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Wireless Remote Patient Monitoring in Older Adults

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Abstract— **Wireless patient monitoring systems are emerging as a low cost, reliable and accurate way of healthcare delivery. In this paper we present a wireless remote vital sign monitoring system with audio/video data transmission. Vital signs include; blood pressure (systolic and diastolic), heart rate, pulse, oxygen saturation, body temperature, lungs air volume and blood glucose level. In addition, a two-way audio/video communication link connects patients to their healthcare providers. The proposed system employs a computer-based software application that effectively incorporates current data with electronic medical record in order to enhance patient care. We evaluated this system with 10 individuals for assessing its acceptability by the users and its compatibility with other medical devices. A clinical trial with more than 30 participants aged over 65 years is also in progress at a local hospital.**

I. Introduction

This Advanced information technology and communication devices enable healthcare providers to facilitate complex medical problems, minimise errors and reduce the overall healthcare costs. According to the World Health Organization (WHO):

"*The delivery of healthcare services, where distance is a critical factor, by all healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of healthcare providers, all in the interests of advancing the health of individuals and their communities*" [1].

Recent research is highly focused in the area of remote/wireless patient monitoring, using body sensors, wireless devices and/or wearable garments. Patient monitoring systems are playing a critical role in decision support, early diagnosis and knowledge-based support to the healthcare professional.

Today, such expert systems are being designed and developed for every possible healthcare scenario i.e. emergency department, remote monitoring of indoor and outdoor locations [2]. Remote monitoring systems, in particular, play an important role when patient-doctor is at a distance and such systems are capable of reducing healthcare related costs and enhancing the quality of patient healthcare delivery [2]. Commonly monitoring vital signs are; blood pressure (systolic and diastolic) (BP), heart rate (HR), pulse rate (PR), oxygen saturation (Spo2) and body temperature (Temp). This study aims to develop a clinically useful patient monitoring and alarm system. Initially, the proposed system will be installed and implemented at an older adults ward in a hospital setting with the aim of collecting patient's physiological signals (vital signs) wirelessly for early diagnosis and/or intervention. Ultimately, the developed system may be employed as an efficient monitoring system in a broader community.

II. System Review and Challenges

Majority of work in the area of wireless remote patient monitoring can be divided into two types of systems; body attached sensor-based monitoring (wired or wireless) and medical device-based wireless monitoring. The development of 'Electronic Doctor's Bag' [3], with mobile communication link, is an example of the latter for home medical services. This system was tested in two clinics and one hospital with three medical doctors and two nurses. It measures physiological data such as ECG, BP and blood sugar level as well as performs ultrasonic diagnosis of the patient with compressed and coded video images. A case study has been set up with a pilot trial of the system in integrating tele-healthcare and decision support in the patient care management of chronic obstructive pulmonary disease and chronic heart failure [4]. The system was able to identify any risks when individual measurement exceeds the predetermined or adaptive thresholds limits. This process was performed by its core decision support system and knowledge-base. Up to 24 hours of constant monitoring of older adults was proposed with possible extension to a longer term monitoring and detecting abnormal events and emergency cases. Such events can be reported to the relatives or healthcare professionals by telephone, SMS and e-mail. However, these systems should be able to deal well with security and privacy issues [5].

A computer-aided bedside vital signal monitoring system consists of a bedside monitor and a central monitor was developed based on an industrial standard [6]. The central monitor allows real-time access to the bedside data via standard software interfaces to facilitate the communication between the devices. This system performed well in a robust and real-time handling of up to 16 bedside monitors.

McLean et al. [7] was conducted a research to identify the technological impact of wireless remote patient monitoring systems on people living with prolong medical conditions and also people living in remote areas with limited mobility. It is reported that such systems are cost-effective and can offer significant enhancement in the healthcare delivery. These systems are evidently useful in early diagnosis [8] and are low cost [9] and in some cases

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can reduce hospitalisation [10]. Therefore, accuracy, reliability, delay in communication and security and privacy are some of the challenges facing wireless remote patient monitoring systems. More attention towards the user acceptability and feedback should be considered in the design and development of such systems.

III. Proposed System Model

A. Medical Devices Connectivity and Data Transmission

Fig. 1 shows off-the-shelves medical devices and a set-top-box used in this model to achieve high data reliability and accuracy. The system is capable of collecting multiple physiological parameters simultaneously from multiple patients. A brief description of the devices are shown in Fig. 1 is given below (number 1-8 refers to the medical device shown in Fig. 1);

1. Set-top-box: It runs an application which receives patient’s physiological data from different medical devices and transmits the data in real-time over a secure internet connection to a PC or laptop.

2. Blood pressure monitor: Boso-medicus prestige BP monitor is a wireless Bluetooth device which measures BP and pulse rate [11]. It can record the data at user defined time intervals using a simple user interface feature.

3. Pulse Oximeter: Nonin’s Onyx II finger clip oximeter is a wireless Bluetooth device which records oxygen saturation and heart rate continuously [12].

4. Blood glucose meter: Accu-Chek Compact plus blood glucose meter is a wireless infrared connected device which records blood glucose level [13].

5. Ear temperature: Omron’s instant ear thermometer is an instant and compact ear temperature measurement device [14].

6. Body temperature: G-plus wireless remote body temperature used for continues body temperature

Figure 1: Medical devices used for the proposed patient monitoring system.

measurement [15].

7. Spirometer: nSpire’s Piko-6 meter is a wireless infrared connected device which measures forced expiratory volume at one and six seconds FEV1/FEV6 [16] and presents numbers related to inhale exhale air volume.

8. Accelerometer: Gulf Coasts Data Concept’s accelerometer/Magnetometer Data Logger X8M-3mini [17] is a compact, continues data collection device used for fall detection in the proposed system.

B. System Working Model

Fig. 2 shows the proposed system’s working architecture as a clinically useful monitoring and diagnosis system. Patient’s physiological data is collected wirelessly using off-the-shelves medical devices which are integrated into the set-top-box for collecting and transmitting patient’s vital signs in real-time to PC-based software application. The diagnostic module then reads the data file, converts to a readable format and pre-processes the data using the batch processing technique.

Fuzzy logic approach is used to best interpret the pre-

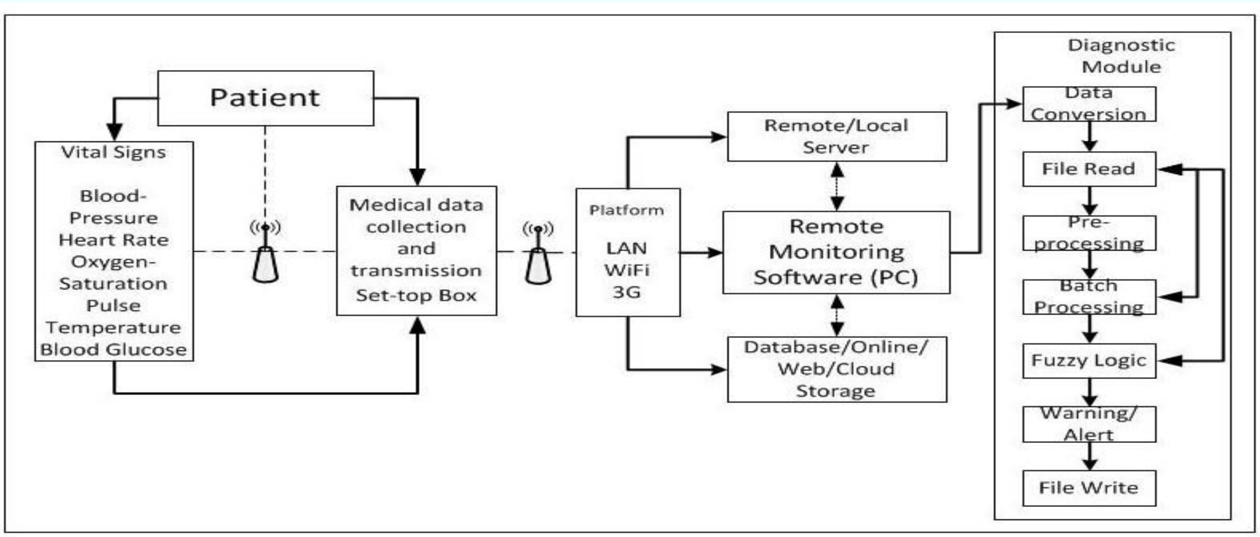

Figure 2: Block diagram of the remote monitoring system with diagnostic module.

processed data in association with a diagnosis concept such as; ‘Hypertension’ and ‘Hypotension’ instead of a set crisp values. Using Fuzzy logic, the continuous coinciding shift from ‘Hypertension’ to ‘normal BP’ feeds our module to sense that 150 mmHg (mean arterial pressure) is 70% ‘Hypertension’ and 30% ‘normal’ which would be expressed as ‘hypertension likely’. Fuzzy sets, membership functions and rules are derived using normal and abnormal vital sign ranges annotated by a physician as well as from the literature [18].

C. Experimental Results of Diagnostic Module

The diagnostic module was tested offline using approximately 200 hours of patient data related to hypertension. Diagnosis results are compared with medical expert’s offline diagnosis using Kappa analysis. Alarms were classified into four categories; true positive (TP), true negative (TN), false positive (FP) and false negative (FN). The accuracy, sensitivity and predictability values are calculated using these four parameters [19] with the results presented in Table I. A comparison was made between the proposed system and the Auckland City Hospital’s Datex-Ohmeda S/5 monitor as presented in Table I.

TABLE I

HANDLING OF ALARMS IN THE PROPOSED DIAGNOSTIC MODULE

Alarms	Proposed System	
	Diagnostic module	Datex-Ohmeda S/5 monitor
TP	117	104
TN	296	327
FP	26	82
FN	7	35
Total Alarms	446	548
Accuracy (%)	92.60	78.64
Sensitivity (%)	94.35	74.82
Specificity (%)	91.92	79.95
Predictability (%)	81.81	55.91

Where TP is true positive, TN is true negative, FP is false positive, FN is false negative.

IV. SYSTEM EVALUATION AND EXPERIMENTAL RESULTS

A. Technical Verification of Medical Devices

Medical devices as shown in Figure 1 were tested individually before integrating into the system and starting the data collection. Automatic BP meter was evaluated with the manual mercury column meter and showed that the wireless BP meter was more accurate on left hand and in the sitting position. Pulse oximeter was verified using a one-minute manual test and showed accurate results but in some cases wireless meter took longer than 10 seconds to provide stable measurements due to the finger clip movements. Ear thermometer was verified with the mercury thermometer and found to be accurate with both ears.

Wireless data transmission test was also showed no errors in real-time data transmission from patient set-top-box to PC based software. We used a mobile internet USB data stick for a 3G network with good internet connectivity.

B. Device Specifications

Table II shows the specification of medical devices in terms of size, power, data collection and cost. These are critical factors to be considered by the patients (users) and medical professionals. The medical devices listed in Table 2, were selected for their low cost, accurate, medically approved, and most importantly their wireless connectivity features.

TABLE II

MEDICAL DEVICE SPECIFICATION AND THEIR FUNCTIONALITIES

Medical Device	Model	Connectivity/ Transmission
Blood Pressure	Boso-Medicus Prestige BT	Wireless/ BT
Pulse Oximeter	Onyx-II	Wireless/ BT
Blood Glucose	Compact Plus	Wireless/ IR
Ear Temp.	Instant ear thermometer	Wireless
Body Temp.	Wireless body thermometer	Wireless/ BT
Spirometer	Piko-6	Wireless/ IR
Accelero-meter	8-XM3-mini	Wireless

Where BT is class-2 Bluetooth, IR is infrared.

C. System Evaluation

Ten individuals including (6 males and 4 females), average age 60 years were asked to participate in this part of system’s evaluation. They evaluated the characteristic of each device in terms of mobility (size and weight), usability, comfortability and overall acceptability using a score of between 0 to 10 (10 is completely satisfied, 5 is neutral and 0 is completely unsatisfied). Table 3 shows more than 70% acceptability for all devices with the exception of blood glucose meter which achieved 63% because of the use of needle onto the fingertip.

V. CONCLUSION

The proposed system is evaluated with 10 individuals for mobility, usability, comfortability and overall user’s acceptance. The results (Table III) show high acceptance from the users. The most important and critical aspect is the configuration of different medical devices in one system (set-top-box), which collects and transmits the patient’s physiological data in real time without any time dely. In addition, the collected data is analyzed and an alert/warning for any potential abnormal event is sent to medical professional. This paper focuses on investigating current limitations of this technology from different points of view such as; interoperability, complexity, high cost and user acceptability using the proposed solution [20]. It also introduces a combination of a number of off-the-shelves

TABLE III

EVALUATION OF MEDICAL DEVICE FOR MOBILITY, USABILITY AND COMFORTABILITY

Device/User	Categories	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Total Score	Overall Average Score (%)
Blood Pressure	Mobility	5	8	5	5	8	8	7	6	6	5	63	80.33
	Usability	10	10	10	8	10	9	9	7	8	10	91	
	Comfortability	8	7	8	10	10	9	9	8	9	9	87	
Pulse Oximeter	Mobility	10	10	10	10	10	10	10	10	10	10	100	95.66
	Usability	10	10	10	10	10	10	10	10	10	10	100	
	Comfortability	9	8	9	8	7	8	9	10	9	10	87	
Blood Glucose	Mobility	6	5	8	6	8	6	9	7	4	5	64	63
	Usability	6	8	6	7	9	7	8	5	5	7	68	
	Comfortability	5	7	6	8	7	5	8	4	2	5	57	
Ear Temp.	Mobility	8	10	9	8	7	9	10	8	9	7	85	78
	Usability	7	7	8	5	9	8	10	8	7	9	78	
	Comfortability	8	7	9	8	10	7	8	10	9	10	86	
Body Temp.	Mobility	8	9	7	8	7	9	8	7	8	9	80	78.75
	Usability	10	9	8	9	8	9	10	9	7	8	87	
	Comfortability	6	7	8	5	6	9	7	9	8	5	70	
Spirometer	Mobility	9	8	9	9	7	8	9	6	7	8	80	70.66
	Usability	4	5	8	9	6	5	7	8	9	5	66	
	Comfortability	6	8	5	7	6	5	8	9	7	5	66	
Accelerometer	Mobility	8	9	7	5	6	8	7	8	9	5	72	85.66
	Usability	9	9	10	10	10	9	9	8	9	8	91	
	Comfortability	10	10	9	10	9	10	10	8	9	9	94	

P1-P10 represents 10 participants and overall average score is calculated by averaging the total score for mobility, usability and comfortability of each device.

medical devices and a set-top-box to address the limitations and offers more features such as; reliability, efficiency, data quality and security and privacy. The proposed solution can be implemented in home; as a remote and continues home monitoring or in hospital; as point of care. Clinical trial of this system is underway in a local hospital, which will give us an immense opportunity to implement this solution in real medical environment and help older adults as well as medical professionals.

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