"hitoe", A Functional Material That Allows for Continuous Measurement of Biological Information

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1. Introduction

NTT began developing a soft and conductive composite material that allows constant monitoring of heart rate and heart electric potential by coated fabric materials such as silk with a conductive polymer (PEDOT-PSS) for use in clothing items. Furthermore, through collaboration with Toray Industries Inc. in material development and sewing technologies, research and development efforts toward practical realization were accelerated and the material, named "hitoe", was released in January 2014. Here, we introduce the technology used to synthesize "hitoe" and practical examples with regard to the application of biosignals measured by "hitoe".

2. About the functional material "hitoe"

"hitoe" is a functional material developed by applying "conductive fabric technology", which is the impregnated fabric with a conductive material (PEDOT-PSS) developed by NTT, to a "nanofiber", an advanced fiber material developed by Toray Industries Inc. (Figure 1)

However, simply impregnated a general material (fiber diameter: around 15 μm) with a conductive polymer does not result in a material that can provide stable biosignal measurements due to the low contact between the cloth and the skin that results in gaps between them. Furthermore, the conductive polymer that impregnated in the material gradually peels off when washed, with repeated washings resulting in unstable biosignal measurements (Figure 2).

Figure 1: Functional material "hitoe"

Figure 2: Use of general fiber material

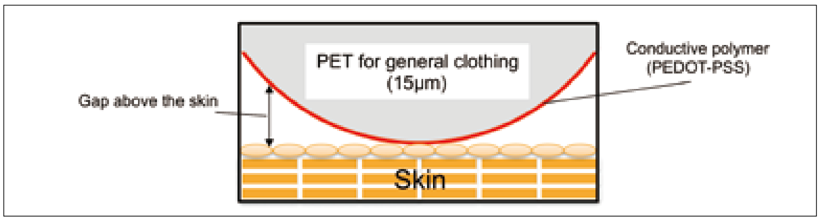
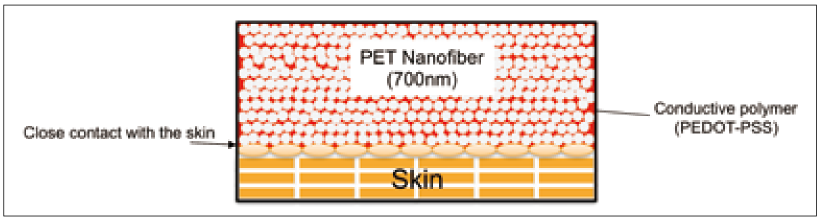


Figure 3: Use of the functional material "hitoe"



However, by using Toray's "advanced processing technology", high impregnation of the conductive polymer into the space around the "nanofiber" (fiber diameter: around 0.7μm) increases fiber contact to the skin thus producing stable biosignal measurements. Additionally, this high impregnation into the fiber results in a conductive polymer that is not easily peeled off, thereby offering durability even with repeated washings (Figure 3).

By combining the "hitoe" material with an inner shirt, we have developed a wearable sensor that can measure biological information such as heart beat and heart electric potential through the simple act of wearing a shirt (Figure 4). In order to function with various body types, the base fabric is made from a stretch material that applies an approximately constant pressure on bodies of different sizes. In addition, the material can also be worn for an extended period of time and has high conformance when worn during exercise.

These characteristics, namely the ability to maintain a good fit on various body types and the ability to measure biosignals reliably, have enabled stable biosignal measurements to be obtained during the performance of various activities simply by wearing a shirt.

3. Examples of biosignal measurements using "hitoe"

Measurement of heart rate and heart electric potential over an extended period of time in daily activities is now possible simply by wearing an undershirt made from "hitoe". Below are 3 examples of measurements and occasions for their usage.

- Measurement of heart electric potential that conventionally could only be performed in hospitals has been made possible using a combination of an undershirt composed of "hitoe", a measurement terminal and a smartphone. By employing an electrode configuration on the undershirt that was developed and optimized in

Figure 4: An undershirt made of the functional material "hitoe"

this study, we were able to obtain a waveform similar to the CC5 induction used in the Holter electroradiogram. In the future, it is expected that this method will be applied in the health care and medical field to manage and understand health conditions through long-term measurements taken in the home or other locations. (Figure 5)

- The use of a material from Toray that can control pressure in the shirt's fabric has made it possible to measure biological information even during activities that require significant body movement such as sports. Figure 6 shows the heart rate variability exhibited on a golf course, in which heart rate was seen to increase before and after each shot, with mistakes observed on shots while the heart rate remained high. Not only it is possible to observe a wearers physical condition during activities such as golf, but in sports that are affected by a person's mental state, it is possible to simultaneously observe heart rate variability during play, for example, with the aim of achieving a higher score.

- Figure 7 indicates the degree of stress and relaxation as heart rate variability. In general, heart rate fluctuation decreases during stress, indicating that the sympathetic nerve, a part of autonomic nervous system that controls heart beat, is dominant. On the other hand, heart rate fluctuation increases during relaxation, indicating that the parasympathetic nerve, a part of autonomic nervous system, is dominant. Heart rate variability can be visualized using a visualization tool called a Poincare plot. With a Poincare plot, the spacing between two R waves (R-R spacing) over a certain period is plotted along the x-axis and the R-R spacing during the subsequent period is plotted along the y-axis. The plot is more concentrated during periods of stress, with a low variability in heart rate. In contrast, during periods of relaxation, the plot is more distributed. Using this figure, it is possible to assess whether an individual is in a nervous or relaxed state.

With this method, it is therefore possible to determine a person's mental state simply by having him/her wear an undershirt made of "hitoe".

Figure 5: Measurement of heart electric potential using a smartphone

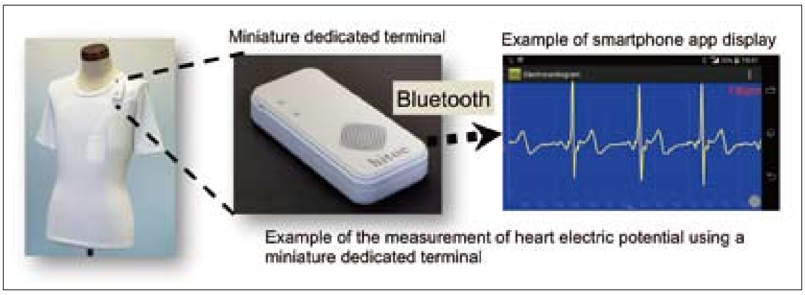


Figure 6: Example of heart rate fluctuation on a golf course

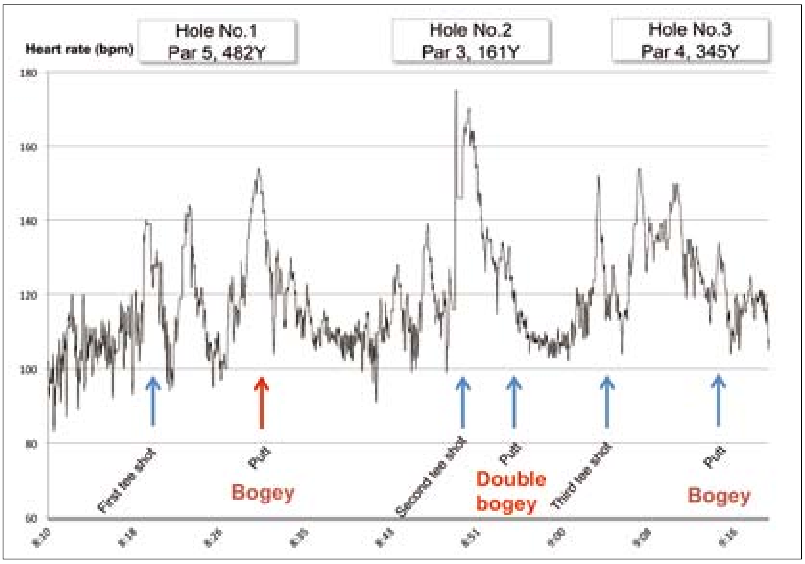
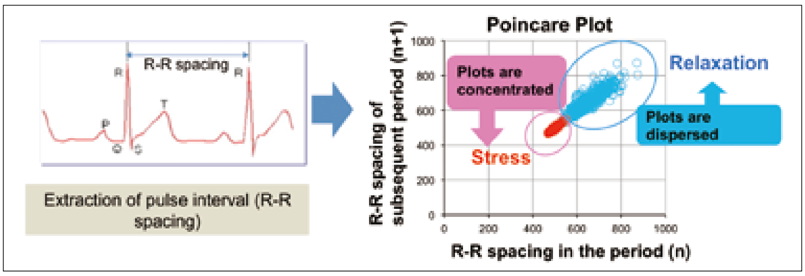


Figure 7: Fluctuation of heartbeat interval during stress/relaxation moments



4. Future developments

Clothing items made of "hitoe" have the following features: high durability, good fit, comfortable even when used for extended periods and able to measure biological information even during exercise.

We aim to utilize these features to make products that can be applied in training while measuring biological information during sports activities. Moreover, we also aim to further develop products that can monitor various health conditions for extended periods during daily life to contribute to the promotion of health. With the ability to store biological information obtained under various conditions in the cloud via the internet utilizing smartphones, computers or other tools, analysis of big data and combinations with other sources of information can be developed, which we believe can provide new value.

Furthermore, together with population aging, the need for various medical examinations performed in the home is rising. In such situations, this product can be used to acquire biological information over extended periods without the wearer ever leaving the home. We are also considering applications of this product in the aforementioned field of medical care.

Through the application of "hitoe", with its unique features that had never been achieved until now, in a variety of usage scenarios, we will continue to contribute to a variety of fields such as sports, health care and the medical field.