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A LOW-COST IOT-BASED HEALTH MONITORING SYSTEM FOR HOME-CARE PATIENT

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Abstract— Higher cost of commercial Health Monitoring System potentially hinders the wide-usage of it, especially at homes. This article presented a development of a low-cost IoT-Based Health Monitoring System, using an ATMega328p microcontroller, integrated with different low-cost sensors to monitor pre-determined health parameters related to heart problem such as heart rate, pulse rate, body temperature and blood pressure of a home-care patient. The health data are sent wirelessly to an IoT-platform, where they can be monitored real-time by doctors or nurses. The system is battery-powered, and the sensors used in the system are attached to a home-care patient, where the patient's health can be recorded and monitored in real-time. Any abnormal changes will trigger an alert system to alert the doctors and nurses. It was found that the performance of the low-cost system fare comparably (~95% accuracy) with commercial devices tested. A time-series monitoring of a patient's health can thus be done remotely to ensure optimum monitoring of a home-care patient, where a potential saving in time, cost and money are expected. In the future, we may incorporate other low-cost sensors available such as blood pressure sensor and oximeter to monitor blood pressure and oxygen level of a heart-related patient.

I. Introduction

Heart problem refers to a problem related with the abnormal function of heart such as aortic stenosis, heart failure, heart attack, myocardial infarction and ischaemic, and can pose severe danger, including fatality, to those at risk, if not attend to as quick as possible. In [1], it was reported that cardiovascular is the leading cause of death in Malaysia and most Malaysian develop excessive fat in the blood, due to many reasons such as unhealthy diet, such that it becomes abnormal and contributes to the development of atherosclerosis, which in turns lead to cardiovascular problems manifested by heart attacks, strokes and even death. It was also reported that Cardiovascular problem (CVD) is the leading cause of death in Malaysian men and women for over a decade and in an upwards trend. From 2011 to 2013, 96.8% of patients had at least one cardiovascular risk factor, where 65% is high blood pressure, 46% is diabetes and 37% is dyslipidaemia.

Increase in the number of heart problem patients lead to the development of many health-related devices and systems. Many of these devices and systems unfortunately, either do not work remotely, or with higher cost operationally. One of the many technologies that could address this is the use of the Internet of Things (IoT) technology, with low-cost sensors, as presented in this work. In a nutshell, IoT refers to the physical devices around the world that are connected to the internet and to each other. The devices can collect and share the data among them [2]. Many other IoT-based applications can be found such as smart homes – an idea coined to show the house is 'smart' enough to control its 'daily home operation'. This means connecting home appliances such as home lighting, home security systems and cameras, audio videos and others, and at the same time enable the homeowners to control their operations remotely using devices such as cell phones and computers.

In this article, a development of a low-cost IOT-based health monitoring system for home-care patient is presented. The system focuses on heart-related conditions and is developed such that the home-care patient data can be monitored in real-time by doctors and nurses at other location. This is to potentially reduce the risk of a sudden death due to late attendance to the patient. It involves monitoring of the patient's condition such as temperature and heart rate, using suitable sensors. The data is also displayed real-time on IoT platform. If abnormal conditions are detected by the sensors, the system will automatically alert the doctors so that appropriate actions can be taken quickly.

The rest of this paper is organized as follows: The following section provides an overview of material and methods which include the architecture of the system and how the system's prototype is being developed using only low-cost sensors and freely available IoT platform. Results and discussion are presented in section III. Conclusion and future work are discussed next in section IV.

II. Material and Method

A. The system's architecture

In this proposed low-cost health-monitoring system, the system's architecture consists of a prototype device, which houses sensors and run using ATmega328P microcontroller [3], the IoT platform connected using Wi-Fi module, and IoT monitoring platform. Figure 1 below shown the system's architecture.

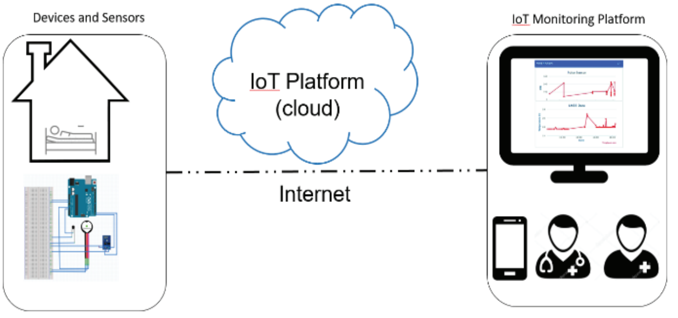


Figure 1: The overall system architecture

LM35 temperature sensor is used due to its specified temperature range, which is suitable for human body's temperature range. It is considered as a precision integrated-circuit temperature sensor, as its output voltage is linearly proportional to the Centigrade temperature, and accurate measurement of body temperature in degree Celsius is easily obtained. Additionally, its temperature ranges of operation, which is rated between -55°C to +150°C, provides advantageous when compared with other typical temperature sensors such as thermocouple and thermistor. Most importantly, LM35 sensor is used because of its very low self-heating and very low current drawn from the power supply, which is less than 60µA [4]. The Table 1 below shows the specification between four types of temperature sensors [5].

Next, a SEN-11574 pulse sensor is used to measure heart rate. It was chosen due to its easiness to handle and used by users. As the sensor is built with a bright LED and a light detector, it must be used at the fingertips. The LED will shine the light onto the fingertip and when the sensor touches the fingertip, the amount of light that bounces back will be read by the light detector. The heart pumps blood through the blood vessel, which in turn makes the finger becomes opaquer. This opacity changes the amount of light that can reach from LED to the light detector. An electrical pulse is then generated from this varied signal and correspond to the measured heart rate.

Table 1: Temperature sensors specifications

Criteria	RTD	Thermistor	Thermocouple	IC sensor
Temperature range	-250°C to +750°C	-100°C to +500°C	-267°C to +2316°C	-55°C to +200°C
Accuracy	Best	Depends on calibration	Good	Good
Linearity	Good	Worst	Good	Best
Sensitivity	Less	Best	Worst	Good
Circuitry	Complex	Depends on accuracy/power requirements	Complex	Simplest
Power consumption	High when taking measurement		Low-high	Lowest
Relative system cost	$$-$$$	$-$$$	$$-$$$	$

Additionally, ATmega328P is used as a microcontroller due to its low power consumption and is cheaper in price. Figure 2 below shows the schematic drawing of the system, while Figure 3 shows the actual prototype of the system developed in this work.

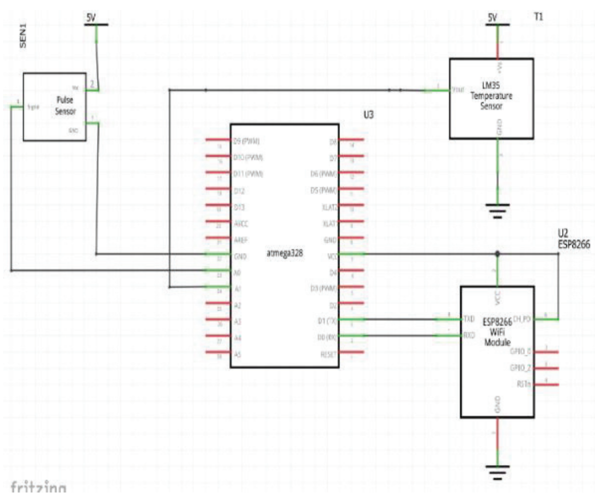


Figure 2: The system's schematic drawing

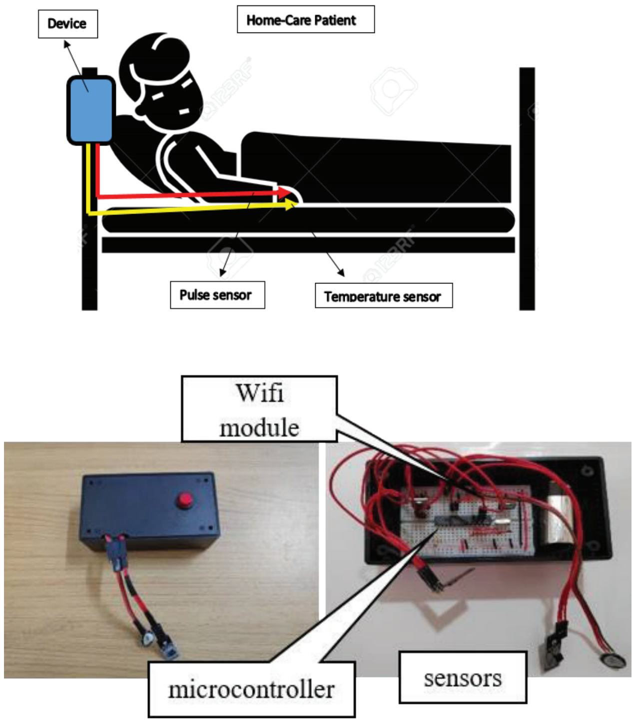


Figure 3: (top left) The external view of the actual prototype, with the red panic button shown (top right) The internal view of the actual prototype, (bottom) how the system can be potentially used by a patient

B. Integrating with IoT Platform

The IoT platform used was ThingSpeak. It is chosen as it is a free web service where the data collected by the sensors can be stored in cloud and can be analyzed and visualized remotely at any workstation. User can freely register an account and can use the platform anywhere. To develop a process of sending the data to the IoT platform, the Wi-Fi module ESP8266 (see Fig 3.2) is tested using the Arduino UNO before replacing it with ATmega328p microcontroller chip. For the microcontroller to communicate wirelessly with IoT platform through ESP8266 Wi-Fi module, AT commands are used in the programming part using C-language. By using AT commands, the Wi-Fi module can be controlled to send and update the data. ESP8266 Wi-Fi module uses its serial port to communicate with Arduino/ATmega328p where TX pin of ESP8266 is connected to pin 10 microcontroller and RX pin of ESP8266 is connected to pin 11 microcontroller.

An example of the codes for the ESP8266 to send the data of patient to the IoT platform are as shown in Figure 4 and Figure 5. The Wi-Fi name, password, and IP of thingspeak.com is set in the coding so that this module can trace the SSID of Wi-Fi and connect. The IP address of the IoT platform is also set for the module to send the data at the right platform. The declaration of String is declared to update the data on the channel of IoT platform. An API key, given by the IoT platform channel, is also needed to communicate, and used in the codes.

In the setup function, the baud rate is set for communication between Arduino serial monitor and ESP8266. The ESP communication is started by giving AT command to it and connect it by calling *connectWi-Fi();* function. After that, call *t.every(time_interval,do_this);* that will initialize Timers, which means the readings will be sent and updated on the IoT platform.

002_IOT_HEALTH_MONITORING_SYSTEM

```
#define USE_ARDUINO_INTERRUPTS true
#define DEBUG true
#define SSID "zulkiflidaud61"     // "SSID-WiFiname"
#define PASS "zulkiflidaud" // "password"
#define IP "184.106.153.149"      // thingspeak.com ip

#include <SoftwareSerial.h>
#include "Timer.h"
#include <PulseSensorPlayground.h>     // Includes the PulseSensorPlayground Library.
Timer t;
PulseSensorPlayground pulseSensor;

String msg = "GET /update?key=72WH4GLK5TK4SFOT";
SoftwareSerial esp8266(10,11);
```

Figure 4: An example code to connect to WIFI and API key used

```
void setup()
{

  Serial.begin(9600);
  esp8266.begin(115200);
  pulseSensor.analogInput(PulseWire);
  pulseSensor.blinkOnPulse(LED13);       //auto-magically blink Arduino's LED with heartbeat.
  pulseSensor.setThreshold(Threshold);

  // Double-check the "pulseSensor" object was created and "began" seeing a signal.
   if (pulseSensor.begin()) {
    Serial.println("We created a pulseSensor Object !");  //This prints one time at Arduino power-up,  or on Arduino reset.
  }
  Serial.println("AT");
  esp8266.println("AT");

  delay(3000);

  if(esp8266.find("OK"))
  {
    connectWiFi();
  }
  t.every(5000, getReadings);
   t.every(5000, updateInfo);
}
```

Figure 5: An example code to connect to WIFI, get readings and update the info on the IoT platform

III. Results and Discussions

An example of the display developed on an IoT web-based platform is shown in Figure 4. On the left, the heart rate and temperature data are displayed in the form of a graph. The data displayed are updated in real-time whenever there is a new reading from the sensor attached to a patient remotely. Apart from monitoring this data in real-time, which is important for the nurses or doctors, the pattern of the health data collected can be also observed over time. On the right is the alert indicator. When the value of the heart rate or temperature exceeds beyond or drops below normal level, the indicator will turn red, indicating abnormal condition of a home-care patient that needs immediate attention.

The system was also developed with the panic button in place (red button in Figure 3). Whenever the patients are in emergency, or in need of an immediate attention, they can press the panic button which was installed on the device. An emergency email will immediately be sent to the nurses and doctors. A line of code is configured such that it triggers the Thingspeak platform when a signal from the panic button is received. The email is triggered by ThingSpeak and sent by IFTTT [9]. IFTTT is a free web-based service to create chains of simple conditional statements, called applets. An applet is triggered by changes that occur within other web services such as Gmail. Figure 5 shows the snapshot of an email received when the button is pressed due to an emergency.

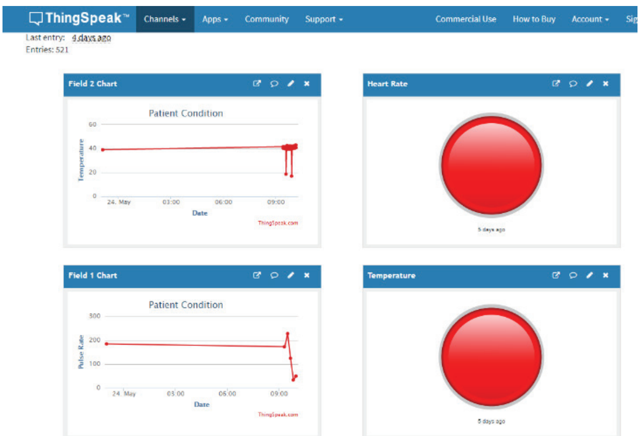


Figure 6: The IoT platform developed to display the data in real-time

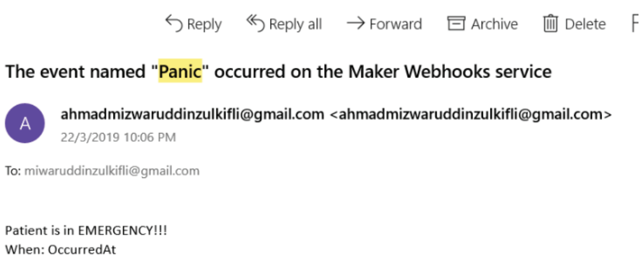


Figure 7: An example of an emergency email message sent by the system to doctor

A. Sensor accuracy analysis

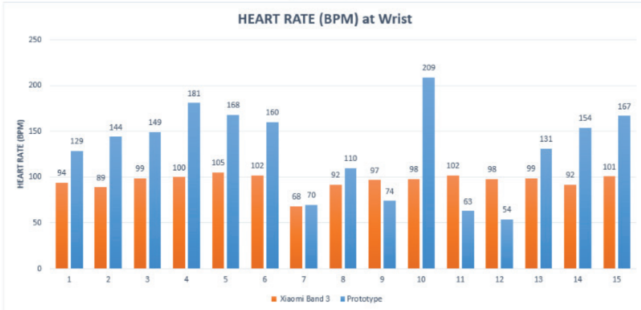
The pulse sensor's accuracy is tested by comparing it with commercially available device, Xiaomi Band 3 smartwatch [6]. Any other smartwatch can also be used, but for the purpose of this study, only Xiaomi Band 3 is available. The data collected from both Xiaomi Band 3 and the pulse sensor used are recorded and analyzed. Using wrist and finger as the location of the device, the data collected from both devices are compared. Figure 6 (top) shows the comparison of the heart rate data when the device is worn at the wrist, and Figure 6 (bottom) shows the same data when the device is worn at the finger. The orange graph shows the Xiaomi Band 3 measurements, and the blue graph shows the pulse sensor measurements. Using the Equation (1):

$$Percent\ of\ different = \frac{Average\ of\ Prototype - Average\ of\ Commercial\ Device}{Average\ of\ Commercial\ Device} \times 100\% \quad (1)$$

It was found that using these readings (more readings are preferable, but we presented for 15 readings as a sample), on average, the difference was recorded at only 18% difference from the reference (Xiaomi Band 3), which translated to 82% accuracy.

The temperature sensor's accuracy is tested by comparing it with commercially available device, Infrared Body Thermometer [7] as it is commonly use device to measure body temperature. Again, the data collected from both sensors are recorded and analyzed and is shown in Figure 7. The temperature sensor is place on the finger.

Using Equation (1), it was found that the accuracy of the sensor used is not far off from the reference (commercial device), with 5% difference, translated to about 95% accuracy.



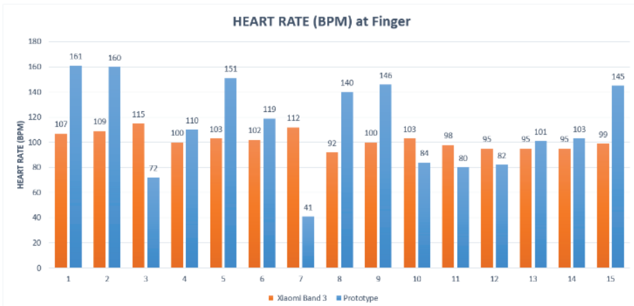


Figure 8: Comparison of the heart rate data when the device is worn at the wrist (top) and at the finger (bottom)

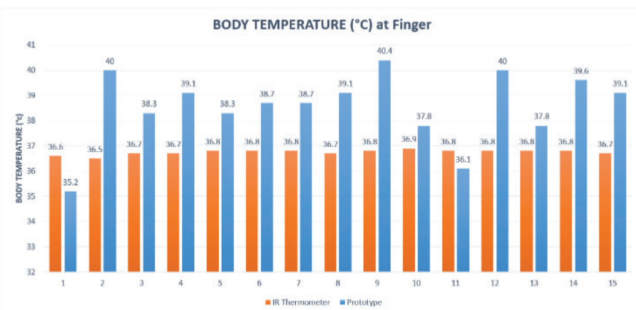


Figure 9: Comparison of body temperature data with commercially available device

B. Cost Analysis

The cost analysis for each component of the prototype and commercially available devices is compared and tabulated in Table 2. From the table, the total cost for all components and materials is RM92.31 (*note that this is only raw material cost, excluding other real factory cost* *such as manufacturing cost, manhour cost and likewise*). This price is considered relatively affordable because the standard price health monitoring device is ranging from RM335.50 (US$80) to RM1216.30 (US$290) based on the online product price [8].

Table 2: Cost Analysis of the Prototype

No	**Component**	**Quantity**	**Price per unit (RM)**	**Total (RM)**
1	LM35 Temperature Sensor	1	8.30	8.30
2	SEN-11574 Pulse Sensor	1	8.30	8.30
3	ESP8266 Wi-Fi Module	1	17.80	17.80
4	Box	1	6.00	6.00
5	ATmega328P	1	15.00	15.00
6	Breadboard	1	5.60	5.60
7	Crystal Oscillator 16MHz	1	2.00	2.00
8	Capacitor 22nF	2	0.33	0.66
9	10K Ohm Resistor	1	0.05	0.05
10	LM7805 Voltage Regulator	1	2.00	2.00
11	LM1117 Voltage Regulator	1	1.00	1.00
12	9V Battery	1	11.30	11.30
13	Jumper Wire	10	0.10	1.00
14	Battery Connector	1	0.90	0.90
15	Push Button	1	2.90	2.90
	Total		92.31	

IV. Conclusion

This article presented a prototype development of a low-cost IoT-based Health Monitoring System, using an ATMega328p microcontroller, integrated with only a low-cost temperature sensor and a low-cost pulse sensor, and connected to a free IoT platform for remote and real-time monitoring of patient data. These low-cost sensors are primarily chosen because it can monitor pre-determined 'fundamental' health parameters most likely related to heart problem, which are body temperature and pulse rate. The prototype of the system has been successfully developed and was shown to successfully connected to the IoT platform using a Wi-Fi module. Patient data were sent accurately in real-time, and subsequently manage to alert the emergency condition to the doctors whenever and wherever they are. As the system is in its prototype stage, the accuracy of the system is acceptable for now and considered usable for the purpose of monitoring remotely, when compared to commercially available device. In the future, we may incorporate other low-cost sensors available such as blood pressure sensor and oximeter to monitor blood pressure and oxygen level of a heart-related patient. We may also design the system such that the emergency condition will be alerted to doctors automatically, without the need to push a button. We foresee the prototype can be further scaled down to ensure practicability when attached to patient's hand.

V. Acknowledgement

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