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Green Cognitive Body Sensor Network: Architecture, Energy Harvesting and Smart Clothing based Applications

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***Abstract*—The human-centered body sensor network (BSN) becomes one of the Internet of Things (IoT) development directions in the future due to interdisciplinary advantages in the fields of wireless communication technology, embedded microelectronic technology and mobile internet technology. Only depending on the terminal perception and transmission technology is not enough to make up the weak data storage, computing and analysis capacity. Thus, in combination with green sensors, smart clouds computing, artificial intelligence technology and BSN, this paper proposes a concept of green cognitive body sensor network(Green-CBSN). Starting from three aspects including green active sensor, energy harvesting and efficient data collection, health big data recognition and interaction, this paper introduces the architecture and thought of Green-CBSN in details. Then, we invite some volunteers equipped with wearable devices such as smart clothing and smartphone, and carry out the physiological signal collection, heart rate monitoring and physiological data emotion analysis experiments of electrocardiograph (ECG) and photoplethysmogaphy (PPG). At last, this paper summarizes the open issues and research directions about IoT security, health big data recognition algorithm optimization, energy saving and green energy harvesting, to provide the reference for Green-CBSN.**

***Index Terms*—artificial intelligence, body sensor network, cognitive computing, electrocardiograph, photoplethysmogaphy**

I. Introduction

The rapid development of wireless communication technology, embedded micro electro mechanical systems, super scale integration circuit, and other fields promoted the realization of new type sensor, which is more "miniaturized", "intelligent" and "networking". IoT is developing at top speed in the direction of "more thorough perception, more extensive interconnection, and deeper intelligence". In the future, the IoT should be human oriented and serving human beings, and also should be personalized, intelligent and green.

As an important form of expression of human-centered Internet of Things, BSN further demonstrates some new characteristics in view of the human body design compared with sensor networks [1]. Firstly, BSN has smaller scale with precise sensors placing on the human body. Thus one of the characteristics of BSN with a person as a carrier is mobility [2]. Secondly, different from the sensor for environmental information collection, BSN includes two types of sensors. One type is human body sensor, in charge of collecting the physiological information. The other type is dynamic sensor (such as camera, voice sensor, acceleration, gyroscope, and GPS), which can perceive the action and audio-visual information [3]. Then, BSN can integrate the surrounding and self information perception of humans, and speculate the human emotion by the complex model analysis to a certain extent. This is a tremendous progress. The previous machine and network processing tasks [4] mostly stay at the material level, rather than analysis on the spiritual level. BSN breaks through the limitation.

BSN is the emerging IoT application field concerning the human psychological and physiological health [5]. It realizes the psychological and physiological signal detection of human by deploying the sensor under, in or around body surface. Also, BSN introduces the perception data into the fields such as psychological illness intervention, medical health care, sports, and entertainment. As the late-model IoT application in recent years, BSN is an important way to facilitate the development of medical health industry and the improvement of people' s living quality. Compared with the "thing-centered" traditional IoT, BSN adheres to the "human-centered" aim [6]. All network access, data analyses and services of BSN focus on humans. The multimodal sensors in the data collection layer collect the human's psychological and physiological health parameters and energy harvesting, rather than ordinary sensors.

Nevertheless, with ever-increasing demands of users today, people have higher and higher requirements for the quality of service offered by IoT, while the massive sensor data presents the exponential explosive growth. Only depending on the terminal perception and transmission technology is not enough to make up the weak storage and computing capacity. The artificial intelligence technology brings new opportunity for us. BSN combining with the green sensors and artificial intelligence technology called as green cognitive body sensor network(Green-CBSN).

We proposed Green-CBSN to make up the shortage of bogy sensor networks in sensor design, energy harvesting and intelligence. The contributions of this paper can be summarized as follows:

- **Green active sensor design**: The existing sensor fails to supply the power for a long time, which is partic-

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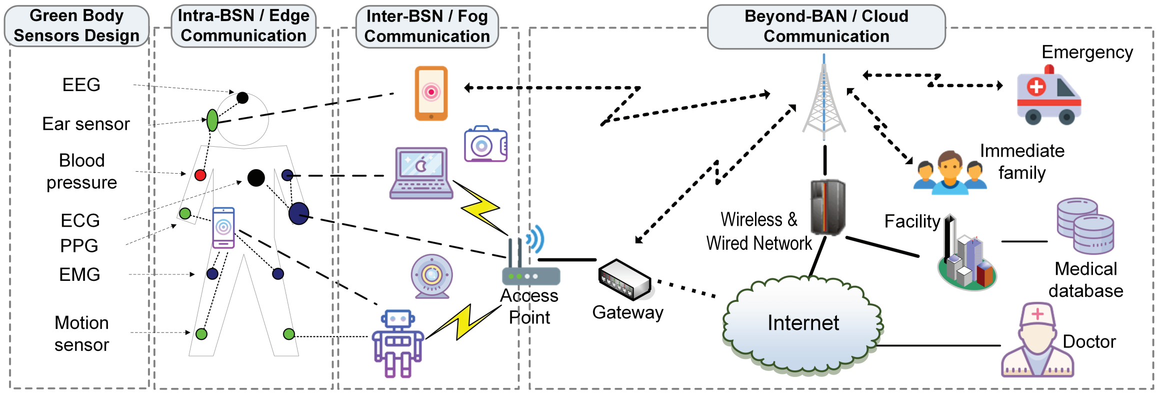

Fig. 1. Green cognitive body sensor network architecture

ularly detrimental to the wearable devices, because the healthcare application needs the persistent and stable data collection and transmission. How to design the small and exquisite sensor module with long-time power supply is one of the key difficulties in research of Green-CBSN. In addition to adopting the extra USB charging port sensor, the energy supply by electret, dry electrode or from energy conversion of human body is also a new thought. Such green active sensor can collect multimodal data signals continuously and have little interference with the users.

- **Energy harvesting and efficient data collection**: For healthcare application, the physiological and psychological data is the important basis for the system intelligence. The data sources from the users include video, audio, image and physiological data, etc. The health big data collection becomes the first step of such intelligent applications. How to acquire the massive health data of users and transmit the data acquired to the background efficiently without error is the important issue to be considered by the data collection intelligence.
- **Intelligent recognition and computing of health big data**: The accuracy rate of health big data recognition and computing can reflect the application intelligence most directly in the interactive experience of users. If a robot, application or wearable device fails to identify the physiological and psychological conditions of users accurately, the feedback results or subsequent interactive information will deviate from the true healthy conditions of users. Here, we introduce the wearable devices such as smart clothing [7] and smartphone as Green-BSN platform. Then, we analyze the health conditions of users based on ECG and PPG signal recognition, and multi-modal emotion recognition. Such multidimensional data recognition can enhance the accuracy rate and bring better user experience.

The reminder of this paper is arranged as follows. Section II provides the architecture of Green-CBSN and introduces the composition and functions of each part in details. Section III shows the ECG signal detection, PPG signal detection and emotion recognition experiments based on ECG data using Green-CBSN. Section IV discusses some open issues about security, emotion recognition algorithm, energy saving and energy conversion. Finally, Section V summarizes our work.

II. Green Cognitive Body Sensor Network Architecture

Green-CBSN collects the human physiological and psychological data by the wearable devices, i.e. smart clothing based applications, with independently designed green active sensor. Then, Green-CBSN conducts the data fusion by intra-BSN [8] and local data verification. It transmits the massive data to inter-BSN by the mobile communication technologies such as 5G [9], Bluetooth and WIFI. After that, it transmits data to the remote cloud [10] data center (beyond-BSN) through the inter-BSN (wireless access point and gateway, etc.). This process realizes the energy harvesting, efficient data collection and transmission. In the cloud, the system can analyze the potential implications of harvested energy data by the artificial intelligence algorithm (machine learning / deep learning), gain the health conditions of users, and feed back the results to the user-related application or group. Fig. 1 shows the overall system architecture of Green-CBSN. We will introduce our idea in details from three aspects as follows, i.e. green active sensor, energy harvesting and efficient data collection, health big data recognition and interaction.

A. Green active sensor

People in the IoT environment consisting of various devices carry out the self regulation and information interaction with themselves and surroundings constantly every day. The wearable devices and smartphone are favorites of healthcare application [11] due to their good mobility and comfortable QoE [12]. Fig. 2 shows the prototype of smart clothing and the energy consumption measured by different physiological indexes. The wearable device (smart clothing) or portable intelligent electronic device can collect various physiological and psychological data of humans by multi-modal sensor. The sensors equipped by smart home, telemedicine [13], internet of vehicles in surroundings, and battlefield environment [14] can also acquire the multi-modal data of human. These big data

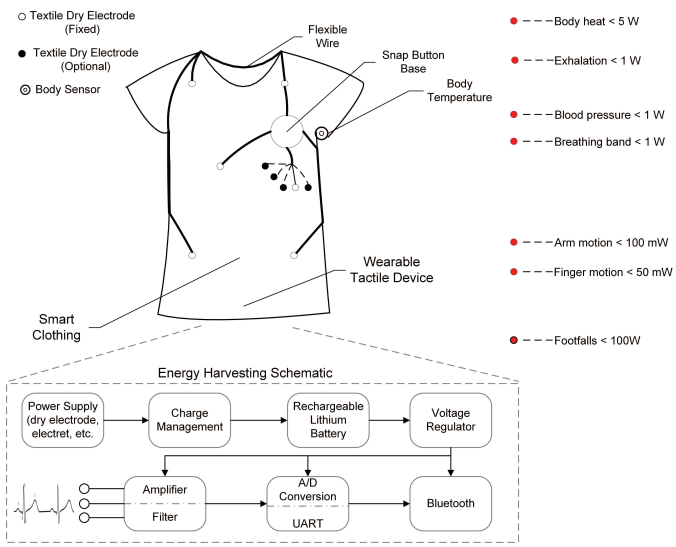

Fig. 2. Design of smart clothing based on green active sensor

are important dependence of analyzing the health conditions. Designing and using the stable and reliable sensor is the first step of healthcare application. However, the existing sensor fails to supply the power for a long time, which is particularly detrimental to the wearable devices [15]. Because the healthcare application needs the persistent and stable data collection and transmission. How to supply the power for the wearable electronic devices constantly (the comfort degree and user experience by USB charging sensor is very bad)? How to design the small and exquisite external sensor module with long-time power supply [16] is one of the difficulties in research of Green-CBSN. The following three methods are the latest mode for green energy supply.

The energy supplied by power source from conversion of human body provides a new thought for us. An adult consumes the energy of about 100 J every day [17]. If these energy can be converted into the electric energy, the power supply problem of the sensor can be solved effectively. Such green active sensor can collect various data signals continuously and have little interference with the users [18]. It will provide the comfortable user experience and powerful popularization effect for our Green-CBSN. The energy produced in the moving process of human body include mechanical energy, thermal energy, biosignal energy, etc.

In addition, as an electronic material, the electret reveals its potential in the energy supply field. The electret is a solid dielectric with persistent polarization. It can produce the electric field in the surrounding space, so it is a charged body analogous to the permanent magnet. The polarized state of electret at room temperature can be kept for a long term, but will be attenuated quickly at high temperature.

Dry electrode refers to the electrode without using in coordination with the conductive paste. It is mainly used for measuring the biopotential signals such as electrocardio, electroencephalogram, and electromyographic signals. Without needing the skin preparations and coating of conductive paste, the dry electrode is very suitable for the detection of healthcare, recovery, disease diagnosis and treatment, and brain-computer interface, and the demands of human-machine interactive system in the future. Fig. 2 shows the smart clothing prototype with dry electrode as the energy supply [19]. In this paper, we choose dry electrode as the power supply module of smart clothing.

B. *Energy harvesting and efficient data collection*

The perceptive technology, as the foundation of Green-CBSN, provide the important support for the upper application of Green-CBSN. It can provide the ubiquitous and comprehensive perception service for the human society. Combining with the existing basic network facilities, it perceive the whole physical world by intelligent device and sensor. Green-CBSN connects with numerous objects, expands and extends continuously, and involves in many technologies.

The body sensor is the key component of Green-CBSN with the main function of human physiological and psychological information collection. Then, it converts the physical quantity, chemical quantity, and biological quantity from the physical world into the digital signals. Thus, the Green-CBSN can provide the original information source for perceiving the human health and surrounding physical world, and connecting the physical world with the electronic world. Now the physical signals perceived by the body sensor include heat, force, light, electricity, sound and displacement. These signals provide the original information for data processing, transmission, analysis and feedback. With advances in circuit design and micro electro mechanical systems (MEMS), the advanced sensor components can also conduct the format conversion, logical operation, data storage and transmission of the information. A sensor node is generally composed of sensor module, processor module, wireless communication module, and power supply module. The sensor module is responsible for monitoring the information collection and data conversion (converting the physical quantity into the electronic signal) in the area. The processor module is responsible for controlling the operation of the whole sensor node, and storing and processing its collected data and the data transmitted by other nodes. The wireless communication module is composed of wireless transceivers in network layer, MAC layer and physical layer. It is responsible for conducting the wireless communication [20] with other sensor nodes or computers, exchanging the control information, and receiving and transmitting the collected data. The power supply module is responsible for the energy supply of the entire wireless sensor node.

In addition to the carry-on intelligent communication device of the user (collecting the video, voice, and facial image data of the user for emotion analysis), various body sensors equipped in the wearable device can collect different physiological data, as shown in Fig. 1. Fig. 2 provides the schematic diagram of multimodal perception of body sensor with smart clothing as prototype. The body sensor can collect many types of physiological data, involving electrocardiograph (ECG), photoplethysmogaphy (PPG), blood pressure, and electromyography (EMG) [21], etc.

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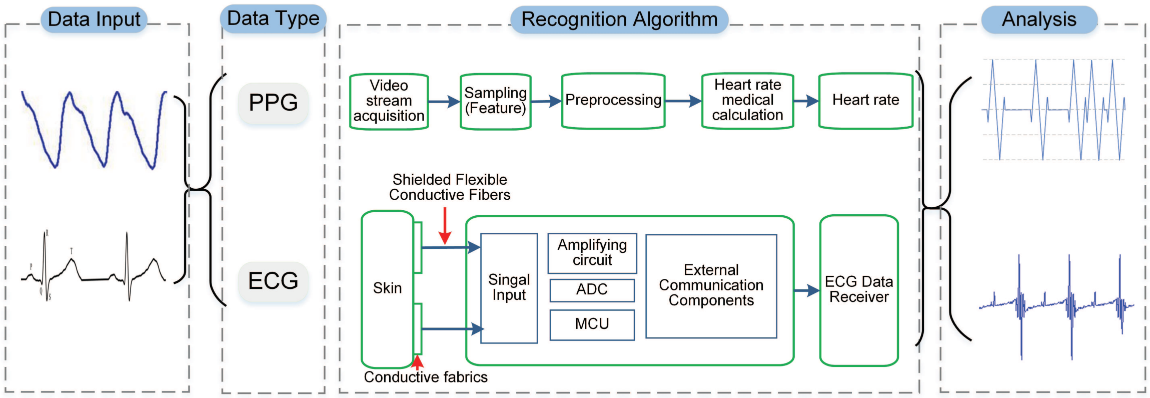


Fig. 3. ECG and PPG data processing flow chart

C. Health big data recognition and interaction

When the terminals have less data identification and cognitive ability, the common practice is to transmit all data to the cloud and enable the cloud to conduct the data processing and computing [22]. Another choice is deploying AI algorithms as lightweight intelligent recognition algorithms at the terminal and recognize the physiological and psychological conditions of users. Besides, AI is used to distinguish the data validity, upload the important data, and filter the redundant data. Based on difference in the user' s gender, age and body type of the user, we can recognize and compute the health data more accurately. In other words, we can reduce the data transmission quantity and computing quantity to a large extent in the case of equivalent intelligence effect and the same intelligent streaming.

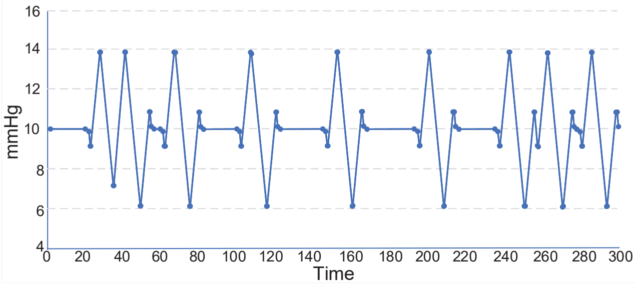
After deploying the green active sensors in the smart clothing extracting the external health data, we excavate the potential correlation between different human signals by artificial intelligence technology. This process does not require too much human participation and not just rest on the superficial meaning of the collected information [23]. In addition, if transmitting the health big data to the data center, we can also reduce the computing costs by the parallel computing ability and storage ability of computer science [24]. The ultimate goal is to produce an intelligent computing and decision-making brain, i.e. cognitive engine of Green-CBSN. Starting from the data perspective, we combine materials, energy, photoelectricity and communication, computer, electronics, and applied medicine, and realize the full coverage of cognitive medical treatment and healthcare application. Fig. 3 shows the data processing flow of some physiological indexes (ECG and PPG) of Green-CBSN.

At present, PPG signal collection and processing provides two methods of measuring the heart rate, i.e. fingertip and human face. However, the algorithm of measuring the heart rate by human face is relatively complex. It is greatly influenced by the surroundings, face stability and measurement duration, with lower accuracy rate. Thus, we adopt the method of fingertip to measure the heart rate, and install the heart rate measurement function into an healthcare application on the smartphone. When collecting PPG signal, the rear camera of the mobile phone will turn on the flash light. The user covers the fingertip on the high definition camera, to produce the video streaming. The system collects the video streaming data, takes the samples, extracts the characteristic value, and carries out the data preprocessing, as shown in Fig. 3. Here the PPG characteristic value means the shadow changes and vasoconstriction of fingertip video streaming per frame. The change of heart rate value with the time can be measured by the medical heart rate computation function.

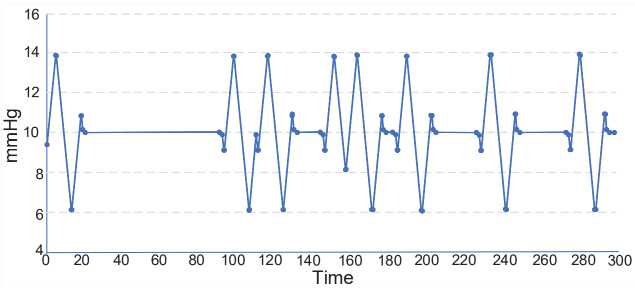
ECG signal can be measured after connecting with the sensor electrode in multiple body parts, which is the advantage of smart clothing. The smart clothing is a new type wearable technology with seamless fusion of electronic textile and wearable device, and can sustainably monitor the physiological index with high comfort. Its technical principle involves in various research fields such as washable clothing design and manufacture based on textile dry electrode / electret, low power wireless communication, sensor network, microelectronic technology, and telemedicine. As comprehensive interdisciplinary research field, it can collect the human physiological indexes such as body temperature, blood oxygen, breathe, electrocardiography, and heart rate. The smart clothing overcomes the deficiencies of traditional wearable device in the healthcare application, including low comfort, low accuracy, complex operation, and unsuitable for long-term monitoring. It can collect various human physiological indexes constantly, and build the mobile health cloud platform in virtue of mobile internet, cloud computing, big data, machine learning, and other technologies. In addition to PPG signal collection, this paper also takes electrocardiography (ECG) monitoring as an example to demonstrate the Green-CBSN physiological signal collection and processing based on smart clothing. On the basis of realizing the physiological index monitoring, the system can also offer the value-added services such as health guidance, emergency medical aid, and emotional care in accordance with the collected physiological data.

III. Experiment

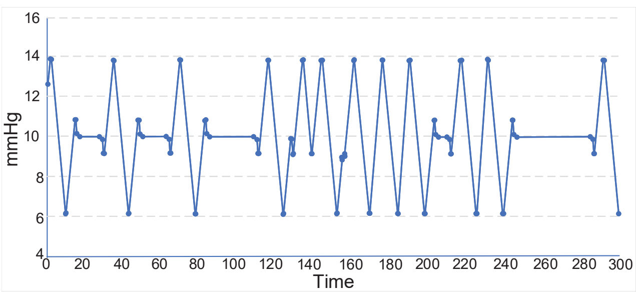
We invite four students to take part in the Green-CBSN data collection experiment. Fig. 5(a) is the ECG data collected from four students in smart clothing while reading under the



(a) Sitting.



(b) Standing.



(c) Walking.

Fig. 4. PPG data collection.

calm state. The oscillogram data are shown above the portrait. Fig. 5(b) is the photo taken during the walking process of four students. From the results, ECG signal during the walking process is more rapid than the data under the calm state.

In addition, in view of PPG monitoring function included in Green-CBSN, we also test the PPG heart rate measurement experiments. The waveform is shown as Fig. 4. We invite a student to conduct the PPG signal collection and data analysis experiment under the sitting, standing and walking states. The experiment duration is 300ms. The smartphone PPG interface shows the average pixel value is 244 and the number of pulses is 1. Fig. 4(a) shows the PPG heart rate measurement result under the calm state, and the heart rate is 78 / min. The entire waveform is relatively stable, indicating that the user emotion is in the stable state during the period of test time. Fig. 4(b) shows the PPG heart rate measurement result under the standing state of the user, and the heart rate is 88 / min. The entire waveform is less stable than the waveform in the sitting state. Fig. 4(c) shows the PPG heart rate measurement result under the walking state of the user, and the heart rate is 127 / min. The entire waveform is more rapid than that in the sitting and standing states, indicating that the user emotion is in the unstable state during the period of test time.

ECG signal is strongly linked to human emotion, so we can make use of ECG signal to analyze human feeling. Extracted ECG feature can be used in emotion detection, and then realize the sentiment detection. Therefore, after ECG data collection experiment, we adopt the deep learning algorithm to conduct the emotion analysis of ECG data. The emotion categories include calm, angry, happy and sad. ECG diagram corresponding to each emotion is different. The emotion recognition accuracy rate in view of high quality ECG data under the experimental environment can be up to 80% ultimately. Fig. 6(a) shows the ECG signal waveform when the user is angry with bigger signal fluctuation. Fig. 6(b) shows the ECG signal waveform when the user is happy with smaller signal fluctuation. Fig. 6(c) shows the ECG signal when the user is sad with small valley point value of signal waveform. Finally, Fig. 6(d) shows the oscillogram under the calm state.

IV. Open Issues

A. Security

The information security issue is one of the core technologies concerning whether the Green-CBSN can develop safely and sustainably. Meanwhile, Green-CBSN collects more and more personal information, which puts forward higher requirements for the privacy protection. Therefore, how to set up the reasonable security architecture and privacy protection strategy will have the significant influence on development of Green-CBSN. The Green-CBSN is composed of a large number of devices and relatively lack of the human management and intelligent control. Therefore, Green-CBSN should be confronted with the traditional communication network security issue, and also should be confronted with the special security issue relevant to its own features including IoT perception layer, network layer, encryption mechanism, and etc. At the same time, a unified safety technical standard, authentication mechanism and mature security system should be built and perfected. Admittedly, the development of Green-CBSN is inseparable from the technical progress, but more importantly, it refers to the perfection of supporting laws and regulations in various aspects of planning, management and security, unification and coordination of technical standard, and security system architecture and construction [25].

B. Health big data recognition algorithm optimization

Nowadays, the customers have higher and higher requirements for the quality of service and cost performance. The service providers presents the new challenges to themselves while meeting these demands. It is specifically embodied in the aspects of health big data acquisition, data privacy and security, and intelligence of emotion recognition algorithm [26]. There are also some challenges in the assessment of recognition accuracy rate. Because in the traditional physiological (ECG, PPG, EMG and EEG, etc.) and psychological (emotion) recognition, the data sets are generally from the same corpus or have the same data distribution which are closely related to the personal physiological and spiritual world. However, in fact, the emotion data acquired from different objects, devices and

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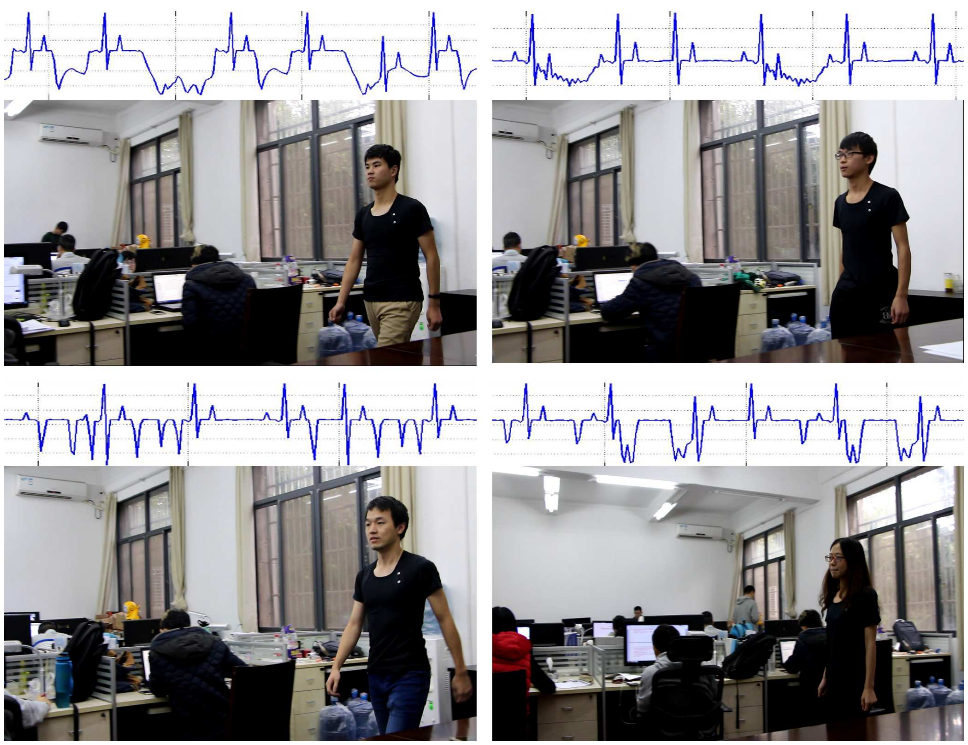
(a) Sitting.



(b) Walking.

Fig. 5. ECG data collection.

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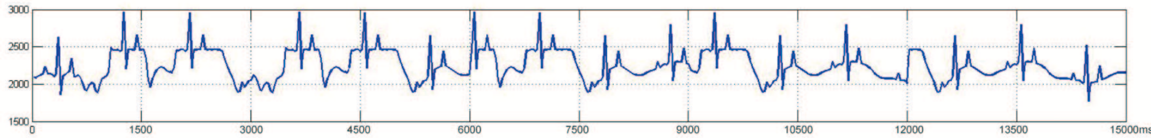
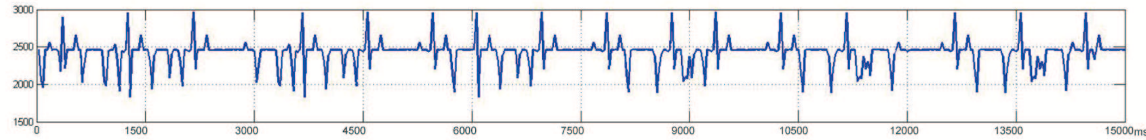
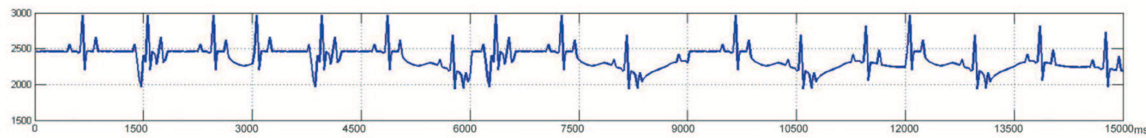


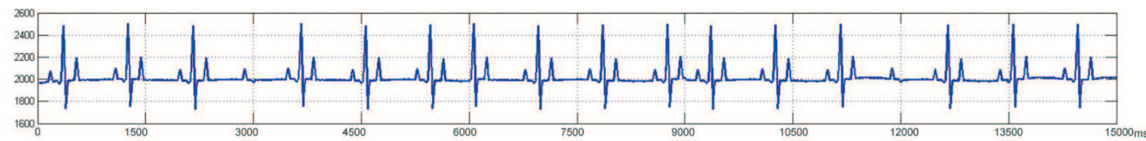
(a) Angry.



(b) Happy.



(c) Sad.



(d) Calm.

Fig. 6. ECG waves for different emotional states.

environment have great differences. They are generally embodied in the aspects of physiological index, language, emotion expression mode, data marking scheme, and acoustic signal conditions. Thus, the performance of trained model in the other data set is reduced [27]. Thus, the future health big data recognition needs to be paid more attention to the personalized long-term model building, promoting the recognition accuracy rate, optimizing the deep learning algorithm, so that to give more intelligent feedbacks and services to the users [28].

C. Energy saving and green energy conversion

The energy saving and conversion of Green-CBSN is one of the difficulties. But the theory and technology in this respect are not mature and still in the development stage [29]. In the design of sensor node, we should pay more attention to the node miniaturization and energy saving. Besides, we should focus on how to avoid the heating of sensor implanted in human body or close to the human body surface from damaging the human body [30]. While designing the data processing algorithm and communication protocol [31], the energy consumption problems also need to be paid attention to. In addition, Green-CBSN is closely related to the human health (the stability and reliability of power supply are very important), so we need making more efforts in many aspects such as converting the human body energy to the power supply and converting the ambient energy of human body to the power supply. In a word, Green-CBSN is a multi-field and multi-disciplinary integration, and solves the key technical problems in the relevant field. The researchers need the further exploration.

V. Conclusion

Based on body area network, combining with sensor technology, big data analysis, and artificial intelligence technology, we put forward the Green-CBSN. Starting from three aspects of green active sensor design, energy harvesting and efficient data collection, intelligent recognition and computing of health big data, this paper introduces the innovation point and architecture of Green-CBSN in details. Then, based on the wearable devices, i.e. smart clothing and smartphone, we invite the volunteers and carry out the experiments of heat rate monitoring through ECG and PPG. The physiological signal collection, heart rate monitoring and physiological data emotion analysis experiment results show that, our Green-CBSN can effectively collect the physiological data of users, reflect the current emotion and health conditions, and provide the comprehensive knowledge and experimental foundation for BSN research. Finally, this paper summarizes and prospects the open issues and future works from three aspects of security, recognition algorithm optimization, and green energy conversion.

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