Implementation of wireless sensor network for medical applications

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Abstract. There is an important requirement for additional cost-effective solutions for the supervision/monitoring of a patient’s tests during and after surgery or old patient as whenever the patient is at home or in the hospital. Advanced sensors combined with wireless communication can provide reduced expenses, improved observance, and higher life quality for the patient. In this paper, the Prototype will be developed for initial control of the basic vital functions of the patient’s body, whether patients of old age or even patients who are in hospital. This prototype is designed in a way to be effective and suitable for mobility because it is lightweight and can be carried by humans’ arm. Wireless communication using technology for 433 MHz through the product of HC-12 has many advantages including the distance up to 1000 meters as a wireless transmission range and several channels of 433.4 - 473 MHz, up to 100 communication channels. This prototype is developed, designed and tested with the primary version of a biomedical detector network for the long run wireless hospital and home care. The sensor network comprised of four completely different sensors and was tested in exceedingly hospital surroundings.

Keywords: Arduino; biomedical sensors; blood pressure sensor; Heart rate sensor; IOT; Temperature sensor; Wireless communication; WSN

1. Introduction
To provide health services in new and an easy way with low cost to patients, using information technology and medical sensors are effective and quick. Where the information technology allows the improvement of health care, enable patients to follow their normal lives while continuing to maintain health. also those technologies enable health and medical institutions to collect medical information through those techniques, monitor patients' vital signs without stagnation or need acute care in hospital, which saves time and cost for both patients and the institutions[1]. There are many requirements in case of need to measure the vital signs of the patient periodically and the most important of these requirements is the nursing health care professionals’. IOT eliminates the need for multiple visits of health professionals by providing the sensors, monitoring systems, gateway, and clouds, to decide what the professionals do. Where the specialist physician can brief the patient's information through any computer program or smartphones and describe the appropriate treatment method. Therefore, IOT and WSN for medical applications improve health performance much easier for the patient and the clinician, also ensures the financial costs of the patient and the health institutions[2]. It is expected that the wireless sensor network development will be integrated into the Internet of things and will work in conjunction with some wireless networks that will work in a precise and synchronized manner. The main purpose of the IOT is to exchange relevant qualitative information in a specific order that can control or obtain certain information to be adapted to an industrial, medical or other application. Radio-
Frequency-Identification (RFID), wireless sensor networks, or other technologies feed these technologies. This technology is becoming more and more expansion as shown in the following figure.1 [3].

![Figure1. Connected objects and IOT expansion](image)

There are some limitations in the implementation and design of wireless sensor networks such as the cost of sensors, as well as the consumption of high power, others limitation of the number of Bluetooth nodes that communicate with each other at any time [4] while some networks are designed Wi-Fi network, which need to High power consumption, some networks need very short sense’s time and very low power’s consumption for longer system’s life. HC-12 is a technology that uses a frequency of 433 MHz and is a good alternative to wireless technology as it is suitable for the frequencies allowed to the human body as well as long-distance wireless transmissions of 1000 m in open space/baud rate of 5000 bps in the air. Maximum 100 mW (20 dBm) transmitting power (8 gears of power can be set) with three working modes, adapting to different application situations [4]. The compact and wireless systems are small size and can be used by simple training that has been highly popular, particularly in medical and health applications. In this paper we will explain in detail a wireless system used to measure the temperature of the human body and also the number of heartbeats and the proportion of oxygen in the blood SPO2, with the possibility of showing the results of the examination through the Internet and obtain a set of results for a specific time to enable the user and the physician to collect sufficient information for use in medical diagnosis. Where the system was developed using Arduino of two types as well as a group of sensors will be explained in detail in subsequent sections.

2. System discretion

The general form of the system is explained and shown in figure. (2). The main part is Arduino Nano, which represents the central processing unit through which all vital signals sent by the sensors are received (temperature sensor, heart rate sensor, SPO2 sensor, Blood pressure sensor) and sends it to the HC-12 transceiver unit, which operates at a frequency of 433 MHz. This segment is the mobile part of the patient. The second part is also the HC-12 part of the receipt to the signal by the nodes and attached to the receiving unit D1 Arduino, through which the transmission of vital signs displayed or send through the Internet and viewed everywhere on the website.

2.1 Wearable gadget

The wearable part contains sensors, microcontroller, and wireless communication, each one of them works to complete the desired purpose of the system and we will describe in detail each of them later.
2.1.1 Arduino Nano microcontroller
This part is the main processing unit powered from two types of unregulated (6-20V) or regulated voltage supply (5V) and has many good specifications such as very light, small size with processor ATmega328, 32 KB makes it suitable for use in the wearable gadget. This type of Arduino with 14 pins I/O digital and 8 input analog that make it also suitable for many types of sensors and support several communications protocol such as SPI, MOSI, SCK, MISO and support serial communication port that use to monitor the I/O data sent to or from Arduino board [6].

2.1.2 Arduino software
The Arduino program is a platform for the Java language and the C++ languages, which makes it easy to set up all of the systems in the program's steps for the mobile part as shown by figure 4. The code that we used consists of the parts below:
1- Libraries.
2- Internet connectivity.
3- Definition of portals.
4- Open a matrix to receive the data.
5- Sensor program.
6- HTML definition to display results on a website.

2.1.3 HC-12 Radio
Medical and industrial sensors that have direct contact with the human body use frequencies between 403MHz and 405MHz, where this range is universally accepted. This ring has a specific power transmission in the air of 25 microwatts and divided into 300 kHz channels [7]. The human body consists of many materials, multiple sources, and compositions. These structures change from one generation to another and from one region to another as they change with increasing weight and decrease. All these important reasons make it very difficult to design a calculated communication mechanism for the communication of the human body [8]. HC-12 very small dimensions (27.8 * 14.4) Communication module of the system (wireless interface) with many specifications and suitable for medical use. It operates on a frequency band between 433.4 to 473.0 MHz with multiple channels up to 100 and each step of frequency 400 kHz, the highest transmitting power 20 dBm with Receiving sensitivity is -117 dBm as will a transmission speed of 5000 bps (baud rate) with a distance of 1000 m in open spaces. It has an internal MCU and does not need to be programmed separately. Multiple modes internally are responsible for transmitting and receiving data, those working modes can be choosing according to transmission distance and baud rate of serial port. FU2 is the suitable mode for this system due to very low power consumption and good baud rate up to 4800 bps, below table (1) clarifying the baud rate, time delay, and power consumption [4].
Table 1. This table clarifying the time delay, idle current of the modes [4].

| Mode               | FU1  | FU2  | FU3  | Remark                       |
|--------------------|------|------|------|------------------------------|
| Ideal current      | 3.6 mA | 80 µA | 16 mA | Average value                |
| Transmission time delay | 15-25 ms | 500 ms | 4-80 ms | Sending one byte            |
| Loopback test time delay 1 | 31 ms |      |      | Serial port baud rate 9600 sending one byte |
| Loopback test time delay 2 | 31 ms |      |      | Serial port baud rate 9600 sending ten bytes |

2.1.4 Temperature sensor
MLX 90615 is a heat sensor that uses infrared technology and has been characterized by very high specifications of precision and its most important feature is heat-sensing without direct contact (non-contact) as shown in Figure 3. The sensor consists of two thermopile detectors and a signal processor on the same board and has high accuracy with a readout resolution of 0.02 °C. The benefits of this sensor are many for this system, small size, factory calibrations achievement, the advice on its use in medical applications, the low cost. This type of sensor supports the SM Bus protocol which allows communication between the main device (MD) and the server (SD), and this protocol supports sleep/wakeup modes to make the sensor power efficient [9]. The low power consumption and sleep mode make the thermometer ideally suited for handheld mobile applications and the MLX 90615 works as a slave only.

![Figure 3. Block diagram of the temperature sensor [8].](image)

2.1.5 Heart rate and SPO2 sensors
MAX30102 a small-scale electronic chip designed to measure the number of heartbeats and the percentage of dissolved oxygen in the blood. This sensor includes an internal LED, a light sensor, and an optical component. This sensor is very suitable for use in mobile devices, had the possibility of connecting through I2C, and can be stopped through the software. The state of standby mode with very low power consumption (low heart rate power consumption (<1 mW)) with a high ratio of SNR. The sample rate of the sensor output also can be varied from 50 sps (sample per second) to 3200 sps. We can change the setting of the sensor to get better resolution by configuring the sensor's register to a higher
sample rate but also related to consumption power (a higher sample rate with higher current consumption). There is an internal temperature sensor to evaluate the sensor's ICs temperature because of its effect on the wavelength of IR and red light of the MAX30102, this sensor automatically corrects the effects of increment in IC temperature. Figure 4 shows the blocks diagram of MAX30102 [10].

![Figure 4. Block diagram of MAX30102 heart rate and SPO2 sensors [9].](image)

2.2 Receiver sink
This part of the system consists of two sections each section responsible for a specific task associated with the system. the first section is a microcontroller (D1 Wemos) with appropriate memory capacity and the ability to create a specific IP for the Internet access of the site that views the results directly from sensors in real-time. The second section is the receiver of the signal from the wearable gadget part's (HC-12) which has been explained in paragraph 2.1.4 above.

2.2.1 D1 Wemos
D1 Wemos is a microcontroller (Arduino UNO compatible Wi-Fi) that fits the requirements of this project. It is characterized by low power consumption and small dimensions, also supports two systems for transmitting information at the same time. It is possible to connect any transceiver to it, in addition to the built-in Wi-Fi transceiver.

The technical specification of this microcontroller based on ESP8266 Wi-Fi, which is manufactured by Espressif supports TCP/IP and thus supports Wi-Fi, in which 9I/O pins digital support I2C protocol with proccing speed 80 MHz and can be powered from mini-USB or external adaptor. Free and open resources Arduino IDE can program D1 Wemos with the installation of additional libraries of ESP8266 [11].

3. System Implementation
The system has been implemented as shown in figure 5 where the sensors are composed of the MLX90615 temperature sensor and the sensor of the oxygen saturation ratio in the blood (SPO2) as well as the heart rate sensors MAX30102. All these sensors have been connected with the microcontroller the Arduino Nano and wireless module HC-12, these components represent the wearable or the mobile part. The receiver sink of the system consists of microcontroller Wemos D1 with the wireless module is connected to the internet in any way, this system has been connected to the Internet via Wi-Fi module located in the Wemos D1.

In addition, D1 responsible for generating IP to the server for vital signs transmitted directly to the recipient whether the doctor or medical staff. In Figure 5, the design of the whole system shown. The system consists of two main parts, the wearable part, and the sink part. The wearable part consists of three sensors, a temperature sensor, a heart rate sensor, and an SPO2 sensor. These sensors connected to an Arduino microcontroller and HC-12 wireless model. The Arduino Nano receives the data from the sensors and process them, then send them to the sink part through the HC-12. The data are received in the sink part wirelessly via the model HC-12, and then sent to the microcontroller Wemos D1. The latest
results are presented to the recipient the medical staff or the patient via a browser link that is designed within the Wemos D1 code. Below Figure 6 clarify the implementation.

![Diagram of system structure](image)

**Figure 5.** Diagram of system structure.

![System implementation images](image)

**Figure 6.** System implementation.

After the implementation of the system and connecting the sensors on the human body, the system shows the results with high accuracy and data transferred in real-time by the steps of flowchart Figure 7.

The values of the vital signs received from the sensors are programmed and treated in a way that gives to the recipient whether the physician, the patient or the medical staff every 10 seconds. These results are obtained from a very high number of readings in fact, such as in the blood oxygen sensor SPO2, the program obtains 100 readings from the sensor and processing them. Then sending only one result to the recipient, but in the sensor of the number of heart rate is obtained from the reading of it and take the average then send this average to the recipient. The temperature sensor includes calculating the temperature of the body taking into account the temperature of the sensor itself.
4. Results
When the system is fully implemented and the connection is correct in the prototype, whether it is the internal wiring of the prototype or the sensors attached to the patient's body, the initial results obtained from the sensors has been read by the Arduino Nano processor in the wearable node as shown in Fig.8, where the results are in the first four seconds it's getting 100 values from the sensor and enter it to the array, 25 reads entered every one second, the number of heart rate is calculated and taken the average, while in the calculation of SPO2 the result is a reading from the sensor directly. Since the browser is refreshed every 10 seconds, the reading rate displayed will be approximately 1% of the readings obtained. Figure 8 shows the results of the sensor in the wearable part and sends them to the receiving sink part. In Figure 8, the results are extracted from all the sensors attached to the body, where they are continuously detected. The temperature sensor is continuously working as it is programmed to receive temperature from 33 to 42 degrees. This range is medically applicable and no other temperatures range shown to avoid the readings of other objects or ambient air. The temperature of the body measured in the testing experiment of this system are ranged from (36.79 - 36.94) (body's surface temperature), this range of degrees was processed by the program within the Arduino Nano to calculate the true body temperature and it was presented to the recipient in the website in figure 10, which is 37.1. In the case

Figure 7. Flow chart of system simulation process.
of measuring the number of heart rate, the sensor receives the values of the IR and enter these values in a special algorithm to convert these values to heart rate.

The rate of heart rate in the physical examination of the human body measured from 60 to 72 as in figure 8, the rates have been taken to calculate the number of heartbeats, where every 25 readings obtained within 4 seconds by the sensor produces the average value of heart rate, the results on the web page as in figure 10. In the blood oxygen readings (SpO2), 100 readings of the sensor were obtained as shown in figure 8, The value of SpO2 can be calculated based on Equation (1) [12].

$$SpO2 = 10.0002R^3 - 52.887R^2 + 26.817R + 98.293$$

(1)

where $R$ refers to the ratio between two LEDs (infrared and red light).

In Figure 9 shows the receipt of readings from the sensors after receipt by the Arduino Nano and processed, then sent to the transceiver HC-12 in wearable part to send them wirelessly to the transceiver with microcontroller D1 in the sink part. Figure 10 shows the presentation of results to the recipient, whether the specialist doctor or nursing staff, where these results are in real-time with the system and with the vital signs of the patient.
Figure 10. Results from website.

5. Conclusions
Preliminary results revealed that it is possible to establish a WSN in medical applications and to collect results without the urgent need for medical staff in a permanent manner with the patient, as well as data collection more broadly and easily at very low cost with safe means, which facilitates group medical work and reach to automatically medical solutions without need to a physician directly. The results show that it is possible to monitor the vital signs of humans on the mobile and outside the medical care rooms, which supports the movement with monitoring of many patients and people at the same time, it made it possible to add amendments to the needs of experts to achieve comprehensiveness in the integration of the health service. The integration of WSN and IOT has made it easier and faster to share medical data for the patient and to simplify the medical specialists’ access to the required information, thus be slapdash the diagnosis without the need for medical signals directly from the patient.

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