Application for Rehabilitation Medicine Using Wearable Textile "hitoe"

Takayuki Ogasawara, Kenichi Matsunaga, Hiroki Ito, and Masahiko Mukaino

Abstract

NTT, Toray Industries, Inc., Fujita Health University, and NTT DOCOMO have begun trials on patient rehabilitation support using the functional material called "hitoe," which can take continuous measurements of biological data simply by having patients wear it. As innovation progresses in medical and nursing care, it is necessary to improve the quality of rehabilitation, especially for elderly patients, in the recovery progress and return to daily life, and in preventing the recurrence of debilitation. This article introduces new initiatives to develop wearable technology in light of these social issues.

Keywords: wearables, rehabilitation, medicine, smart clothing

1. Rehabilitation during convalescence

Systems for providing medical and nursing care services are being reformed by the government in Japan [1, 2]. As part of this effort, there has been a strategy to reduce the number of hospital beds where advanced, acute medical care has been provided till now and to increase the number of beds that can more fully meet regional medical care needs (**Fig. 1**). Rehabilitation during convalescence plays an important role in these reforms. Patients who engage in focused rehabilitation after receiving acute medical treatment, when their condition first begins to stabilize, can accelerate the recovery of function and improve their activity in daily life. Such rehabilitation can also help prevent patients from becoming bedridden, return them to family and society, and limit recurrences of debilitation. Providing high-quality rehabilitation is therefore an important social issue in an aging society, going beyond the scope of private enterprise. As such, NTT, Toray Industries, Inc., Fujita Health University, and NTT DOCOMO began practical testing to improve the quality of rehabilitation services using "hitoe" wearable technology in February 2017 [3].

2. Smart clothing and "hitoe" functional material

NTT and Toray developed "hitoe," which is a functional material that can take continuous measurements of biological information when a person wears it [4]. The material is created by coating the surface of fibers with a conductive polymer (PEDOT-PSS: poly(3,4-ethylenedioxythiophene):poly(styrenesulfo nate)), resulting in a very flexible, hydrophilic, and durable material that is also electrically conductive [5]. Smart clothing incorporating this material can be used to measure changes in heart rate over long periods of time in a range of scenarios. It can also be combined with other sensors such as accelerometers, and new, higher-order feature values can be computed to expand the range of possible applications in various ways [6–8] (**Fig. 2**). This article describes an example of an application in the area of rehabilitation.

3. Clinical research with rehabilitation patients

The medical effects of rehabilitation can be broadly classified into general effects, in which exercise

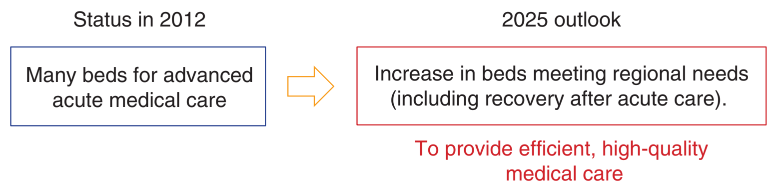


Fig. 1. Innovation in medical care system.

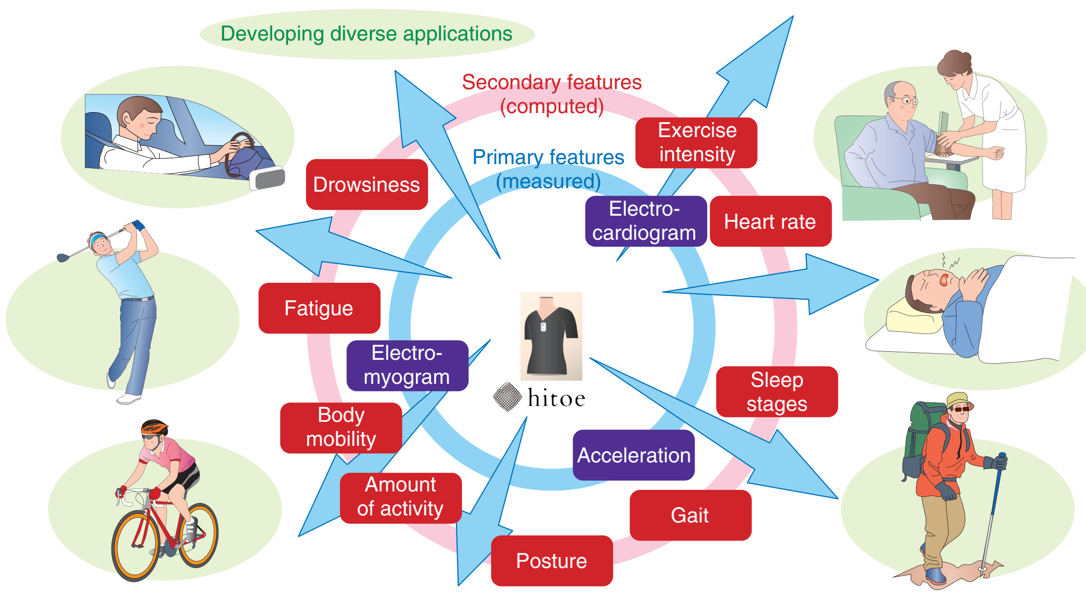


Fig. 2. Expanding applications of “hitoe.”

affects the entire body, and specific effects, which contribute to addressing particular motions or functions in the patient’s life. For general effects, the goal is to affect the whole body by ensuring that a safe and appropriate amount of exercise is achieved in the daily routine in the rehabilitation environment, but there have not been strong, clinical, and measurable indices for this. However, heart rate and activity data can be collected easily using “hitoe” 24 hours a day, and not just during the limited rehabilitation training period with therapists.

An overview of the system is shown in **Fig. 3**. Patients needing rehabilitation wear smart clothing incorporating “hitoe.” Biological data measured from the patient by the clothing are sent to a server through a smartphone or a relay device (an Internet of things (IoT) gateway) in the hospital and can be examined using a viewer. Doctors can use the collected data to evaluate the suitability of the activity in the treatment environment and can evaluate the general effects. The system also gives an understanding of patient lifestyle patterns, so it can help in giving safe and high-quality guidance and managing everyday risks more easily. It could also be useful for developing more comprehensive rehabilitation treatment systems. The components of the system are described below.

3.1 Smartphones

Most wearable devices on the market strive to reduce energy consumption by using simple displays with light emitting diodes and low-energy wireless communication such as Bluetooth so they can operate over long periods of time. Smartphones can be used to maximize the value of such devices. They can convey real-time feedback to patients on a high-quality display and send data to servers on the network using LTE (Long-Term Evolution) or Wi-Fi. Extensibility using applets is also a major benefit. NTT is studying

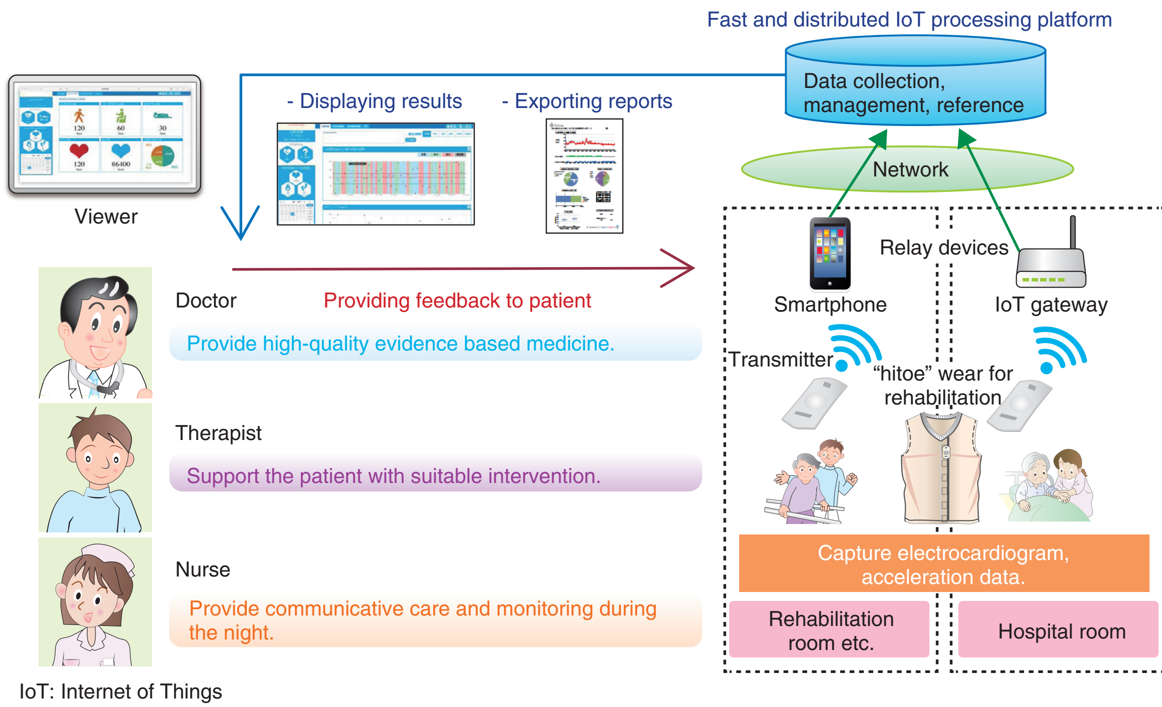


Fig. 3. Rehabilitation support system using "hitoe."

new ways to provide rehabilitation support using smartphones to increase patient motivation and actively encourage exercise.

3.2 IoT gateway

IoT gateways are installed in buildings and other environments. They enable free measurement of sensor data without patients having to hold their smartphones, and they transmit the collected data through the network to a storage device. The NTT laboratories developed an IoT gateway using compact, off-the-shelf hardware and our own time synchronization and protocol control software [9] (**Fig. 4**).

The time synchronization technology provides accurately synchronized timestamp data on the IoT gateway by estimating the time using the Network Time Protocol and correcting for effects including transmission delay on the wireless segments and packet retransmission times when bandwidth is congested, so that times can be recorded accurately for data from sensors that do not maintain time information.

The protocol control technology enables data transmission independent of the type of sensor by converting among transmission protocols with different communication standards and sensor data formats. In the future, these technologies will enable data collection and analysis to be coordinated among a wide range of sensors in addition to "hitoe" with video, location, and other data.

In these experiments, approximately 50 IoT gateways were installed in patient wards in hospitals—in rooms, corridors, rehabilitation facilities, and other areas—to maintain stress-free 24-hour data collection. The amount and frequency of data sent to the server was controlled by processing data signals collected on IoT gateways, which enabled collection of sensor data from approximately 100 patients.

3.3 Data collection, aggregation, referencing

The system handles data storage, aggregation, and referencing on the server. The server part of the system consists of two functions: one to store the biological data gathered from "hitoe" via the smartphones and IoT gateways, and another to process, aggregate, and display the stored biological data. Using both smartphones and IoT gateways to gather data enables the data to be collected continuously and with flexibility, no matter where the patients are. This is not only within the hospital but can include home care after leaving the hospital.

Commercial applications linked with "hitoe" for

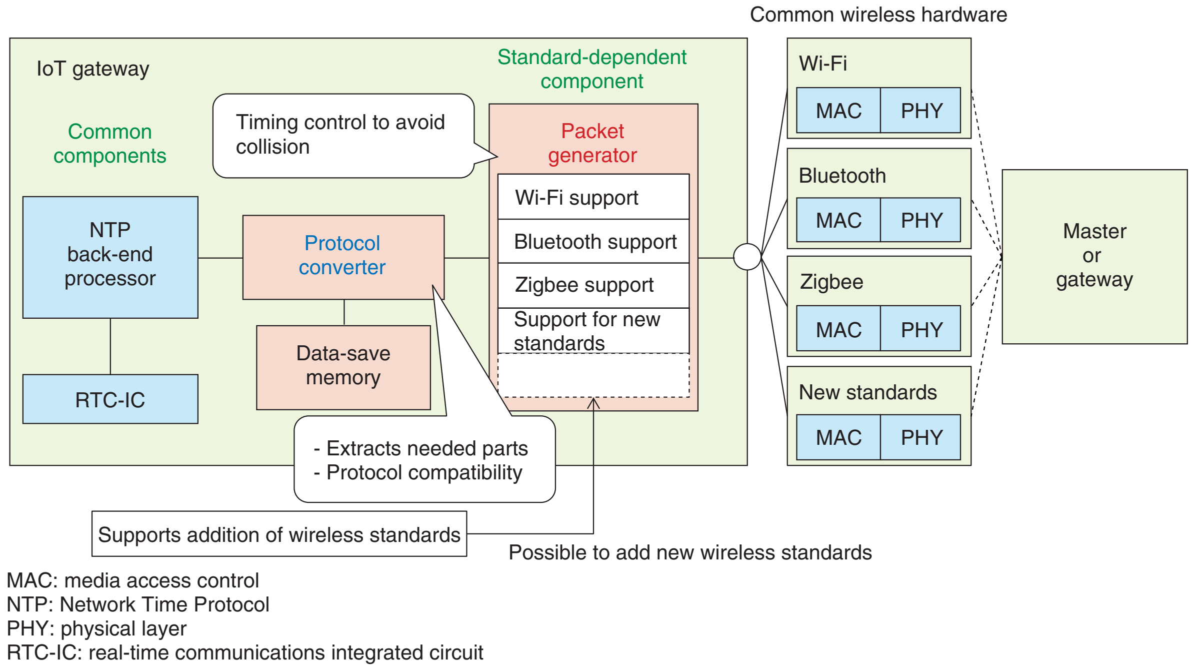


Fig. 4. IoT gateway architecture.

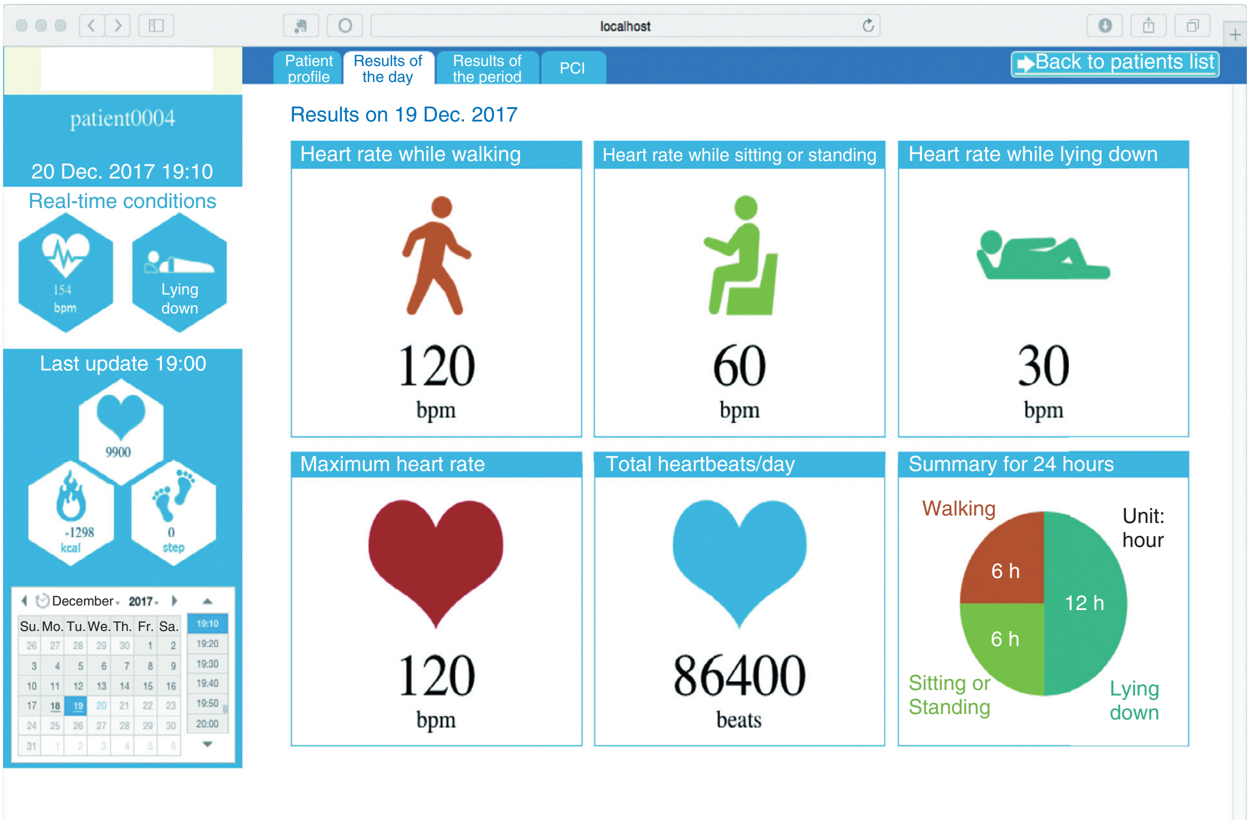
collecting biological data have already been developed, and customer needs can be met using a fast and distributed IoT processing platform [3] that is easy to scale out when the volume of data increases. For our experiments, we implemented an application using the fast and distributed IoT processing platform, with functionality to aggregate and display the collected data. Aggregating and displaying the data enables the data to be used for medical research and makes it possible to provide practical feedback to patients in the actual rehabilitation environment.

To ensure that the biological data collected on the IoT processing platform are suitable for applications in medical research, the system maintains relatively frequently sampled data. For this reason it can be difficult, for example, for a doctor to give feedback to a patient using a real-time graph of trends over longer periods of time. Therefore, for these experiments, we also prepared an application to aggregate and display results, compensating for such difficulties. The aggregation function aggregates biological data stored on the fast and distributed IoT processing platform over set periods of time, calculates statistics such as overall heart rate and total calorie consumptions, and stores the results in a database. The display function then provides access to the biological and statistical data from personal computers connected to the hospital network using a web-based user interface (**Fig. 5**). In addition to providing access to the biological data, the web-based user interface supports entry of comments and downloading of detailed data by doctors.

This system also supports measurement and monitoring of a physiological cost index, which is a typical physiological indicator of performance while walking that is used for patients in physiotherapy. It can be used together with long-term patient monitoring to improve the quality of daily rehabilitation guidance from doctors and therapists and to support the use of data for academic activities.

3.4 Features

The heart rate and state of activity are extracted from sensor data as features for visualizing patient condition. The patient's state of activity can be categorized as lying down, standing/sitting upright, or walking based on computations from data acquired from a three-axis accelerometer in the transmitter attached to the garment (**Fig. 6**). The length of time that patients stayed upright and the number of steps walked are objective indicators to evaluate the patient's condition. An elevation of the heart rate indicates a physiological burden, and this will be used as a personal or subjective indicator.



PCI: physiological cost index

Fig. 5. Example of web user interface.

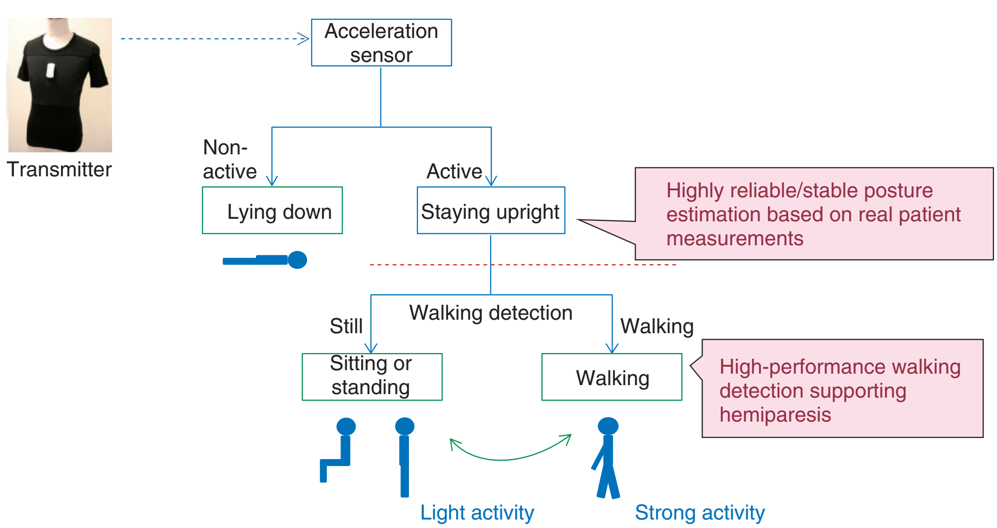


Fig. 6. Activity state estimation using acceleration data.

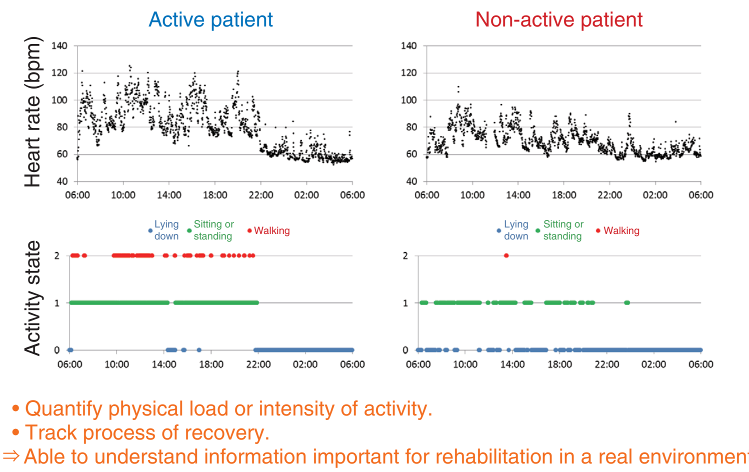


Fig. 7. Example of actual results.

These feature extractions were achieved by using a highly reliable algorithm based on real experimental measurements from various patients. By correlating these types of features, we can obtain detailed information that is important for rehabilitation in real environments, for example, the length of time patients are able to stay upright due to recovery of functionality, and the intensity of exercise patients can tolerate as time passes after their conditions occur. This sort of information is expected to help in improving the quality and efficiency of rehabilitation.

4. Experimental results

In one experiment conducted with this system, measurements were taken for two stroke inpatients with hemiparesis. The results are shown in **Fig. 7**. One of the subjects needed assistance for most daily activities, while the other did not. The differences between the two are clear in the measurement results. The subject not needing assistance was much more active, and there was a strong tendency toward having a higher heart rate while active.

This difference is understandable if we surmise that the subject not needing assistance can use his/her body more easily, making it easier to return to active daily life. However, the system can do more than compare cases of needing or not needing assistance. For cases involving patients who need assistance, when we compare those who are active during hospitalization and those who are more cautious with their activity, it is important to focus on which of these tends to have a better recovery, and why. This is because it could suggest that the general effects we discussed earlier are an important mechanism.

The system also shows the patient's physical condition, so interventions can be optimized for individual patients, and it can provide clues as to the cause if there is a change in condition. We have already conducted measurements with more than 70 patients and have encountered some very interesting cases. We are accumulating studies with this sort of evidence and participating in discussions at medical conferences, and through these activities we hope to develop monitoring methods to improve the quality of rehabilitation.

5. Future prospects

These efforts are aimed at developing systems that provide high-value services to patients and medical treatment providers by proposing monitoring methods using wearable technology and providing medical evidence. In addition to contributing to the development of rehabilitation, we will go beyond rehabilitation in the future, advancing development to reduce the burden on patients and medical providers, including areas such as remote rehabilitation and home support.

References

[1] Agenda of the 208th General Meeting of Central Social Insurance Medical Council, Ministry of Health, Labour and Welfare of Japan, 2011 (in Japanese).
http://www.mhlw.go.jp/stf/shingi/2r9852000001vpkq-att/2r9852000001vpok.pdf

[2] S. Nakamura, "Future of Reginal Medical Services (1)—Medical and Nursing Care Services in 2025," NHK News Commentators Bureau," 2018 (in Japanese).
http://www.nhk.or.jp/kaisetsu-blog/400/292094.html

[3] T. Kondo, Y. Yamato, M. Nakayama, A. Chiba, K. Sakaguchi, T. Nishiguchi, T. Masuda, and T. Yoshida, "Natural Sensing with 'hitoe' Functional Material and Initiatives towards Its Applications," NTT Technical Review, Vol. 15, No. 9, 2017.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201709fa3.html

[4] S. Tsukada, N. Kasai, R. Kawano, K. Takagahara, K. Fujii, and K. Sumitomo, "Electrocardiogram Monitoring Simply by Wearing a Shirt—For Medical, Healthcare, Sports, and Entertainment," NTT Technical Review, Vol. 12, No. 4, 2014.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201404fa4.html

[5] K. Takagahara, K. Ono, N. Oda, and T. Teshigawara, "'hitoe'—A Wearable Sensor Developed through Cross-industrial Collaboration," NTT Technical Review, Vol. 12. No. 9, 2014.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201409ra1.html

[6] N. Kasai, T. Ogasawara, H. Nakashima, and S. Tsukada, "Development of Functional Textile "hitoe": Wearable Electrodes for Monitoring Human Vital Signals," B-plus: IEICE Communications Society Magazine, Vol. 41, pp. 17–23, 2017.

[7] T. Ogasawara, K. Ono, N. Matsuura, M. Yamaguchi, J. Watanabe, and S. Tsukada, "Development of Applications for a Wearable Electrode Embedded in Inner Shirt," NTT Technical Review, Vol. 13. No. 1, 2015.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201501fa2.html

[8] A. Chiba, K. Tsunoda, H. Chigira, T. Ura, O. Mizuno, and T. Tanaka, "Estimating Critical Fusion Frequency from Heart Rate Variability," The 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2015), Milan, Italy, Aug. 2015.

[9] "Expanding the Use of 'hitoe' and Development of Fundamental Technology for Data Collection," Business Communication, Vol. 54, No. 7, pp. 10–12, 2017 (in Japanese).
http://www.ntt.co.jp/dic/theme/pdf/2017/bizcom/bizcom17-7-4.pdf

Trademark notes

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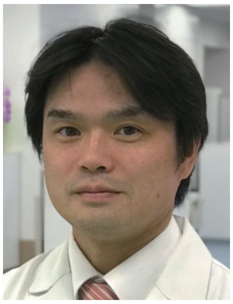

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