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DESIGN AND IMPLEMENTATION OF WEARABLE E-HEALTH MONITORING SYSTEM WITH MEDICAL AND TACTILE SENSORS FOR REMOTE PATIENT SURVEILLANCE

Christodoulos Asiminidis[1], George Kokkonis[2], Ioannis Kazanidis[1] and Sotirios Kontogiannis[1]

[1]Laboratory team of Distributed Microcomputer systems, Department of Mathematics, University of Ioannina, Ioannina, Greece

[2]Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece

E-mail: skontog@cc.uoi.gr, chasiminidis@cs.uoi.gr, gkokkonis@teiwm.gr

ABSTRACT: This paper presents the design and development of an e-health jacket for healthcare monitoring, the architecture of which is based on commercially available and cost-effective hardware components, open-source software and a remote data repository for storage. In particular, the system utilizes a number of wearable medical sensors to measure different patient bio-signals which are all collected to a wearable microcomputer station. Medical sensor measurements are then categorized based on the criticality of the measurement and transmitted to a remote station. This long-range transmission is supported by a new network adaptive protocol designed to mainly transmit real-time medical data. In a prototype system, tests based on real-time and close to real-time transmission architectures have so far yielded favourable results in comparison to other existing protocols

KEYWORDS: HEALTH JACKET, IOT, REMOTE MONITORING, E-HEALTH, HAPTICS, WEARABLE SYSTEMS, SENSORS.

1. INTRODUCTION

Wearable Health Monitoring Systems (WHMS) have drawn a lot of attention during the last decade due to the recent technological advances in miniature bio-sensing devices, microelectronics, wireless communication protocols and equipment, as well as increasing healthcare costs (1).

In this study we will present a WHMS in form of a jacket which is capable of sending medical sensor measurements to the cloud and categorize the sensor data based on the criticality of the measurement.

This paper describes the collection of large-scale medical (e-health) data (BigData) in real-time of sensor devices and actuators. For that purpose, WHMS are worn in patients suffering from chronic, or rare, or health problems. These data are transferred real-time through the Internet to a Cloud Server, and are processed and analyzed in Cloud Computing (CC).

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The rest of the paper is organized as follows: Section 2 presents a related work on Wearable medical systems. Section 3 presents the sensors that were used to monitor the patient's health status. Section 4 describes the high level system architecture of the remote WHMS. Section 5 analyzes the hybrid transport protocol that is used in order to transfer wirelessly medical data to the information system. Section 6, finally concludes the paper.

2. Related Work on Wearable Medical Systems

The rapid growth of the Internet and Cloud computing has brought a rapid increase in data traffic (2). Challenges relating to managing, analyzing, and transferring this huge amount of data are analyzed in (3). These challenges of Large Scale Data mainly concern their representation, redundancies, their quality and variety, life-cycle management, confidentiality, their dependability and extensibility, energy management, heterogeneity and diversity, their speed and accuracy, privacy and security, storage, knowledge mining, the creation or development of their analysis tools and algorithms / techniques, as well as other serious issues that require improvement. A performance evaluation of the transmission protocols that are commonly used for medical data is analyzed in (4) and (5). A protocol for transport of medical data has already been proposed in (6). An interesting study for big data analytics for ehealth data is proposed in (7).

As medical data are extremely sensitive a security issues should be taken into considerations. A research that analyzes IoT security issues is has published in (8).

As patients are freely to move, wireless transmission of data is necessary. For medical data with high update rate specific transport protocols should be enforced (9).

3. Health Monitoring Jacket Design

The main aim of the proposed system is the recording of patient's medical and tactile data by using biomedical and tactile sensors, and sending this data using wireless network infrastructure. Historical recording and statistical processing of data are also collected and stored in a cloud server. This system could be used to monitor medical data of patients in real-time or with post-processing:

- Within the clinic and in general at the hospital where the patient will be hospitalized
- When moving to the hospital (ambulances)
- At the patient's home
- Wherever the patient is located

3.1 System design

Therefore the health monitoring jacket design has some important and essential requirements related to the sensors and data transmission. Since the system is composed by the proposed health monitoring jacket and the information retrieval system that informs doctors and health professionals for the patient's health, the factors that were taken into account at the design process are:

- Mobility: The jacket should be easy to wear, and allow patient work and move without restrictions. Potential problems such as lost signal and battery duration shall be taken into consideration.
- Quality of service: It is very important to have accurate measurements transmitted appropriately to the server. Parameters such as data accuracy, delay, jitter, data rate etc. shall be taken into consideration
- Data sensitivity: The acquired medical data is sensitive and shall not be available only to the patient itself and his/her supervising doctor. Therefore adequate network safety mechanisms shall be applied along with user rights module at the information system.
- Cost: One of our main aim is to propose a system that has affordable cost so as to be a good investment for health organizations and hospitals.

3.2. System Medical Sensors and Data Collectors

The Vest will be able to interface with certified medical sensors that will be able to record:

1. Body temperature (temperature sensor)
2. A special distress button that when pressed, will send an immediate alert to the clinic to send an ambulance to the patient's address. There will also be a GPS positioning feature to send the exact location of the patient when s/he moves outside his/her home or hospital
3. Glucose levels (intercalated sacharometer in the electronic jacket for recording blood glucose levels (external sensor interconnected and removed from the waistcoat)
4. Accelerometer and gyro sensor for recording body movements
5. Galvanic perspiration recording electrode
6. Pressure gauge for pressure measurement (external sensor attached and removed from the vest)
7. Small Electrocardiography Device (3-9 ECG Electrodes for Monitoring Heart and Heart Pulses)
8. Exhalation Inhalation Monitoring Sensor (Patient Breath Monitoring)
9. Oxygen levels of the blood (external oximeter sensor attached and removed from the vest)

10. Tactile sensor for recording hand movements

The sensor’s data collector will be responsible for collecting-storing the sensor’s signals and sending them in a wireless way to the information system database located in the hospital clinic or in the cloud.

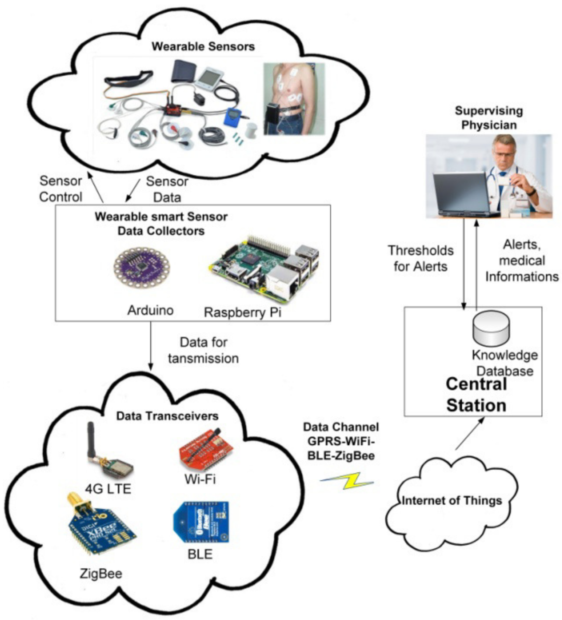
The controller will be positioned at the waist of the jacket. On-demand interconnection sensors will have special terminal interfaces at the top of the vest that will be connected via conductive fibers to the recorder controller.

Sending data from the vest will be either event-based or periodically driven via a low-power (0-14dBm) radio transmitter, low transmission rate, maximum coverage (500m-3Km), and SAR no more than maximum based on the European directives (2W / g on sample 10g-recommended due to continuous exposure of 0.3W / g) placed on the controller.

In the event that the patient's health is in risk by the wireless connection that sends the measurements, it will be possible to save the medical data in the storage area of the controller and to send it via a wired cable. Hence, the patient will be able to connect his/her jacket with a cable through the home network at regular intervals of the day and send the patient's measurements to the clinic's information system.

The controller will be powered by a battery that is located around the waist of the jacket for at least 2 days and a dedicated charging socket as well as a visual and audible alert for the battery charge level.

4. SYSTEM ARCHITECTURE



A WHMS is developed based on wearable sensors to exchange patient data with a Central Station. The data transmission is performed using services over existing wireless technologies (3G/4G or Wi-Fi) and protocols.

The proposed jacket utilizes low-cost off the shelf sensors, computing and transmission components, to provide an economical solution to personalized health care monitoring problems, while retaining all the functionality and flexibility of more expensive systems.

The health monitoring jacket will consist of the following basic components:

- The jacket with the interfaces (sensor interface plugs) and the interface sensors. From these, it will be possible to select the desired sensors and the vest controller will automatically recognize which ones are used or interconnected in the vest at any time.
- The jacket controller and the sender (wired - wireless) subsystem of the controller.
- The controller power supply system (battery-charging system - charging indication).
- The processing subsystem, which will process in real time all the indices mentioned in the next subsection. The information subsystem for storing and further processing the recorded data coming from the jacket. This subsystem will be located at the institution's premises, and may be related (through data export) to the overall medical history of the patients.

5. MIDDLEWARE COMMUNICATION PROTOCOL

In order to transfer the sensitive medical data, a hybrid wireless data transmission protocol is proposed. This protocol takes into account all modern wireless data transfer methods. The specificities of each wireless network has been examined. The data transmission protocols that have been tested are the ZigBee, the Bluetooth Low Energy, the LoRaWan, the WiFi 802.11ac and 4G/LTE.

If the patient is near the Internet access point, at a distance closer to 50m, and the energy of the vest is adequate, the health jacket will use the wireless protocol WiFi 802.11ac to directly send its data to the cloud. If the patient is more than 50 meters apart and less than 500 m from the Internet access point and that the vest has limited power, the ZigBee protocol will be used using a modified data transfer protocol based on the CoAP protocol.

If the patient distance from the internet getaway is more than 500m and closer to 3000m the LoRa protocol will be used to send only crucial medical data.

If the patient is in an area not covered by the above protocols then the 4G / LTE mobile network will be used.

The maximum data transmission rate relative to distance for each of the above protocols has been recorded and is illustrated in Table I. The power consumption of the two protocols is depicted in Table 2.

TABLE I. THROUGHPUT MEASUREMENTS FOR ZIGBEE AND LORA WIRELESS TECHNOLOGIES

Transceiver	**Range (m)**	**Signal Power (dBm)**	**Throughput (Kbit/s) – Packet loss <3%.**
SX1276 LoRa	500	-72	120
Xbee	500	-78	94
SX1276 LoRa	1500	-89	64
Xbee	1500	-	-
SX1276 LoRa	4000	-104	3.6
Xbee	4000	-	-

TABLE II. BASIC CHARACTERISTICS OF ZIGBEE AND LORA WIRELESS TECHNOLOGIES

Transceiver	**BW (KHz)**	**Carrier Freq. (MHz)**	**Tx Power (dBm)**
SX1276 LoRa	125	433/868	23
Xbee 63mW	125	2400	17

It is understood that the Lora protocol sends data to a far greater distance than the Zigbee protocol, but the Lora protocol consumes 6 dbm more power than Zigbee. Zigbee can send data to a distance greater than 500m but this threshold has been chosen for security reasons.

If the patience is in the WiFi area, then all medical data are sent real-time, as WiFi's throughput is adequate for this transmission. If the patient is in Zigbee, LoraWan or LTE area, then only the crucial medical data are sent real-time. All the other data are stored in a local data base and send to the cloud when the patient reaches the WiFi area.

As medical data are sensitive, the encryption of data is necessary. The AES128 encryption is used for every data that is transmitted.

6. CONCLUSION

As medical information is growing with geometric progress, the ability to inform real-time the physicians about their patient's health is crucial. E-health mobile devices are a powerful tool for managing medical information, enhancing medical knowledge and supporting medical action. This paper proposed a Wearable Health Monitoring System for monitor patient's health real-time. A hybrid communication protocol for this wearable monitoring system is proposed. An evaluation of the wireless technologies that are used is presented. The proposed communication protocol takes into account the battery of the wearable system, the distance between the patient and the access point, and the nature of the medical data that have to be transmitted. The high level architecture of the monitoring system is depicted and analyzed. The medical, motion and tctile sensors that can be used from the monitoring system are described. The factors that should be taken into account for the design of wearable medical systems are presented and analysed.

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