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Implementation of a Patient Body Temperature Monitoring System Using Wireless Technology

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Abstract— *A thermometer is used in health care centers to measure and monitor body temperature. Temperature readings should be taken on a regular basis to detect deviations from normal and to assess the effectiveness of current medications or therapies. The challenge with most health care centers is that, these repeated measurements of temperatures are usually done periodically by the caregiver and in the same room with the patients, this process is demanding and not sufficient enough to have a comprehensive history of patients' temperature especially those patients' that are in critical condition and that will require constant monitoring. That is why wireless and remote monitoring of patients' temperature was introduced in this work using a transmitter and a receiver. The transmitter unit which is to be located at the patients' ward comprises of transducers (LM 35) for converting temperature signals to voltage signals linearly, a microcontroller converts the voltage signals from the transducer to digital signal by the help of an in-built analogue-to-digital converter, and XBee PRO S2B radio (Zigbee firmware) used to transmit these digital signals to the receiver. The receiver unit which is to be located at the caregiver's office comprises of XBee PRO S2B radio (Zigbee firmware) which is used to intercept the digital signals, PIC 18F4520 microcontroller which is programmed to activate a buzzer when the temperature of a patient exceeds the range of normal body temperature (36°C – 38°C) and an LCD to display temperature values. The prototype has been developed and tested. The maximum range realized in this work between the transmitter and receiver is 100m. The modules used the unlicensed ISM band (2.4GHz) to communicate.*

Keywords— *LCD Display:Measurement:* Temperature: *Thermometer: Wireless: Zig bee.*

I. INTRODUCTION

Measurement plays an important role in human existence. It is a wide field in both Engineering and Sciences as it helps in analysis and record keeping, providing means of describing natural, human and artificial activities in quantitative terms. It can be seen in temperature detection, data acquisition, and temperature control systems. Due to the recent advancement in science and technology, many sophisticated and high precision measurement devices and systems are developed. Among these devices are temperature measurement systems which play an important role in our lives. It is important for health care centers to improve on their temperature monitoring process due to problems experienced when using the traditional temperature monitoring methods. Problems such as not having a comprehensive data of the patients' temperature, Checking the temperature of patient a number of times a day using the manual thermometers is not sufficient and will not give a detailed assessment of the patients' temperature history especially when the patient needs to be monitored periodically due to his critical condition. Wireless device advancements have infiltrated the medical field with a wide range of capabilities. Not only does wireless technology improve patient quality of life and doctor-patient efficiency, but it also allows clinicians to remotely monitor patients and provide them with timely health information, reminders, and support, potentially expanding the reach of health care by making it available anywhere, at any time (Tam Vu Ngoc 2018).

This paper is aimed at using wireless technology to effectively monitor patients' temperature remotely and more frequently from a nurses' office using XBee modules that has Zig Bee firmware on it; this is an automated way to connect patients and health professionals seamlessly.

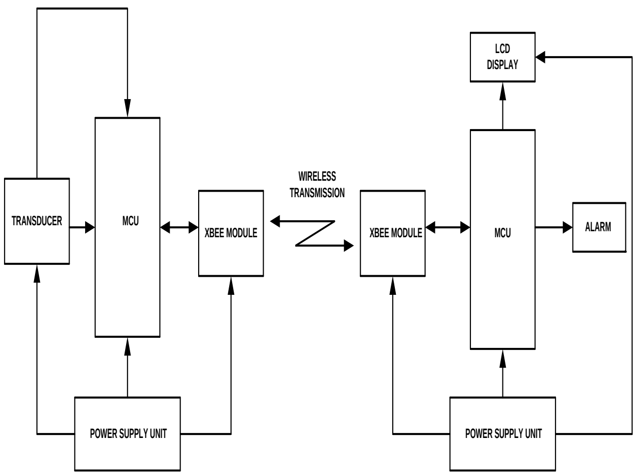

Fig. 1. Block Diagram of a wireless remote temperature monitoring system

The choice of ZigBee protocol is because it is officially a wireless network protocol that is designed to be used with low-data-rate sensor and control networks. If a sensor doesn't need to broadcast its status all of the time and can put the sensor-support electronics and radio to sleep for the majority of the time, Zig Bee was intended for it. Zig Bee can also eliminate the need to string wires all over the place (Fred Eady 2019). The Zig Bee standard provides network, security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard. It employs a suite of technologies to enable scalable, self-organizing, self-healing networks that can manage various data traffic patterns, it is an established set of specifications for wireless personal area networking (WPAN), i.e. digital radio connections between computers and related

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devices. The through-rate of Zig Bee devices is purposefully limited to 250Kbps, compared to Bluetooth's much bigger pipeline of 1Mbps, which operates on the 2.4 GHz ISM band, which is widely available throughout the world (S.S.Riaz & Ahmed 2010 – 2019).

II. REVIEW OF RELATED WORKS

The first and most basic option available for monitoring of patients' temperature was the alcohol thermometer. Savants had figured out that using air and water, they should be able to create a "ruler" that would mark the grades from cold to hot and back again. They experimented with thermoscopes (non-calibrated thermometers) that involved a column of air in a tube with one end immersed in coloured water. Galileo is credited with inventing the first alcohol thermometer when he tried it with wine in 1610. In 1641, for the Grand Duke of Tuscany, the first sealed thermometer was designed: it used alcohol and featured degree markers (Tim Radford 2019). An enhancement to the alcohol thermometer was the invention of mercury thermometer which could measure higher temperatures. Mercury Thermometer (also known as mercury-in-glass thermometer) was invented by German physicist Daniel Gabriel Fahrenheit in 1714. Mercury Thermometer is actually a thermometer in a glass tube. (Narang Medical Limited 2019) Advancements were continuously made is this field of technology.

In 2005 a thermometer designed by Germes LLC that is currently available in the market is a waterproof digital thermometer. This design implemented a thermistor contained within a metal probe to detect temperature change due to the resistance change proportional to the temperature. This resistance change produced a change in the voltage output of the system and a temperature could be detected. This design used basic technology to keep the cost relatively low (N. Benkovich, et.al 2009).

Red Free Circuit Design Company designed a digital remote thermometer intended for precision centigrade temperature measurement, with a transmitter section converting to frequency the sensor's output voltage, which is proportional to the measured temperature.

The frequency bursts from the output are carried through the mains supply connections. The receiver component counts the bursts from the mains and displays the results on three 7-segment LED screens. The least significant digit displays tenths of degree and then a 00.0 to 99.9 ºC range is obtained. Transmitter-receiver distance is 100m, provided both units are connected to the mains supply within the control of the same light (Red Free Circuit Design,1999)

In 2007 Nooraihan Binti Rasip from Universiti Teknikal Malaysia Melaka worked on a dissertation titled 'Digital Remote Thermometer'**.** In his dissertation, he stated that digital remote thermometer in the market currently; mostly the output is represented in BCD display to show the measured temperature. Besides, digital remote thermometer is usually used in certain areas such as office buildings and factories where the temperature has to be stable in order to produce a quality product. However, most of these digital remote thermometers are not user friendly because they only display the temperature of the room without giving a clear warning to the user (Rasip, N. B. 2007). In view of the preceding works, this paper seeks to contribute the following:

(a) Replace wired transmission of patients' temperature measurement to a wireless means of transmission therefore taking care of intentional or accidental cutting of wires in order to avoid hindering the transceivers from communicating effectively;
(b) offer a short range wireless networking capability with low cost;
(c) to reduce low power consumption significantly because of the use of nanoWatt Technology when PIC 18F4520 Microcontroller is used in this work;
(d) Accommodate 64000 nodes in its network when fully implemented in a mesh topology. Hence patients can easily be monitored at the same time

III. METHODOLOGY

The methodology employed involves the selection of the design of the following individual units:

i. Power supply unit
ii. Transmitter and receiver units
iii. Coding in C language using PIC KIT2.
iv. Display unit.

These units are finally integrated into a complete workable system.

System Design: The design comprises of two parts, namely: Hardware design and the Software design

Hardware Design: This section comprises the power supply unit for the microcontroller and the transceivers at the patient ward and the nurses' office.

Power supply unit: The microcontrollers used in this design need a supply of 5V and XBee RF modules require a voltage of 3.3V. Fig. 2 shows the power supply circuit for the system.

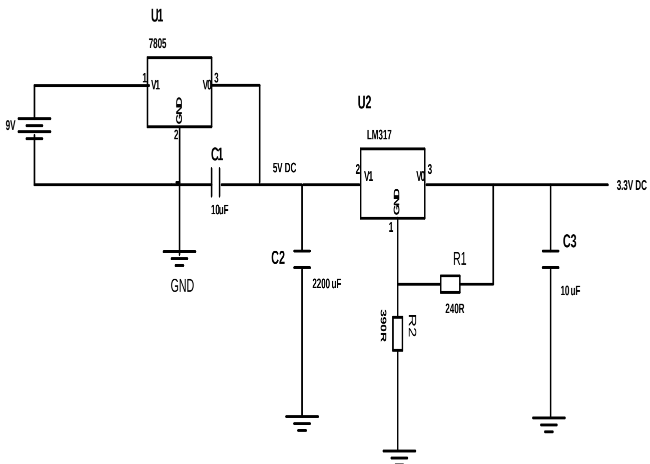

Fig. 2. Power supply unit for the system

A 9V DC battery is connected to a positive LM 7805 voltage regulator as shown in Fig. 2 to give an output voltage of between 4.75V to 5.25V (Tinysine Electronics 2014). The required voltage for PIC18F4520 microcontroller to function effectively is 5V. The circuit connection is a fixed-output regulator type and values of both capacitors can be seen from

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LM 7805 data sheet (Fairchild Semiconductor 2020). The power requirements of the XBee module is between 2.7 - 3.6 V, this can be obtained by feeding the 5V DC into an LM 317 positive adjustable voltage regulator to give a voltage output range of between 1.2V to 37V which can be obtained from LM 317 data sheet. The circuit connection and values of both capacitors and resistors can be seen from LM 317 data sheet (Fairchild Semiconductor 2020).

To obtain the output voltage of 3.3V which the XBee module requires, a fixed resistor, R_1 was calculated and used instead of a variable resistor which the data sheet used (Fairchild Semiconductor (2020). This is shown from equation 1.

$$V_0 = 1.25(1 + R_2 \div R_1) + I_{ADJ} R_2 \qquad (1)$$

Where

V_O = 3.3V (Required voltage for XBee module), R_1 = 240Ω, R_2 = Unknown

I_{ADJ} = 100µA

Substituting the values into equation1 and making R_2 the subject of the formula gives

$3.3 = 1.25 (1 + R_2 \div 240) + 0.0001R_2$

$3.3 = 1.25 + 0.00521R_2 + 0.0001R_2$

$3.3 – 1.25 = 0.00531R_2$

$2.05 = 0.00531R_2$

$R_2 = 2.05 \div 0.00531$

$R_2 = 386Ω$

But a 390Ω resistor was used in the design because of tolerance and it is one of the closest values of a standard resistor that can be obtained.

Circuit diagram of Transceiver (patients' ward)

The circuit diagram shown in Fig 3 represents a transceiver which is placed at a ward to be able to monitor the temperature of a particular patient.

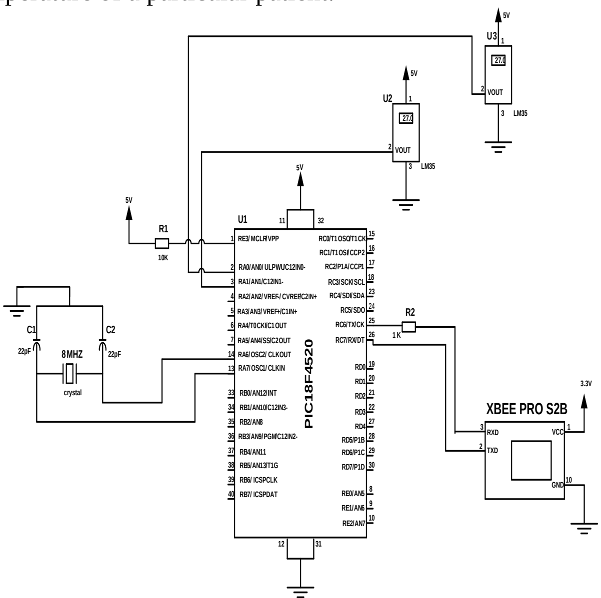

Fig. 3. Circuit diagram of the transceiver (patients' ward)

When temperature is sensed by the transducers (LM 35) which is connected to the PIC18F4520 microcontroller via its analogue input pins (2 & 3), as shown in Figure 3, the transducers converts temperature in centigrade to voltage linearly (+10mV to 1°C).

The PIC18F4520 microcontroller is clocked using an 8MHz quartz crystal oscillator on both pin 13 (CLKIN) and 14 (CLKOUT) and is programmed to use its internal analog-to-digital converter (ADC), this analog-to-digital converter allows conversion of an analog input signal (voltage) to a 10-bit binary representation of that signal via successive approximation and stores the conversion result into the ADC result registers (ADRESL and ADRESH).

The ADC positive voltage reference is software selectable to V_{DD} (pin 11 & 32). Likewise, the negative voltage reference is also software selectable to V_{SS} (pin 12 & 31). XBee S2B module receives the generated 10-bit binary data through pin 25 of the microcontroller and communicates back to the microcontroller through pin 26. This binary data are transmitted wirelessly to the transceiver (nurses' office).

Transceiver (nurses' unit) Circuit diagram

The circuit diagram shown in Figure 4 represents a transceiver which is placed at the nurses' office to be able to monitor the temperature of patients remotely without having to always go to check patients physically.

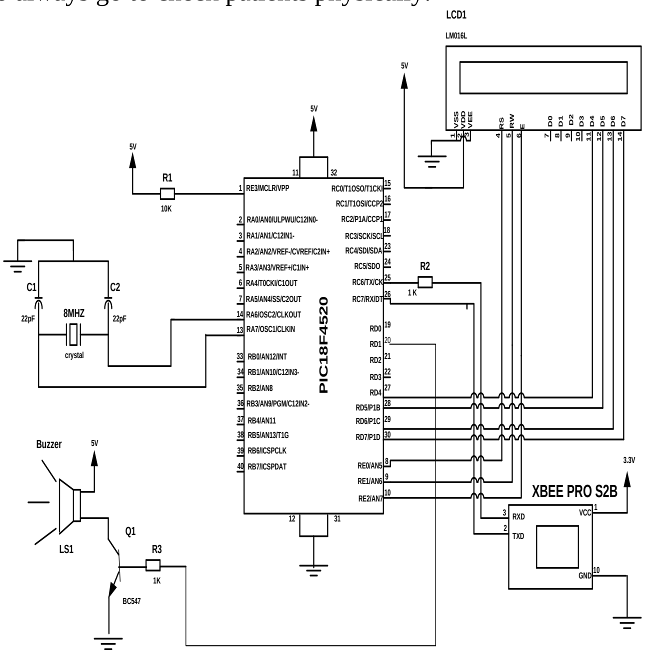

Fig. 4. Circuit diagram of the transceiver at the nurses' unit

XBee S2B module receives the generated 10-bit binary data wirelessly from XBee S2B module of the transceiver (patients' unit) and transmits to the microcontroller via pin 26. PIC18F4520 microcontroller shown in Fig. 4 is clocked using an 8MHz quartz crystal oscillator on both pin 13 (CLKIN) and 14 (CLKOUT) and is programmed to display the data received from the transceiver (patients' unit) unto a 16 x 2 character LCD which is connected to the microcontroller through pin 8, 9, 10, 27, 28, 29 & 30. Pin 20 has a buzzer connected to it. The purpose of the buzzer is to alert health personnel in a clinical environment, whenever the temperature of a patient rises above or below the normal range of body temperature.

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Software Design: The software design involve writing a program for sending and receiving signals on the PIC18F4520 microcontrollers after which Proteus 7.10 software with advanced simulation was used for circuit simulation.

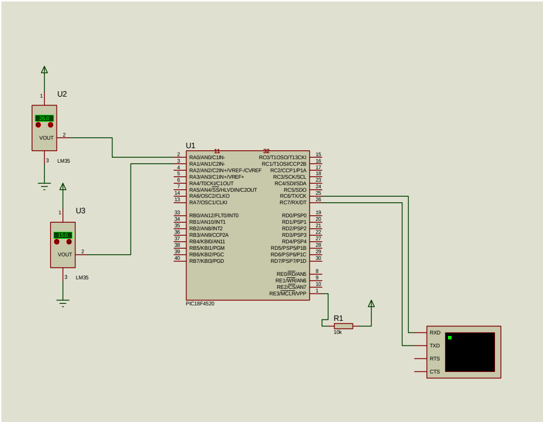


Fig. 5. Simulation for transceiver (patients' ward)

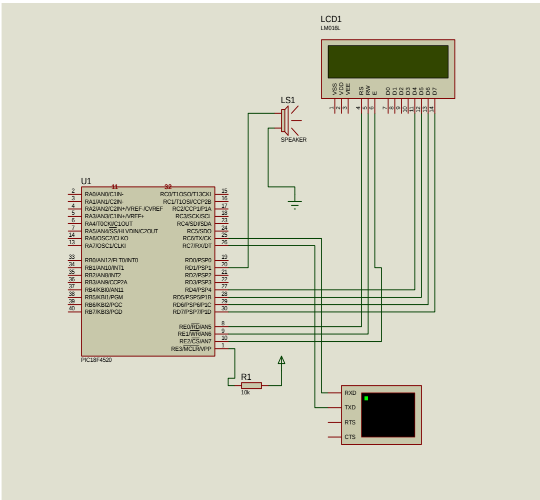
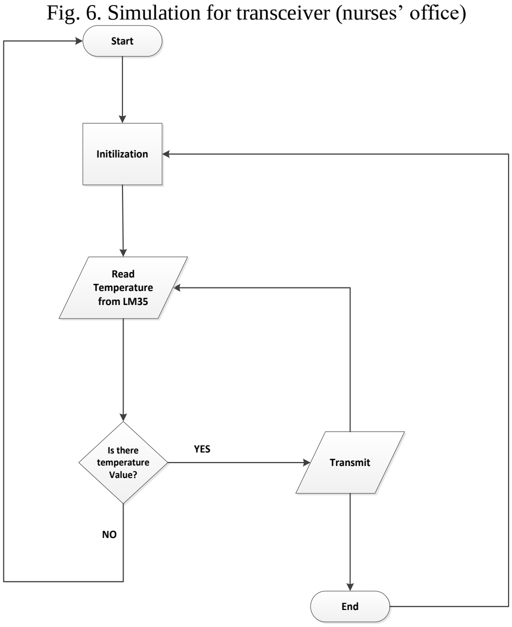


Fig. 6. Simulation for transceiver (nurses' office)



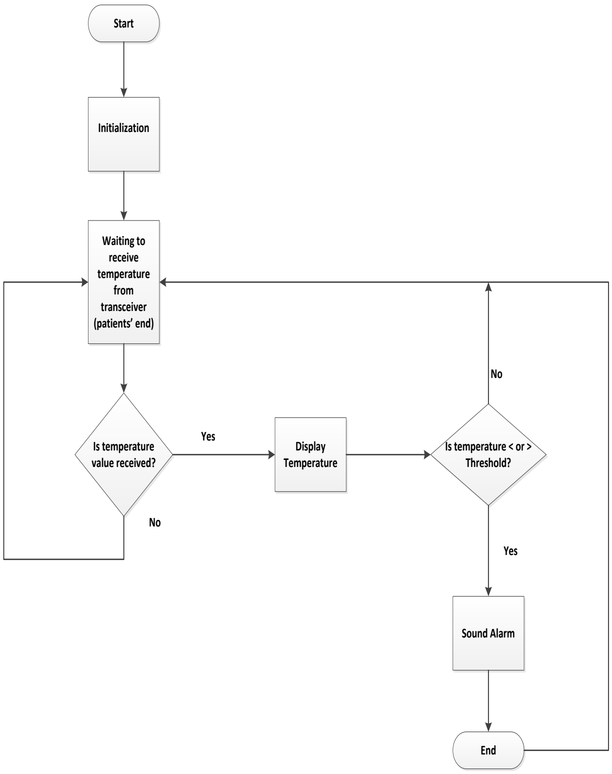


Fig. 7. Flow charts for the transceivers

Fig. 8. A snap shot of the prototype

IV. Results and Discusion

This section shows the range test carried out and results obtained. This feature can be found in X-CTU software, it allows a range test between a local radio module and any of the remote modules working in the same network as the local one. The tool is able to perform range tests of 802.15.4, ZigBee and DigiMesh protocols regardless of the working mode (AT or API) of the modules.

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Fig. 9. Radio range test using X-CTU GUI software at 10 meters and 20meters

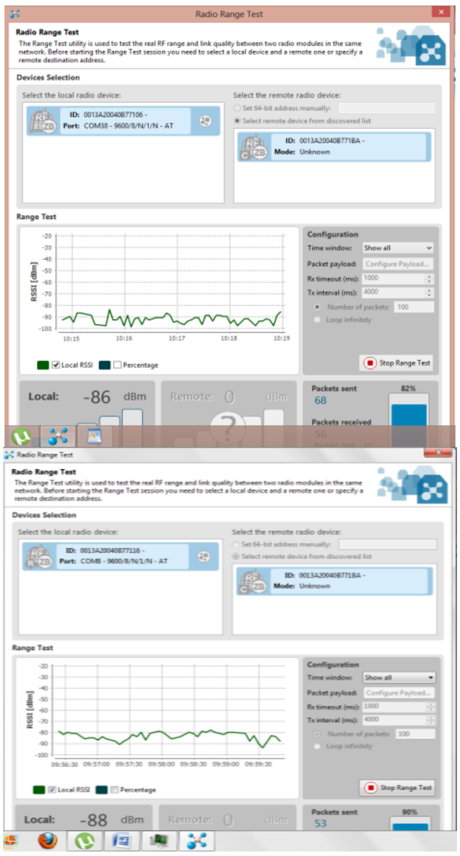

Fig. 10. Radio range test using X-CTU GUI software at 90

TABLE I. Received signal at different distances

Distance [m]	Received Signal Strength indicator (RSSI) [dBm] {within 10 seconds}	Average Received Signal Strength Indicator (RSSI) {Average Received Power}[dBm]
10	-77, -75, -72, -70	-73.5
20	-71, -69, -67	-69
30	-79, -77, -78	-78
40	-81, -82, -81, -80	-81
50	-75, -77, -79	-77
60	-76, -75, -87	-79.3
70	-81, -77, -78	-78.7
80	-84, -85, -83, -82	-83.5
90	-82, -87, -86	-85
100	-86, -88, -84	-86

Table I shows the received signal strength at different distances and average received signal strength. The following values of signal strengths of the coordinator obtained from the router in an outdoor environment (at the laboratory premises of the Kaduna polytechnic Tudun Wada, Kaduna,) between the hours of 10:00am to 11:00am on the 5th of December, 2021. The weather was a bit windy and sunny. The ambient temperature was 29^{o}C.

Received signal strength indicator (RSSI) was found fluctuating even at the same distance; this can be seen in Table I which explains why different values of received signal strength are seen for the same distances.

At the beginning (10 meters) up until 70 meters, the received signal strength indicator (RSSI) was found fluctuating (zigzag manner) but signal strength began to decrease with distance at some point (80 meters) until the end (100 meters)

V. CONCLUSION AND RECOMMENDATIONS

The aim of this paper was to develop a system that could monitor the temperature of patients' in a hospital remotely. This was accomplished with the help of a wireless sensor network. In this paper, the network is a pair network which is the simplest network with just two X-Bee radios. One of the X-Bee modules was configured as a coordinator (receiver) while the other was configured as a router (transmitter).

The transmitter and receiver both communicate to one another at an unlicensed band of 2.4GHz and a maximum realizable distance of 100 meters. The transmitter unit which is to be located at the patients' ward has temperature sensors that convert temperature to voltage. The microcontroller of the transmitter converts the analogue signals from the temperature sensors into its digital equivalent with the help of an in-built analog-to-digital converter. The transmitter at the patients' ward propagates the temperature signals in digital form to the receiver at the nurses' office. The receiver intercepts the signals and decodes it and display the decoded information on an LCD and a buzzer is activated when the temperature exceeds the range of specified values (36^{0}C – 38^{0}C).

The following recommendations were made

a. RF ID chip should be used to achieve wireless connections between the patients and the transceiver (patient's unit) in order to completely eradicate wires.
b. A reset button can be incorporated into the circuit, so that when the alarm is activated and any health personnel hear

the sound, after attending to the patient, he/she could deactivate the alarm by resetting the button. This is to reduce noise pollution in the hospital premises.

c. There should be storage of the past records of patient's temperature. This can be implemented by introducing a server that runs a database and a web based interface on a computer, for any health personnel who wishes to access current and past temperature reading for different patients.
d. An alternative power supply aside using only batteries such as DC supply can be incorporated

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