A Wireless Body Area Network for Remote Observation of Physiological Signals

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***Abstract*—The objective of this work is to describe the design process of a wireless body area network (WBAN) for the remote observation of multiple physiological signals from a patient. Various sensors such as temperature, heart rate monitor utilizing electrocardiography, and accelerometer to detect fall and seizure conditions were integrated in the WBAN. Sensed data is wirelessly transmitted to the central control unit (CCU) that is associated with a remote base station. For benchmarking, medically certified sensors were employed to validate wearable sensors data. The sensor information can be ported in the cloud environment using CCU-based gateway with Global System for Mobile communication (GSM) modem capability. This mechanism is facilitating remote access to sensors information. To connect Radio Frequency (RF) units wirelessly, Zigbee mesh topology was adopted. In this way, they can be remotely overseen, managed and controlled by assigned staff. The presented prototype featuring the desired WBAN system performance was evaluated with different human postures and moving scenarios.**

Wireless body area network (WBAN) platforms have evolved significantly over the last few years. These typically integrate sensing and radio modules for remotely observing patient health and physical parameters.[1,2] With WBAN, individuals can easily keep track of their beloved ones in addition to healthcare professionals while they are away. Continuous monitoring and

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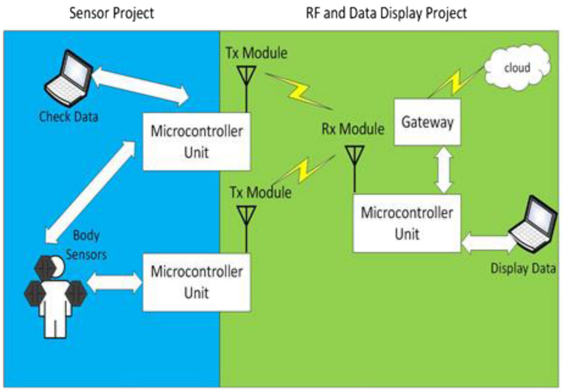

Figure 1. Presented system architecture.

Figure 2. Wearable sensor units featuring the developed WBAN.

data collection shown to significantly reduce medical complexities at later stages.

In the past few years, a number of topologies has been developed for WBAN and remote observation.[3,4] However, most of these developed prototypes are not sizably compact to be worn by patients. In the work done by Abiodun et al.,[5] an algorithm to reduce power consumption in WBAN by dropping the non (and semi)-urgent signals while transmitting only the urgent data to the medical server was presented. However, only one node (a diabetic sensor) is considered. Also in the work done by Abiodun et al., [5] the testing was done using OMNET++ simulator without implementation.

This work aims to build a reliable multisensor WBAN for personal health observation with emphasis on monitoring vital physiological signals such as heart rate and muscles acceleration. The proposed system uses accurate and compact medical sensors selected carefully to assure a robust low-cost system intended to help and facilitate remote monitoring of patients' physical health.

SYSTEM OVERVIEW

The work presented in this article can be divided into two phases; selection of sensing units and integration of wireless communication modules. Figure 1 outlines the architecture of the system framework including the two, sensing and communication, phases.

The first task was picking the appropriate sensors. The heart rate sensor was the hardest to select since it supposed to overcome artifacts due to body movements. Detection of fall and seizure of lonely patients is also important. Room and body temperatures were also recorded estimate body activity levels and fever condition.

In addition to these four sensors, more biomedical sensors can be incorporated in the proposed system due to its modular architecture.

SENSOR INTERFACE

Since the microcontroller board would influence the selection of sensors, Arduino Uno board with ATmega328 microcontroller is selected. Polar Heart Rate Monitor Receiver (HRMI) and Polar T31C wearable sensor were identified to be suitable for measuring heart rate signal.[6] The receiver unit converts the received heart rate information from the wearable sensor to electrocardiography (ECG) data. This method is convenient since the patient can wear a strap at any time and in any position.

A wearable accelerometer (ADXL345) was used to record the falling and seizure events and trigger an alert if necessary. An onboard HTU21D temperature sensor is used to monitor the indoor temperature and humidity.[6] The HTU21D offers a precision of +/– 0.3 °C for temperature and +/– 2% for moisture which is adequate. MLX90614 was used to log body temperature.[6] This infrared sensor reads skin temperature with a precision of +/– 0.5 °C in the extent of 0–60 °C which is satisfactory.

The sensors were placed in chosen locations deliberately, offering a high level of patient solace. As shown in Figure 2, HTU21D and MLX90614 units are connected to the arm, where ADXL345

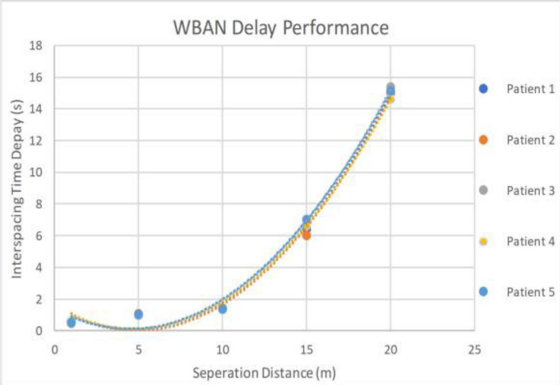

Figure 3. Arrival times of data from patient.

Table 1. Results of the falling trials.

	Trial test1	Trial test2	Trial test3
Forward falling	Detected	Detected	Detected
Backward falling	Detected	Detected	Detected
Sideway falling	Detected	Not Detected	Detected

and Polar HRMI units are appended to the belt. An Xbee unit is used as the Radio Frequency (RF) module to transmit the collected data.

WIRELESS SYSTEM CONFIGURATION

First, Xbee modules' operation was evaluated in a point to point arrangement. The coordinator of the network (CCU) was configured in the application programming interface mode to administrate the system topology.

The ad hoc on-request distance vector mesh routing approach[6] was employed to control the information packets between different wireless modules. The route identification process starts with the broadcasting request command. When the destination module gets the request, it would perform a comparison with previously received requests and send back to that module if it has a better cost to establish the link with the source point. All intermediate nodes will receive and forward data packets to the desired destination. In order to pass information to the cloud-based administrative web, thinkspeak server and Xbee CCU were chosen to act as the middle agent.[6] This arrangement flawlessly bridges the Xbee modules with the Internet showing all types of network interactions.

PERFORMANCE EVALUATION

One objective is to measure the time delay that packets will take to be delivered to the final destination, by conducting tests on a number of patients. This was done by recording the received time at the CCU from each patient at different locations ranging from 1 to 20 m on tests performed with 5 patients. These are shown in Figure 3. It is obvious that the time delay is comparable for all five patients and it is fewer than 2 s for less than 10 m separation.

Temperature

The HTU21D and MLX90614 functionalities were assessed to verify the precision and possible correlation. The tests were run for a roughly 17 h. The sensors were close to each other to guarantee a reasonable estimating condition. Tests run showed the comparable performance of both sensors clearly in reading the temperature with a small maximum margin of approximately +/– 0.75°C.

Acceleration

The fall recognition was studied by utilizing Triaxial accelerometer incorporating falling postures in various ways. Tests were performed by falling onto a dozing cushion on the floor from the defined sites. Falling backward, forward, and sideways were three tested possible conditions.

Correct detection rate of 80% was set as the threshold for accurate fall identification. Table 1 exhibits the three-run tests coordinated at the three falling conditions.

Just a single run sideway condition failed the test, however, this can be clarified due to nonideal settings of the equipment. Following the design plan, the free fall hinder is activated when the free fall limit setting is surpassed amid the free-falling expected time. These settings were suggested as empirical figures with the goal that they would be touchier in identifying the fall occasion.

Muscle acceleration signals can also be utilized to detect different types of seizure. Accordingly, our sensors were placed on both arms and lower legs to gauge the seizure muscle activities utilizing the fused seizure discovery calculation.[7]

Table 2. Pilot test results.

Age	Gender	Test timeframe (minutes)	Level of sensitivity	False rate
20–32	F	114	0.614	0.307
	M	158	0.685	0.364
33–47	F	357	0.722	0.363
	M	272	0.776	0.379
48–65	F	73	0.652	0.401
	M	95	0.653	0.395

Pilot trials were performed to gauge the performance of our seizure measuring system in comparison with video based clinical EEG testing. Table 2 shows the information gathered from the seizure observations during the pilot tests. 65% was set as an acceptable sensitivity factor. The platform tests were satisfactory with less than 40% a negative false rate and around 11% a positive false rate.

Heart Rate

The observed heart rate information was compared with the data read by the polar watch and a bicycle grasp heart rate activity screen. This was done under four conditions. These were, while the patient was 1) resting, 2) with light movement, 3) in direct action, and 4) in energetic action. The heart rate information acquired from the sensors clearly indicated the associated behavior under each condition.

For benchmarking, medically certified sensors were employed to validate wearable sensors data. Initially some discrepancies were found, however, after increasing the sampling rate to 10 samples/second seems to improve the performance significantly.

The relationship between false alarms and missed detection depends on the characteristics of the decision making process. The ideal scenario would be for both probabilities to be extremely small. In the real world this is not possible, because a reduction in false alarms often leads to an increase in missed detection and vice-versa. But we can get close by using an appropriate decision making rule and the threshold value algorithms according to Neyman–Pearson lemma. The outcome, however, depends on the probability density functions of the events under concern.

CONCLUSIONS

In this article, a new WBAN platform utilizing multiple biomedical sensors was developed for recording physiological signals to medicinal applications. The presented WBAN architecture can be useful in remote patient care.

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