Energy-Efficient Remote Temperature Monitoring System for Patients Based on GSM Modem and Microcontroller

Sadik Kamel Gharghan
Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University (MTU), Al Doura 10022, Baghdad-Iraq
Email: sadiq_gharghan@yahoo.com

Abstract —This study presents a real-time remote monitoring system (RTRMS) for the temperature of patients admitted to hospitals. A GSM modem was interfaced with microcontroller PIC16F877A to alerts physicians in real time via short message service (SMS) in emergency cases when the temperature of a patient rises. A sleep/wake energy-efficient algorithm has been implemented inside the microcontroller to reduce the power consumption of GSM and microcontroller. The microcontroller and GSM modem can be in a sleep mode when the temperature of a patient is steady. Consequently, power consumption can be improved and battery lifespan can be prolonged for RTRMS. In addition, the measurement accuracy was confirmed relative to the benchmark (digital thermometer) based on the mean absolute error (MAE). Results show that the proposed RTRMS is achieved 99% power savings relative to traditional RTRMS (i.e., without sleep/wake algorithm). The obtained MAE of 0.205 suggested a close agreement between the benchmark and the proposed RTRMS. The proposed system is a real-time monitoring, applicable, cost-effective, and efficient means for transmitting information because it utilizes the advantages of the infrastructure of GSM network and features a ready mobile device connected with physicians. In addition, the RTRMS can be used in numerous applications and for others parameters rather than temperature with simple modifications (e.g., heart rate, respiratory rate, and electrocardiography for monitoring health care, rehabilitation for monitoring gait speed and cadence, and muscle activity and patient fall detection for safety monitoring).

Index Terms—Energy-efficient, GSM modem, microcontroller, mobile phone, Remote temperature monitoring, sleep/wake algorithm

I. Introduction

Real-time remote monitoring system (RTRMS) for patients facilitates early diagnosis and prompt treatment for risky diseases via wireless channels. Wireless monitoring systems are continually becoming important, especially in the case of patients who are outlying or traveling and are far from a health care center. Using wireless communication between mobile users has become increasingly common because of the developments in computer and wireless technologies. RTRMS must be inserted in small wearable devices with low cost and power consumption, and these devices should feature an interface usable for patients.

Technologies used in RTRMS, such as ZigBee [1], [2], Bluetooth [2], [3], ANT [4], Wi-Fi [5], and GSM/GPRS [6], [7], are incorporated. In these systems, the physiological parameters of patients may be wirelessly transmitted to the monitoring room of doctors or the health care center. ZigBee, ANT, Bluetooth, and Wi-Fi support low communication within the range of 10–100 m [8], thus limiting their applications specifically in situations when extensive coverage is necessary such as in the RTRMS context; therefore, using these wireless technologies becomes futile. The communication range of network for these wireless protocols can be extended using router nodes at the expense of power consumption, size, weight, and system complexity, which are considered critical metrics in medical applications. This work proposes RTRMS using GSM modem to eliminate these constraints, specifically the power consumption and communication range, as well as benefit from the deployment of GSM network. The proposed RTRMS comprises GSM modem (SmartG100), microcontroller (PIC16F877A), and temperature sensor (LM35). The microcontroller program is achieved using a Proton Basic language, which employs Proton IDE Compiler software [9] with AT Commands to the GSM modem.

The remainder of the article is arranged as follows. Section 2 introduces the related works based on available wireless technologies. Section 3 describes the construction of RTRMS. Section 4 explains the hardware and software implementation. Section 5 introduces the power consumption model of RTRMS, whereas Section 6 introduces the current consumption measurements of the proposed monitoring system. Section 7 presents the results and discussions of this work. The comparison with previous works in terms of current consumption will also be presented in this section. Section 8 summarized the main conclusions of the paper and future research directions.

II. Related Works

Patient monitoring system was introduced based on ZigBee wireless protocol in some studies [10]-[13]. However, ZigBee-based patient monitoring system suffers from interference problems with another wireless protocol that work in similar frequency band such as Bluetooth and Wi-Fi, thereby affecting power consumption and limiting communication range. Kim *et*

Manuscript received March 20, 2017; revised August 25, 2017.
doi:10.12720/jcm.12.8.433-442

al. solved the interference problem of ZigBee channels in the presence of Wi-Fi network [10]. However, the communication range of the ZigBee is limited. Power consumption is reduced in wireless body area network based on sleep/wake scheme [13], in which sensor nodes can sleep most of the time when no sensing event occurs. The communication range can be extended using multi-hop ZigBee. An efficient transmission routing schedule for the wireless patient monitoring system is necessary for the multi-hop [11]. However, collision can occur when using multi-hop in the network, and packet loss can increase because all hop nodes work in the same frequency band. System complexity and cost also increase.

Smartphone is employed to monitor the vital signs of patients through smartphone Bluetooth [3]. Tello *et al*. [14] proposed a remote patient monitoring system that sends an alert signal to medical staff in case of a medical emergency. Temperature and electrocardiography (ECG) are transmitted to Wi-Fi or GPRS networks via Bluetooth, which communicate with the Bluetooth of mobile phones. Cheng and Zhuang [15] proposed a patient monitoring system based on Bluetooth to allow early detection of Alzheimer's disease. They employed Bluetooth wireless protocol to track patient motion in indoor environments where GPS is inefficient in indoor positioning [16]. The tracking location can be stored in the database of the proposed system and can be utilized when needed. Magno *et al*. [17] presented a real-time application to assist elderly patients in gait rehabilitation over a closed loop feedback system. Bluetooth Low Energy (BTLE) was used in sensor node, and it can be turned off to reduce the power consumption of the sensor node when communication is not required. However, BTLE possesses a short communication range [18], [19] of up to 10 m [8], which makes it unsuitable for remote monitoring.

Singh [20] employed GSM modem and ZigBee wireless network to design and develop an energy-efficient real-time patient parameter monitoring system, which monitors temperature, ECG, heartbeat, and position. Short message service (SMS) alerts are transmitted to the pre-designed mobile number of specialists in emergency cases using GSM modem interfaced with ARM microcontroller. Tewary *et al*. [21] designed and developed a smart wearable patient monitoring system based on GSM. The system comprises a three-axis accelerometer for patient fall detection and a three-lead ECG to detect hypotension and cardiac abnormalities. The system can also send reports to healthcare specialists in real time in emergency cases to consider the necessary steps. Aziz *et al*. [22] used GSM to monitor the heart beat and temperature of patients in real time and send an SMS to a specialized doctor in an emergency case. In addition, a GPS is used in their work to provide the position of the patient in real time. The mobility of elderly people has been monitored in the work of Scanaill *et al*. [23] based on SMS. Accelerometer sensor is used to monitor the mobility levels of the monitored subject. An SMS alert is sent to the doctor in charge when the movement level of the subject decreases. Most of the preceding previous works were unable to solve the shortcomings of power consumption and communication range. The current work proposes RTRMS that can resolve these problems. The power consumption is reduced and the battery life is prolonged of the RTRMS as well as the communication range is extended using GSM network, where the disseminated data of the proposed system can be monitored at remote locations everywhere in real time. Moreover, the measurement accuracy is verified relative to benchmark device.

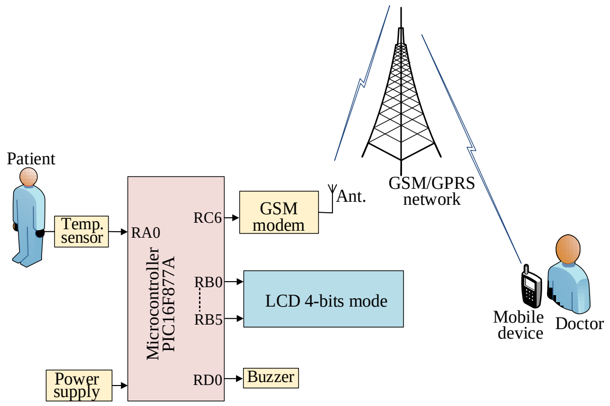


Fig. 1. Proposed RTRMS architecture.

III. RTRMS Architecture

Fig. 1 illustrates the proposed RTRMS architecture. It consists of GSM modem (SmartG100), microcontroller (PIC16F877A), temperature sensor (LM35), liquid crystal display (LCD), buzzer, and power unit (rechargeable battery 7.2 V/1,000 mA). The main components of the RTRMS can be described as follows.

A. *Temperature Sensor*

A temperature sensor determines the temperature in Celsius or Kelvin. The precision integrated-circuit temperature sensor LM35 was employed in this research to measure the temperature of patients in Celsius. LM35 is a small three-pin integrated circuit (Fig. 2). Its power consumption is less than 138 μA current drain, which is appropriate for remote applications; it is also directly adjusted in centigrade, resulting in low cost. This sensor operates from 4–30V DC voltage, and it rises by 10.0 mV/℃ in the linear scale factor. The output of LM35 is analog 6 V– -1 V, which is uniformly linear over the entire range and the temperature range of -55to +150℃ [24], [25]. LM35 creates a greater output voltage than thermocouples [26] and does not require an amplified output voltage; therefore, any external calibration is unnecessary in providing an ideal accuracy of ±0.5 ℃ at room temperature. The output voltage of LM35 is transformed to temperature through soft conversion. Generally, the temperature for a normal adult is approximately 37 ℃. The general mathematical expression used to transform the output voltage of LM35 to temperature is [27].

$$Temperature\ (℃) = V_{out}(100\ ℃/V) \quad (1)$$

where Vout is the output voltage of LM35.

Therefore, if Vout is 0.37 V, then the temperature become 37 ℃. The output voltage of the LM35 linearly alters with temperature. The R-C circuit, which is added to the output impedance to remove the effect of capacitive loads, also provides protection from radiated interference from relays or any other source of electrical noise [28]. The temperature sensor is connected to the patient to check his/her temperature every one minute.

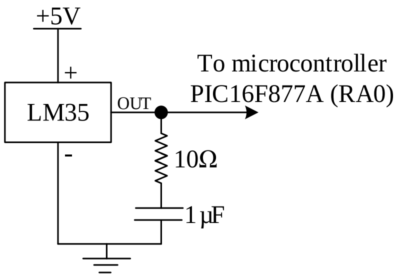


Fig. 2. Schematic of temperature sensor LM35.

B. Microcontroller PIC16F877A

Microcontroller PIC16F877A, which is an 8-bit microcontroller, was considered in this work. Because it is a popular device with the following features: 8 K × 14 words of FLASH RAM, 256 × 8 bytes (EEPROM) of data memory, 368 × 8 bytes of data memory (RAM), 8-channel ADC with 10-bit resolution, on-chip USART, watchdog timer, one 16-bit and two 8-bit timers, 14 interrupt sources, and PWM modules, high-performance RISC microcontroller with only 35 single-word instructions, and 33 bidirectional I/O pins forming five ports (PORT A, PORT B, PORT C, PORT D, and PORT E) [29, 30]. Given these benefits, Microcontroller PICs are the preferred devices for real-time control applications.

The microcontroller PIC16F877A employed in this research works at 4 MHz frequency and executes each instruction as fast as 1 µs. This microcontroller is considered the core of the RTRMS; it performs several tasks. (i) It acquires data (i.e., the temperature of patients) in real time, and the temperature can be converted to digital signal. (ii) It sends the data of the temperature of patients to GSM modem as SMS alert to be sent to the mobile device of physicians via GSM modem. (iii) It displays the temperature and case of the patient on the LCD to be viewed by patients. (iv) It energizes the buzzer circuit to provide an audible alarm in emergency cases. (v) It puts GSM modem and itself in sleep mode for 60 seconds (i.e., no data transmission) to save the energy of the RTRMS based on the proposed sleep/wake algorithm.

When the temperature of patients reaches to the preset urgent or danger values, the proposed algorithm in the microcontroller energizes the GSM modem to transmit an "Urgent" or "Danger" case to the pre-defined phone number of physicians in the form of SMS alert. Therefore, a fast medical care can be performed, reducing the risk level of patients. By contrast, the microcontroller provides a self-audible alert to patients with the display function on the LCD located on the patients' side or worn by patients. In the absence of the increase in the temperature of patients to preset levels, the designed algorithm puts the microcontroller and GSM modem in sleep mode to save the energy of the RTRMS.

C. GSM Modem

The GSM modem SmartG100 (MikroElektronika) [31] was used in this work to transmit the temperature of patients to the mobile device of physicians through GSM network. The GSM module is a breakout board that communicates with the microcontroller via AT Commands. The protocol "AT Commands" was normalized by the European Telecommunications Standards Institute, allowing unlike systems to link via "AT Commands" protocol [32]. The microcontroller algorithm can send SMS alert to physicians when the temperature of patients presents an emergency case. This communication features the three following layers: (i) a physical layer (i.e., GSM modem SmartG100), (ii) a link layer, which is responsible for Asynchronous Serial Communication Protocol (UART), and (iii) an application layer, which is accountable for AT protocol.

The AT Commands are a line prefix. Two modes are used to send SMS from the microcontroller via GSM modem [33]: SMS mode and protocol description unit (PDU) mode. The SMS mode is adopted in this paper. First, the SMS mode can be defined using the AT command "T + CMGF = 1"; thereafter, the mobile number of the physicians can be sent from the microcontroller to the GSM modem by employing the AT command "AT + CMGS." Fig. 3 presents the snapshot of the GSM modem SmartG100, which is a full-featured development tool for the uBlox Leon-G100 GSM/GPRS module. This modem has the following features [33, 34]: (i) data transmission through uBlox Leon-G100 component, (ii) speaker connectors and microphone, (iii) UART port to interface with microcontroller, and (iv) power supply with 9–32 V DC or 7–23 V AC voltage.

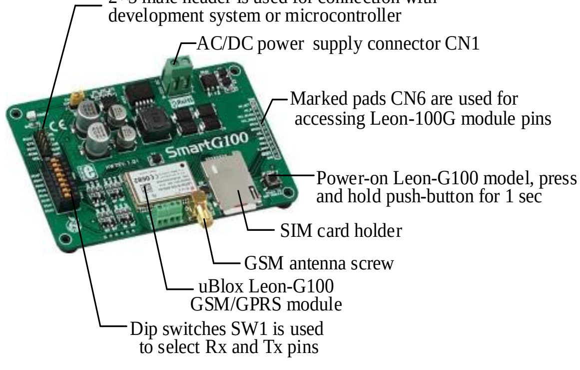


Fig. 3. SmartG100 with uBlox Leon-G100 module.

IV. Hardware and Software Implementation

The implementation of the RTRMS can be classified into two components, namely, hardware and software implementation, as described in the following subsections:

A. Hardware Implementation

The snapshot of RTRMS hardware is shown in Section VII (Fig. 7b). The configuration and operation sequence of the RTRMS can be described as follows:

1. The temperature sensor senses the body temperature of a patient and converts this temperature to a variation in the output voltage of the sensor (0.37–0.41) volt depending on the patient case. The temperature sensor is interfaced with microcontroller using PORTA (RA0).
2. The temperature sensor output voltage is transformed to temperature in Celsius through simple conversion built into the algorithm of the microcontroller PIC16F877A using Equation 1. The microcontroller algorithm energizes the microcontroller to display the value and case of the body temperature of the patient on the LCD to be viewed by the patient. In addition, the microcontroller sends AT commands to the GSM modem in an emergency case to send SMS alert to a doctor regarding the body temperature of the patient.
3. The GSM modem is interfaced with the microcontroller using a serial protocol UART. The microcontroller PIC16F877A uses two I/O lines, in which one is for transmitting (Tx) data configured on PORTC (RC6) and the other is for receiving (Rx) data configured on PORTC (RC7); only the transmitting line RC6 is used in this work. The serial port of the GSM modem uses the same UART protocol to enable communication with the microcontroller.
4. A SIM card is embedded in the GSM modem, and it communicates with the mobile phone of the physician via GSM network as SMS alert in an emergency case when the temperature of the patient increases.

B. Software Implementation

The flow sequence of the proposed algorithm, which is illustrated in Fig. 4, is conducted based on high-level language Proton IDE Basic Proton program [35]. The steps of the algorithm of RTRMS can be briefly described as follows:

1. The microcontroller reads the temperature of a patient. When this temperature is normal or is under the emergency level, the proposed algorithm puts the microcontroller and GSM modem in sleep mode for 60 seconds to save the energy of the RTRMS.
2. The microcontroller and GSM modem wake up after sleeping. If the temperature of the patient increases to the urgent or danger case, the proposed algorithm induces the microcontroller to send the temperature of the patient to the GSM modem as SMS alert. In turn, the GSM modem sends this SMS alert to the mobile phone number of a physician (which is previously defined in the algorithm of the microcontroller) via GSM network. The SMS contains the name and temperature case (urgent or danger) of the patient.
3. The proposed algorithm prompts the microcontroller to display the temperature and case of the patient on the LCD, in which the LCD is interfaced with the microcontroller and is wearable by the patient. In addition, the microcontroller energizes the buzzer to provide an audible alert when the temperature of the patient is in an emergency case (i.e., above 39 ℃) to obtain medical assistance.

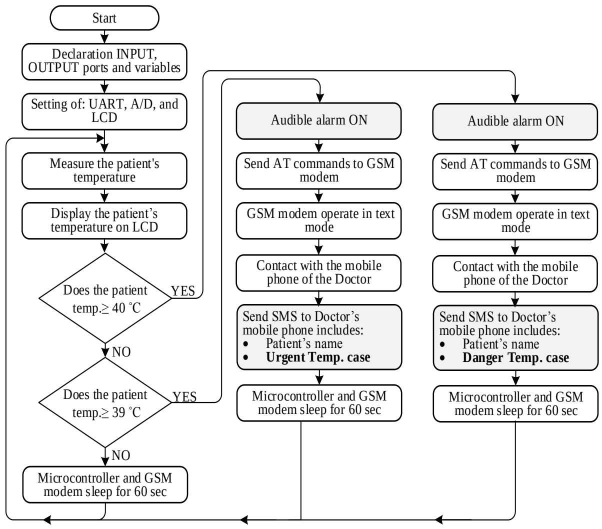


Fig. 4. Flow chart of the temperature measurements of patients and proposed sleep/wake algorithm.

V. Power Consumption Model

This section provides a mathematical equation for the average current consumption of RTRMS based on the sleep/wake algorithm. This model simplifies the calculation of the average current consumption of each component in the RTRMS. Generally, the average current consumption I_{avg} using sleep/wake can be expressed as Equation (2) [36, 37],

$$I_{avg} = \frac{t_{active}}{T_{total}} I_{active} + \left(1 - \frac{t_{active}}{T_{total}}\right) I_{sleep} \qquad (2)$$

where t_{active} and I_{active} are the transmission time and current consumption of RTRMS in active modes, respectively. I_{sleep} is the RTRMS during sleep mode and $(\frac{t_{active}}{T_{total}})$ is the duty cycle of the sleep/wake, which is constant in this work and depends on t_{active} and T_{total}. T_{total} is associated with the time spent on the duty cycle; it is 60.221 seconds in this work. t_{active} is a key parameter governed by the time of the transmitted data of the temperature of patients, which consumes 221 ms. Therefore, the duty cycle is 0.00367. For this value, the

RTRMS is expected to significantly improve power consumption, which is crucial in medical applications.

The power consumption of RTRMS is based on the current consumption by the three following components: (i) temperature sensor LM35, (ii) microcontroller PIC16F877A, and (iii) GSM modem. The average current consumption of the RTRMS can be determined using Equation (3).

$$I_{Avg\_RTRMS} = I_{Avg\_temperature\ sensor} + I_{Avg\_microcontroller} + I_{Avg\_GSM\ modem} \quad (3)$$

By substituting Equation 2 into 3, Equation (4) is yielded.

$$I_{Avg\_RTRMS} = I_{Avg\_temperature\ sensor} + \frac{t_{activ\_\mu c}}{T_{total}} I_{active\_\mu c} + \left(1 - \frac{t_{active\_\mu c}}{T_{total}}\right) I_{sleep\_\mu c} + \frac{t_{active\_GSM}}{T_{total}} I_{active\_GSM} + \left(1 - \frac{t_{active\_GSM}}{T_{total}}\right) I_{standby\_GSM} \quad (4)$$

where $I_{active\_\mu c}$ and $t_{active\_\mu c}$ are the active current consumption and time durations for the microcontroller PIC16F877A, respectively, and $I_{sleep\_\mu c}$ is the sleep current consumption for the microcontroller. I_{active_GSM} and t_{active_GSM} are the active current consumption and time duration during the active state of the GSM modem, respectively, and $I_{standby\_GSM}$ is the standby current consumption during the standby state of the GSM modem.

Equation (4) is employed to evaluate the average current consumed by the RTRMS. Consequently, the RTRMS lifespan (L_S) can be determined with Equation (5) [38, 39].

$$L_S = \frac{I_{battery\ capacity}}{I_{Avg\_RTRMS}} \quad (5)$$

where $I_{battery\ capacity}$ is the current capacity of the used battery in the RTRMS.

VI. Current Consumption Measurement

The current and time consumption for each component of the RTRMS was measured using digital ampere meter for active and sleep modes, as illustrated in Table I. The table shows the current consumption for every component in the RTRMS. Consequently, the average current of the RTRMS of 3.087 mA obtained by applying Equation (4) is lower than the current consumption of 315.138 mA in conventional operation (i.e., without sleep/wake algorithm). Equation (6) [36] can be employed to calculate the percentage power savings and evaluate the performance of the RTRMS in terms of power savings.

$$Power\ savings(\%) = \left(1 - \frac{RTRMS\ current\ consumption\ based\ on \frac{sleep}{wake}\ algorithm}{RTRMS\ current\ consumption\ based\ on\ conventional\ operation}\right) \times 100\% \quad (6)$$

Table I: Average Current and Time Consumption of Each Component of the Rtrms

Parameter	Temperature sensor LM35	Microcontroller PIC16F877	GSM modem SmartG100
Active current (I_{active})	0.138 mA (always ON)	15 mA	300 mA
Sleep current or standby state (I_{sleep} or $I_{standby}$)	Cannot sleep (always ON)	0.2 mA	1.6 mA
Active time (t_{active})	60.221	0.221 s	0.221 s
Sleep time (t_{sleep} or $t_{standby}$)	N/A	60 s	60 s
Total period (T_{total})	60.221 s	60.221 s	60.221 s
Duty cycle (t_{active} / T_{total})	Always ON	0.00367	0.00367
Average current consumption	0.138 mA	0.254 mA	2.695 mA

VII. Results and Discussions

A. Simulation Results

The simulation results were obtained based on the ISIS professional program [40]. The microcontroller algorithm examines whether the temperature of a patient is normal every 60 seconds. If the temperature of the patient is in an urgent (i.e., 39 ℃) or danger (i.e., 41 ℃) case, the microcontroller sends the temperature value of the patient in a short time (i.e., 221 ms) to the GSM modem, which in turn transmits the temperature to the mobile phone of a doctor as SMS alert. By contrast, when the temperature of the patient is in a normal case, the microcontroller and GSM modem is in sleep mode for 60 seconds. The transmitted data of the temperature of the patient can be simulated using the DIGITAL ANALYSIS-PROSPICE tool of the ISIS professional program.

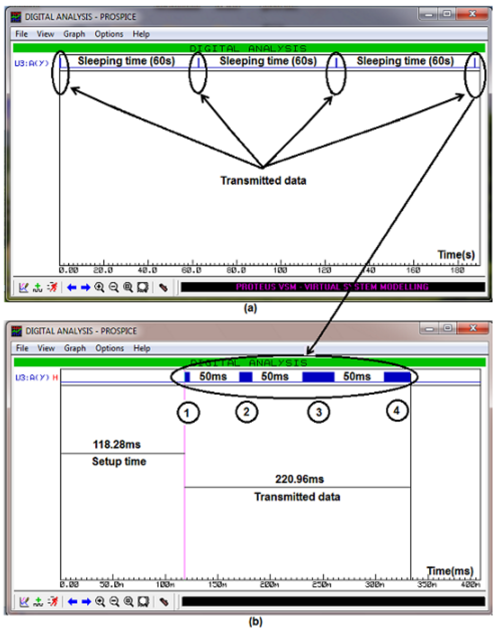
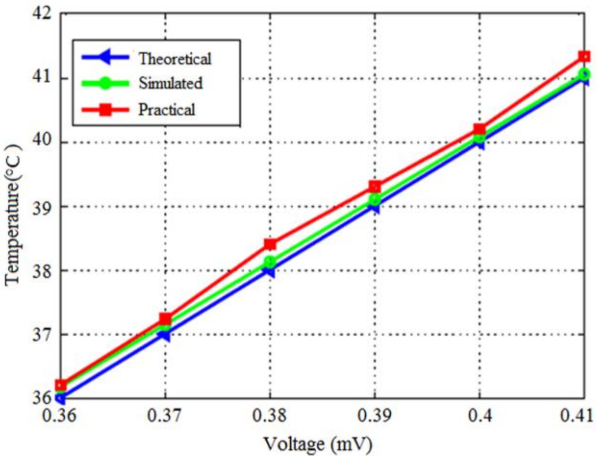


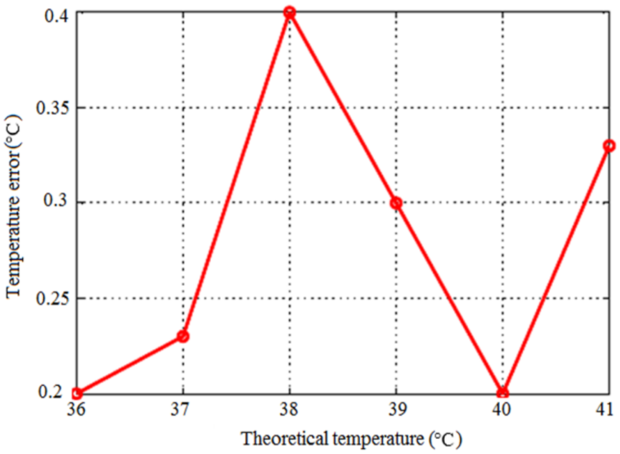
Fig. 5. Digital analysis of (a) transmitted data with sleep time and (b) transmitted data for one packet.

The digital analysis of the transmitted data is illustrated in Figs 5a and b. Fig. 5a shows the transmitted data in a fraction of time and sleep time (i.e., 60 sec), whereas Fig. 5b presents the active transmission time (i.e., 221 ms) for one data packet of the temperature of the patient.

B. Experimental Results



(a)



(b)

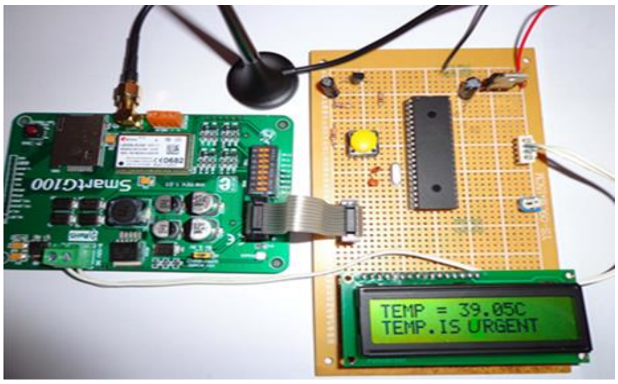
Fig. 6. (a) Temperature measurements of patients relative to theoretical and simulated values and (b) Errors of determined values of the temperature of patients relative to theoretical values.

The output voltage of the temperature sensor LM35 is plotted on the *x-axis*, whereas the measured, simulated, and theoretical temperature values are plotted on the *y-axis* (Fig. 6a). In the figure, the temperature measurements were compared with the simulated and theoretical values to validate the measurements of the RTRMS. The figure shows a close agreement between the determined values and theoretical values on one hand and simulated values from the other hand. Fig. 6b shows the errors of the measured values of the temperature of the patient relative to the theoretical temperature values. This figure also shows that the determined values deflect from 0.2 ℃ to 0.4 ℃. This deviation does not significantly affect the measurement accuracy of the temperature of the patient. The average temperature error was found to be 0.24 ℃. This error approximately the same result that presented by Wannenburg and Malekian in their work [3], where the measurement error computed at 0.25 ℃ using DS18B20 temperature sensor and Bluetooth wireless protocol. The results showed that the adopted temperature sensor LM35 is suitable for the temperature measurements of patients. Figs 7a and b show the snapshot of the RTRMS hardware in the case of urgent and danger temperature of patients. The urgent or danger case of the temperature of the patient is received by the mobile phone (Nokia N8) of a doctor as SMS in real time, which includes the name and temperature case of the patient (Fig. 8).

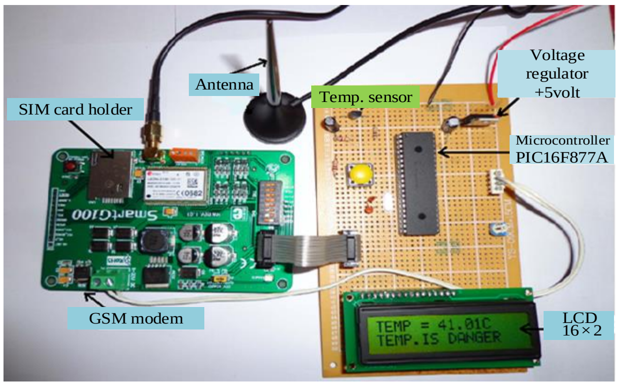
To validate the RTRMS measurement accuracy, the temperature measurements obtained by LM35 are compared with those of a benchmark device, such as digital thermometer which shown in Fig. 9. Fig. 10 confirmed a close agreement between benchmark and obtained data of the proposed RTRMS, where the correlation coefficient R^2 value is 0.987. In addition, the mean absolute error (MAE) can be taken into consideration to evaluate the temperature measurement error as in Equation (7). The MAE was found 0.205 ℃ which suggested minimal error.

$$MAE = \frac{1}{N}\sum_{i=1}^{N} |Temp._{benchmark} - Temp._{RTRMS}| \quad (7)$$

where *N* is the measurement samples.



(a)



(b)

Fig. 7. RTRMS at (a) urgent case and (b) danger case.

C. Power Savings and Battery life Estimation

Implementation of the sleep/wake algorithm confirms that this method can minimize the current drain of the

RTRMS to 3.087 mA, thereby extending the battery lifespan (L_S) to 324 hours using a rechargeable battery with 7.2 V/1,000 mAh. In addition, 99% of power can be conserved (obtained from Equation [6]), which is relative to the conventional operation without the sleep/wake scheme that produces a current drain of 315.138 mA. The L_S is 3 hours in the conventional operation. The L_S for a specific battery capacity ($I_{battery\ capacity}$) based on Equation (5) at the current usage of RTRMS is shown in the direct relationship in Fig. 11. The figure also reveals the development of current consumed by the RTRMS when the *sleep/wake* algorithm is employed. The RTRMS using sleep/wake algorithm is compared with the previous works in terms of current consumption to validate the proposed system.

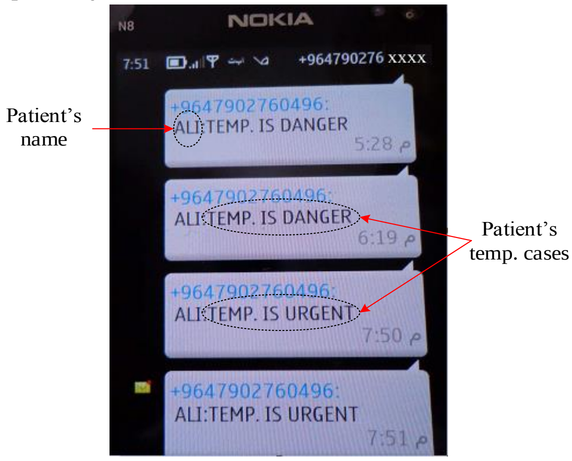


Fig. 8. Mobile phone of the physician.

Fig. 9. Benchmark (digital thermometer) adopted in the experiment.

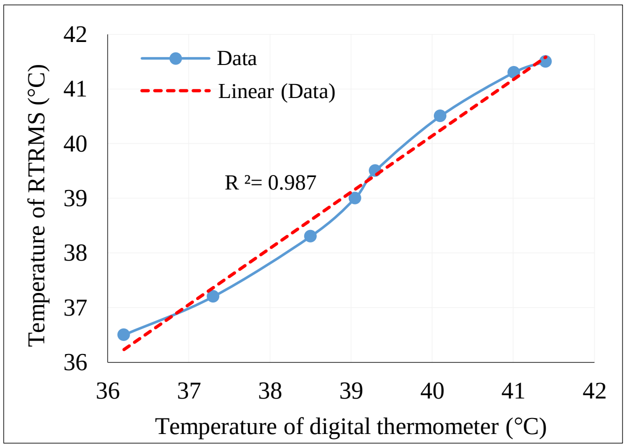


Fig. 10. Correlation between RTRMS and benchmark.

Fourteenth reliable existing works [1], [4], [11], [12], [17], [22], [41]-[48] similar to our work in terms of medical applications which are measured the vital signs of patients (e.g., temperature) are considered for comparison with our proposed RTRMS. These works have employed different wireless technologies such as GSM modem, ZigBee, and Bluetooth to transmit the physiological parameters of the patients. Our proposed RTRMS based on sleep/wake algorithm outperforms the power consumption of these other studies with its current consumption of 3.087 mA as shown in Fig. 12.

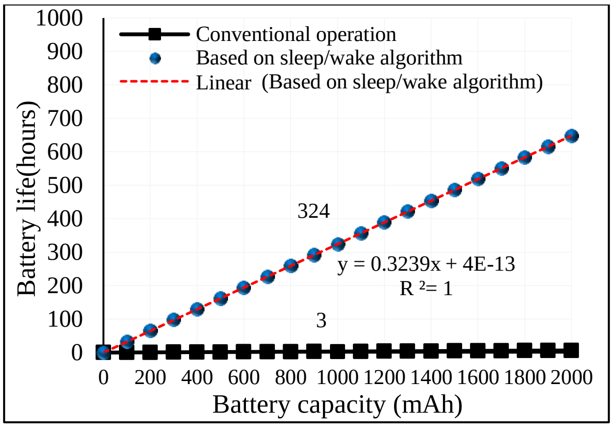


Fig. 11. Expected battery life versus practical battery capability in the RTRMS.

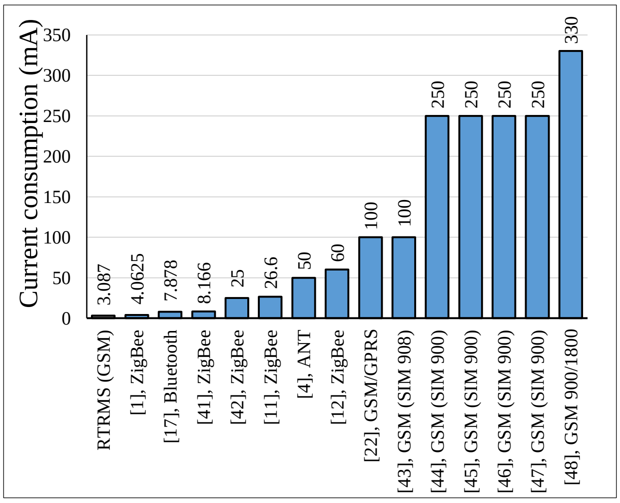


Fig. 12. Bar chart comparing current consumption requirements for existing works with proposed RTRMS.

VIII. Conclusion and Future Work

In this work, the RTRMS was designed and conducted to monitor the temperature of patients recumbent in the hospital in real time. The proposed RTRMS can be used in detecting the temperature of patients who are located in remote places or mobile and cannot inform their physician of their need for instant treatment. Patients can stay at home and enjoy family life while their doctor can check their temperature case upon receiving SMS alert via mobile phone. A prototype was designed and implemented to provide mobility to both physicians and patients. The proposed RTRMS is an efficient system in terms of measurement accuracy as well as power saving because of its extended battery life based on the sleep/wake algorithm, wherein the battery lifespan is prolonged to 324 hours, which is relatively more than that in conventional operation (i.e., 3 hours). The results showed that the power consumption of the RTRMS can be improved based on the sleep/wake algorithm, in which the obtained power saving is 99%. In addition, the current consumption of the RTRMS was significantly reduced relative to conventional system and some previous research works which considered in this study. The RTRMS presents a minimal error, where the MAE was 0.205 relative to the benchmark. The RTRMS offers other advantages, such as real-time monitoring, practicality, and low cost because it utilizes the infrastructure of the GSM network and does not require any additional component of the doctor except for personal mobile phone. The temperature of patients may be transmitted anywhere in the world as long as a GSM network coverage is present and it can also be utilized as a warning system for observation during usual sports exercises or activities. The proposed RTRMS remains restricted in the size of the microcontroller PIC16F877A and the GSM modem (SmartG100), which are relatively substantial. Therefore, reducing the size to make an easily wearable device with low cost and power consumption is planned in future works.

Acknowledgment

The authors would like to thank the staff in Department of Medical Techniques Engineering, College of Electrical Engineering Techniques, Middle Technical University (MTU) for their support to conduct this work.

References

[1] E. Spanò, S. Di Pascoli, and G. Iannaccone, "Low-power wearable ECG monitoring system for multiple-patient remote monitoring," *IEEE Sensors Journal*, vol. 16, no. 13, pp. 5452-5462, 2016.

[2] Y. Ding, S. Gang, and J. Hong, “The design of home monitoring system by remote mobile medical,” in *Proc. 7th IEEE International Conference on Information Technology in Medicine and Education*, Huangshan, China, 13-15 Nov. 2015, pp. 278-281.

[3] J. Wannenburg and R. Malekian, “Body sensor network for mobile health monitoring, a diagnosis and anticipating system,” *IEEE Sensors Journal*, vol. 15, no. 12, pp. 6839-6852, 2015.

[4] T. Vuorela, J. Vanhala, V. P. Seppa, and J. Hyttinen, “Two portable long-term measurement devices for ECG and bioimpedance,” in *Proc. IEEE Second International Conference on Pervasive Computing Technologies for Healthcare*, Tampere, Finland, 30 Jan.-1 Feb. 2008, pp. 169-172.

[5] R. Yang, “Remote medical care monitoring system design and implementation based on computer network,” in *Proc. IEEE International Conference on Intelligent Transportation, Big Data and Smart City*, Halong Bay, Vietnam, 19-20 Dec. 2015, pp. 592-595.

[6] B. S. Lin, A. M. Wong, and K. C. Tseng, “Community-Based ECG monitoring system for patients with cardiovascular diseases,” *Journal of Medical Systems*, vol. 40, no. 4, pp. 1-12, 2016.

[7] B. Townsend, J. Abawajy, and T. H. Kim, “SMS-based medical diagnostic telemetry data transmission protocol for medical sensors,” *Sensors*, vol. 11, no. 4, pp. 4231-4243, 2011.

[8] S. Adibi, “Link technologies and BlackBerry mobile health (mHealth) solutions: A review,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 16, no. 4, pp. 586-597, 2012.

[9] S. Morsalin, A. Rahman, A. B. Siddiqe, P. Saha, and R. Halim, “Password protected multiuser wireless electronic noticing system by GSM with robust algorithm,” in *Proc. 2nd IEEE International Conference on Electrical Information and Communication Technologies (EICT)*, Khulna, Bangladesh, 10-12 Dec. 2015, pp. 249-253.

[10] Y. Kim, S. Lee, and S. Lee, “Coexistence of ZigBee-based WBAN and WiFi for health telemonitoring systems,” *IEEE Journal of Biomedical and Health Informatics*, vol. 20, no. 1, pp. 222-230, 2016.

[11] S. K. Chen, T. Kao, C. T. Chan, C. N. Huang, C. Y. Chiang, C. Y. Lai, *et al.*, “A reliable transmission protocol for zigbee-based wireless patient monitoring,” *IEEE Transactions on Information Technology in Biomedicine,* vol. 16, no. 1, pp. 6-16, 2012.

[12] K. Malhi, S. C. Mukhopadhyay, J. Schnepper, M. Haefke, and H. Ewald, “A zigbee-based wearable physiological parameters monitoring system,” *IEEE Sensors Journal*, vol. 12, no. 3, pp. 423-430, 2012.

[13] O. Omeni, A. C. W. Wong, A. J. Burdett, and C. Toumazou, “Energy efficient medium access protocol for wireless medical body area sensor networks,” *IEEE Transactions on Biomedical Circuits and Systems*, vol. 2, no. 4, pp. 251-259, 2008.

[14] J. P. Tello, O. Manjarres, M. Quijano, A. Blanco, F. Varona, and M. Manrique, “Remote monitoring system of ECG and human body temperature signals,” *IEEE Latin America Transactions*, vol. 11, no. 1, pp. 314-318, 2013.

[15] H. T. Cheng and W. Zhuang, “Bluetooth-enabled in-home patient monitoring system: Early detection of Alzheimer's disease,” *IEEE Wireless Communications*, vol. 17, no. 1, pp. 74-79, 2010.

[16] L. Luoh, “ZigBee-based intelligent indoor positioning system soft computing,” *Soft Computing*, vol. 18, no. 3, pp. 443-456, 2014.

[17] M. Magno, T. Polonelli, F. Casamassima, A. Gomez, E. Farella, and L. Benini, “Energy-Efficient context aware power management with asynchronous protocol for body sensor network,” *Mobile Networks and Applications*, pp. 1-11, August 2016.

[18] D. Contreras and M. Castro, “Impact of polling on bluetooth piconet performance,” *IEEE Communications Magazine*, vol. 49, no. 9, pp. 84-89, 2011.

[19] U. T. Pandya and U. B. Desai, “Bluetooth Electrocardiogram: Its evaluation in a hospital environment,” *IEEE Pulse*, vol. 4, no. 3, pp. 35-40, 2013.

[20] S. P. Puneet, “Zigbee and GSM based patient health monitoring system,” in *Proc. IEEE International*

Conference on Electronics and Communication Systems, Coimbatore, India, 13-14 Feb. 2014, pp. 1-5.

[21] S. Tewary, S. Chakraborty, J. Majumdar, R. Majumder, D. Kundu, S. Ghosh, *et al.*, "A novel approach towards designing a wearable smart health monitoring system measuring the vital parameters and emergency situations in real-time and providing the necessary medical care through telemedicine," in *Proc. IEEE Students' Conference on Electrical, Electronics and Computer Science*, Bhopal, India, 5-6 March 2016, pp. 1-8.

[22] K. Aziz, S. Tarapiah, S. H. Ismail, and S. Atalla, "Smart real-time healthcare monitoring and tracking system using GSM/GPS technologies," in *Proc. 3rd IEEE MEC International Conference on Big Data and Smart City*, Muscat, Oman, 15-16 March 2016, pp. 1-7.

[23] C. N. Scanaill, B. Ahearne, and G. M. Lyons, "Long-term telemonitoring of mobility trends of elderly people using SMS messaging," *IEEE Transactions on Information Technology in Biomedicine*, vol. 10, no. 2, pp. 412-413, 2006.

[24] C. Liu, W. Ren, B. Zhang, and C. Lv, "The application of soil temperature measurement by LM35 temperature sensors," in *Proc. IEEE International Conference on Electronic & Mechanical Engineering and Information Technology*, Harbin, China, 12-14 Aug. 2011, pp. 1825-1828.

[25] R. S. Ransing and M. Rajput, "Smart home for elderly care, based on wireless sensor network," in *Proc. IEEE International Conference on Nascent Technologies in the Engineering Field*, Navi Mumbai, India, 9-10 Jan. 2015, pp. 1-5.

[26] S. Sharma, J. Boddu, G. S. Charan, S. Sharma, S. Sivanantham, and K. Sivasankaran, "Home automation through FPGA controller," in *Proc. IEEE Online International Conference on Green Engineering and Technologies (IC-GET)*, Coimbatore, India, 27-27 Nov. 2015, pp. 1-4.

[27] S. J. Selvarani, "Online health monitoring system using zigbee," *International Journal on Computer Science and Engineering*, vol. 3, no. 4, pp. 1578-1583, 2011.

[28] Texas Instruments LM35 Precision Centigrade Temperature Sensors. [Online]. Available: http://www.datasheetarchive.com/dl/2e677c1c6334ef14afe251a8eea3bdc6abcb6a/P/thermometer+lm35

[29] M. P. Bates, *Programming 8-Bit PIC Microcontrollers in C with Interactive Hardware Simulation*: *Newnes*, Edition 2008, Elsevier Ltd. UAS, 2008.

[30] M. P. Bates, *Interfacing PIC Microcontrollers: Embedded Design by Interactive Simulation*: *Newnes*, Second edition, Elsevier Ltd. UAS, 2013.

[31] MikroElektronika development tools,compilers and books. [Online]. Available: http://www.mikroe.com/

[32] E. Hassan and K. Mohammed, "Design and implementation of an embedded system for ambulatory cardiac monitoring," *Journal of Telecommunications and Information Technology*, vol. 1, pp. 23-32, 2012.

[33] SmartG100 development manual. [Online]. Available: http://www.mikroe.com/eng/products/view/526/smartg100-board/

[34] H. Elbehiery, "Underwater GPS navigation," *Journal of American Science*, vol. 8, no. 9, pp. 978-987, 2012.

[35] PROTON IDE special edition program version IDE 1.0.0.1 and loader version 1.1.2.8. (2005). [Online]. Available: http://www.mecanique.co.uk/

[36] S. K. Gharghan, R. Nordin, and M. Ismail, "Energy efficiency of ultra-low-power bicycle wireless sensor networks based on a combination of power reduction techniques," *Journal of Sensors,* vol. 2016, p. 21, 2016.

[37] A. M. Efendi, S. Oh, A. F. P. Negara, and D. Choi, "Battery-less 6lowpan-based wireless home automation by use of energy harvesting," *International Journal of Distributed Sensor Networks*, vol. 9, no. 1, p. 924576, 2013.

[38] S. K. Gharghan, R. Nordin, and M. Ismail, "Energy-efficient ZigBee-based wireless sensor network for track bicycle performance monitoring," *Sensors*, vol. 14, no. 8, pp. 15573-15592, 2014.

[39] S. K. Gharghan, R. Nordin, and M. Ismail, "An ultra-low power wireless sensor network for bicycle torque performance measurements," *Sensors*, vol. 15, no. 5, pp. 11741-11768, 2015.

[40] Proteus Professional Program release 7.1 SP4 (build 3854) Advance Simulation. [Online]. Available: https://www.labcenter.com/

[41] M. Benocci, C. Tacconi, E. Farella, L. Benini, L. Chiari, and L. Vanzago, "Accelerometer-based fall detection using optimized ZigBee data streaming," *Microelectronics Journal*, vol. 41, no. 11, pp. 703-710, 2010.

[42] N. Andre, S. Druart, P. Gerard, R. Pampin, L. Moreno-Hagelsieb, T. Kezai, *et al.*, "Miniaturized wireless sensing system for real-time breath activity recording," *IEEE Sensors Journal*, vol. 10, no. 1, pp. 178-184, 2010.

[43] S. Tarapiah, M. Daadoo, and S. Atalla, "Android-based real-time healthcare system," *International Journal of Medical Engineering and Informatics*, vol. 9, no. 3, pp. 253-268, 2017.

[44] D. U. Ijaz, U. Ameer, H. Tarar, A. Ilyas, and A. Ijaz, "E-health acquisition, transmission and monitoring system," in *Proc. 2nd IEEE Workshop on Recent Trends in Telecommunications Research*, Palmerston North, New Zealand, 10-10 Feb. 2017, pp. 1-4.

[45] D. Sunehra and P. Ramakrishna, "Web based patient health monitoring system using Raspberry Pi," in *Proc. 2nd IEEE International Conference on Contemporary Computing and Informatics*, Noida, India, 14-17 Dec. 2016, pp. 568-574.

[46] R. K. Megalingam, P. S. Veliyara, R. M. Prabhu, R. R. Krishna, and R. Katoch, "Wheeled patient monitoring system," in *Intelligent Computing, Communication and Devices: Proceedings of (ICCD), Volume 1*, L. C. Jain, S. Patnaik, and N. Ichalkaranje, Eds., ed New Delhi: Springer India, 2015, pp. 779-786.

[47] R. Prakash, A. B. Ganesh, and S. V. Girish, "Cooperative wireless network control based health and activity monitoring system," *Journal of medical systems,* vol. 40, no. 10, pp. 1-14, 2016.

[48] Y. Liu, X. M. Xu, and M. Liu, "GPRS based embedded wireless physiological monitor for telemedicine applications," in *Advanced Research on Computer Science and Information Engineering: International Conference (CSIE), Zhengzhou, China, Proceedings, Part II*, G. Shen and X. Huang, Eds., ed Berlin, Heidelberg: Springer Berlin Heidelberg, 21-22 May 2011, pp. 503-506.

Sadik Kamel Gharghan received his B.Sc. in Electrical and Electronics Eng. from the University of Technology, Iraq in 1990, his MSc. in Communication Eng. from the University of Technology, Iraq in 2005, and his PhD. in Communication Eng. from the Universiti Kebangsaan Malaysia (UKM), Malaysia in 2016. He is with the Department of Medical Instrumentation Techniques Engineering, Electrical Engineering Technical College, Middle Technical University (MTU), Baghdad-Iraq, as Asst. Professor. His research interests include, energy-efficient wireless sensor networks, biomedical sensors, microcontroller applications, WSN Localization based on artificial intelligence techniques and optimization algorithms, indoor and outdoor pathloss modeling, wireless power transfer, and jamming on direct sequence spread spectrums.