

A Wireless Oxygen Saturation and Heart Rate Monitoring and Alarming System Based on the Qatar Early Warning Scoring System

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Abstract— Monitoring vital signs and alarming healthcare emergency response units whenever measurements are outside the normal range could be life-saving for high-risk patients who are living alone or sleeping. This paper presents a system that wirelessly obtains the oxygen saturation and heart rate from patients using a pulse oximeter. An SMS alarm with the measurements is then sent to hospitals to contact the patient or dispatch an ambulance in case he/she does not respond. The SMS also contains the patient's GPS coordinates. The decision whether an alarming SMS should be sent is based on the Qatar Early Warning Scoring (QEWS) system. In this work, a base station unit to receive and analyze data coming from the sensor was developed and tested.

Keywords- Heart rate; Oxygen saturation; Pulse oximeter; Qatar Early Warning System.

I. INTRODUCTION

The innovations in wireless communication and vital sign sensors allow the continuous and remote monitoring of patients suffering from pulmonary and cardiovascular diseases, sleep disorders, and respiratory infections. The aim of this technology is to detect such disorders and alert healthcare authorities as soon as possible so that patients receive the appropriate treatment with minimal delay. Two of the most critical vital signs in the human body that can reflect its health status are the oxygen saturation in the blood (SpO₂) and Heart Rate (HR). Pulse oximetry or arterial blood saturation stands for saturation of peripheral oxygen. It is a non-invasive diagnostic tool used to measure oxygen saturation concentration in the blood as well as HR. Continuous monitoring of HR and SpO₂ is considered essential for high-risk patients. Decreased SpO₂ level, termed hypoxemia [1], may exist due to several medical conditions that include cardiovascular diseases [2], Chronic Obstructive Pulmonary Diseases (COPD) [3] and anemia [4]. On the other hand, the HR is a useful indicator of certain types of arrhythmias and can also vary due to other factors like emotional state, sleep, level of exercise, age, gender, temperature, and circulating chemicals [5].

The work presented in this paper describes the design and implementation of a standalone, portable and easy to use system for acquiring SpO₂ and HR measurements wirelessly as well as the patient's Global Positioning System (GPS) coordinates. The acquired parameters are

then sent by the proposed system to an emergency response unit via a Short Message Service (SMS) whenever the SpO₂ and HR values are outside the normal range. The normal ranges for these measurements are determined according to the Qatar Early Warning Scoring (QEWS) system. This system is used by the ambulatory services in the state of Qatar. Clinical personnel may then communicate with the patient or relatives to confirm his/her health status or dispatch an emergency unit.

The rest of this paper is organized as follows. Related work and their limitations are presented in section II. Section III is concerned with the overall system description and implementation. Obtained results are discussed in section IV. Finally, section V concludes the paper and proposes future work.

II. RELATED WORK

The suitability of non-invasive pulse oximeters for continuous monitoring of SpO₂ and HR have led to the development of several systems which consist of a pulse oximeter sensor, a processing unit and a display [5]. Several systems have been developed entirely by researchers [6, 7, 8], including the sensor, while others have utilized commercially available sensors [9, 10, 11]. For portable applications, data from the sensor are sent wirelessly via ZigBee [6, 12, 13] or Bluetooth [3, 10, 14] to a base station, like a PC/laptop, PDA or smartphone for further processing and display. A disadvantage of using PCs or laptops as base stations is that portability is lost and the system range becomes limited. PDAs or smartphones are then more suitable for portable applications. On the other hand, from a financial point of view, owning one could prove to be difficult for some people. Moreover, patients need to be familiar with such devices in order to use the software applications associated with the oximeter system. This could be a difficult task for some patient groups, like the elderly.

In addition to the aforementioned it was observed that related work have the following limitations:

- Similar systems based on wireless communication that transmit the data from the sensor to a PC or a smartphone for further processing are more expensive.

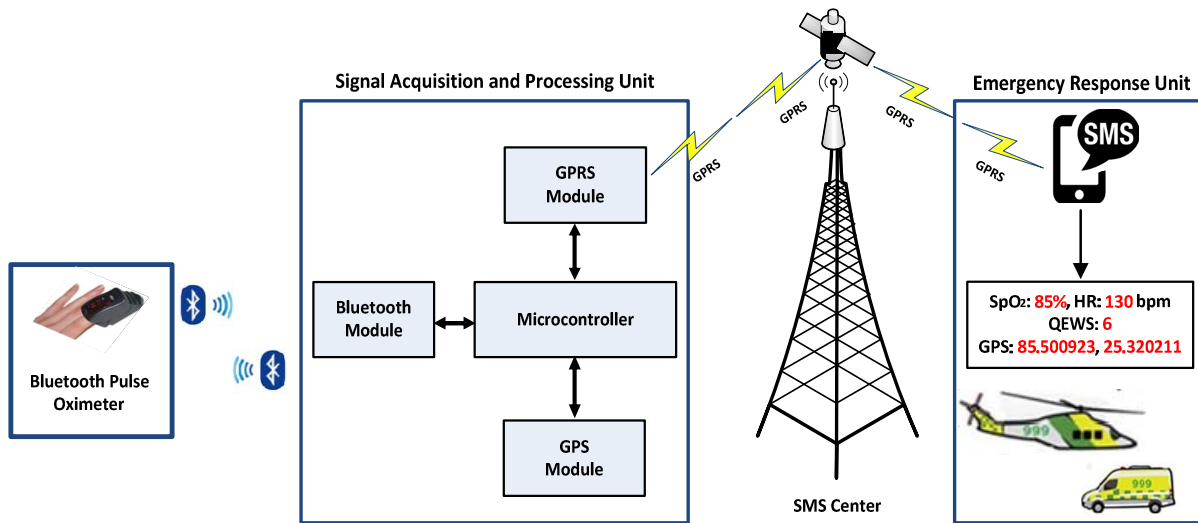


Figure 1. Overall System Design

- Previously developed systems do not include the SMS alarming option and they focus only on transmitting SpO₂ and HR readings to a PC or a smartphone.
- None of the existing ones transmit GPS coordinates of patients. This is important since from an ambulance service point of view, determining the exact location of the patient is the most important factor for improving response time.
- Finally, existing systems do not provide any initial assessment regarding the criticality of the patient's health.

III. SYSTEM DESCRIPTION AND IMPLEMENTATION

The proposed system aims to address the abovementioned limitations by: 1) providing a cheaper solution that will utilize a microcontroller instead of a PC/laptop/smartphone, 2) including an SMS alarm that will enable data transmission over longer distances, 3) transmitting GPS coordinates so that ambulatory services are aware of the patient's location, and 4) providing an early assessment about the health status of the patient based on a well-established scoring system such as the QEWS that was mentioned earlier. The overall structure of the system, which consists of three stages, is shown in Fig. 1.

In the first stage, the readings of SpO₂ and HR are obtained in real-time from the patient using a Bluetooth-enabled finger pulse oximeter. In this design, the Onyx® II 9560 (Nonin Medical Inc., USA) pulse oximeter was used. It operates with the ISO/IEEE 11073-20601 Personal Health Data Exchange Protocol and ISO/IEEE 11073-10404, which provides interoperability as a pulse oximeter [15]. The Bluetooth technology used in this device is Serial Port Profile (SPP) with an operating range of 100 meters. The oximeter transmits a 4-byte data packet every second via

Bluetooth. The data packet includes the SpO₂ and HR measurements. The first seven bits of the second byte and the two least significant bits of the first byte are used to represent the HR and the third byte represents the SpO₂. The accuracy of the measurements is ± 2 digits for SpO₂ and ± 3 digits for HR. The device weighs 63 grams, including batteries, and has an operating life of 600 spot-checks (30 sec/spot-check) in a 6-month period [15].

During the second stage the obtained readings are received over Bluetooth by the signal acquisition and processing unit. At the heart of this unit is a microcontroller which is Bluetooth-enabled by a mini Bluetooth adapter v2.0 (Bluetooth dongle). The used microcontroller is an mbed LPC1768. The microcontroller is connected to a GPS and a GPRS module through the microcontroller's serial ports. The GPS module provides continuous latitude and longitude coordinates to the microcontroller. The received data by the microcontroller consist of the 4-byte packet from the oximeter and the GPS coordinates. The SpO₂ and the HR readings are then processed and a decision is made whether an alarming SMS should be sent or not to an emergency response unit based on the QEWS system shown in Fig. 2 [16].

QEWS	3	2	1	0	1	2	3
Respiratory Rate	<8			9-20	21-25	26-35	>36
Heart Rate	<31	31-40	41-50	51-100	101-110	111-129	>129
Systolic BP	<70	71-89	90-109	110-179	180-199	≥200	
Temperature		C		N		H	
SPO ₂	<90	90-92	93-95	>95			
AVPU	U	P	V	A			
A Score of 4 or more is a marker for Priority 1 transport							Total=

Figure 2. Qatar Early Warning Scoring System

The QEWS chart is a guide system used by ambulance services in Qatar to early detect a patient's severity of illness. It is based on patient vital signs and the level of consciousness. These physiological measurements (e.g. HR, respiratory rate, and SpO₂) are scored from 0 to 3 based on specific ranges of the readings. The total QEWS score is then computed by adding the scores of the individual physiological measurements. A total score of 4 or more is an indication for a patient at high-risk, however, an alarming SMS should be sent whenever the total QEWS score is 1 or more in order to check the patient's health status.

The core of the proposed system is the acquisition and processing unit. The design of this unit involves both hardware and software parts. It consists of a microcontroller, a GPS module, a GPRS module, a Bluetooth dongle and a 9 V battery. The language that was used to program the microcontroller is C++. This includes interfacing, data processing and transfer.

The third and final stage is concerned with sending the alarming SMS to the emergency response unit over the GPRS network using the GPRS module in case the received SpO₂ and HR measurements are outside the normal range. This means that the total QEWS score for this case is 1 or above.

Fig. 3 and Fig. 4 illustrate the flow chart for the processing of SpO₂ and HR measurements to obtain the individual QEWS scores based on the QEWS chart.

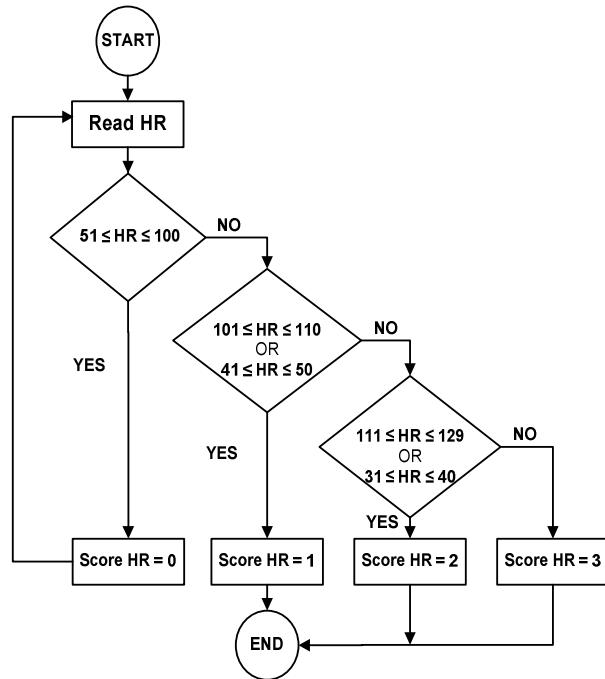


Figure 3. Calculation of QEWS score for HR

Fig. 5 shows how the total QEWS score is computed, which is achieved by adding the individual scores for HR and SpO₂. Whenever the score is 1 or above an alarming SMS is sent. However, it is worth mentioning that the

calculation processes for HR, SpO₂, and total QEWS scores illustrated in figures 3, 4 and 5 are repeated twice before sending the SMS alarm in order to avoid false alarms.

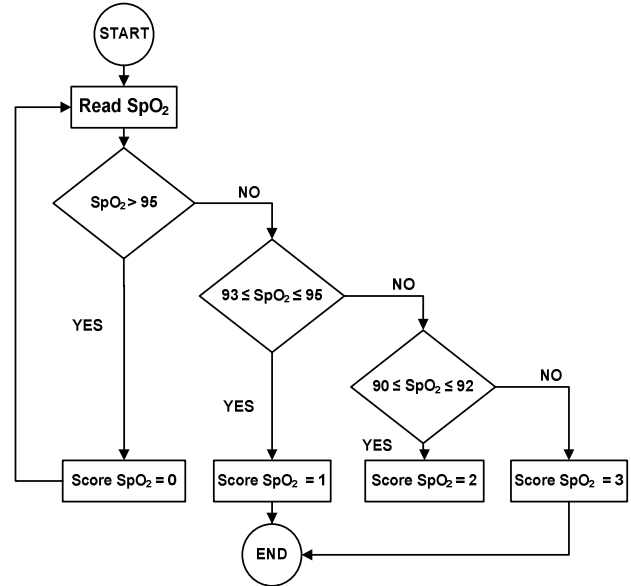


Figure 4. Calculation of QEWS score for SpO₂

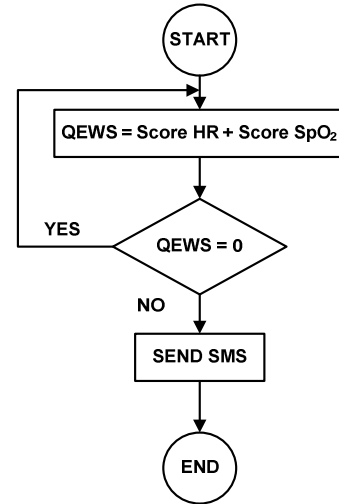


Figure 5. Total QEWS score calculation.

IV. RESULTS AND DISCUSSION

The system was implemented and successfully tested as a standalone unit. To verify the accuracy of the SpO₂ and HR readings of the developed system, a comparison test with a commercially available device (LIFEPAK[®] 15 monitor/defibrillator, Physio-Control, USA [17]) was performed. The accuracy of the LIFEPAK[®] 15 is ± 3 bpm for HR and ± 2 digits for SpO₂. The test was done by placing the Onyx[®] II 9560 and LIFEPAK[®] sensors on the right and left index fingers of a subject respectively for 3 minutes.

Both systems gave identical readings over this time period (0% error). In order to test the SMS alarm feature of the system, SpO₂ data received from a healthy subject were manipulated so that they were outside the normal range to trigger an SMS alarm. This was done due to lack of access to unhealthy subjects. To test the alarm feature due to increased HR, a healthy subject was asked to run on a treadmill until the HR was elevated above the normal range. An example of a sent alarm SMS is shown in Fig. 6.

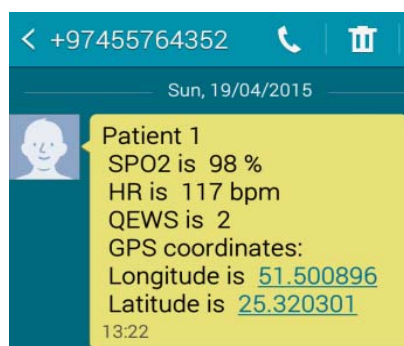


Figure 6. SMS Alarm

The cost of individual system components are \$330 for the oximeter, \$40 for the mbed microcontroller, \$2 for the Bluetooth dongle, \$35 for the GPS module, and \$60 for the GPRS module. The total cost of the system adds up to \$467. The cost of the system excluding the oximeter sensor is \$137, which is much cheaper than using a PC/laptop or smartphone for the processing and alarming part.

In the proposed system only two physiological measurements were used (i.e. SpO₂ and HR). This is the main limitation of the work; however, additional sensors for acquiring the remaining physiological measurements are currently being investigated. Another limitation is related to the fact that significant delays in delivering the alarm SMS may occur in the case that there are problems in the GSM network. A solution that will be investigated in the future would be to include a dual SIM module that will carry SIM cards from two different network providers. Finally, it is planned to develop a smartphone application as an extra feature that will allow patients who already own a smartphone to use it instead of the mbed-based unit.

V. CONCLUSION

Remote vital signs monitoring for high-risk patients who are living alone or sleeping could be life-saving. In addition, the hospitalization time can be reduced. In this paper, the design and implementation of a wireless portable and user-friendly SpO₂ and HR monitoring and alarming system has been presented. The designed standalone unit has been successfully tested using the QEWS system. In terms of future work, it is planned to include the patient's past medical history in the alarming SMS which will aid in the decision making process of the type of needed help. Moreover, additional body vital signs are planned to be

included in the system. Approval for clinical tests will also be sought in the near future.

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