Wearable 2.0: Enabling Human-Cloud Integration in Next Generation Healthcare Systems

Min Chen, Yujun Ma, Yong Li, Di Wu, Yin Zhang, and Chan-Hyun Youn

The authors propose a Wearable 2.0 healthcare system to improve QoE and QoS of next generation healthcare systems. In the proposed system, washable smart clothing, which consists of sensors, electrodes, and wires, is the critical component to collect users' physiological data and receive the analysis results of users' health and emotional status provided by cloud-based machine intelligence.

ABSTRACT

With the rapid development of the Internet of Things, cloud computing, and big data, more comprehensive and powerful applications become available. Meanwhile, people pay more attention to higher QoE and QoS in a "terminal-cloud" integrated system. Specifically, both advanced terminal technologies (e.g., smart clothing) and advanced cloud technologies (e.g., big data analytics and cognitive computing in clouds) are expected to provide people with more reliable and intelligent services. Therefore, in this article we propose a Wearable 2.0 healthcare system to improve QoE and QoS of the next generation healthcare system. In the proposed system, washable smart clothing, which consists of sensors, electrodes, and wires, is the critical component to collect users' physiological data and receive the analysis results of users' health and emotional status provided by cloud-based machine intelligence.

INTRODUCTION

Due to the ever growing number of elderly people coupled with limited resources in terms of medical facilities and personnel in many countries, the burden that conventional healthcare systems carry is becoming heavy. On the other hand, traditional human face-to-face communications are mostly replaced by networking in social and cyber spaces, which causes various unhealthy living habits, such as insufficient physical exercise, unhealthy diet, irregular sleeping, and more frequent "burning the midnight oil." All these factors are usually the keys to triggering chronic diseases, including cardiovascular disease, hyperlipemia, diabetes, tumor, obesity, and chronic respiratory disease. As reported in "The Leading Causes of Death and Disability in the United States,"[1] 50 percent of people in the United States suffer from one or more kinds of chronic diseases at different levels, while 80 percent of medical funds in the United States are used to treat chronic disease. In 2015, the United States spent $2.7 trillion on chronic disease treatment, which accounts for 18 percent of the U.S. gross domestic product.

Therefore, it is a great challenge to design a cost-effective heathcare system for handling chronic diseases, especially considering the large population of elderly people and empty nesters, most of whom suffer from one or more chronic diseases. To address this issue, we should lower the operating cost and improve their scalability of healthcare systems, which are expected to provide various basic healthcare services [1], such as physiological monitoring, early warning via abnormal vital signs, and online patient consultations [2]. Fortunately, with the assistance of cloud computing and big data, various advanced services become possible by the use of big data analysis for chronic disease detection and intelligent health monitoring [3]. However, it is difficult to solve the following undesirable issues in existing healthcare systems.

Physiological Data Collection: Without considering users' mobility, traditional physiological data collection is uncomfortable for users because they must wear multiple sensors or related devices. On the other hand, if only simple devices (e.g., smart bracelet and smart watch) are carried, the collected data is inaccurate. Thus, how to accurately collect sufficient physiological data in a comfortable way is still an unsolved problem..

Negative Psychological Effects: Besides uncomfortability, users might feel that they have health problems when they wear body sensors, which further causes stress and other negative emotions. More seriously, the negative psychological effects will result in some mental illness, especially when patients feel lonely or depressed. Hence, we need to rethink the design for an innovative healthcare system in terms of physiological data collection in a more comfortable, energy-efficient, and sustainable way [4–6]:

Sustainable Big Physiological Data Collection: Nowadays, wearable techniques are widely accepted in the market, including smart watches, smart bracelets, wearable sleep aid devices, sport monitoring and promotion, and so on. Although users may not have observable discomfort while wearing such devices in their daily life, the collected physiological data are usually simple and cannot be called "big data," even for long-term monitoring. Thus, these insufficient data have limited reference value for chronic disease diagnosis. If medical-level data are needed, more complicated medical devices should be used. In this case, a user's normal life will be disturbed. For example,

[1] http://www.cdc.gov/chronicdisease/overview

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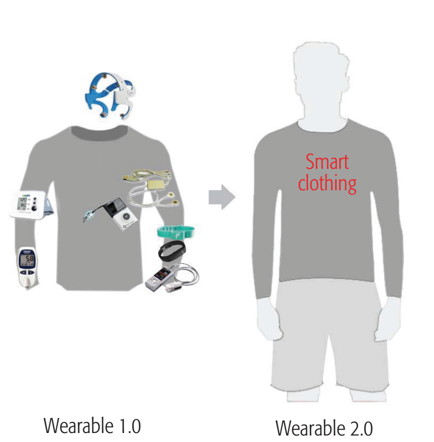

Product name	Category	Comfort index	Usability	Machine wash	Accuracy	Sustainability	Physiological index	Real-time
Smart bracelet	Wearable 1.0	High	Very easy	No	Low	Yes	Simple	Yes
Smart watch	Wearable 1.0	High	Very easy	No	Low	Yes	Simple	Yes
ECG monitoring instrument	Wearable 1.0	Low	Hard	No	High	Yes	Simple	No
Heart rate monitor	Wearable 1.0	Middle	Easy	No	High	No	Simple	No
Fall detection device	Wearable 1.0	Middle	Easy	No	Low	No	No	Yes
Smart clothing	Wearable 2.0	High	Very easy	Yes	High	Yes	Complex	Yes

Figure 1. Motivation for proposing Wearable 2.0: a) comparison of a conventional wearable system and smart clothing; b) features of Wearable 1.0 and Wearable 2.0.

a portable electrocardiogram (ECG) monitoring device can be used for collecting detailed ECG curves, but long-term wearing is implausible, especially considering a user's mobility.

Anti-Wireless for Body Area Networking: In traditional body area networks (BANs), wireless technology is encouraged to replace wired cables [7]. However, there are various factors, such as user mobility and surrounding environment, that create wireless interference, bringing challenges to achieve high stability and accuracy during physiological data collection. On the other hand, the wireless bandwidth in BANs is limited to support medical-level data transmissions, while the energy consumption of wireless networking is also a main concern. In the next generation BANs, wireless should be avoided as much as possible for green communications.

To address the above challenges, this article investigates innovative wearable devices, especially washable smart clothing. When wearing these innovative wearable devices, users may not experience any different feeling compared to a normal T-shirt, as shown in Fig. 1a. The traditional wearable system is considered Wearable 1.0, where there are problems of insufficient data collection when carrying small or "uncomfortable wearing when professional devices are adopted [8, 9]. With continuous improvement of wearable techniques, Wearable 2.0 is proposed to incorporate multiple connected devices and cloud services that, together, offer more meaningful enhancements to users' lifestyles [10]. In Fig. 1b, we compare Wearable 1.0 with Wearable 2.0 in terms of comfort, usability, accuracy, washability, and support for real-time monitoring. Obviously, Wearable 2.0 is a good solution to the challenging issues in terms of sustainable data collection for health big data. Therefore, in this article we propose a Wearable 2.0-based healthcare services to improve quality of experience (QoE) and quality of service (QoS) in the next generation healthcare system.

In the remaining part of this article, we present the design and implementation issues of Wearable 2.0. The architecture of Wearable 2.0 is proposed. It describes a testbed of Wearable 2.0. Based on this testbed, applications of emotional care are discussed. We then conclude the article.

Design Issues of Wearable 2.0

In order to integrate body sensors and cables with textile material perfectly, various issues need to be considered in Wearable 2.0 design, including details of the sensors, availability of the system, and the user experience. We classify the functional components of the smart clothing representing Wearable 2.0 into the following categories.

Sensors Integration: In our design, the pulse sensor is installed around the wrist; the body temperature sensor is put in the underarm seam; a set of ECG sensors are mounted on the chest, shoulders, and ribs; the myocardial sensor is embedded in the left part of the chest; and the SpO_2 sensor is deployed on the triceps of the left (or right) arm. As shown in Fig. 2b, more bio-sensors can be selected without the consideration of deployment cost.

Electrical-Cable-Based Networking: Generally, elastic textile cloth material should be selected for smart clothing. Furthermore, in order to guarantee comfort, flexible electrical cables should be embedded along the stitching of the cloth, as shown in Fig. 2a. In this way, the smart clothing is also more durable after it is washed repeatedly.

Digital Modules: Strictly speaking, digital modules do not belong to the components of smart clothing, since they are not washable. However, these add-on devices are closely attached to the smart clothing.

For example, the power module should be miniaturized or flexible, but it does not need to be an independent module, so the power module can be combined with the signal collection terminal (i.e., Smart Box), and provide power supply to both the Smart Box and the sensors in smart clothing. The common design for the Smart Box is expected to possess the capabilities of signal collection, short-term data storage, and local processing.

In our Smart Box, the sensory data is preprocessed through the digital signal processor (DSP) sub-module, compressed by the storage sub-module, and then transmitted to mobile devices (smartphone, portable computers, etc.) via the wireless communication sub-module. However, it is a challenging problem for the Smart Box to obtain an optimal trade-off among signal sample rate, complexity of signal processing, and computing cost.

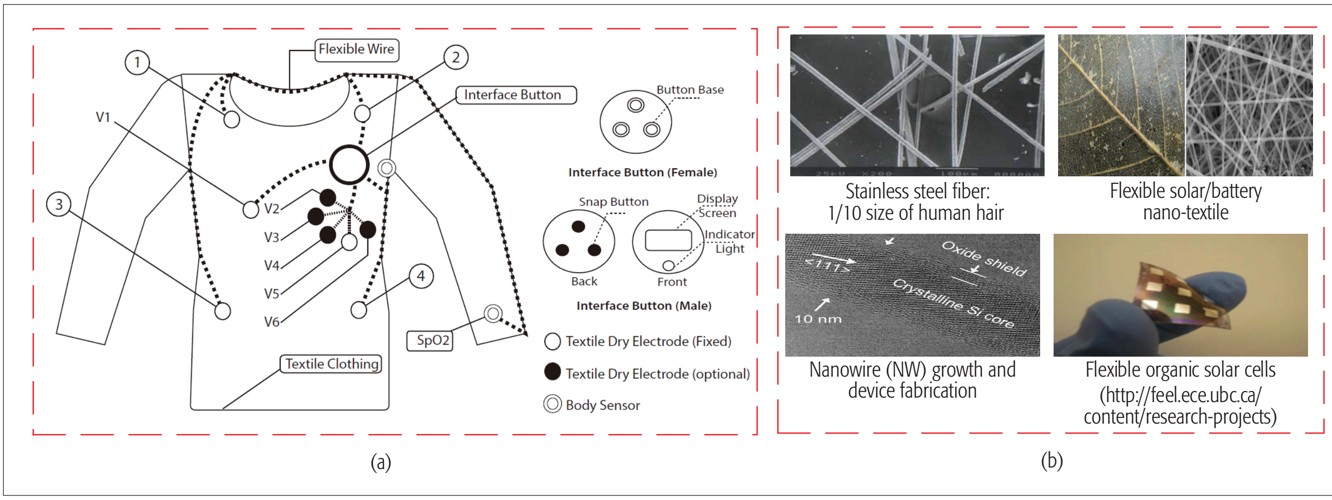

Figure 2. Key design issues for Wearable 2.0: a) design of the conductive network based on the washable power cable; b) raw materials for smart clothing.

To address the above three challenging issues, Wearable 2.0 design exhibits the following features:

- All the sensors are wrapped and protected by textile cloth. Textile electrodes are covered under clothing, that is, they are invisible from the front side, as shown in Fig. 1a. These sensors are powered by miniature battery to collect physiological data.
- The sensors do not have to touch human skin tightly or continuously, since tight body contact causes discomfort for users. Opportunistic contacts during a user's movements will be enough to collect adequate data if the user feels comfortable and wears the smart clothing for a long time. Due to this feature, smart clothing can be personalized for a user as normal clothing.
- Digital modules are not merged with smart clothing directly. Instead, there is an "interface button" to interconnect smart clothing with the Smart Box, as shown in Fig. 2a.
- Before washing the smart clothing, theSmart Box should be disassembled through the interface button, since it is not waterproof. When the smart clothing is dried, the Smart Box can be installed again.

The interface button is a bridge to connect smart clothing with an outside communication device (i.e., the important interface for human-cloud integration). Thus, it is critical to decide where it is located. The interface button can be disguised as a shoulder strap or chest card, as shown in Fig. 2a. The selection of its position should consider comfort, aesthetics, and convenience for the user. In Fig. 2a, three buttons are designed: two of them are used for power supply, and the other one may be used to connect a data cable. If only two buttons are adopted, the cables will work as both electrical wires and data cables. In the proposed smart clothing, four basic physiological data are collected: ECG, oxygen saturation, body temperature, and heartbeat rate.

In Fig. 2a, 10 fixed electrodes are placed for ECG data collection. Electrodes 1 and 2 are close to the shoulders, while electrodes 3 and 4 are located in the lower front part of the clothing. Specifically, electrode V1 corresponds to the position of the fourth rib gap of the body right parasternal, while electrode V5 corresponds to the position of the body left anterior axillary line. Another four electrodes (i.e., V2, V3, V4, and V6) are optional. Based on the specific requirements of sensory data accuracy, the user's comfort and wearing duration, those optional electrodes can be flexibly snapped on or taken off. When all 10 electrodes are used, standard medical-level ECG signals can be obtained. Practically, the various combinations of fixed and optional electrodes lead to different trade-offs between data accuracy, comfort, and power consumption.

Moreover, the energy cost of the Smart Box is also critical for Wearable 2.0. We recommend some recent radio technologies, such as Bluetooth 4.0+, which is convenient to connect with a smartphone in an energy-efficient fashion. Meanwhile, IEEE Low Power Wi-Fi (IEEE 802.11 ah) is also a good selection, since it has the features of long distance, low power, and low data rate, which is suitable for Internet of Things (IoT) applications.

It is obvious that the Wearable 2.0 healthcare system is complicated, which involves various research areas and technologies, including material science (Fig. 2b), costume design, electronic engineering, embedded systems, wireless communications, mobile networks, cloud computing, big data, and so on.

Thus, application-driven design is recommended for the implementation of the proposed system. It needs to decide which kinds of body signals should be measured, and then sensor types and corresponding data rates can be determined, as shown in the following scenarios.

Patients with Cardiovascular Diseases: Five physiological data are essential, including ECG, heart rate, inspiration, body temperature, and SpO_2. Among these five kinds of data, ECG and heart rate have higher data priority in terms of accuracy and timeliness. According to the emergency level of a patient's illness, a specific sample rate can be decided.

Long-Stay Patients Lying in Bed: Due to lack of movement, indoor environments are more sensitive to long-term bed-ridden patients. Thus, the surveillance system can be deployed to monitor environmental parameters, such as temperature, humidity, noise, air quality (e.g., PM 2.5, volatile chemicals), and electromagnetic radiation. By jointly analyzing

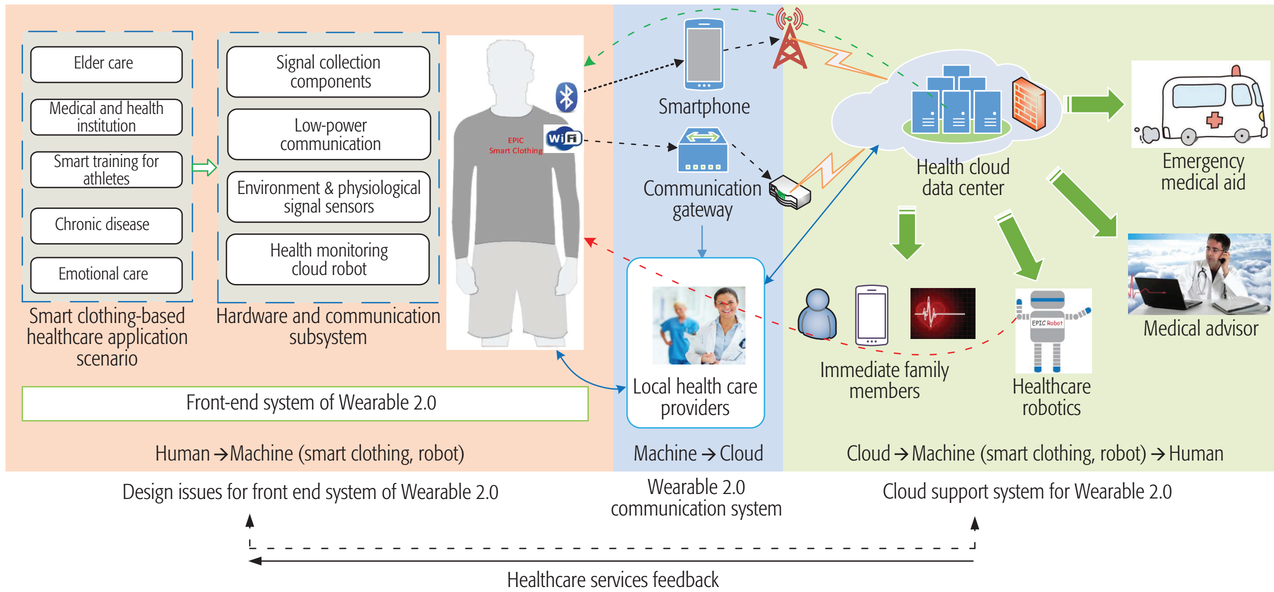

Figure 3. Design for a smart clothing-based healthcare system.

smart clothing-based physiological and environmental data, personalized diagnosis can be provided by medical experts for a healthier life. Therefore, the software system of smart clothing includes two parts: mobile applications for users and the applications for doctors or medical personnel.

Architecture of the Wearable 2.0 Healthcare System-

In this section, the smart-clothing-centric sustainable health monitoring system is introduced. In Fig. 3, the whole Wearable 2.0 healthcare system includes the front-end system, communication system, and cloud supporting system.

The Front-End System of Wearable 2.0

The front-end system of Wearable 2.0 includes various sensors, and works as a long-term data source that plays an important role in collecting health big data. Moreover, the front-end system also works as a user interface. To achieve high user experience, healthcare robots can be implemented in the proposed front-end system. In particular, a mobile robot with a human-like shell can provide more friendly and personalized healthcare services. For example, when a heart attack occurs, and the user loses verbal capability, a healthcare robot can send a video recording and pictures to the remote medical center or immediate family members. Furthermore, when emotion-aware services are required, a humanoid robot with walking capability plays an important role in affective interaction. Thus, the integration of smart clothing and a humanoid robot is beneficial to increase the interoperability of the system in various complicated situations.

With the support of a mobile cloud system, healthcare big data can be stored over a long period, and big data analytics in the cloud can greatly enhance the intelligence and cognitive capability of a humanoid robot. Thus, real-time affective human-computer interaction is available with the support of the humanoid robot through a certain understanding of human emotion and the user's intent. Furthermore, the robot also can work as a mobile sink to collect environmental data. In a word, the smart clothing supports high mobility, while the robot provides efficient data sensing and health monitoring.

The Wearable 2.0 Wireless Communication System

In the Wearable 2.0-based healthcare system, a wireless communication system for smart clothing is critical to achieve human-cloud integration.

Seamless design for interconnecting smart clothing and other devices should focus on energy efficiency and user experience:

Normal Users: Because of self-care ability and mobile capability, smartphones carried by users serve as personal gateways to forward the sensory physiological data to the cloud. As the major communication bridge between smart clothing and the cloud, the smartphone also stores, processes, and visualizes the health data locally. The mobile healthcare applications also enable users to understand their health status.

Special Users: There are still some users who seldom use smartphones or have difficulty using smartphones (e.g., elderly, children, disabled people, and patients with Alzheimer diseases). For those users, access points should be deployed in the areas where frequent activities happen. Therefore, Wi-Fi with low power consumption is the most suitable for smart clothing to connect with the cloud in this scenario.

Back-End Supporting Clouds for the Wearable 2.0 System

The back-end supporting cloud is the brain of the whole system to provide intelligence for cognitive healthcare applications. The health data from the lower layer are stored in the mobile local cloud (e.g., ad hoc cloudlet, edge cloud, and mobile cloud at the network edge) for further physiological data fusion [11]. The upper layer applications are available to get computing resources support, as shown in Fig. 4. In order to provide elastic services based on the real-time healthcare dataset and

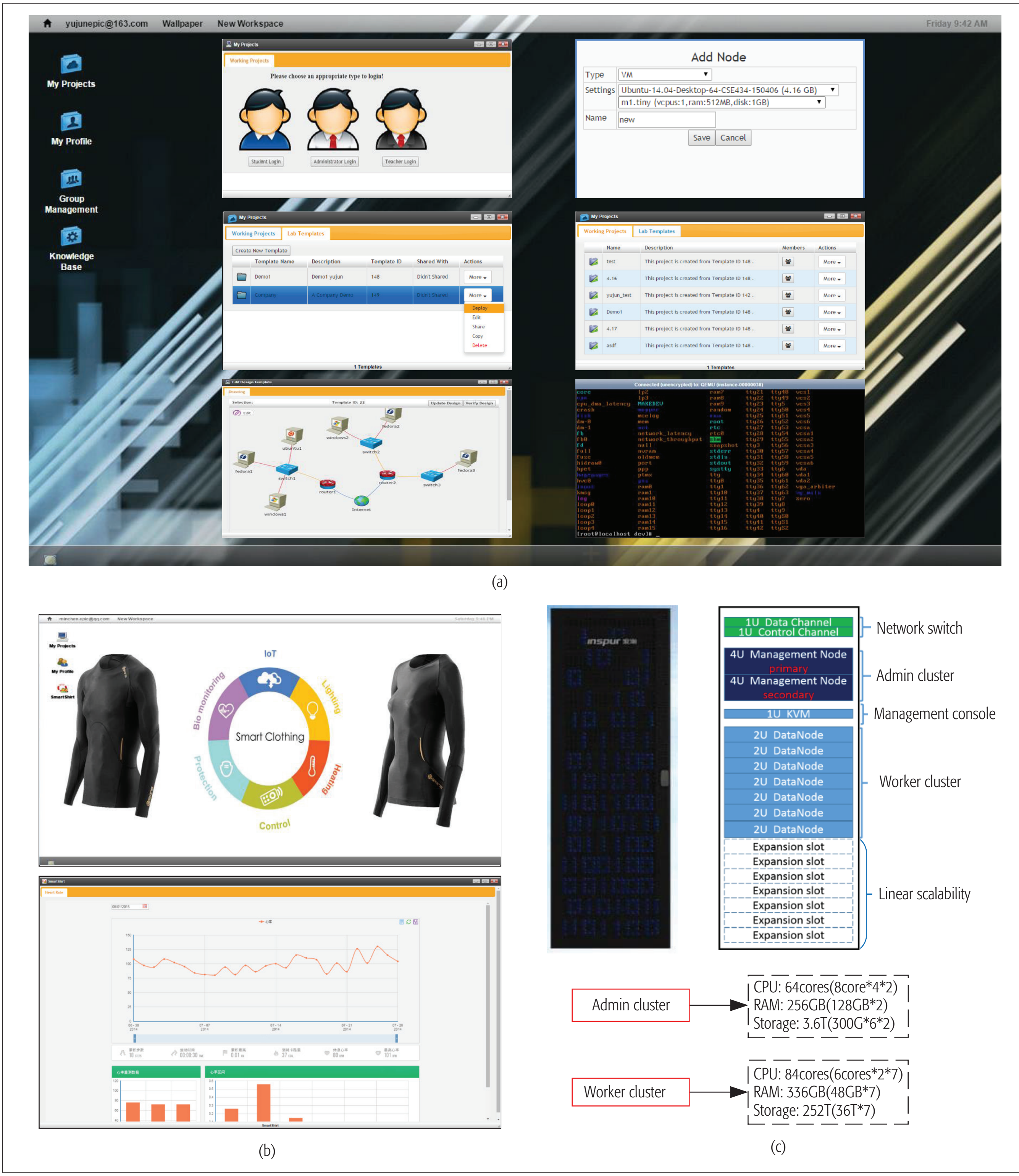

Figure 4. Supporting cloud system Wearable 2.0: mobile health cloud platform: a) control panel for system administrator of mobile clouds; b) interface for mobile cloud user; c) supporting hardware system (i.e., Inspur SDA30000 data center) for mobile clouds.

available hardware devices, software defined networking can be used to enable flexible network control by separately personalizing the data collection, data analysis, and action feedback [12]. Furthermore, the cloud also provides support to the applications for the end-user and third-party medical care institution. In summary, smart clothing software is the foundation of data collection; mobile applications are the bridges of human-cloud integration; and the cloud is the center of various healthcare services and cognitive applications.

Testbed for the Wearable 2.0 Healthcare System

In this section, we briefly introduce the Wearable 2.0 healthcare system developed by the Embedded and Pervasive Computing (EPIC) lab at

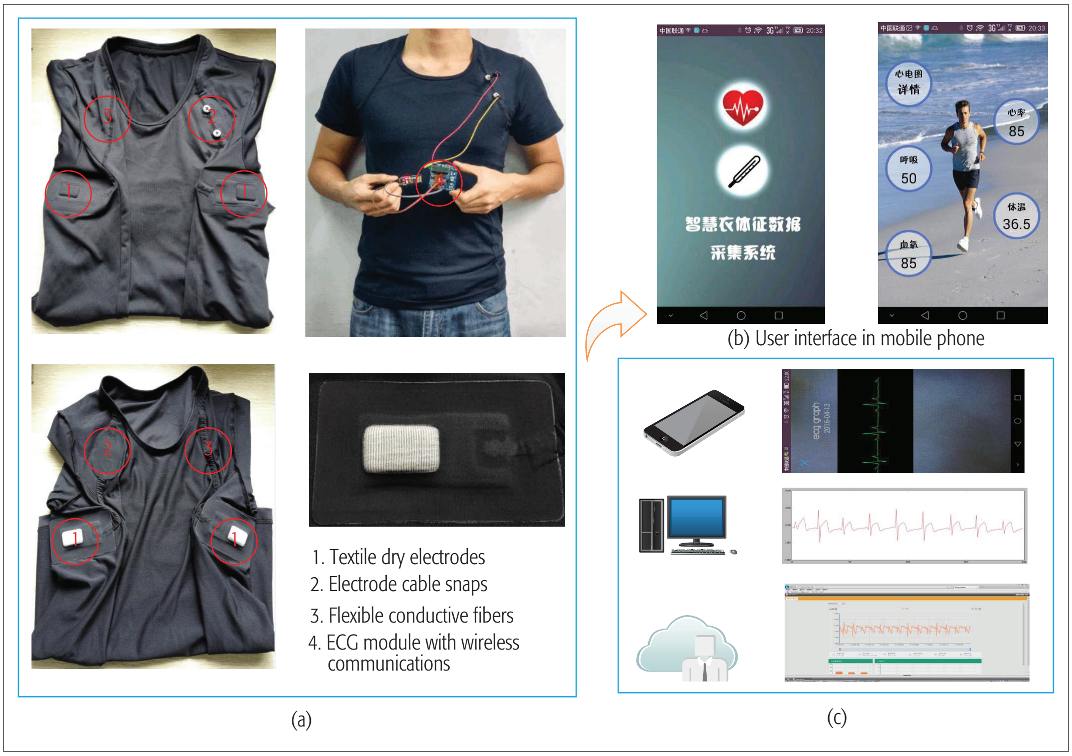

Figure 5. Wearable 2.0 testbed: a) ECG dry electrodes and signal acquisition module in the EPIC Wearable 2.0 testbed; b) three modes for body signal visualization: mobile phone, PC, and cloud.

Various software is deployed on the smart clothing, smartphone, and mobile cloud platform, which involves the embedded system development, mobile application software development, and big-data-based cloud software development.

Huazhong University of Science and Technology. The EPIC Wearable 2.0 system mainly consists of smart clothing, a smartphone, big data cloud, and a humanoid robot. Although there is various software providing different services independently, all the software modules work cooperatively and form a comprehensive software ecosystem. Furthermore, the kernel software is deployed at our data center with Inspur SDA30000, while the basic architecture of the mobile heath cloud is based on Openstack. On the other hand, mobile applications are developed based on Android 5.0, which has the following main functions:

- Connecting to smart clothing for gathering the physiological data, and setting the parameters and transmitting sensory data
- Providing personalized services, such as healthcare data visualization and early health alert

Specifically, when ECG monitoring is implemented in EPIC smart clothing, two electrodes are selected in order to decrease the cost and complexity. The ECG electrodes are made of textile, as shown in the circles marked 1 in Fig. 5. Then flexible wire (marked 2) is used to connect two snap fasteners (marked 3). ECG data is collected and transmitted through a black box. Finally, the ECG module transmits an ECG signal via wireless to the smartphone, computer, or cloud.

In the cloud, real-time detection and analysis are available to process the user's health data through the established health indicator threshold and data model based on the user's health (e.g., the user's ECG model). The analysis results of the user's health status are provided immediately to the user or health service providers so as to provide timely health care. In order to improve the accuracy of health monitoring, other related data should be transmitted to the cloud for deep analysis, such as the user's location, indoor environment condition, social network data, facial expressions, and voice records. Based on the big data processing platform and machine learning algorithms, a cognitive healthcare system can be developed in which the smart clothing is an important component for accessing cloud computing and big data technology. Various software is deployed on the smart clothing, smartphone, and mobile cloud platform, which involves the embedded system development, mobile application software development, and big-data-based cloud software development.

An ECG signal strongly reflects human emotion, so it is usually used for emotion detection and analysis. Therefore, the user's emotional models based on an ECG historical dataset are established in the cloud for supporting realtime user emotion prediction, and its availability is verified through testbed. Moreover, 10 volunteers (including four men and six women, aged from 23 to 30 years old, average age is 25.2 years old) are recruited for the experiment and evaluation, and their ECG signals are tagged with five emotional states (based on the original emotion proposed by Krech *et al.* [13]): normal, happy, angry, fear and sadness. All the ECG data are divided into training set (70 percent) and testing set (30 percent) for feature extraction separately.

Specifically, support vector machine is used to analyze the training set and establish the classification model, which is evaluated through testing set. Finally, in the emotion prediction result of the 10 users, only the accuracies of User2 and User7 are relative lower (80.17 percent and 81.23 percent respectively), and the average accuracy has reached 87.13 percent. Because there are different

The Wearable 2.0 healthcare system is based on smart clothing integrating various physiological sensors. Therefore, the system can collect various important human physiological indicators, and has the potential to achieve high user experience, QoS and QoE.

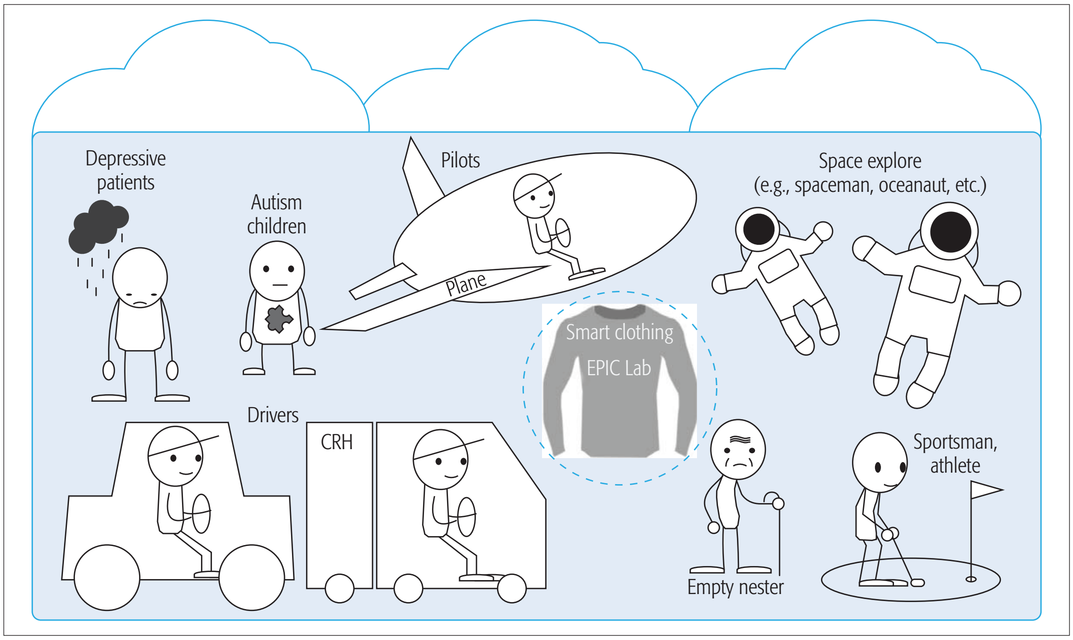

Figure 6. Wearable 2.0 based emotion care and health monitoring for special groups of population.

numbers of the samples for different emotions in the collected sample data, which may affect the model outputs accuracy during the training, and cause the different accuracy in emotion recognition. Specifically, the emotional detection accuracy of normal and happy reach 90 percent+, the accuracy of angry is 88.83 percent, the accuracy of fear and sadness are 85.65 percent and 81.28 percent.

Wearable 2.0 Healthcare Applications

The Wearable 2.0 healthcare system is based on smart clothing integrating various physiological sensors. Therefore, the system can collect various important human physiological indicators, and has the potential to achieve high user experience, QoS and QoE. As shown in Fig. 6, the representative Wearable 2.0 healthcare applications include chronic disease monitoring, elderly people care, medical and health institution, smart training for athlete, emotion care, etc.

Chronic Disease Monitoring: Chronic disease monitoring is the main application of Wearable 2.0 healthcare system. Chronic disease patients wear smart clothing in their daily life for non-invasive physiological data collection. By processing and analyzing of the physiological data, cloud obtains realtime health status of the user and predicts the disease trend or health condition through learning from a large number of historical data with the support of big data technology. Based on the diagnosed health status, the system provides users with personalized healthcare services in multiple ways. For example, if heart attack is detected, the system will immediately notify the medical first aid agency or the user's family. Besides, if there is a health care robot in home, the system will control the robot to deliver emergency medicine to the patient immediately.

Auxiliary Athlete Training: For the sports project with less intensity but higher skill, some new challenges are brought. For instance, the accuracy of action has a decisive effect on the performance in the golf race. Thus, the system needs to deploy the sensors which can detect the movement of the athletes through three-axes acceleration apparatus, gyroscope, etc.

Emotion Care: Emotion care is especially helpful for the empty nesters living alone, the long-distance truck drivers and patients suffering from mental diseases. Based on the physiological data related to the user's emotion, the system is available to provide emotion care. When detecting the user with a bad mood, the system supports emotional feedback, such as voice reminder, tuning suitable music, or playing selected video contents etc. If there is an interactive emotion-care robot, it will carry out a more accurate emotional interaction with the user, after receiving the user's emotion state and emotion interaction commands from the cloud. Traditional emotion detection methods are usually based on the data source from a single space, such as facial expression video, body signals, or posts on social networks. To overcome this shortcoming, the emotion detection of Wearable 2.0 can be more accurate by utilizing multi-dimensional data from Cyber-Physical-Social spaces. With the deployment of dedicated mobile terminal applications, it is convenient to integrate the user's social network data, location information, mobile phone call records, and so on. The physiological data from the health cloud platform can greatly improve the accuracy of emotional care. The concrete implementation method is to store and train the emotion model based on physiological data in the cloud and establish a unique emotion recognition model for each user. Specifically, according to the emotion recognition model, the user's emotional state is predicted by the trained model, while the related data are collected from the mobile terminal. When any negative emotions are detected, the relevant equipment with various resources are allocated to interact with users. For example, if sadness is detected, appropriate music is played to ease the grief of the user, and the system even sends a command to the indoor robot for effective interaction with users through a series of combinations of actions.

The Applications of Virtual Reality/Augmented Reality Based on Smart Clothing: The applications of virtual reality(VR)/augumented reality(AR) based on wearable technologies have shown great potential for the game industry or smart factory [14]. Specifically, because smart clothing may be closely integrated with the human body and collect more accurate physiological signals, the VR/AR applications (film and television, home computer games/video games, medical surgery, etc.) can implement more natural human-computer interaction with the help of smart clothing [15].

Conclusion

In this article, we comprehensively investigate the disadvantages of the existing healthcare system and the trend of wearable computing. Then a Wearable 2.0 healthcare system is proposed based on smart clothing to improve QoE and QoS of the next generation healthcare system. In the proposed system, the user's physiological data is unconsciously collected, and personalized healthcare services are big data analytics on clouds. Furthermore, this article presents system architecture, functional components, and the design details of smart clothing based on a Wearable 2.0 healthcare system. Finally, a testbed with various compelling scenarios are presented to verify the feasibility of the proposed architecture.

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Because smart clothing may be closely integrated with the human body and collect more accurate physiological signals, the VR/AR applications (film and television, home computer games/video games, medical surgery, etc.) can implement more natural human-computer interaction with the help of smart clothing.