"hitoe"—A Wearable Sensor Developed through Cross-industrial Collaboration

Kazuhiko Takagahara, Kazuyoshi Ono, Naoki Oda, and Takashi Teshigawara

Abstract

NTT succeeded in developing a novel composite material consisting of a flexible conductive fiber fabricated by coating fiber material such as silk with a conductive polymer (poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate): PEDOT-PSS). A press release on this development was issued in February 2013. Then, in January 2014, after forming a tie-up with NTT DOCOMO to spearhead the development of related services, NTT jointly announced with Toray Industries, Inc. and NTT DOCOMO the development of this composite conductive fiber material under the brand name "hitoe." This article introduces the technology behind the hitoe material and discusses future scenarios in which the biomedical signals measured by hitoe should prove useful.

Keywords: wearable sensor, electrocardiogram, biomedical signal monitoring

1. Introduction

"hitoe" is a functional material capable of measuring biomedical signals to obtain, for example, a person's electrocardiogram or electromyogram. This material was developed by applying NTT-developed conductive fiber technology, in which fiber material is coated with a conductive polymer (poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate): PEDOT-PSS), to the cutting-edge nanofiber material developed by Toray Industries, Inc. (Toray) (**Fig. 1**). Compared with conventional fiber material (fiber diameter: about 10 μm) used in ordinary clothing, nanofiber (fiber diameter: about 0.7 μm) improves adhesion to the skin, thereby facilitating stable measurement of biomedical signals. In addition, high conductivity and durability have been obtained in hitoe material by filling the gap between nanofibers with conductive polymer using Toray's advanced high-order processing technology.

The hitoe material has been embedded in an inner T-shirt to make it easy to wear on the human body. This has resulted in the development of a wearable sensor that can record a person's electrocardiogram (**Fig. 2**). The base material of this T-shirt makes use of PROGRESKIN, a material whose compressive force on the human body fluctuates very little even when the shirt is stretched. This material provides a good fit by accommodating differences in body types, and it conforms well to physical movements. In addition, the parts of the T-shirt embedded with the hitoe material have a material configuration that has high moisture retention, which reduces contact impedance with the human body.

The above features make it possible to detect a person's biomedical signals in a comfortable and stable manner in a variety of everyday scenarios simply by having the person wear this newly developed T-shirt.

2. Examples of measuring everyday biomedical signals using hitoe

The hitoe material is a cloth-based electrode

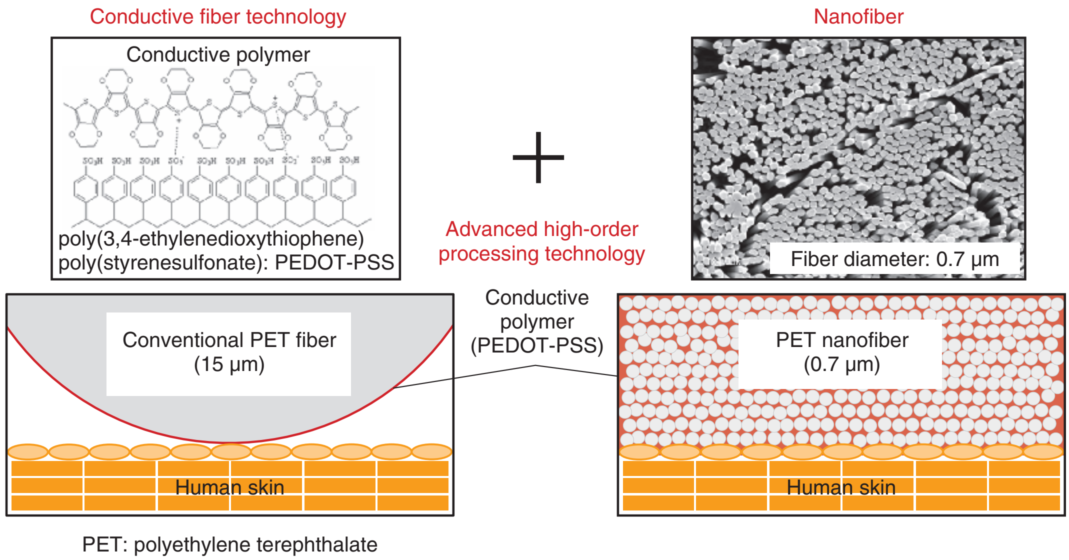

Fig. 1. Elemental technologies of hitoe.

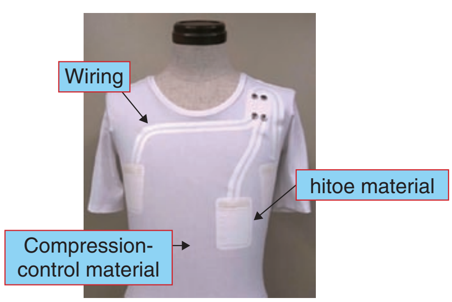

Fig. 2. hitoe-embedded inner T-shirt.

material with superior elasticity and breathability. When embedded in an inner T-shirt that is worn by a user, it can be used to easily obtain long-term recordings of the user's heart rate and electrocardiogram in a variety of everyday scenarios.

Changes in a person's mental state can be visualized by analyzing fluctuations in that person's heart rate over time. An example of heart rate fluctuation obtained within a business scenario is shown in **Fig. 3**. The horizontal and vertical axes represent time and heart rate, respectively. In the figure, periods A and C correspond to deskwork, while period B corresponds to a presentation made in front of a large number of people. As shown, the heart rate is higher, and heart rate turbulence (variation) is lower in period B compared with periods A and C. This response demonstrates that the sympathetic nervous system holds a dominant position in the autonomic nervous system that controls a person's heart pulsations, and that the person in question was under considerable stress in period B. Another example of a technique for visualizing changes in heart rate is shown in **Fig. 4**. Five minutes' worth of heart rate fluctuation is extracted from periods A and B and shown as a Poincaré plot. Given an electrocardiogram waveform, a Poincaré plot represents the interval between one heartbeat's R wave to the next R wave (R-R interval) at a certain time on the horizontal axis and the immediately subsequent R-R interval on the vertical axis. The results of such a plot become concentrated as heart rate turbulence becomes smaller (stress state) and, conversely, become dispersed during a period of relaxation. In this way, an inner T-shirt embedded with hitoe material can be used to measure heart rate intervals with high accuracy over the long term based on the person's electrocardiogram waveform, and the obtained results can be applied in an analysis of that person's mental state.

This newly developed inner T-shirt embedded with hitoe material is fabricated using Toray's compression-control material as the base material for the shirt itself. This enables long-term recording of a person's heart rate fluctuation or electrocardiogram even for lifestyle scenarios that include intense physical movements, as in sports.

The results of measuring an athlete's heart rate

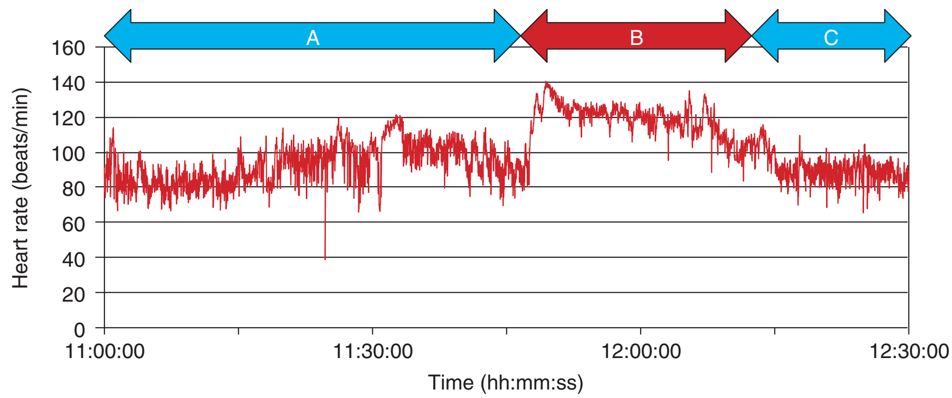

Fig. 3. Fluctuation in heart rate obtained in a business scenario.

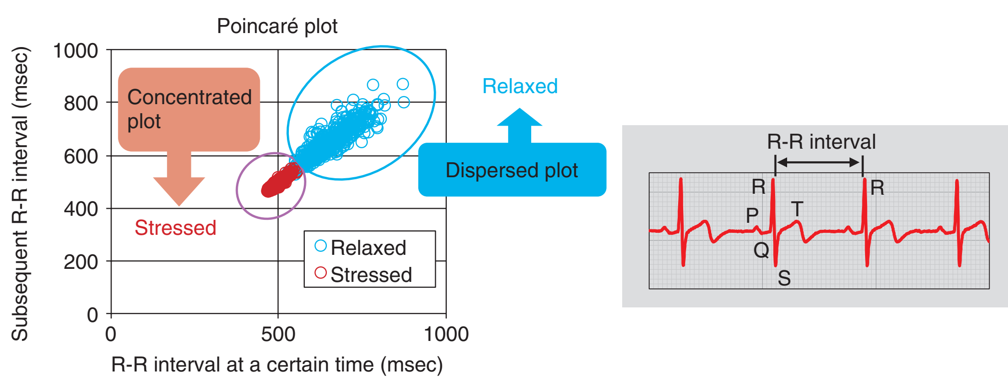

Fig. 4. Poincaré plot of heart rate variability.

fluctuation during a badminton doubles match are shown in **Fig. 5(a)**. These results demonstrate that heart rate fluctuation can be captured throughout a period of about 40 minutes even during a match involving strenuous movement in the upper body. The heart rate fluctuations of an experienced player and a beginner during the match are compared in **Fig. 5(b)**. It can be seen here that the heart rates of both the experienced player and the beginner jumped during rallies. However, on entering an interval (break) between rallies, the heart rate of the experienced player immediately dropped, while that of the beginner maintained a high value. Such fluctuation in heart rate can be viewed as a useful index for determining the extent of exercise load and recovery. Accordingly, highly effective training and health management can be obtained by having users wear a hitoe-embedded inner T-shirt while their heart rate fluctuation is managed.

3. Electrocardiogram-waveform transmitter

An inner T-shirt embedded with hitoe material can obtain electrocardiogram waveforms in addition to heart rate fluctuation. Moreover, the electrocardiogram waveform can be transmitted to a smartphone via wireless means (Bluetooth) when the T-shirt is affixed with an electrocardiogram-waveform transmitter, as shown in **Fig. 6**. The electrode arrangement in this T-shirt can obtain a waveform similar to that of CC5 leads in a Holter monitor. In addition to sharp QRS waves, preceding and succeeding P and T waves can be cleanly measured and displayed.

4. Looking ahead

Looking forward, we aim to contribute to the expansion of the sports, health-management, and

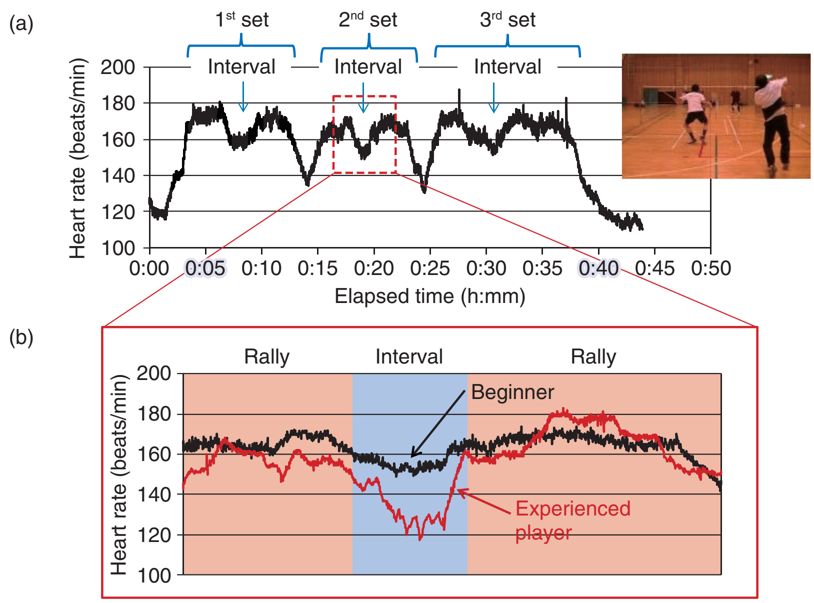

Fig. 5. Heart rate fluctuation during badminton doubles match.

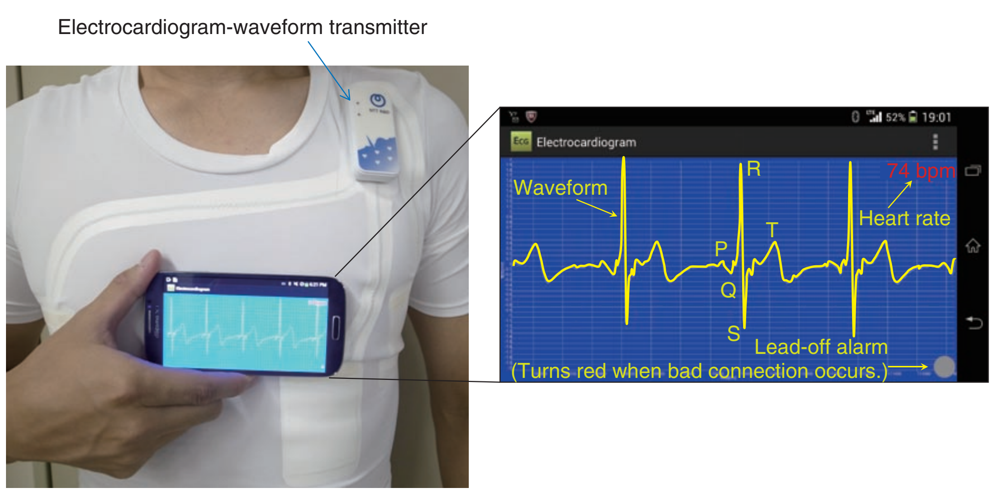

Fig. 6. Electrocardiogram measurement using smartphone.

medical care fields by creating innovative services based on our hitoe material. For example, we can envision the transmission of electrocardiogram-waveform data and other types of biomedical information to the Internet from smartphones and the use of cloud services and big data analysis in conjunction with health-support services offered by NTT DOCOMO.

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He received the B.E. and M.E. in mechano-informatics from the University of Tokyo in 2006 and 2008, respectively. He joined NTT Microsystem Integration Laboratories in 2008 and studied microelectromechanical systems (MEMS) devices for radio frequency and optical communication applications. He is currently studying biosensing devices and systems for life-care services. Due to the organizational change as of July 1, 2014, he is now with NTT Device Innovation Center. He is a member of the Japan Society of Applied Physics (JSAP).

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