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Big Health Application System based on Health Internet of Things and Big Data

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ABSTRACT The world is facing problems, such as uneven distribution of medical resources, the growing chronic diseases, and the increasing medical expenses. Blending the latest information technology into the healthcare system will greatly mitigate the problems. This paper presents the big health application system based on the health Internet of Things and big data. The system architecture, key technologies, and typical applications of big health system are introduced in detail.

INDEX TERMS Big health, wearable computing, cloud computing, Internet of Things, big data.

I. INTRODUCTION

The medical resources of many countries are limited. For example, in China, the development of medical resources is not balanced that 80% people are living in areas with limited medical resources while 80% medical resources are allocated at the big cities. Building big health application system by effectively integrating medical health resources using intelligent terminals, health Internet of Things (IoT), big data and cloud computing is the important way to solve the above problems [1]–[3].

Big health is a promising industry, which is characterized by people-center, managing a person's health from birth to death, from prevention to rehabilitation and involving industry from government to market. The domain of big health covers health products field (including the drugs, medical devices, elder products), health service field (including medical services, pension services, mobile healthcare), health realestate field (including pension, healthcare) and health finance field (including health insurance and other financial products).

Human suffers from the diseases of which one third could be completely prevented, one third could be detected early and one third could be done with aggressive treatment to improve quality of life. Major diseases could be controlled by strengthening the early detection. Everyone experiences the process from health to disease. In general, the status of health is from health to low-risk status, to high-risk status, to the occurrence of early lesions status, to clinical symptoms status and finally to the disease status (as shown in Fig. 1). This process can be very long, often takes years to ten years, or even decades , which is highly correlated with genetic factors, people's social and natural environmental factors, medical conditions and personal lifestyle. The change of the process is imperceptible. However, big health system can be applied to scientific health management by detecting and evaluating risk factors for the occurrence of disease which may help people conduct targeted intervention before the disease is formed and eventually achieve the maintenance of health [4].

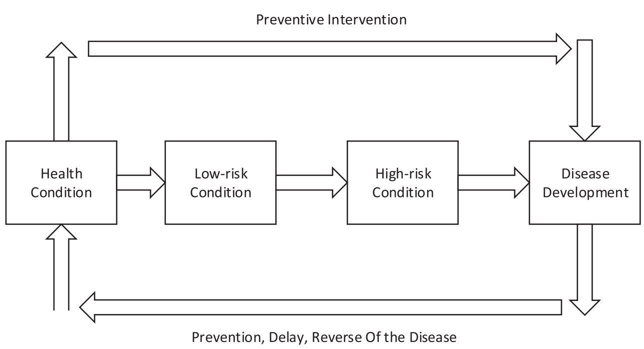

FIGURE 1. Health management model.

Big health could use mobile medical health system, big data, wearable device, a new generation of mobile communications technology to integrate the primary medical services and improve primary healthcare quality, residents' health index, control the growth rate of a variety of common acute and chronic diseases and increase residents' awareness of health management and disease prevention [5]–[7]. In particular, big health can also be integrated with intelligent connected vehicle technologies, such as the robust vehicle-to-vehicle forwarding [8] and heterogeneous vehicle-to-roadside communications [9], [10], to support diverse real-time onboard health services. Establishing a complete health service system for residents with disease screening, early diagnosis, health management, treatment and prognosis of patients, could facilitate doctor to control patient's health status [11]. By monitoring the long-term health-related information, a scientific and health management system could be established using the limited medical resources to intervene health risk factors and achieve effective interaction of patients and medical institutions, making illness prevented early and reducing the national health insurance spending [12].

Big health application system integrates various resources and allows the existing health system be extended in the aspects of time, space, participants, object and scope of services. The macroscopic model of big health application system is shown in Fig. 2.

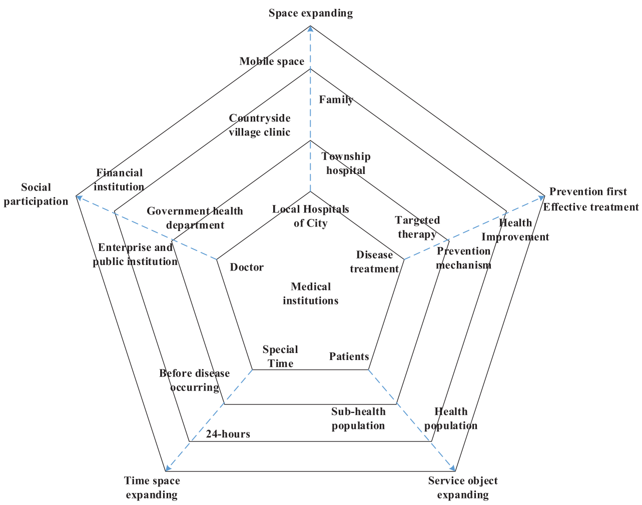

FIGURE 2. Big health macro model.

Building a system with medical cloud data center as the core, which exceeds time and space constraints of the existing healthcare system and makes intelligent decisions based on it, could achieve optimal healthcare services and mitigate the financial burdens [13]. With organizing research institutions, community enterprises and financial institutions and other parties active in public health welfare investment, we could achieve the sustainable development of the core medical technology research and development, promotion and application, investment and management.

The remainder of the paper is organized as follows. Section II describes the cloud-to-end fusion system architecture for big health application system. Section III describes the key technologies closely related to the big health system. The typical applications of big healthcare systems are presented in Section VI. Finally, We conclude the article in Section V.

II. BIG HEALTH SYSTEM ARCHITECTURE BASED ON CLOUD TO END FUSION

This paper presents the cloud to end fusion big health application system architecture which is supported by health IoT and big data. The whole system includes health perception layer, transport layer, big health cloud service layer. Big health cloud layer is divided into two sub-layers, cloud service support sub-layer and cloud service application sub-layer as shown in Fig 3. We will briefly introduce the function and composition of each layer bellow.

A. BIG HEALTH PERCEPTION LAYER

Big health perception layer has two targets: (1) Collecting the original signal of the world, its main components are the different types of sensors. (2) Collecting a variety of physiological signals associated with human health. For better transmission of perceptive data, perception layer usually preprocesses the collected original signal without overly consuming the sensor nodes' energy and with computing power enough to support. In addition, short-range wireless communication is an important part of the perception layer which is used to collect data and transfer it to the upper layer [14]–[16].

Because people are the most important object for the signal acquisition and service, the importance of body area network at perception layer is particularly prominent. In many complex signal acquisition scenarios, for example, in healthcare applications, except for human physiological signals, the surrounding environment and the video signal are also needed, you need multiple sensor nodes working together [17]. The cooperative communication signals between these nodes also need the help of short-range wireless communications technology in perception layer [18].

The main challenges which the perception layer faced: sensor technology (acquisition accuracy, miniaturization and intelligence, etc.), energy optimization, node security, embedded operating system, multi-protocol gateway.

B. TRANSPORT LAYER OF BIG HEALTH SYSTEM

The transport layer plays a connecting role which sends the control instructions of upper applications to sensor nodes and receives data collected by perception layer. It uses a variety of network technologies (including mobile communication networks, the Internet and other private networks) to transfer data to the upper application. The main challenges faced by the transport layer include: (1) Integrating of existing networks (including computer networks, communication networks and private networks) and perception layer networks (mainly are a variety of low-power short-range wireless sensor networks) is a big challenge [19], [20]. Currently, the solution is to use multi-protocol gateway, but the development of network gateway is hard due to the complex of existing

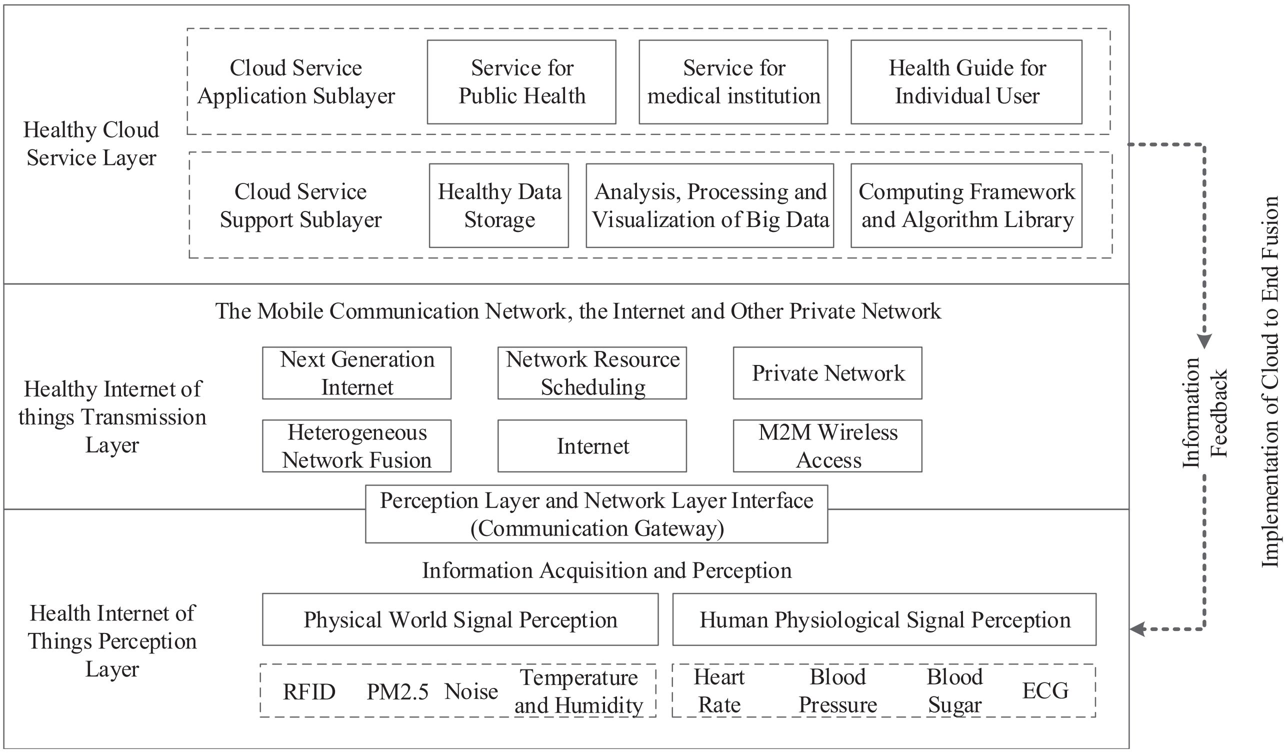

FIGURE 3. Big health medical application system architecture based on Cloud-End convergence.

network technology and specification. Therefore, it is difficult to find a common solution. (2) The scope of health IoT is widely. It not only covers a large scale IoT (i.e., city-based smart healthcare which is dominated by government or large companies), but also a small scale health IoT (i.e., self-family health service, community-oriented health services, etc.). The difference of network technologies and communication requirements are so great that it becomes a challenge of multi network fusion technology to satisfy the actual demands of health IoT. (3) Existing network technology is lack of scalability which are caused by the original design. The network has been running for many years and the investment of equipments is huge. In order to grab high profits, manufacturers are usually not disclosed technical details which seriously hampered technological innovation and cannot meet the urgent needs of these emerging applications on the evolution of network technologies. Therefore, to carry out researches for the emerging applications such as network technology is a big challenge.

The main equipments of transport layer include relay module, communication networks, short-range low-power wireless communication components. Relay module can be comprised by smart phone, desktop computer, tablet and smart terminal device enabling 4G, 3G, 2G or Wi-Fi. These devices have a corresponding software system and can receive and preprocess data from the perception layer (encode, decode and filter operating). The processed data will be send to the network later with wireless network. Communication network is the communication infrastructure of the information service platform. The relay module and related software system make the transmission of data secure.

In addition, short-range low-power wireless communication components also play a crucial role. Energy consumption of wearable device is an important technical indicators and is also an important challenge which constraints its development. In addition to the energy consumed by wearable device itself, the most energy consumption comes from the wireless communications between wearable device and smart phones. Bluetooth communication is a standard part of smart phones, so it is the most suitable way of communication between a smart wearable device and smart phone. Bluetooth 4.0 whose primary feature is the low power consumption introduces Bluetooth Smart. Bluetooth Smart device can run for several months and even years with a button battery. Bluetooth Smart's flexible configuration also allows applications to better manage the connection interval to optimize the cycle of the receiver.

C. BIG HEALTH CLOUD SERVICE LAYER

1) BIG HEALTH CLOUD SERVICE SUPPORT SUB-LAYER

The main task of cloud service support sub-layer is to collect physiological data of the physical world and human data which will be compressed, stored, formatted and analyzed. This layer is the major support of the IoT top health services and application. Because the exponential growth of terminal equipments which are connected to the Internet, this layer needs cloud computing to process massive data real-timely. Based on this, intelligent information processing, data mining, predictive analysis and other advanced analysis will be achieved. The analysis layer's computing and storage resources of large internet architecture always adopts virtual technology resources pool. System will allocate and deallocate resources dynamically based on the task requirements. In addition to traditional methods of data analysis, analysis layer also need to choose another method of analysis based on the specific type of data and application requirements (For example, surveillance cameras captured video data requires the analytical tools in the field of computer vision, trends of infectious disease and traffic flow prediction algorithm requires machine learning based on big data). IoT produces large amounts of unstructured data. For this kind of data processing capacity, processing efficiency and related algorithms are also facing enormous challenges.

2) BIG HEALTH CLOUD SERVICE APPLICATION SUB-LAYER

Health cloud service application sub-layer is the user interface between the public health networking and the users, which directly reflects economic and social benefits generated by IoT. Cloud service application sub-layer is responsible for the control of all sensor nodes, the visual presentation of data, the scheme of workflow and business. The technical challenges of this layer include: (1) Because both the needs of each specific IoT and the related hardware are very different, it makes the system customized which lacks versatility, develops hardly and inefficiently. Therefore, it becomes a very urgent task to develop frameworks and middleware which are suitable for general purpose. (2) Machine interaction technology is another major technical challenges IoT facing. As described above, with the evolution of IoT, traditional human-computer interaction technology puts forward higher requirements. Human-computer interaction based on big data and cloud computing attains a great concern. Applying virtual reality (VR) and augmented reality (AR) to the Internet of Things (i.e., smart home) has become a hot research [21], [22].

In addition, big health service cloud application sub-layer is also a layer of cloud to end fusion in health IoT. In addition to its traditional application service function, it also needs deep integration with devices of health IoT perception layer.

D. CLOUD TO END FUSION

Cloud to end fusion has been far beyond the traditional scope of IoT in the control of application layer for device. Since people are the center of the IoT and device-aware layer is no longer a simple sensor or controller, the intelligent and humane equipments will play a greater role (i.e., robots), which makes health clouds and ends together closely. Below the cloud robotics and healthcare are examples which describe the integration of cloud to end in health IoT [23].

Robotics technology had a tremendous impact on society, the economy and human life. The breakthrough of wireless networking and cloud computing paved the way for the robot from the industrial sector to the service sector [24]. Currently, the robot on the market focused on family education, entertainment and service sectors (such as sweeping robot). The functions which are controlled by embedded software of these robots are single. Networked robot connects to a group of robots through a wired / wireless network, which makes the robot with the capabilities of remote operation and management, can achieve multi-robot cooperation. In order to solve limited resources and communication and lack of learning capacity which robots exist, the cloud robot is proposed.

The architecture of cloud robot has two layers: M2M(Machine to Machine) layer and M2C(Machine to Cloud) layer. M2M layer is composed of a set of robots which are connected by wireless to form a cloud computing infrastructure based on ad-hoc. M2C layer provides a shared pool of computing and storage resources, allowing the robot to offload resource-intensive computing tasks to the cloud. Several studies have explored the integration of cloud computing technologies into some robot application scenarios, for example, Google's research group has developed a robot driven by smart phone and learniing from each other by the cloud. Existing M2M solutions include, but are not limited to, that Sheng *et al.* in [25] extensively studied the energy-efficient M2M communication scheme by cooperative relaying in wireless multimedia networks. Liu *et al.* [26] presented a novel concept of quality of service (QoS) index to integrate the multidimensional QoS requirements to ensure the degree of QoS satisfactions. Gkelias *et al.* [27] proposed a novel MIMO routing scheme to ensure QoS in M2M environment.

At present, medical institutions have used some medical robotic applications (i.e., surgical robot, rehabilitation robot) for Medical assistance. But these robots have a high degree of specialization, expensive and complicated operation, etc. It is hard to apply it to the public health service system.

With the promotion and popularization of human-computer interaction and the progress made in the area of cloud computing, applying cloud robotics to healthcare applications is an important development trend in the field of robotics. The integration of health cloud and robots can achieve emotional care applications. Make the robot as the emotion interactive feedback terminal, design a shape of human and mimic human behavior (voice, smiling, nodding and other actions). Emotional robots interaction feedback which are received instructions from the health service cloud platform layer in real time could achieve emotional interaction with the user.

III. KEY TECHNOLOGIES

A. WEARABLE DEVICE

Wearable devices have become very important physiological data acquisition channels in the perception layer of health IoT. Wearable devices collect a variety of physiological parameters from the human body, including: EEG, ECG, blood pressure, blood oxygen, respiration, EMG and other signals. Such equipments that are wearable or implanted in the human skin are mainly in close contact with the human body [28]. It can acquires, amplifies and quantifies body's physiological signal which is transmitted to external network device via wireless way. Since human body may wear a variety of wearable devices, there may be mutual interference between these devices, as well as data transmission priority issues. It has become an important problem at perception layer. We will introduce traditional wearable device and smart clothing proposed in this paper for physiological signal acquisition below.

1) TRADITIONAL WEARABLE DEVICE OF HEALTH SIGNAL ACQUISITION

Currently, intelligence community and some nursing homes have a lot of empty nesters who have chronic diseases or critically ill needing real-time monitoring on physiological parameters. Some communities begin to use wearable health monitoring devices such as watch, bracelet, heart rate belt, etc which have the following problems [29], [30]: (1) Most of the life of these devices are about two to three months. The main problem is the severe false judgement. For example, the case of the elderly fall detection, health bracelet fall detection which is based on a single point of data, often reports falsely. Even combined heartbeat, it also remains not accurate. After a long time, users of these products lose faith. (2) Related healthcare physiological signal acquisition is limited. Currently related healthcare products which are put into physiological signals collection are less. Application on health and medical care are limited. (3) Collecting physiological signals is too simple and has many errors. It is difficult to apply to the healthcare field. For example, heart rate is the most valuable physiological parameter collected by smart bracelet. But the application on it in the field of healthcare is very limited. At present, the existing product smart ring cannot collect the ECG signal, other ECG acquisition device is complicated and cumbersome.

2) PHYSIOLOGICAL SIGNAL ACQUISITION TECHNOLOGY BASE ON SMART CLOTHING

This paper presents wearable clothing to collect human physiological signals at perceived layer of health IoT. Smart clothing integrates multiple micro-physiological signal acquisition sensors to achieve multi-modal physiological signal acquisition [31].

Bioelectric signal of the human body is an important indicator which disease diagnosis, health assessment need. Electrode is one of the most important biological signal acquisition technology. In recent years, the textile structure of the electrode made significant progress in the manufacturing and service lifetime. Using textile structure of the electrode to measure and monitor human biological signals gets a universal concern. Therefore, the paper proposes the dry textile electrode as an electric signal sensing device, integrating it into clothing, improving the comfort of the user while overcoming the psychological feeling of being monitored and monitoring the biological signals anywhere. Textile structure of the electrode are soft, breathable, and washable especially for prolonged using compared with traditional electrode.

Smart clothing can collect a variety of physiological signals [32]. We will describe smart clothing physiological signal acquisition technology with example of human ECG, heart rate signals and oxygen saturation. Since smart clothing uses washable dry textile electrode, users simply wear it which would monitor ECG signal, respiration signal, heart rate and other physiological signals which require specialized signal acquisition module. These signals can be used in disease diagnosis, health assessment applications.

At present, the electrocardiogram (ECG) signal is collected by the measuring electrode which is placed in specific parts of the body surface. Electrode can catch a regular biological signals change each cardiac cycle in human body.

The oxygen content of the blood called blood oxygen saturation is generally represented as a percentage of total hemoglobin oxyhemoglobin in blood. Smart clothing's theory of oxygen saturation is based on Lambert-Beer's law which using the principle of near infrared spectroscopy absorptiometry measurement. The blood in different components of the same kind of light absorption varies by measuring the attenuation of light passing through the blood.

In summary, smart clothing acquires ECG and other physiological signals, which overcomes the traditional shortcomings of wearable devices. It can be widely used in disease diagnosis, chronic health monitoring and personalized value-added services and other fields. The principle of smart clothing involves the design and manufacturing of washable dry textile electrode, low-power wireless communication, sensor network, microelectronic technology, telemedicine and other research areas. It belongs to comprehensive and strong interdisciplinary and its specific content in more detail will be introduced in subsequent sections of the paper.

B. MOBILE COMMUNICATION TECHNOLOGY

Service range of big health system covers urban, rural, mountainous areas, the wireless communication technologies become an important guarantee of system construction and operation. In recent years, mobile devices' (especially smartphones) performance improvement and popularity promote the rapid development of mobile healthcare. With virtual reality, augmented reality and other new technologies applied in the field of telemedicine, there are higher demands on the existing mobile communication network for delay, bandwidth and throughput.

With the bandwidth and capacity increase of wireless mobile communication system, mobile communication-related industrial ecology will change gradually. 5G is no longer just an air interface technology with higher rate, greater bandwidth, and greater capacity, but an intelligent network facing business-oriented applications and user experience [33]. 5G mobile communication system is a network of multi-service and multi-technology [34]. Through the evolution and innovation of technology, it can meet the future needs of the rapid development of a wide range of data that contains a variety of services and connectivity and enhance the user experience, which will meet the demand on network communications in big health system.

Another emerging trend is to use smart wearable devices to collect health related data. Liu *et al.* in [35]–[38] proposed a novel framework and subsequent participant selection and incentive mechanism for participatory crowdsourcing including the smart device users, central platform and multiple task publishers. In [39], existing incentive mechanism are extensively surveyed to efficiently motivate users' participation, and then future research directions are clearly given. Liu *et al.* [40] extensively analyzed the relationship between energy consumption and smart device user behaviors, and then proposed a novel approach to select the optimal amount of participant while considering possible user rejections. Song *et al.* [41] introduced an energy consumption index to quantify the average degree of how participants feels disturbed by the energy cost, and proposed a suboptimal approach for participant selection under the multi-task sensing environment. Furthermore, Zhang *et al.* [42] focused on privacy leakage issues of participatory sensing and presented a participant coordination based architecture and flow to successfully protect user privacy. Liu *et al.* in [43]–[45] presented a novel resource negotiation scheme bridging between dynamic sensing tasks and heterogeneous sensors equipped in smart devices. Finally, Yurur *et al.* in [46] presented a few posture detections schemes by using the sensor equipped smart devices.

C. COGNITIVE COMPUTING

Human health problems include not only physical health but also spiritual health. Mental health has attracted much attention. Early health IoT are around the physiological information to conduct a study. With the progress of wearable device and deep research on factors of human emotions [47]–[49], mental health will be the focus, which is the trend of health IoT. Future health IoT concerns not only the physical health of the user but also mental health. With wearable device establishing emotional interaction feedback with the user, it provides comprehensive services including physical health and mental health. Wearable devices collect a variety of information about human emotion condition (including physical information, location information, social networking information, etc.), human emotions are obtained through big data analysis human and then diversity of feedbacks are used to influence human emotions. Currently, cognitive analysis can be divided into physiological signals based cognitive analysis, video-based analysis and text-based analysis [50]. Based on different types of emotional data, machine learning methods can be used to find the most optimal combination of emotional states in different environments, and the information fusion theory, data mining, fuzzy theory, decision trees, probability theory, genetic algorithms, and semantic web technology could improve the accuracy of cognitive analysis.

Analyzing the situation of human emotion cannot achieve the goal of a health IoT on spiritual care. Using the results of the analysis of human emotion to interact with human can achieve the goal of alleviating the psychological pressure and treating mental illness. However, existing cognitive analysis systems are lack of effective means and methods of emotional interaction. With the popularity of wearable computing and networking applications, almost all devices can be networked. All networked devices can act as a carrier of emotional interaction. This requires health IoT cloud computing to analyze the user's current environment in which the most appropriate emotional interaction devices are selected to achieve the cooperation work of a variety of emotional interaction devices.

D. HEALTHCARE CLOUD ROBOT

Service robot having healthcare function is one of the key areas of development in the robotics industry [51]. healthcare robot involves many fields that include artificial intelligence, machinery and electronics, intelligent voice recognition, mobile multimedia communications, sensor networks, telemedicine, cloud robotics, which is a comprehensive strong interdiscipline.

In the past 20 years, the rapid development of microelectronics, communications, computers, artificial intelligence, automatic control and image processing, greatly promoted the development and popularization of robotics in industry. Especially in recent years, machine learning, big data, cloud computing have made great progress which paved the way for the robot to the home and consumer markets. A growing number of research institutions and high-tech companies continue to increase investment in robotics. Trying to use the progress of new technologies to develop friendly interactive features' (i.e., natural voice interaction, action/gesture recognition, face recognition) robot (i.e., identify people's emotion and be capable of emotional care; analyze human activity, diet and exercise to guide people's daily diet of health living). With the robot marketing to the home and consumer markets, it can get high profits at the same time, the robot can better serve human life.

The main technologies of early robotics are automation and computer technology. It integrates various information technologies and has single operation system, which is used in industrial control field. Due to the constraints of low level of intelligence of hardware and software resources, we can only achieve some simple control functions. As needs change, there are some robots with networking capabilities which can constitute a simple robot control networks and has simple communication between them. However, because of the constrains of link stability, communication bandwidth and link distance, the robot with long-distance wireless communication is not very common. With the 4G-LTE (Long Term Evolution) technology developing, the robot with long-distance wireless communication capabilities is possible.

Leveraging the advantages of LTE can achieve some robot functions which the conventional wireless communication technology can not (or difficult) achieve. For example, a mobile robot has real-time wireless video transmission function. Typical applications for this robot are: 1) a robot with home healthcare function can acquire and transport physiological monitoring indicators, at the same time, it can conduct real-time video communications in emergency situations (eg, remote emergency); 2) at the special needs of dangerous job, it can complete special tasks without laying a dedicated communication network (e.g., fire rescue). In short, LTE technology is a good solution for the communication problems faced by remote mobile robot.

Cloud computing is a new computing and service model, provides resources and services to users. In this way, pooling software, hardware and network resources and information can be provided to a service requester according to the actual needs. In the cloud computing environment, users no longer need to build their own infrastructure and do not need to know the details of the "cloud" infrastructure and related expertise. Traditional robots are often limited to hardware and software features of the robot itself, hardware processing and software intelligence are the shortcomings. As the rise of cloud computing, it provides good support for robot technology. We can easily make cloud computing and robotics technology together and build "cloud robot". Robots as front-end equipment, is responsible for collecting the signal, performing specific actions, analysis and processing some simple tasks. These tasks which need to use more sophisticated large-scale computing clusters are completed by the cloud. Cloud uses its powerful storage, computing capability and advanced machine learning algorithms for training and learning to establish an effective model. The calculated results of the final analysis will be transferred back to the end of the robot. Thus, with the cloud's powerful analysis and processing capabilities, the robot is equipped with a second "wisdom of the brain".

E. HEALTH CLOUD AND HEALTH BIG DATA

Big health system needs to build health IoT. The types and quantity of networking devices are more than ever before and the amount of data increases much faster. Traditional computing models and data analysis techniques have been far from satisfying the demands of massive concurrent user access and explosive growth of data. Therefore, leveraging cloud computing and big data to build big health services platform is important. At the same time, as people continue to focus on the human spirit world, adding emotional care function has become one of the important characteristics of cloud computing and big data analysis techniques compared with past. Except 4Vs broad definition of big data, according to the characteristics of mobile healthcare technologies, health big data based on mobile health cloud has the following features:

- Heterogeneity: This is mainly reflected in two aspects [52]: On the one hand, the different parts of the body, different categories of different organizations and different countries and regions store health data with different standards of medical standard and complicated storage format. There are structured relational data and semi-structured data. For example, CDA (Clinical Document Architecture). There are text, images, video, audio, and other unstructured data, such as medical records, X-ray, B ultrasound, cardiac EEG. On the other hand, with the development of technology and the advance of information technology, the same kinds of data may also be changed in the structure [53]. For example, with the development of medical technology, more blood test indicators can be measured, while these indicators in the previous detection could not be measured, it will inevitably lead to inconsistent format of the historical data and the current data.
- High correlation: Medical health data including the body's vital signs have closely linked. Alone or a small portion of the data, does not accurately describe the function of the body. For example, human leukocyte data being detected as high cannot determine the illness, even cannot determine what kind of the disease. Its causes may be acute infection, tissue injury, hepatitis, leukemia. However, if the white blood cells in urine is detected to be high at the meantime, you can preliminarily estimate that it is suffering from renal disease.

In addition to aboving two basic features, mobile medical big data has the following three characteristics:

- Real-time: Due to the special nature of health care, the data must be real-time detected. At sudden event, it also needs for timely treatment. For example, when faced with an acute illness, it not only is able to promptly detect unexpected situations, but also timely responds to such requests aid. Even it needs to provide vital signs of patients to help prepare rescue measures for healthcare workers. With the development of mobile intelligent devices and sensor equipment, we can collect data and access to medical health data at any time without professional institutions and equipment. Thus, the data acquisition process has better continuity in time.
- Time and space correlation: Healthcare has significant time and space characteristics which is mainly manifested in two aspects: First, the different regions' people have some differences. For example, the amount of hemoglobin of the people at high altitude is generally higher than the plains. In addition, the same physiological parameters of the human body at different times will have some fluctuations. For example, the body's blood pressure is relatively high during the day. In the morning and evening it is peak, and at night is relatively low, generally in the morning drops to the bottom. In addition, the concentration of the human adrenal cortex hormone shows high during the day and low at night. With mobile smart devices and sensing devices, we can easily collect data with time and space properties.
- Low proportion of valid data: Mobile smart devices and conventional sensing devices cannot provide accurate test results like professional medical devices. It will generate a lot of noise when transferring. Since the mobile

healthcare big data is real-time, it will produce large amounts of data. According to the theory of information entropy, the valuable part is just some very small exception data. For example, in the collection process of heart rate data, only the heart rate beyond the normal range will attract patients and medical personnel's attention.

IV. TYPICAL APPLICATIONS OF BIG HEALTH SYSTEM

A. REMOTE HEALTH DETECTION PRIMARY DIAGNOSTIC SERVICES

In many developing countries, rural health resources are of serious shortage, so it is necessary using advanced detection technology to integrate rural medical resources and establishing "big health project" suitable for rural area. According to the requirements of grassroots medical institutions and the characteristics of all kinds of illness group, by providing targeted remote health detection primary diagnosis service, farmers can get scientific diagnosis service at any time, and can obtain their health information timely. So the growth of all kinds of common acute, chronic disease patients can be controlled. Improving attention, early discovery, early diagnosis and early treatment can improve the quality life of chronic disease patients and reduce the burden of disease. Turning serious disease late treatment to prevention, will effectively reduce the national health insurance.

Rural Big health project integrates rural grassroots medical resources, establishes rural health information service platforms for farmers, provides remote health detection primary diagnosis service. After effective integration, Rural health service system has been reasonable expanded in time, space, main participation body, service object and service scope:

- Time scope: turn the regular health detection one or two times a year to the case that the person can get health detection or disease diagnosis service at the community clinic or rural clinic at any time of 365 days a year according to each person's health condition.
- Space scope: from the community hospitals and township hospitals to all rural health clinics, the advanced medical detection equipment and intelligent analysis system will be used in rural grassroots disease prevention and treatment, this makes the farmers get the advanced detection of health services without leaving the country. It can effectively improve the rural grassroots medical service quality and farmers' health index, control the growth of various common acute and chronic disease patients.
- Mainly participant: in the past, the government will pay for the projects that are good for the people, so the financial burden of the government is serious. If research institutions, enterprises and individuals, fund companies and financial institutions actively participate in various public health investment, the sustainable development strategy of medical core technology research, promotion, application, investment and management can be realized.
- Service scope: scientific health management uses professional detection to evaluate the risk factors of possible diseases, it can help people to preventively intervene before the disease formed, it can also successfully block, delay or reverse the disease occurrence and development process, to achieve the purpose of health maintenance.
- Service object: Improve farmers' awareness of disease prevention and health management, establish the concept that every farmer should be responsible for his own health, turn serious disease late treatment to prevention, and effectively reduce the national health insurance.

By providing targeted remote health detection primary diagnostic services, it will reduce the time of queuing, waiting, transportation costs, accommodation costs, and the energy and time of accompanying staff, a significant reduction in the cost of medical expenses will be achieved.

With the development of social economy, the changes of lifestyle and diet, the deterioration of the environment and acceleration of the population aging process makes our disease spectrum changed a lot, chronic non communicable diseases have become an important health problem threatening the health of residents. Health detection and disease filter is the only means of early detection of disease, but also the first step in health management. Scientific and accurate physical examination indicators and data, objective and accurate detection results and health trend analysis are the basis and guarantee of grassroots health management and disease treatment. So how to establish a more perfect health service system to integrate the existing primary healthcare resources is an urgent problem to be solved.

To effectively solve these problems and improve primary health care institutions, it adopts international advanced detection technology to build "big health projects phased development plan" to spread to nursing homes, community health service centers, rural health clinics and other primary healthcare institutions.

The project aims to establish a comprehensive system of primary healthcare services. Supporting system equipment with automatic data analysis will automatically alarm if detecting abnormal index. Test results are transmitted to the backend server through the network. Background will give a variety of physical health trend indicators based on test results and establish a permanent health records. Through comprehensive health monitoring and health management, help residents find health problems. Solve the lack of professional testing equipment problems which community health service stations, rural clinics and other primary healthcare institutions exist. For example, Liu *et al.* [54] presented a quite novel family-based healthcare monitoring system for long-term chronical disease caring. The doctor can make a preliminary diagnosis and treatment recommendations on the health condition of the patient based on the results of the automatic analysis system [55]–[57]. If necessary, inform patients go to township hospitals or above the county level hospitals for further testing and effective treatment. The project establishes a complete set of health management programs for the residents that contain disease screening, early diagnosis, treatment and prognosis of patients and health management, facilitating doctor to control patient's health status and make appropriate and timely disposal, reducing the risk of the patient's treatment.

B. SUSTAINABLE HEALTHCARE BASED ON SMART CLOTHING

Since smart clothing integrates a variety of physiological sensors into flexible textile laundry, it can capture a variety of important physiological indicators and has the advantages of comfortable, suitable for elderly, children, and the people with chronically ill and mental illness. Thus, using these emerging wearable clothing products, we can build a new healthcare system which integrates low-power wireless communications, cloud computing, big data and machine learning techniques to realize personalized health care services based on basic physiological information monitoring.

We propose the smart clothing as the core of a sustainable health care system. The system consists of three parts: 1) health care scenarios based on smart clothing, 2) signal acquisition subsystem and 3) cloud platform for process, analysis and forecasting on big health care data. As shown in Fig. 4, its main components are introduced in details below.

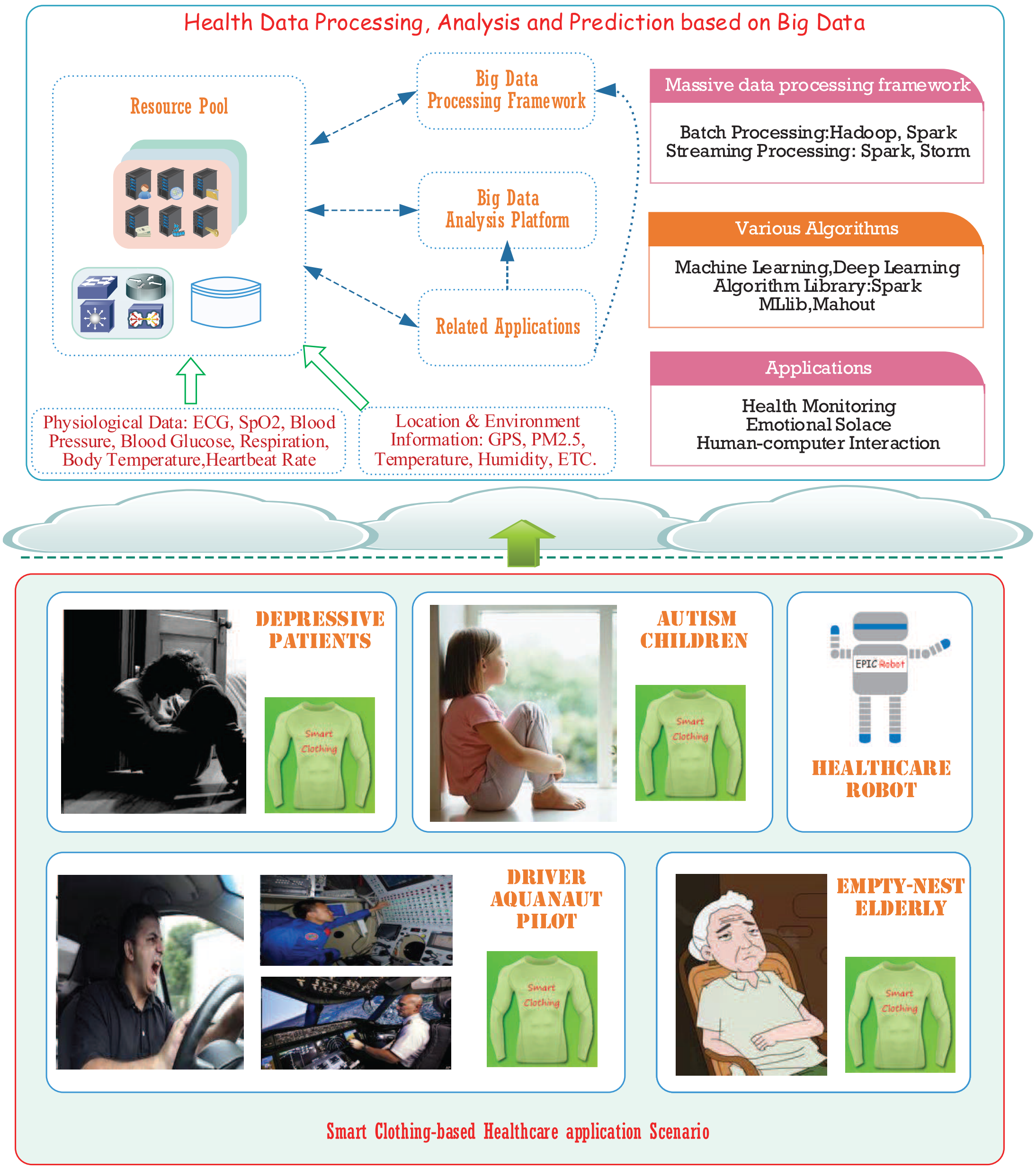

FIGURE 4. Healthcare system architecture based on smart clothing.

In healthcare scenarios based on smart clothing, it needs to provide health care services for end-users (such as the chronically ill, the car driver, autistic children, empty nesters, etc.). In their daily work and life, smart clothing collects their physiological data. Due to a variety of sensors having been integrated in clothing, it will not have any impacts on the user's daily work and life, user will not feel the presence of the acquisition device. Signal acquisition subsystem collects a variety of physiological signals of users. These primitive physiological signals would be preprocessed at user-end (signal amplification, denoising) and then be uploaded to the cloud. The user's current health status can be obtained at cloud through the physiological signal processing and analysis. Conducting big data analysis on large amount of historical data cloud forecast the development trend of the disease or health of users, and further provide personalized health services for users. For example, the system will immediately notify emergency medical institution or the user's family once the user's heart attack is detected. If the family has health care robot, the robot would be commanded to immediately sent rescue medication for patients. For those who need emotional care, emotional comfort would be given (such as voice reminders, play music, etc.). The robot accesses the user's emotional health and interacts with user closely.

C. LTE-BASED TELEMEDICINE

Currently, the main medical resources are concentrated in a few large hospitals. Telemedicine technology provides a solution of sharing different parts of existing medical resources, which is one of the effective measures to achieve health equality.

Telemedicine services meet customer's demand timely, understand the patient's latest health states, enhance communication between doctors and patients and shorten the waiting time for medical treatment, which will improve customer satisfaction and increase efficiency in the hospital at the same time.

There are six main reasons for limiting the development of telemedicine: First, telecommunications transmission quality is not high. The bandwidth is the biggest bottleneck. Second, the telemedicine system's communication standard is still not compatible with the local hospital, there is no uniform standard. Third, it is diffcult to process substantial medical images. Fourth, there is a security problem for long-distance transmission which is vulnerable to be attacked by hackers and virus. Fifth, telemedicine penetration is still very low. Sixth, the network construction cost constraints the popularity of remote consultation center.

The real telemedicine is able to achieve a uniform standard. It can be high-quality, compatible, open and safely and at any time, any place, any exchange of medical personnel. Modern mobile wireless communications realize the connection between healthcare workers and patients in space and time.

With the rapid development of global wireless communications network, the latest fourth-generation mobile communications technology 4G network has unparalleled advantages in communication speed, transmission quality, network spectrum, cost and other aspects. The features include: high-speed, broadband digital technology-based, good compatibility, strong flexibility, the coexistence of multiple types of users, the integration of multiple services, advanced technology, a high degree of self-organizing and adaptive network.

The key issues that LTE-based telemedicine needs to solve are:

- 4G-LTE telemedicine services network has the balance problem between enhanced intelligent wireless link and signal interference of existing medical equipment. Signal fading is one of the key factors that affect the wireless communication system. The telemedicine network is able to take full advantage of mobile radio channels, at the same time, solve the problem of interference with the medical device. It can meet communication requirements according to the changing of consultation. Intelligent signal processing technology for different channel conditions could normally send and receive information consultation.
- Transport and display of medical images through 4G-LTE-based mobile communication network. The data collection, transmission, and display on a PDA of medical images could be realized through 4G network, thus PACS information could be displayed on PDA during the remote medical consultation.
- Security mechanism based on 4G-LTE telemedicine systems. Since quasi-4G is an open system, with rich computing and storage resources of the mobile terminal, the mobile operating system and a variety of wireless applications continue to come out. Quasi-4G-based telemedicine system should focus on the problems of hacking, virus attacks, and the patient's medical information privacy, network security and other core issues [58]. So such study become an important part of the work. General hospital information system databases exist in the internal network, so to solve the secure problem of data exchange and achieve information transmission between internal and external quasi-4G network are necessary.

D. EMOTION INTERACTION BASED ON ROBOT

Emotion care is an important part of big health system. We propose a big health interactive application framework which is consisted of four layers that include emotion information acquired layer, emotion interactive control center layer, emotional support layer and end-user interaction layer. As shown in Fig. 5. Emotion information acquired layer gets data from emotional perception layer, then transfers the data to the emotional interactive control center which identifies the user's emotional state with emotional knowledge and data. Emotional interaction agent receives the result of emotion recognition, and then controls the emotional interaction carriers to interact with end users to achieve the emotion care.

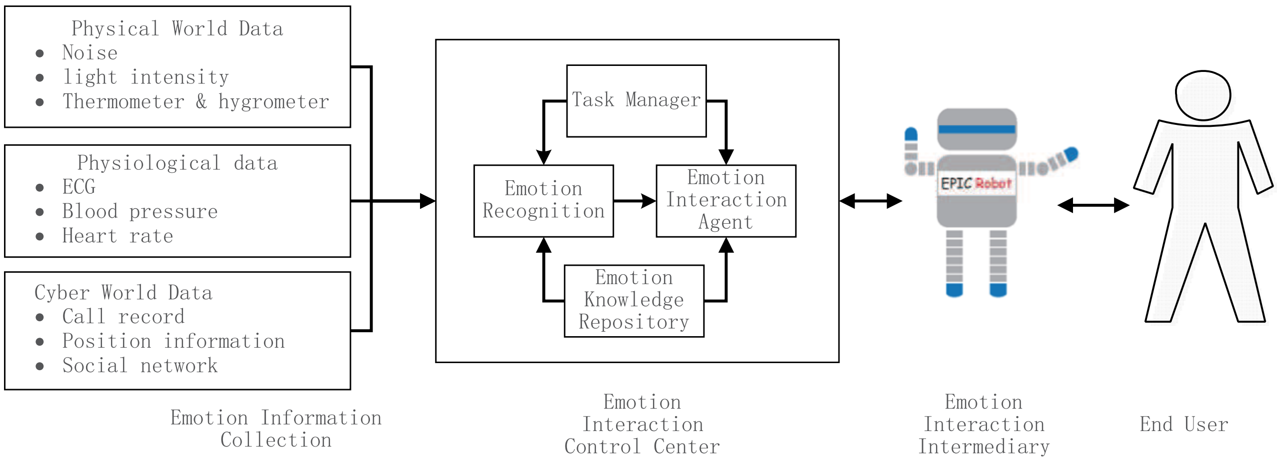

FIGURE 5. Emotion interaction application framework based on service robot.

Getting the data related with emotion is the base of emotion perception and emotional interaction. Smart mobile devices and wearable devices facilitate the emotion data acquisition. Emotional interaction plays an important role in the whole application framework. The robot's capabilities are increasingly complete, making it the best emotional support interaction. For example, the healthcare robot not only has regular healthcare function, but also interacts with user when integrating robot with health cloud. Services of emotional robots interaction include music, video, movement, dance, LED lighting, and voice synthesis. Robots can also be combined with smart phones and smart home devices together for emotional interaction.

V. CONCLUSION

The latest information technologies can be used into healthcare field to overcome worldwide health problems such as uneven distribution of medical resources, the growing chronic diseases, and the increasing medical expenses. In this paper, we present a big health application system which is based on the health IoT applications and big data. We introduce the big health care system's architecture, technology challenges and several typical large health applications.

REFERENCES

[1] Y.-J. Ma, Y. Zhang, O. M. Dung, R. Li, and D.-Q. Zhang, "Health Internet of Things: Recent applications and outlook," *J. Internet Technol.*, vol. 16, no. 2, pp. 351–362, 2015.

[2] C. Perera, C. H. Liu, S. Jayawardena, and M. Chen, "A survey on Internet of Things from industrial market perspective," *IEEE Access*, vol. 2, pp. 1660–1679, Jan. 2014.

[3] L. Foschini, T. Taleb, A. Corradi, and D. Bottazzi, "M2M-based metropolitan platform for IMS-enabled road traffic management in IoT," *IEEE Commun. Mag.*, vol. 49, no. 11, pp. 50–57, Nov. 2011.

[4] M. Chen, S. Gonzalez, V. Leung, Q. Zhang, and M. Li, "A 2G-RFID-based e-healthcare system," *IEEE Wireless Commun. Mag.*, vol. 17, no. 1, pp. 37–43, Feb. 2010.

[5] G. Li, "Big data related technologies, challenges and future prospects," *Inf. Technol. Tourism*, vol. 15, no. 3, pp. 283–285, 2015.

[6] Y. Zhang, M. Qiu, C. W. Tsai, M. M. Hassan, and A. Alamri, "Health-CPS: Healthcare cyber-physical system assisted by cloud and big data," *IEEE Syst. J.*, vol. 11, no. 1, pp. 88–95, Mar. 2017.

[7] M. Chen, S. Mao, and Y. Liu, "Big data: A survey," *Mobile Netw. Appl.*, vol. 19, no. 2, pp. 171–209, Apr. 2014.

[8] D. Tian, J. Zhou, Y. Wang, G. Zhang, and H. Xia, "An adaptive vehicular epidemic routing method based on attractor selection model," *Ad Hoc Netw.*, vol. 36, pp. 465–481, Jan. 2016.

[9] D. Tian, J. Zhou, Y. Wang, Y. Lu, H. Xia, and Z. Yi, "A dynamic and self-adaptive network selection method for multimode communications in heterogeneous vehicular telematics," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 6, pp. 3033–3049, Dec. 2015.

[10] D. Tian, J. Zhou, Z. Sheng, and V. C. M. Leung, "Robust energy-efficient MIMO transmission for cognitive vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 6, pp. 3845–3859, Jun. 2016.

[11] Y. Zhang, M. Chen, S. Mao, L. Hu, and V. Leung, "CAP: Community activity prediction based on big data analysis," *IEEE Netw.*, vol. 28, no. 4, pp. 52–57, Jul./Aug. 2014.

[12] M. Chen, "NDNC-BAN: Supporting rich media healthcare services via named data networking in cloud-assisted wireless body area networks," *Inf. Sci.*, vol. 284, pp. 142–156, Nov. 2014.

[13] Q. Liu, Y. Ma, M. Alhussein, Y. Zhang, and L. Peng, "Green data center with IoT sensing and cloud-assisted smart temperature control system," *Comput. Netw.*, vol. 101, pp. 104–112, Jun. 2016.

[14] G. Aloi *et al.*, "Software defined radar: Synchronization issues and practical implementation," in *Proc. Int. Conf. Cognit. Radio Adv. Spectr. Manage. (CogART)*, Barcelona, Spain, Oct. 2011, pp. 1–5.

[15] M. Chen, Y. Zhang, L. Hu, T. Taleb, and Z. Sheng, "Cloud-based wireless network: Virtualized, reconfigurable, smart wireless network to enable 5G technologies," *Mobile Netw. Appl.*, vol. 20, no. 6, pp. 704–712, Dec. 2015.

[16] V. C. Gungor, P. Pace, and E. Natalizio, "AR-TP: An adaptive and responsive transport protocol for wireless mesh networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2007, pp. 3740–3745.

[17] M. Chen, D. O. Mau, X. Wang, and H. Wang, "The virtue of sharing: Efficient content delivery in wireless body area networks for ubiquitous healthcare," in *Proc. IEEE Int. Conf. e-Health Netw., Appl. Services*, Oct. 2013, pp. 669–673.

[18] J. Wang, Y. Zhang, J. Wang, Y. Ma, and M. Chen, "PWDGR: Pair-wise directional geographical routing based on wireless sensor network," *IEEE Internet Things J.*, vol. 2, no. 1, pp. 14–22, Feb. 2015.

[19] E. Sakhaee, T. Taleb, A. Jamalipour, N. Kato, and Y. Nemoto, "A novel scheme to reduce control overhead and increase link duration in highly mobile ad hoc networks," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Mar. 2007, pp. 3972–3977.

[20] S. Yessad, F. Nait-Abdesselam, T. Taleb, and B. Bensaou, "R-MAC: Reservation medium access control protocol for wireless sensor networks," in *Proc. 32nd IEEE Conf. Local Comput. Netw. (LCN)*, Oct. 2007, pp. 719–724.

[21] G. S. Ruthenbeck and K. J. Reynolds, "Virtual reality for medical training: The state-of-the-art," *J. Simul.*, vol. 9, no. 1, pp. 16–26, 2015.

[22] P. Baudisch, "Technical perspective: Virtual reality in your living room," *Commun. ACM*, vol. 58, no. 6, p. 92, 2015.

[23] Y. Ma, Y. Zhang, J. Wan, D. Zhang, and N. Pan, "Robot and cloud-assisted multi-modal healthcare system," *Cluster Comput.*, vol. 18, no. 3, pp. 1295–1306, 2015.
[24] Y. Ma, C. H. Liu, M. Alhussein, Y. Zhang, and M. Chen, "LTE-based humanoid robotics system," *Microprocessors Microsyst.*, vol. 39, no. 8, pp. 1279–1284, 2015.
[25] Z. Sheng, J. Fan, C. H. Liu, V. C. M. Leung, X. Liu, and K. K. Leung, "Energy-efficient relay selection for cooperative relaying in wireless multimedia networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 3, pp. 1156–1170, Mar. 2015.
[26] C. H. Liu, K. K. Leung, and A. Gkelias, "A generic admission-control methodology for packet networks," *IEEE Trans. Wireless Commun.*, vol. 13, no. 2, pp. 604–617, Feb. 2014.
[27] A. Gkelias, F. Boccardi, C. H. Liu, and K. K. Leung, "MIMO routing with QoS provisioning," in *Proc. ISWPC*, 2008, pp. 46–50.
[28] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. M. Leung, "Body area networks: A survey," *Mobile Netw. Appl.*, vol. 16, no. 2, pp. 171–193, 2011.
[29] T. Taleb, D. Bottazzi, M. Guizani, and H. Nait-Charif, "Angelah: A framework for assisting elders at home," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 4, pp. 480–494, May 2009.
[30] D. Bottazzi, T. Taleb, M. Guizani, and A. S. Hafid, "Supporting context-aware applications for eldercare," *J. Commun. Netw.*, vol. 13, no. 2, pp. 95–101, Apr. 2011.
[31] M. Chen, Y. Ma, J. Song, C.-F. Lai, and B. Hu, "Smart clothing: Connecting human with clouds and big data for sustainable health monitoring," *Mobile Netw. Appl.*, vol. 21, no. 5, pp. 825–845, 2016.
[32] M. Chen, Y. Ma, Y. Li, D. Wu, Y. Zhang, and C. H. Youn, "Wearable 2.0: Enabling human-cloud integration in next generation healthcare systems," *IEEE Commun. Mag.*, vol. 55, no. 1, pp. 54–61, 2017.
[33] X. Ge, J. Ye, Y. Yang, and Q. Li, "User mobility evaluation for 5G small cell networks based on individual mobility model," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 3, pp. 528–541, Mar. 2016.
[34] M. Chen, Y. Zhang, Y. Li, S. Mao, and V. C. M. Leung, "EMC: Emotion-aware mobile cloud computing in 5G," *IEEE Netw.*, vol. 29, no. 2, pp. 32–38, Mar./Apr. 2015.
[35] C. H. Liu, J. Fan, P. Hui, J. Wu, and K. K. Leung, "Toward QoI and energy efficiency in participatory crowdsourcing," *IEEE Trans. Veh. Technol.*, vol. 64, no. 10, pp. 4684–4700, Oct. 2015.
[36] C. H. Liu, P. Hui, J. W. Branch, C. Bisdikian, and B. Yang, "Efficient network management for context-aware participatory sensing," in *Proc. 8th Annu. IEEE Commun. Soc. Conf. Sensor, Mesh Ad Hoc Commun. Netw. (SECON)*, Jun. 2011, pp. 116–124.
[37] C. H. Liu, B. Yang, and T. Liu, "Efficient naming, addressing and profile services in Internet-of-Things sensory environments," *Ad Hoc Netw.*, vol. 18, pp. 85–101, Jul. 2014.
[38] C. H. Liu, P. Hui, J. W. Branch, and B. Yang, "QoI-aware energy management for wireless sensor networks," in *Proc. IEEE Int. Conf. Pervasive Comput. Commun. Workshops (PERCOM Workshops)*, Mar. 2011, pp. 8–13.
[39] H. Gao *et al.*, "A survey of incentive mechanisms for participatory sensing," *IEEE Commun. Surveys Tut.*, vol. 17, no. 2, pp. 918–943, 2nd Quart., 2015.
[40] C. H. Liu, B. Zhang, X. Su, J. Ma, W. Wang, and K. K. Leung, "Energy-aware participant selection for smartphone-enabled mobile crowd sensing," *IEEE Syst. J.*, to be published.
[41] Z. Song, B. Zhang, C. H. Liu, A. V. Vasilakos, J. Ma, and W. Wang, "QoI-aware energy-efficient participant selection," in *Proc. 11th Annu. IEEE Int. Conf. Sens., Commun., Netw. (SECON)*, Jun./Jul. 2014, pp. 248–256.
[42] B. Zhang *et al.*, "Privacy-preserving QoI-aware participant coordination for mobile crowdsourcing," *Comput. Netw.*, vol. 101, pp. 29–41, Jun. 2016.
[43] C. H. Liu, K. K. Leung, C. Bisdikian, and J. W. Branch, "A new approach to architecture of sensor networks for mission-oriented applications," *Proc. SPIE*, 2009.
[44] C. H. Liu, T. He, K.-W. Lee, K. K. Leung, and A. Swami, "Dynamic control of data ferries under partial observations," in *Proc. WCNC*, 2010, pp. 1–6.
[45] C. H. Liu, J. Fan, J. W. Branch, and K. K. Leung, "Toward QoI and energy-efficiency in Internet-of-Things sensory environments," *IEEE Trans. Emerg. Topics Comput.*, vol. 2, no. 4, pp. 473–487, Dec. 2014.
[46] O. Yurur, C.-H. Liu, and W. Moreno, "Unsupervised posture detection by smartphone accelerometer," *Electron. Lett.*, vol. 49, no. 8, pp. 562–564, Apr. 2013.
[47] M. Chen, Y. Hao, Y. Li, D. Wu, and D. Huang, "Demo: LIVES: Learning through interactive video and emotion-aware system," in *Proc. 16th ACM Int. Symp. Mobile Ad Hoc Netw. Comput.*, 2015, pp. 399–400.
[48] T. Taleb, D. Bottazzi, and N. Nasser, "A novel middleware solution to improve ubiquitous healthcare systems aided by affective information," *IEEE Trans. Inf. Technol. Biomed.*, vol. 14, no. 2, pp. 335–349, Mar. 2010.
[49] M. Chen, Y. Zhang, Y. Li, M. M. Hassan, and A. Alamri, "AIWAC: Affective interaction through wearable computing and cloud technology," *IEEE Wireless Commun.*, vol. 22, no. 1, pp. 20–27, Feb. 2015.
[50] K. Hwang and M. Chen, *Big-Data Analytics for Cloud, IoT and Cognitive Learning*. Hoboken, NJ, USA: Wiley, 2017.
[51] M. Chen, Y. Ma, S. Ullah, W. Cai, and E. Song, "ROCHAS: Robotics and cloud-assisted healthcare system for empty nester," in *Proc. Int. Conf. Body Area Netw.*, 2013, pp. 217–220.
[52] M. Qiu, Z. Ming, J. Li, K. Gai, and Z. Zong, "Phase-change memory optimization for green cloud with genetic algorithm," *IEEE Trans. Comput.*, vol. 64, no. 12, pp. 3528–3540, Dec. 2015.
[53] M. Qiu and E. H.-M. Sha, "Cost minimization while satisfying hard/soft timing constraints for heterogeneous embedded systems," *ACM Trans. Design Autom. Electron. Syst.*, vol. 14, no. 2, 2009, Art. no. 25.
[54] C. H. Liu, J. Wen, Q. Yu, B. Yang, and W. Wang, "HealthKiosk: A family-based connected healthcare system for long-term monitoring," in *Proc. IEEE Conf. Comput. Commun. Workshops (INFOCOM WKSHPS)*, Apr. 2011, pp. 241–246.
[55] Y. Zhang, M. Chen, D. Huang, D. Wu, and Y. Li, "iDoctor: Personalized and professionalized medical recommendations based on hybrid matrix factorization," *Future Generat. Comput. Syst.*, vol. 66, pp. 30–35, Jan. 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0167739X15003842
[56] Y. Zhang, D. Zhang, M. M. Hassan, A. Alamri, and L. Peng, "CADRE: Cloud-assisted drug recommendation service for online pharmacies," *Mobile Netw. Appl.*, vol. 20, no. 3, pp. 348–355, Jun. 2014. [Online]. Available: http://dx.doi.org/10.1007/s11036-014-0537-4
[57] Y. Zhang, "GroRec: A group-centric intelligent recommender system integrating social, mobile and big data technologies," *IEEE Trans. Serv. Comput.*, vol. 9, no. 5, pp. 786–795, Sep./Oct. 2016. [Online]. Available: http://dx.doi.org/10.1109/TSC.2016.2592520
[58] Y. Li, W. Dai, Z. Ming, and M. Qiu, "Privacy protection for preventing data over-collection in smart city," *IEEE Trans. Comput.*, vol. 65, no. 5, pp. 1339–1350, May 2016.

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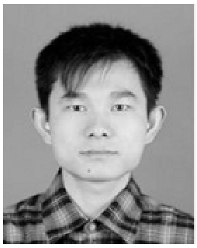

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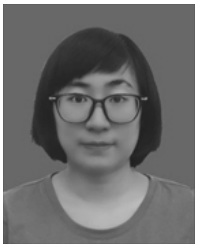

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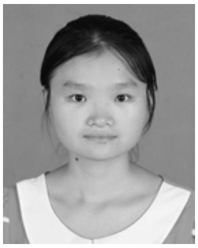

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