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Research Article

Remote Monitoring of Vital Signs for The Development of Decision Support Systems in Medical Health Services

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ABSTRACT

Monitoring patients' vital signs such as pulse, body temperature, systolic-diastolic blood pressure, and SpO_2 plays a significant role in healthcare systems for post-operative patients, emergencies, infants, individuals with heart failure, pandemics, and similar situations. In this study, two different real-time remote monitoring and early warning systems (RTMEWS) are proposed to assist healthcare professionals and physicians in measuring and monitoring patients' vital signs. In the first proposed RTMEWS, SpO_2, pulse, and body temperature can be measured using a pulse oximeter developed with an ATMEGA328P microcontroller and MAX30100 sensor, and monitored via wireless transmission from the OLED GLCD screen on the prototype through an interface developed with the MIT2 application on a smartphone. In the second proposed system, when the measured pulse rate, body temperature, and systolic-diastolic blood pressure findings exceed the threshold range determined by the physician, a warning message can be sent to the mobile phone of the healthcare worker, doctor, or desired recipient via an MC35i terminal (GSM/GPRS modem) controlled by an AT command set connected to the computer where the data is stored. In conclusion, many factors influence the determination of normal and abnormal ranges of vital signs and intervention priorities. When unforeseen situations arise in clinical care processes, RTMEWS has been shown to assist professional interventions by generating timely alarms. The system provides a foundation for clinical decision support systems by offering real-time remote monitoring and autonomous threshold-based alerts.

1. Introduction

Cardiovascular diseases include peripheral artery disease, stroke, aortic disease, coronary heart disease, transient ischemic attack, and other heart-related conditions. Long-term irregular heart rhythm can pose a life-threatening risk. According to the World Health Organization, cardiovascular diseases remain a major cause of global mortality, leading to approximately 18 million deaths annually [1]. When a heart-related health emergency occurs, healthcare services are often not called in time. Therefore, engineers are developing various medical devices to monitor and diagnose a range of diseases [2]. Healthcare expenditures are one of the most significant concerns for both individuals and society. Numerous factors affect heart rate, including diabetes, age, gender, cholesterol level, and cardiovascular diseases. In recent years, significant advances have been made in health technologies and biomedical devices to meet the demands of modern health diagnosis and treatment. Although advanced medical equipment in health centers provides rapid and accurate analyses, real-time monitoring of patients, especially those with chronic conditions and the elderly, is essential [3, 4]. With the increasing elderly population and the prevalence of chronic diseases, routine healthcare services have become inadequate [5]. Today, it has become crucial that remote monitoring and decision support systems developed by engineers can transmit

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patients' vital signs to healthcare professionals in real time, especially for patients who cannot access healthcare services during emergencies [6]. In such systems, the security and privacy of patient data must also be addressed as critical issues [7].

RTMEWS are information systems designed to interactively support the decision-making process by tracking the patient's condition [8]. RTMEWS has been demonstrated to assist in various healthcare delivery and patient care decisions and is currently actively used in providing comfortable care. Support for RTMEWS continues to grow in the era of digital medical records [9, 10]. Today, with the increasing elderly population, home care is more challenging than clinical care due to the short duration of home visits [11]. Many current remote monitoring applications collect data from a single device, such as blood glucose monitoring. In the future, home care environments will increasingly incorporate user-friendly e-health technologies that provide multiple data inputs, including remote monitoring and remote patient data entry [12, 13]. A low-cost, real-time sleep apnea monitoring system has been developed for the possible detection of obstructive sleep apnea, a common sleep disorder [14, 15]. A study explaining the link between real-time remote health monitoring and big data characteristics in the patient prioritization process and highlighting open issues and challenges related to big data [16].

In both systems proposed in this study, the aim is to offer a low-cost alternative compared to today's commercial solutions and to develop a modular prototype that can be used in home environments or pre-clinical processes. The focus of the study is to ensure and demonstrate a functional system architecture and data transmission reliability; therefore, the clinical accuracy of the systems has not been tested with extensive patient participation.

2. Material and Methods

This study proposes two different RTMEWS architectures.

2.1. Recommended first RTMEWS

In the first proposed system, a new device capable of measuring pulse, SpO_2, and body temperature parameters and transmitting them wirelessly to a smartphone application has been designed and prototyped.

The prototype device is named "Bab-ı Sıhhat" (Gate of Health). The device consists of an Atmel ATMega328P microcontroller [16], an 8x64 Oled I2C GLCD, an HC-05 Bluetooth module, a MAX30100 sensor, and connection terminals.

Figure 1. Block Diagram of the First Proposed RTMEWS

To obtain precise data and reduce measurement error, the MAX30100 sensor from MAXIM IC was selected [17]. The signal processed by the ADC unit in the sensor module is transmitted to the microcontroller via the microBUS I2C interface, where the data is processed, and digital data is retrieved from the module pins.

To prevent the prototype device from being affected by environmental conditions such as daylight during the measurement of pulse, SpO_2, and body temperature parameters, it was placed inside a cube designed in SolidWorks and produced via 3D printing.

Figure 2. Comparison of Measurement and Prototype

To remotely monitor the vital signs of patients in medical healthcare settings, whether in a hospital or home environment, an interface running on a smartphone was designed and implemented using the MIT2 application [18]. With this application, the patient's relatives or healthcare professionals can remotely monitor the patient's vital signs.

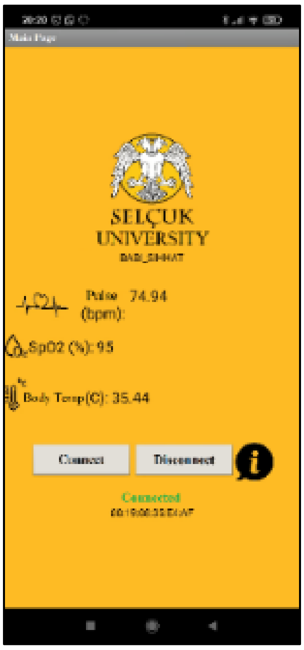

Figure 3. Mit2 Application GUI Interface

2.2. Recommended second RTMEWS

The other proposed RTMEWS consists of two sections. In the first section, the patient's vital signs are measured and transmitted wirelessly to the receiver section via an RF transmission method [19].

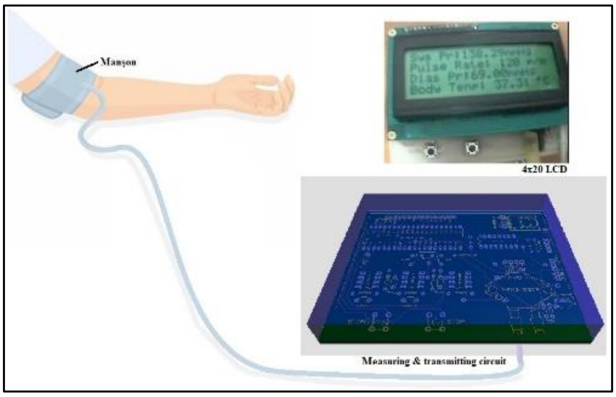

Figure 4. Block Diagram of the Measurement-Transmission Section

In the measurement-transmitter section, the patient's pulse, systolic-diastolic blood pressure, and body temperature are measured from the arm, displayed on a 4x20 LCD screen, and transmitted wirelessly to the receiver section via RF communication. The measurement circuit uses an MPX2100DP pressure sensor, a Microchip Pic16F877 microcontroller, a Texas Instruments OP07 op-amp, an Analog Devices AD620 op-amp, a DS18B20 digital temperature sensor, and an RF transmitter module [20].

Measurement process:

The output voltage range of the MPX2100DP pressure sensor is 0–40 mV. During measurement, the output voltage will be approximately 18 mV, as the maximum pressure will be 160 mmHg. Since this level is outside the measurement range of the microcontroller, amplification is performed using the AD620. The DC output voltage of the DC amplifier is selected between 0–4V, and the gain is calculated to be approximately 200. The signal from the DC amplifier is passed through two band-pass filters to reduce the noise value of the output voltage. The AC component in the band-pass filter is crucial for detecting systolic and diastolic pressures.

The motor inside the blood pressure monitor attached to the arm or wrist inflates the cuff by pumping air up to 160 mmHg [21]. The motor then stops pumping air, the air release valve is slightly opened, and the cuff is deflated. The pressure inside the cuff begins to decrease linearly over time. At this moment, the Pic16F877 microcontroller starts measuring. The PIC measures systolic and diastolic blood pressure based on AC signal changes at the ADC0 pin. Blood pressure measurements are made by detecting pressure pulses inside the cuff.

Since a healthy person's systolic blood pressure can be up to 140 mmHg, the motor initially pumps air into the cuff up to 160 mmHg at the start of the measurement. The cuff then begins to deflate, and systolic blood pressure measurement starts. When the pressure in the cuff drops to a certain value, blood flow begins in the arm. At this moment, a fluctuation is observed, and systolic blood pressure is measured.

After systolic blood pressure measurement, the pulse is measured. Every 40 milliseconds, an AC wave is sampled. The time intervals where the AC wave values coincide with the 2.5 V AC coupling voltage are recorded. The software then averages five time intervals. The measurement is as accurate as possible. After pulse measurement, diastolic blood pressure is measured [22, 23].

While measuring diastolic blood pressure, sampling is again performed every 40 milliseconds. A threshold value is set for diastolic blood pressure. When the cuff deflates, the amplitude of the oscillation decreases at an earlier point before the pressure reaches diastolic blood pressure. The DC value at the point where the oscillation falls below the threshold voltage is recorded. As long as the AC wave does not rise above the threshold value within 2 seconds, the oscillation amplitude is below the threshold. The DC value can be converted to the pressure inside the wrist cuff on the arm, as in systolic blood pressure calculations. Measuring diastolic blood pressure is somewhat difficult and uncertain because the voltage threshold varies from person to person. After diastolic blood pressure is also measured, the valve opens, and the air in the cuff is rapidly released [22, 23].

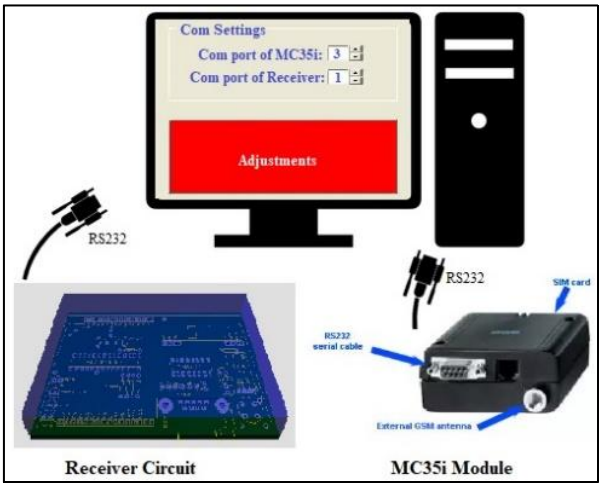

Figure 5. Receiver Section Block Diagram

In the second proposed system, the vital signs measured from the patient via the measurement-transmitter circuit are sent to the receiver section shown in Figure 5. The transmitted RF signals are received by the RF receiver module in the receiver circuit and are both transferred to the 4x20 LCD screen on the circuit and transmitted to the computer's COM port via an RS232 connection. In the GUI interface developed with Visual Basic v6, the min.-max. threshold values for systolic-diastolic blood pressure, pulse, and body temperature data must be set by the healthcare worker or doctor [8]. The data obtained as a result of the measurement is transferred to the GUI interface and saved in the software's database along with the arrival date and time. Figure 6 shows the GUI interface.

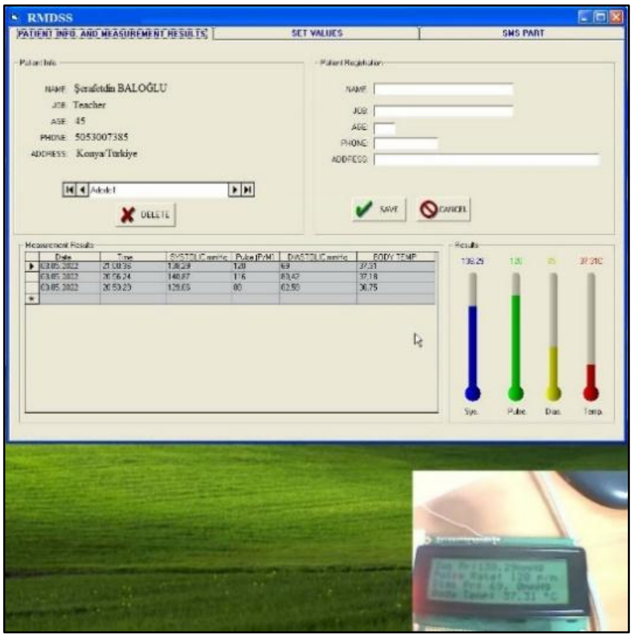

Figure 6. GUI's Patient Info and Measurement Results Tab

Figure 6 shows that data integrity is maintained between the data on the LCD screen in the receiver circuit and the data in the RTMEWS GUI. During data transmission, full compatibility and consistency were observed between the transmitter circuit, receiver circuit, and GUI.

Figure 7. GUI's Set Values Tab

Figure 7 shows the GUI section where the threshold values for vital signs are entered and saved by the healthcare worker or doctor. In this section, in the "Alarm Status" area, red warning LEDs are placed for vital signs that fall outside the threshold value range, and green warning LEDs for vital signs within the threshold range [14]. The same LEDs are also placed as LED diodes on the receiver circuit board. The proposed second RTMEWS provides a visual alarm with the LEDs on the receiver circuit even when used without a computer.

Figure 7 shows that the systolic pressure range is set to 80-120 mmHg, pulse to 50-100 bpm, diastolic pressure range to 60-80 mmHg, and body temperature range to 25-38 °C. When the values obtained in the results section are compared with the set values, it is seen that an alarm condition occurs for systolic blood pressure and pulse rate.

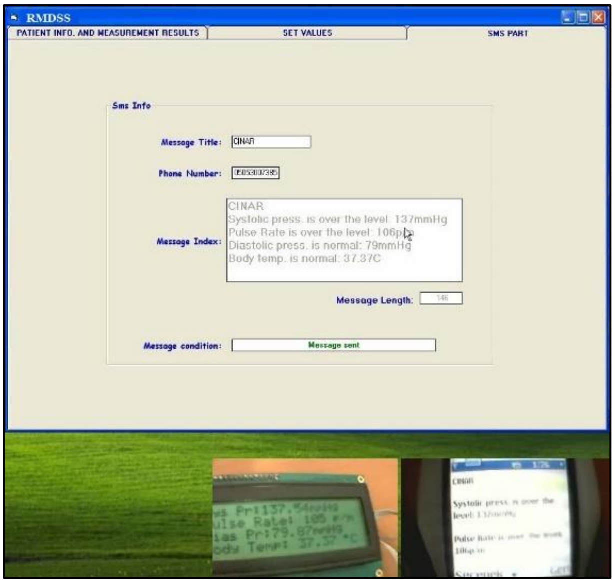

Figure 8. GUI's Sms Tab

Figure 8 shows the section where the patient's vital signs are transmitted via SMS. In the "SMS Information" section, the patient's name and the phone number to which the message will be sent are read from the database where the patient's personal data is stored. After the message content is created from the data received by the GUI interface, the message is sent via the Siemens MC35i Global System for Mobile Communications (GSM) module using the AT command set. Whether the message reaches the recipient can be tracked from the "Message Status" text box. Figure 8 shows that the SMS sent to the smartphone is exactly the same as the message sent from the MC35i GSM module connected to the computer's Com Port, and there was no data corruption during transmission.

Siemens MC35i is an industrial GSM modem and the AT command can be used in any project involving vehicle tracking, remote on/off, and data transfer (machine-to-machine - M2M).

2.3. Experimental Validation Protocol and Limitations

The operation and data transmission integrity of both proposed systems were evaluated. Functional validation of the prototypes was performed with controlled self-measurements conducted by the authors on themselves. In the measurements, the measurement and transmission of each vital parameter were tested. Data transmission tests were carried out in enclosed environmental conditions at distances ranging from 5 to 15 meters. In all tests, data transmission integrity was maintained, and no packet loss was observed. The measurement and transmission continuity of each vital parameter (pulse, SpO_2, blood pressure, body temperature, etc.) was tested, and it was observed that the hardware-software integration provided reliable data flow.

3. 3. Results and Discussion

The patient's vital signs were successfully transmitted to the receiver in both proposed systems. In the first proposed RTMEWS, pulse, SpO_2, and body temperature were measured and transmitted to the smartphone. The first system is simple and easy to use and can be easily used by healthcare professionals such as nurses monitoring patients at home, during travel, and in hospital wards [24].

In the second proposed RTMEWS, the patient's systolic-diastolic blood pressure, pulse, and body temperature were measured, the data was transmitted to the receiver, and recorded in the GUI implemented with Visual Basic v6. When the threshold values set by the doctor were exceeded, the system issued an alarm and the situation was notified via SMS to a predetermined phone. The setup of this system should be done by technical service compared to the first proposed system. Also, it is a more costly system compared to the first system.

In both systems, data transmission integrity was ensured, and no data loss was observed between the receiver, transmitter, and software interface. This statement refers to the reliability of signal transmission rather than clinical measurement accuracy. The goal of the systems being low-cost is supported by the component-based cost analysis (See Table 1). The proposed architecture offers a significantly more cost-effective alternative compared to today's multi-parameter commercial monitors [15]. However, the current state of the systems should be evaluated not as a basic decision support system, but as a remote monitoring and early warning infrastructure that will provide input to decision support systems.

Table 1. Approximate Component-Based Cost Analysis of Both Proposed Systems

Component / System	System 1	System 2
Microcontroller	Atmega328p (~3$)	Pic16f877 (~5$)
Main Sensor	Max30100 (~7$)	Mpx2100dp (~12$)
Bluetooth/RF Module	Hc-05 (~4$)	Rf 433mhz module (~3$)
Display	Oled 8x64 (~6$)	4x20 lcd (~8$)
Other (Op-amp, Sensor, etc.)	DS18B20 (~2$)	AD620 (~5$), OP07 (~2$), DS18B20 (~2$)
Total Approximate Cost	~22$	~35$

Note: Prices are based on component prices at the prototype stage. Commercial multi-parameter patient monitors typically cost over 500$.

4. Conclusions

In this study, two different RTMEWS systems that can be used in patients' home environments or hospital wards are proposed. With the developed systems, the patient's pulse (heart rate), SpO_2, body temperature, and systolic-diastolic blood pressure data can be monitored instantaneously [25]. It was observed that vital signs were reliably transmitted wirelessly to the receiving side. Today, monitoring the patient's vital signs is a great need. When the patient is alone, they may sometimes not accurately assess the urgency of their condition and may be delayed in reaching their relatives or the healthcare institution. With RTMEWS, both the patient and the doctor can monitor vital signs. Also, in case of an emergency with a specific threshold range, a warning SMS is sent to the patient's relatives or doctor. In the future, both proposed RTMEWS can be combined to create a more comprehensive study by developing a GUI in crossplatform applications such as Python [26].

The developed prototypes can be made even more compact by using low-power wearable sensors [27]. The battery life of the systems can be improved with energy-efficient wireless communication protocols [28].

The collected data can also be evaluated for predictive analyses using machine learning algorithms [29], for example, deep learning models can be used for the detection of vital sign anomalies [30].

Declaration of Ethical Standards

This study focuses on electronic system prototyping and functional validation. The tests include measurements performed by the authors on themselves. This study is for prototype validation purposes and is not a clinical human study. Therefore, ethics committee approval is not required. All collected data are anonymous and were used only for evaluating system performance.

Credit Authorship Contribution Statement

Conceptualization and methodology: Serafetdin Baloglu, Ismail Saritas System design and implementation: Serafetdin Baloglu Supervision and article review: Ismail Saritas

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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