A home mobile healthcare system for wheelchair users

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A Home Mobile Healthcare System for Wheelchair Users

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***Abstract*— With more and more applications of Internet of things (IoT) technologies, the quality of life of residents is one of the most important aspects in smart cities. Specially, home healthcare monitoring for the disabled and / or the elderly has become a focus of recent researches and developments. Existing home healthcare systems have drawbacks such as simple and few functionalities, weak interaction and poor mobility. This paper presents a home mobile healthcare (mHealth) system for wheelchair users, based on the emerging IoT technologies. The paper focuses on the proposed system architecture and the design of wireless body sensor networks (WBSNs). The nodes of WBSNs include wireless heart rate and ECG sensors, wireless pressure detecting cushion, home environment sensing nodes and control actuators. A prototype system implementation shows that the proposed people-centric sensing system is efficient in monitoring human activities and in interacting with the living environment.**

Keywords—Internet of things; people-centric sensing; wheelchair users; mHealth; smart object

I. INTRODUCTION

The quality of life of dwellers is an important target of smart cities, and is widespread concerned with the construction of smart cities. Daily home life of urban dwellers trends to intelligent and healthy [1]. And the daily mobile healthcare service becomes more and more important for solitary people with wheelchair, such as the disabled and elderly people [2]. Chronic diseases influence the health of the people living alone in daily life, such as cardiovascular and cerebrovascular diseases affect [3], so that the corresponding motor, sensory and cognitive functions have been lost or compromised, and real-time remote monitoring service is required. It’s hard for wheelchair users to operator home appliances. A method of wireless, centralized manner and interaction with intelligent device is required. There are some important dangerous situations in living environment, such as carbon monoxide and water leak problems, leakage and indoor air pollution. Home security devices which can be remotely monitored and controlled is required to protect daily life. Therefore, intelligent portable instrumentation and system are required to make life more convenience and enhance the quality of life of wheelchair users, via interaction in wheelchair users, guardians and household smart devices.

IoT is considered an effective method for healthcare monitoring system of the disabled and elderly people by the people-object interaction [4]. IoT is mainly to solve issue of interconnection such as Things to Things, Human to Things and Human to Human. All objects in the physical world can take the initiative to exchange information via the Internet, to achieve interconnection each other in any time and place, ubiquitous networking and ubiquitous computing. IoT relate to radio frequency identification technology (RFID), sensor technology, nanotechnology and smart technology etc. [5]. Wireless body area network and smart phone technology are important branches of IoT in the application of people-centric sensing [6, 7].

The goal of this work is to exploit the aforementioned IoT capabilities, and to build an intelligent system with real-time monitor and interaction, for personalized healthcare of wheelchair users at home. The architecture of home healthcare system (HHS) for the wheelchair is presented in section III. Section IV presents the structure of wireless body sensor networks, the components of the sensor nodes which include wireless heart rate and ECG nodes, wireless wheelchair falling detecting nods, wireless pressure cushion, living environment sensing nodes and actuators, and then the methods and circuits of vital physiological parameters are presented. Section V presents the algorithms of the data processing and result of the software. Section VI presents the prototype system implementation. Finally, Section VII concludes the paper.

II. RELATED WORK

Research in home healthcare applications, based on wireless body sensor networks and smart phone, are being under progress all over the world. Many projects are developed or in developing stage[8].

A. Independent LifeStyle Assistant

Independent LifeStyle Assistant has been developed by Honeywell [9], and the system builds a fully automated home environment, via the approach of Internet and wireless sensor networks, to perceive home environment. Once the elderly is in danger in daily life, instant alarm and automation for scene response is triggered. But the system is weak in interaction with the environment and lack of mobility, and focusing on

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one-way automatic processing of data collection, ignoring centralized control and remote interaction.

B. AwareHome

AwareHome is a project for the healthcare of elderly living alone, founded by Georgia Institute of Technology [10]. The project is developed to monitor household equipment and the environment using variety sensors, to indirectly track the behavior patterns of elderly in the daily life, family members or clinicians browse the health information via the Internet to understand the activities of the elderly. And the system makes guidance for the abnormal behavior, according to analyzing a period of historical data on the behavior. But the system is lack of mobility, the sensors and gateways are fixed in the room. When people are outdoors near the house, it's hard to monitor the status. And the system is the lack of real-time healthcare monitoring and early warning for outbreaks of disease and falling.

C. OpenHealth

OpenHealth is carrying out by Professor Estrin Deborah in Cornell University [11], using applications of smart phone and a large number of users to participate, aim to conduct self-health monitoring applications. The users recode their health status and send the data to the public health sector via the mobile phones. After analyzing the data of chronic diseases and health indicators in the behavioral analysis model, the system provides medical advice to the user. However, the system is lack of control and interaction with the surroundings, weak in monitoring real-time vital physiological parameters.

D. Other Home Healthcare Systems

Existing home healthcare systems, such as the University of Rochester's Smart Medical Home[12], Gator-Tech Smart House[13], are based on service-oriented, and can be classified into three main clusters:(i) Safety Enhancing Systems; (ii) Health and Wellness Monitoring, and (iii) Social Connectedness Systems[14]. Comparing with the people-centric sensing system, these systems ignorance the mobility and interaction with living environment.

E. Smart wheelchair

It has been reported the autonomous navigation and human control for wheelchair driving assistive[15]. [16] is to abstract and transfer the human dynamic (sequential) navigational skill to a mobile robot, and some scholars focus on human-machine interactive by voice[17][18], EOG[19] , eye gaze [20], EEG[21] and gesture recognition [22]etc..

Moreover, existing smart wheelchair is designed for healthcare aided, [23] is presented a biomedical system embedded on a wheelchair able to measure heart rate, respiratory rate, and the wheelchair motion state. But this system is limited by WiFi hotspots, not suitable for scenarios of outdoor healthcare. [24] is presented a smart wheelchair that utilizes a smartphone with its built-in sensors to capture and record physical activity of manual wheelchair users in both unstructured and structured environments. But this system is lack of vital physiology parameters because of limited built-in sensors of smart phone.

III. PROPOSED SYSTEM ARCHITECTURE

The architecture of home mHealth system is shown in figure 1. The first part is WBANs and smart objects. The second part is smart phone. The third part is data center layer in the cloud.

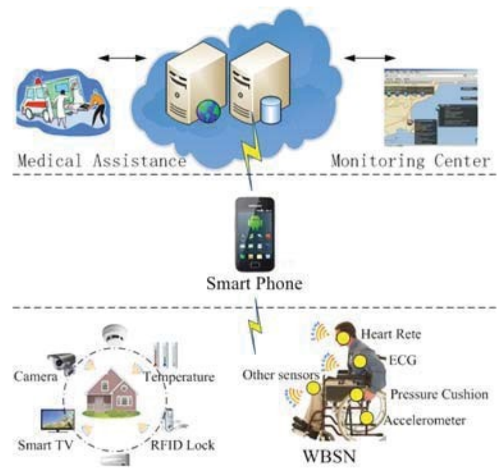

Fig.1. The architecture of home mHealth system

A. WBANs and Smart Object

This presents how to mobility perceive the health status of wheelchair users on vital physiology parameters and living environment. WSN is suitable for healthcare monitoring, and is the data source of whole system [25]. Heart rate and ECG are the primary physiological parameters of chronic disease for the wheelchair users' healthcare. Detecting the falling of the wheelchair is aim to indirectly perceive the falling down of the user. Perceiving the surroundings is aim to monitor the emergency of wheelchair users' home daily life. All of the nodes can process the signal, realize the abnormal of the data and communicates with the sink node in wireless. Specially, the object, such as wheelchair, household equipment, has the ability of computing attached the wireless sensor nodes, and become intelligent and more functions. The sink node of WBANs contains the data of the smart object in its range of radio module. The people-centric sensing networks mix mobile sensor networks and fixed sensor networks.

B. Smart Phone Layer

The smart phone is not only the gateway of local sensor networks, but also the server of managing the smart objects. As a gateway, the smart phone bridge the short range wireless networks to the internet.as a server, the smart phone process ,store, visualize the data from the sink node. Specially, in this paper, the smart phone is also the interface to interact with intelligent device, such as light, RFID lock, spark on the wheelchair Etc., and to change the statue of the equipment via operating the screen. While the wheelchair users move outdoors, the smart phone also perceives the surroundings via the sensors build-in the phone, such as GPS, camera, accelerometer, compass Etc.

C. Data Center Layer

The data center is a software platform to contain data from gateway via internet communication infrastructure, such as NoLA, LTE, 3G, and GPRS Etc., and then to manage and share the data of smart objects. The data center is aim to visualize the real-time data of the human and living environment, to analyzes the historical data of physiological parameter for giving healthcare advices, to send alarm message of emergency to family and clinicians. The abnormal data, after the manually confirmed, is stored to sample trainings library for automation warning.

IV. HARDWARE DESIGN

A. Wireless Body Area Networks

This presents how to connect smart objects to internet. The structure of WBANs is presented in figure 2. In this work, WBANs is people-centric sensing for wheelchair users, contains nodes of vital physiological parameters perceiving, wheelchair falling detecting, environment perceiving and controlling, and is star topology. The communication protocols are Zigbee and Bluetooth, because most of smart phone embedded Bluetooth modules and is convenient for user. The sink node contains the data from children nodes and sends to smart phone, and is also an adapter transforming data from Zigbee to Bluetooth.

This also presents how sensor nodes become smart object. Attached to the wheelchair, human body and equipment, each node is a smart object, and can intelligently process the signal for realizing abnormal status computed by MUC. Each node can join or leave the network online, and contain modules of data acquisition, data processing, data storage, radio communication and power management.

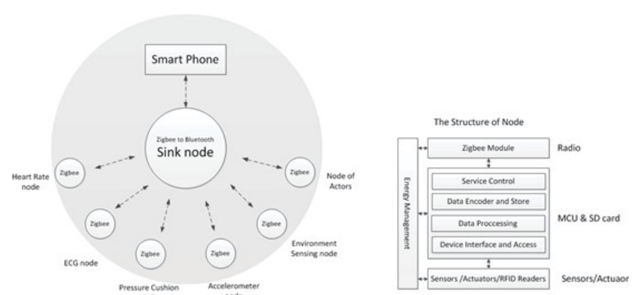

Fig.2. networks and structure of smart objects

B. Sensors of Vital Physiological Parameters

The physiological parameter perceiving networks is made up by the wireless sensor nodes and sink nodes. And the number and type of smart objects is able to expend, according to the kinds of health parameters. This work presents a case that the WWSANs contain sink node, heart rate sensor node and ECG sensor node. CC2530 chip is suitable for radio module of smart objects, and is ultra-low power and cheap. Microprocessor module of smart objects contains a low-power processor of ATmega168p, and is 14 digital I/O pins.

- Sink nodes is an adapt transferring from Zigbee to Bluetooth via the UART. Bluetooth uses CC2540 chip.
- ECG comes from the processes of tissue bioelectric and biochemical of the heart. A typical ECG cycle includes the waves of P, Q, R, S, T and U. this work uses the QRS detection algorithm for real-time ECG abnormalities via the ECG analysis [26]. The product of HKD-10A ECG sensor module is selected, and has an analog signal output single lead ECG acquisition module. Current is less than 4mA, the range of measurement is 0~4mV, signal gain is up to 300 times. Electrode pads and the sensor module connect and transfer data to the CPU through the UART port.
- Using photoelectric pulse sensor to measurement heart rate is based on the principle of photoelectric volume method. The pulse signal is detected by indirectly monitoring the light through the skin.

C. The Status of Wheelchair Perception

The wheelchair for elderly and disabled people is a mobile hardware platform that can fix different kinds of sensors. In this case the wireless sensor networks contain two kinds of sensors:

- Pressure cushion is to detect the human body falling down from the wheelchair or not. The smart cushion is designed by Wuhan University of Technology. And the built-in sensor of cushion is resistive pressure sensor that woven into inside of the wheelchair cushion. In the past work, an algorithm has been designed and can effectively detect whether disabled people in a wheelchair or not. [27]
- Accelerator sensor is build-in wheelchair to detect the falling of wheelchair. The accelerator sensor node is attached to the fixed support structure of the wheelchair, and monitors the rollover of the wheelchair. The product of Wheelchair rollover detecting is developed by Wuhan University, which contains Freescale acceleration chip of Mma7260, and is shown in figure 3. The size of the product is 3cm×2cm×1cm.

Fig.3. accelerator and pressure sensors build in the cushion of the wheelchair

D. Living Environment Perception

The sensors of perceiving living environment parameters, such as temperature, humidity, carbon monoxide , connect and send real-time data to MCU via ISP interface. Then the data is storage in the SD card for offline analysis. Most of the sensors are arranged in an indoor fixed position. When the wheelchair moves in different rooms or buildings, it can receive the data from the surrounding WSNs. The same method is used to connect smart devices to the WSNs, such as RFID locks and other traditional household devices.

E. Intelligent Actuators

There are several communication protocols of controlling household equipment, such as IR, RFID, BUSs, and Bluetooth. An adapter is required for transforming the instructions from the smart gateway to kinds of actuators. A common actuator node is presented, and it contains a low-power processor of ATmega168p and a module of CC2530, and uses UART bridging the household equipment to Zigbee networks. When the common actuator node receives the instructions from the gateway, and then maps the instructions of the gateway to AT commands of household equipment set.

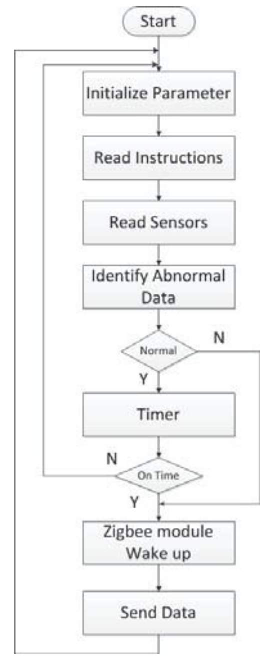

Fig.4. the workflow of radio module

V. SOFTWARE

A. The Radio Working Modes of Smart Objects

This work presents four working modes of radio module of smart objects, according to the feature of energy efficient and types of perceiving.

- The radio module continues working.
- The radio works in fixed interval.
- The radio modes work in case of the smart object realizing the abnormal.
- The smart object processes the data firstly, and realizes the feature data, and then the radio module sends the feature data in fixed interval. While the smart object realizes the abnormal status, the radio module works at once. The smart object is coding in langue of similar C, and is working on the software platform of Arduino, which includes kinds of library for variety of functions.

In this work, the radio module of smart object is working in the fourth mode, and the workflow is shown in figure 4. The smart object waits for instructions of smart gateway after finishing initialization. In case of sensor nodes, the sensor module starts and continues to work, if the CPU realizes the abnormal data, then the radio starts and sends data, else the radio sends in fixed interval. In the most time the radio of CC2530 is in sleeping for energy efficient. While the actuator node revives the operation instruction, the intelligent device execute AT commands immediately.

B. Control Mechanism in Mobile Phone

This presents how to interact with the living environment remotely and locally via smart phones. In the home mHealth care system, a wheelchair person is not only the object perceived but also the beneficiary, who uses the system. The smart phone is the core device of the People-Centric networks, and is not only the gateway for transforming data and instruction between the nodes and internet, but also the interface between human and physical world. Wheelchairs, families or clinicians can remote visit the data or control the nodes of WBSNs. User visits the latest stat of the actuators via the device agent in the smart phone. The Sequence diagram is shown in figure 5. While the user requires for a physical device, the clod platform receives the Http requests and the instructions, and finds the wheelchair in the link table, which map the short URL to the real IP address of the smart gateway connected. Then the smart gateway attached to the wheelchair receives the instructions, for querying the device driver in the smart gateway, to find the AT table to excuse the action of physical actuators.

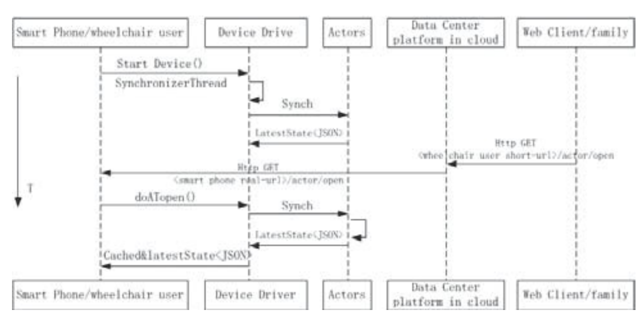

Fig.5. Sequence diagrams of remote control

C. *Data center of Home mHealth*

Figure 6 shows the architecture of data center platform. The data center is the middleware between the smart objects and business layer. There are three modules. Data access module is aim to connect the different smart objects. Cyber physical transformation module is aim to build the interoperation of the virtual nodes for smart objects. Sharing module is aim to share the data to different applications via various interface.

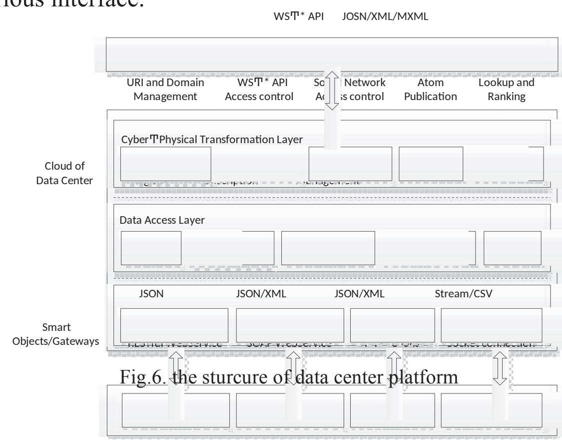

Fig.6. the sturcure of data center platform

(b) ...f Data Center

VI. Prototype System Implementation

To check the validity of the home mHealth system framework, we integrated the framework into an application on SmartLobot. SmartLobt is an IoT platform providing data connection, sharing and controlling services for smart objects, and it is also a platform that has a strong expansion for different applications developed by WUT.

A prototype system has been implemented in a research lab environment. In the physical layer, the fixed sensors and actuators are mounted in a room of 6m×6m, including sensors of smoke, IR, humidity, temperature, light and camera, including lights and air conditions with wireless relays nodes. The human wears watch-like heart rate sensor node at wrist, ECG sensors at waist and sink node at the belt. Wireless pressure cushion and accelerometer node are fixed in the wheelchair.

The control mechanical has been tested in the platform of Android 4.04, Cortex A9 1.2GHz, build-in Bluetooth V2.0. Web service interfaces for receiving data and updating the sensors' working status are implemented with JAX-WS and deployed to the Apache Tomcat server. Some running results are shown in figure 7. Figure 7(a) shows real-time data of heart rate, ECG and stat of wheelchair. Figure 7(b) shows the interface to monitor and control the living environment. The software also has connected to third-party service for SMS and telephone emergency alarm. The case validated that the home mHealth system framework works effectively, and it can deal with large number of wheelchair users in smart cities.

VII. Conclusions and Future Work

In summary, this work has the following characteristics: (i)Mobile data collection. Comparing with the traditional method of space restricted, the method of using wireless body area networks, improves the portability and flexibility of the measurement system; (ii) Indirectly healthcare monitoring based on perceiving the surrounding environment. Indirectly monitoring the status of wheelchair and living environment is used to realize the dangerous status of the wheelchair users. Comparing with the traditional method of measuring the human body directly, the system increases the services more comprehensive; (iii) Remotely interact with surroundings. Remote monitoring center, wheelchair users and families can perceive and operate the home intelligent devices. Comparing with the traditional single-aware approach, the system expands the range of support services for wheelchair users.

Future work is focused on the wireless body area networks combined with social networks, exploring the mobility impaired healthcare services based on social networking, and sharing the information of smart object more security and accuracy.

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