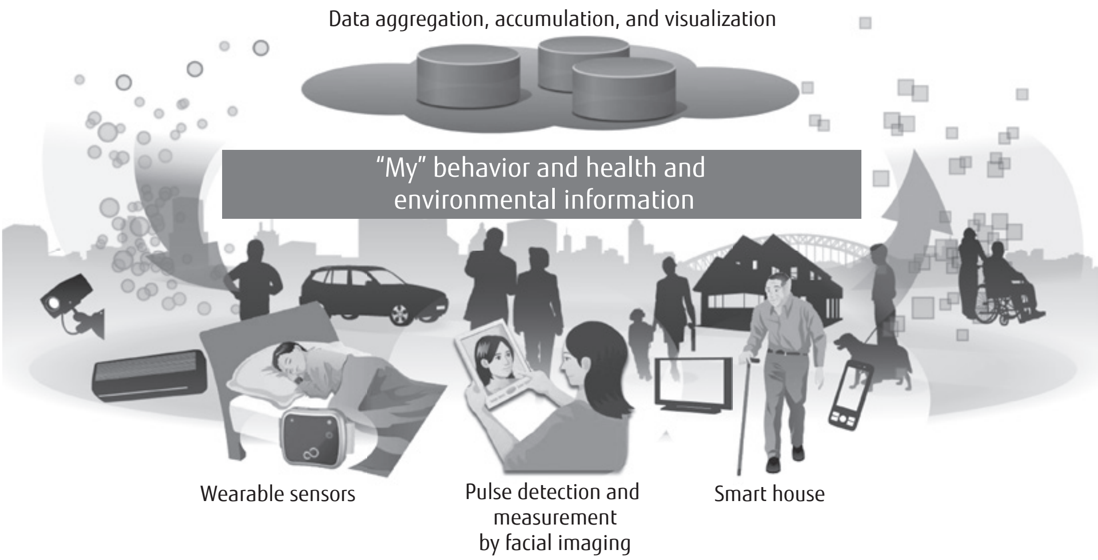

Figure 1
Sensing technologies for health support in daily life.

from blood flow. However, non-contact, pulse rate detection requires the removal of noise such as body motion and environmental light.[6) For this reason, we have developed a method that determines the average values of each of the color components (red, green, and blue) in a facial region for each frame acquired from a video image, removes noise common to all three components, and extracts a brightness waveform from the green component. The pulse rate can then be calculated from the number of peaks in this brightness waveform (**Figure 2**). Combining signal processing with this physical mechanism enables a person's pulse to be detected in as little as five seconds.

Furthermore, on the basis of our finding that there are many moments at which a person is essentially stationary, we have developed a method that automatically removes data from intervals affected by facial or bodily movement. For example, even deskwork involves some movement since a person's face will tend to move sideways during a phone call, and leaving one's desk for whatever reason obviously involves movement. This method detects such movements and automatically removes the data for those time intervals. Processing the data in accordance with the person's behavior makes it possible to continuously record the pulse rate during the day.

3. Intraday variation in pulse rate detected by facial imaging

In a reported experiment,[7)] the fluctuation in the pulse rate of an office worker was detected over the course of a single day (eight hours) using a commercially available Web camera installed on the person's desktop computer. The person performed everyday office work while facing the computer and was completely oblivious to the detection by facial imaging. The median value of the pulse rate detected by facial imaging during intervals unaffected by facial movement was determined every two minutes and later compared with a reference pulse rate that was simultaneously measured using a contact-type electrocardiograph.

The data excluding those for the times when the person was away from the desk for at least 20 minutes are plotted in **Figure 3**. The average difference between the pulse rate by facial imaging and the reference pulse rate was 3.4 beats/min. This means that the intraday fluctuation in pulse rate can generally be accurately detected by facial imaging.

These results show that the pulse rate can be continuously detected by facial imaging rather than by bothersome and lengthy wearing of devices. In future research, we will continue to enhance this technology while investigating ways of using signal-waveform analysis to obtain information on physical phenomena other than pulse rate such as pulse wave velocity and blood pressure.

4. In-home monitoring using wearable sensors

Here we introduce in-house monitoring combining wearable sensors and a digital diary.

We have been conducting joint research with the Innovative Research Center for Preventive Medical Engineering (PME) at Nagoya University on the in-home collection and visualization of health data using newly developed wearable sensors and a system for collecting, analyzing, and visualizing those data.

In this research, we are targeting nocturnal

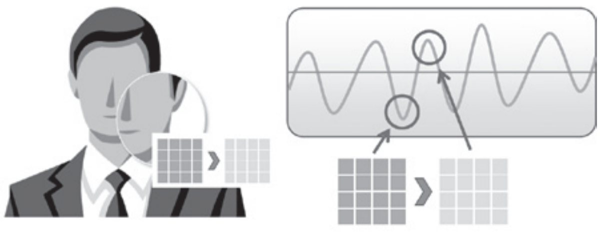

Figure 2
Calculation of pulse rate from number of peaks in brightness waveform.

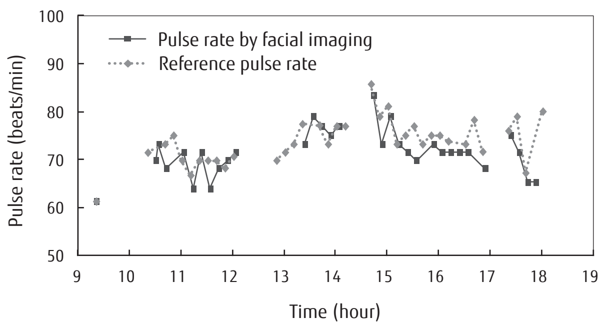

Figure 3
Intraday variation in pulse rate.

enuresis (bedwetting) as a case study. Our objective here is to obtain a good understanding of the daily activities and health status of individual patients and to simplify the sharing of information between the patients and their doctors. In this study, each patient wears a sensor, and the patient or a family member inputs data into a digital diary so that health data obtained from one moment to the next can be aggregated in and visualized from the cloud (**Figure 4**).

Nocturnal enuresis refers to regular unconscious urination while sleeping by children six years of age or older.[8] The reason we targeted nocturnal enuresis as a case study was that the potential number of patients for about 300 medical specialists is said to be as high as 500 000 to 1 million, which means that we can expect a positive information-distribution effect. In particular, the phenomenon of nocturnal enuresis occurs frequently and is clearly identifiable so that analysis focusing on this phenomenon is not difficult to perform. Because a method of treatment that sends a nocturnal enuresis alert to the patient (enuresis alarm treatment) has been used, sensors and data analysis may be able to contribute to a better understanding of how nocturnal enuresis occurs and what mechanisms should be used to treat it. Because nocturnal enuresis can create a long-term burden on the patient and family, optimal provision of information on the basis of a good understanding of this condition has the potential to enhance the quality of life (QoL).

The wearable sensor we developed for this research is compact (3.7 × 4.3 × 1.2 cm) and light (19 g). It is a multifunctional, general-purpose proof-of-concept tool having ten types of built-in sensors, enabling the simultaneous collection of various types of information for up to five days straight. This includes information related to nocturnal enuresis (i.e., measured moisture), information related to the user's physiological condition such as pulse rate, behavioral information such as acceleration, and environmental information such as temperature, humidity, and air pressure. The position on the body where the sensor is worn can be changed as desired depending on the measurement purpose. Once the wearer has fallen asleep, sensor data is automatically collected wirelessly with a personal computer or smartphone and then stored in and visualized from the cloud. Detection of moisture at the onset of enuresis immediately triggers an alert that is sent via a smartphone.

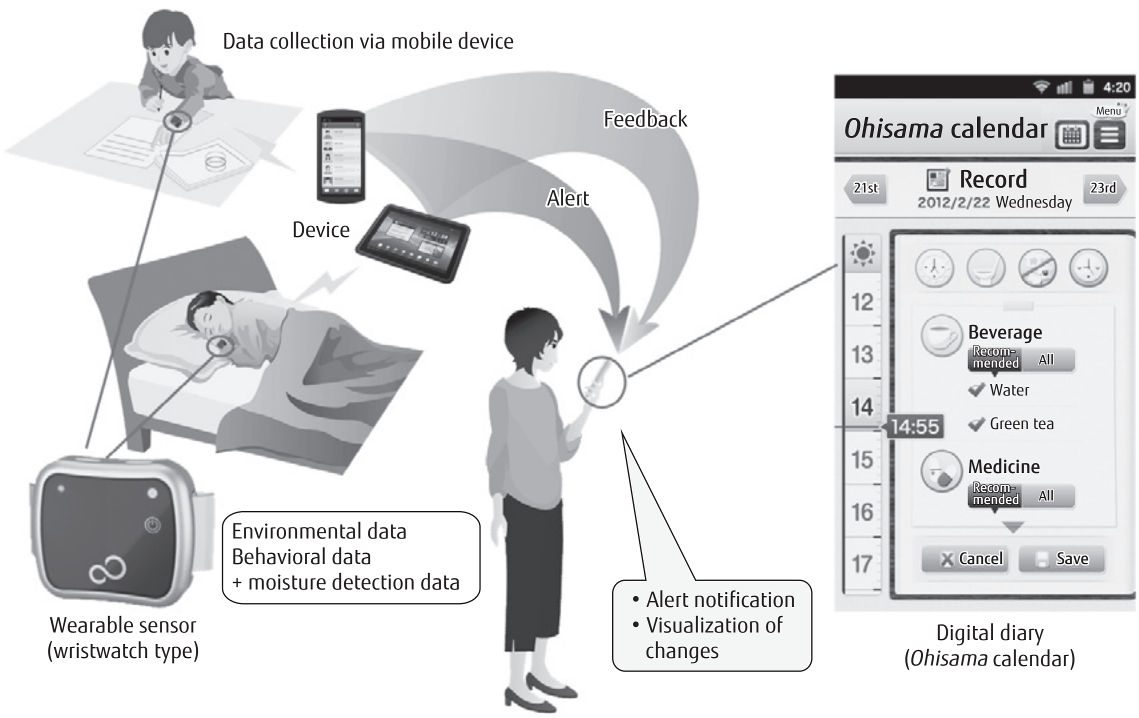

Figure 4
In-home monitoring combining a wearable sensor and digital diary.

This research project also includes the "*Ohisama* calendar" (provisional name), a digital diary that plays a complementary role to sensor data. *Ohisama* means the sun in Japanese. It enables the patient or a family member to record information on the patient's daily behavior or relevant events such as water intake, the number of times and time of day that the patient goes to the toilet, and whether nocturnal enuresis occurred.

We are currently analyzing behavioral information collected using two sensors—one worn on the wrist and the other on the chest—with the aim of visualizing the relationship between that behavior and the detection of nocturnal enuresis.[9] For example, eight days worth of actual sensor data recorded during sleep are visualized in **Figure 5**. These time-series data show the generation of nocturnal-enuresis alerts following moisture detection (solid circles), the state of detecting moisture (gray sections), and the state in which the patient is standing (shaded sections). To begin with, it is obvious that the time of enuresis onset differed from day to day. In addition, the moisture-detection state continued until morning for the first two days, but from the third day on, moisture detection terminated and a standing-up state was detected immediately after enuresis onset. From this we infer that the patient changed clothes immediately after enuresis. In the treatment of nocturnal enuresis, the effects of waking up the person by using an alarm and of providing lifestyle advice have been debated.[8] In either case, the simultaneous, continuous collection of diverse types of sensor data and combined analysis as described here should lead to a deeper understanding of nocturnal enuresis and enhanced QoL.

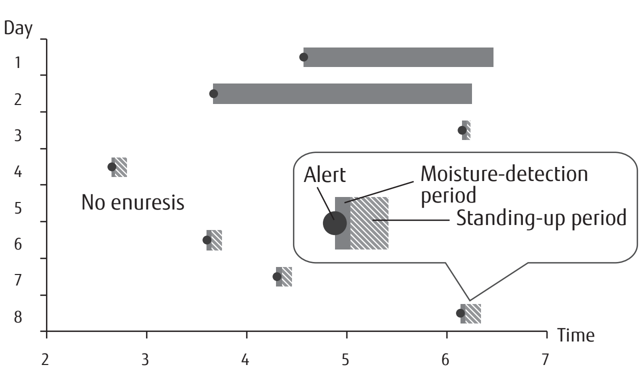

Figure 5
Example of enuresis detection using wearable sensors.

5. Assisted independent living for smart house residents

Finally, we introduce an international research project. Fujitsu has undertaken to explore ways of supporting assisted independent living for elderly people and patients by continuous sensing of behavior and health status in all sorts of everyday scenarios. Specifically, we have launched the *KIDUKU* Project in collaboration with three research institutions in Ireland—Centre for Affective Solutions for Ambient Living Awareness (CASALA),[10] Technology Research for Independent Living (TRIL),[11] Centre for Sensor Web Technologies (CLARITY)[12]—and Fujitsu Ireland Ltd. to support monitoring and assisted independent living for elderly people and patients living in smart houses in Ireland. The project's name, *KIDUKU,* captures the essence of two Japanese words, both pronounced "kizuku," with the first meaning "to be aware" and the second, "to construct." The idea of being aware has to do with the ability to observe changes in different conditions, such as an individual's health, which can lead to changes in behavior and the offering of new support services.

Fujitsu's *KIDUKU* Project aims to create a synergetic effect among the three Irish research institutions in a variety of scenarios including everyday life and medical care by leveraging their advanced capabilities and experience in health monitoring and diagnosis support using information and communications technology (ICT). CASALA manages the Great Northern Haven development of experimental smart houses that it established in the Irish city of Dundalk. After equipping smart houses with sensing facilities, CASALA carries out experiments on diverse types of equipment and devices and holds trials on behavioral monitoring and service provision in cooperation with residents. TRIL is a medical research institution based within hospitals. It researches assisted independent living with a focus on elderly patients using diverse sensing and information-display technologies. CLARITY is a research institution with a history of diverse achievements in visualization and analysis technologies targeting audio, video, and other types of sensing data and in the analysis of human behavior in sports, medical care, and everyday life.

This joint research targets elderly people and patients living in smart houses and seeks to collect all behavior- and health-related data on a daily basis for both indoor and outdoor scenarios using sensors attached to the body and sensors embedded in the house and environment. It also aims to analyze these data from psychological, physical, physiological, and sociological perspectives by combining the knowledge of medical specialists in assisted independent living with medical evidence. Through these activities, we aim to advance the development of technologies for collecting, analyzing, and visualizing human-centric sensing data and to use these technologies as a core platform for creating system functions supporting human activities and health. Looking forward, we plan to research solutions in health management and everyday living support for elderly people and patients using various case studies (fall prevention, chronic obstructive pulmonary disease, etc.).

6. Conclusion

With the aim of contributing to preventive health improvement and prognostic wellness, we are developing sensing technologies and in-home monitoring mechanisms for continuous, hassle-free health monitoring in a person's daily life. Looking forward, we will conduct evidence-based research giving proper attention to privacy issues and the protection of personal information. We will also aim for the early establishment of sensing technologies supporting immediate detection of even slight changes in an individual's physical condition in everyday life. We plan to expand the application of information technology to the development of assisted independent living in the aging society, to enable the progress of an elderly person's or patient's condition to be accurately understood, and to facilitate the sharing of information with family members, the primary physician, and medical specialists.

References

1) Cabinet Office, Government of Japan: "Japan Revitalization Strategy—Japan is BACK—, Strategic Market Creation Plan." May 2013. *http://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/en_saikou_jpn_hon.pdf*
2) Cabinet Office, Government of Japan: Declaration on the Creation of a World-leading IT Nation, June 2013 (in Japanese). *http://www.kantei.go.jp/jp/singi/it2/pdf/it_kokkasouzousengen.pdf*
3) Ministry of Health, Labour and Welfare: "Healthy Japan 21 (Series 2)" (in Japanese). *http://www.kenkounippon21.gr.jp/*
4) Fujitsu Laboratories: Fujitsu Laboratories Develops Real-Time Pulse Monitor Using Facial Imaging. *http://www.fujitsu.com/global/news/pr/archives/month/2013/20130318-01.html*
5) C. Takano et al.: Heart rate measurement based on a time-lapse image. *Medical Engineering & Physics*, Vol. 29, pp. 853–857 (2007).
6) M. Z. Poh et al: Non-contact, automated cardiac pulse measurements using video imaging and blind source separation. *Optics Express*, Vol. 18, No. 10, pp. 10762–10774 (2010).
7) M. Sakata et al.: Continuous Non-contact Heart Rate Measurement Using Face Imaging. Proceedings of the IEICE General Conference 2013, D-7-12 (2013) (in Japanese).
8) Japanese Society on Enuresis: Guidelines to Enuresis Treatment (in Japanese). *http://www.jsen.jp/guideline/index.htm*
9) S. Yoshida et al.: Research Results in the Monitoring of Enuresis using Multi-functional Sensors: 1st Report. 24th Meeting of the Japanese Society on Enuresis, A2-2 (2013) (in Japanese).
10) CASALA (Centre for Effective Solutions for Ambient Living Awareness). *http://www.casala.ie/*
11) TRIL (Technology Research for Independent Living). *http://www.trilcentre.org/*
12) CLARITY (Centre for Sensor Web Technologies. *http://www.clarity-centre.org/*

Akihiro Inomata
Fujitsu Laboratories Ltd.
Dr. Inomata is engaged in research and development of human-centric sensing technologies, analysis and visualization of real-world information.

Yoshinori Yaginuma
Fujitsu Laboratories Ltd.
Mr. Yaginuma is engaged in development of real-world, human-centric solutions and their elemental technologies.