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Miniaturized and Portable Home-Based Vital Sign Monitor Design with Android Mobile Application

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Abstract: Frequent or continuous vital sign monitoring could help to decrease mortality rate as early detection of vital sign abnormality allow prompt medical action to be taken for early prevention measurement, especially to elderly people and patients who suffer from chronic disease or infectious disease. However, most of the vital sign monitor are designed for hospital usage and operated by healthcare professionals, which the devices are generally heavy duty, cost-expensive, and complicated user interface for home user. This paper proposes a miniaturized and portable home-based vital sign monitor, named *myVitalGear*, which can accurately measure heart rate using electrocardiogram (ECG), body temperature and blood oxygen saturation (SpO_2), based on Arduino Nano technology. This device aims to enable frequent vital sign monitoring at home by reducing long distance travel to hospital and long waiting hour at hospital. The device consists of an AD8232 chip to acquire ECG for heart rate measurement and further heart rhythm abnormality detection, a high precision DS18B20 temperature sensor for body temperature measurement, and a MAX30100 pulse sensor for SpO_2 monitoring. In this device, the Arduino Nano microcontroller acts as the master controller to control all the system peripherals and biomedical sensors to acquire and process all the vital signs. The device also equipped with simple interface like light emitting diode (LED), liquid crystal display (LCD) and buzzer as the status indicator for layman user. A mobile application which targeted to Android-based smart phone is also developed to communicate with *myVitalGear* through Bluetooth wireless communication. The mobile app support the functionalities of displaying the vital sign measurement result, automated short message service (SMS) notification message and user location sending to the healthcare provider or guardian, in case of any vital sign abnormality is detected. Validation result has shown that the system able to measure vital sign with accuracy of 99.4%, 99.7% and 98.1% for heart rate, body temperature, and SpO2 respectively.

Keywords: blood oxygen saturation (SpO2), body temperature, electrocardiogram (ECG), home-based monitoring, vital sign measurement

1. Introduction

With the rapid evolution and fast growth of health care technology since the new millennium, it not only results in longer life span in worldwide but also increases complicated and critical health state at the same time. Due to the rising of world population aging, it escalates the number of older adults compared to the whole population. According to the United Nations reports, this ratio is expected to rise twofold between 2007 and 2050, which will reach two billions by 2050 [1]. As aging issues becomes one of the serious concerns, the demand of healthcare treatment at hospital as well as at home increase cautiously. However, the main disadvantages of long term and full-time health care need aid of workforce and financial initiatives [2]. In addition to that, the exacerbated health problem and clinical state are normally the result of vital signs measurement variation [3]. As a result, continuous and reliable vital signs monitoring primarily to critical patients become extremely crucial. Unfortunately, it is a very tedious yet costly journey to stay at the hospital for the purpose of post medical treatment and

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recuperation [4]. In addition, having to stay at the hospital environment is one of the horrifying experiences, since patients and family must endure the main challenges such as costly charge, being far away from home and family members, as well as being boring and restricted to move around due to limited freedom [5]. According to a survey conducted in United States, 30% of those who are more than 65 years old conveyed that they would "rather die" instead of getting into nursing home [1]. As a result, home monitoring is one of the best solutions to enable remote monitoring of the elderly's' health condition in an environment that they feel comfortable.

Besides the rising of world population aging issues, cases of chronic diseases such as cardiovascular diseases (CVDs) also keep increasing in an alarming rate across the globe. According to World Health Organization (WHO), ischemic heart diseases and stroke are the world's top silent killers which contribute for a total of 15.2 million out of 56.9 million deaths worldwide in 2016 [6]. This statistic reveals that the CVDs is still remained as the top killer for last 15 years consecutively. In addition to that, numbers of death in remote area caused by coronary artery diseases are also inclined, where 91% of the patients whose age more than 50 years old die before getting to the hospital. 15 million people in Europe and over 5 million people in the U.S affected by chronic heart failure (CHF), one of the most pertinent diseases in developing countries where it results in 2% of the whole health care spending and predicted to double in 2030 [3]. While in China, 4.2 million people of its population suffered from heart failure, 1 million people in Japan and around 1.3 to 4.6 million people in India also experiencing the same disease [7]. The same scenario happens to Malaysia as well, where according to the Department of Statistics, the principal cause of death for male in this country is ischemic heart disease which causes 8,033 deaths (15.3%) in 2016 [8]. One approach to improve the heart care quality is by deploying the "homecare" to reduce the risk of fatality, so that the public could acquire electrocardiogram (ECG) signal anywhere at any time for frequent monitoring of cardiac condition.

On the other hand, one of the main factors of mortality in children under five years old worldwide is pneumonia. Pneumonia has caused 920,136 deaths of children under the age of 5 in 2015, which is a total of 15% of all deaths of children in that age. It also contributes to the mortality in adults. Every year, there is 151.8 million cases of pneumonia is reported in developing countries, whereas additional 4 million of cases have been reported in developed countries [9]. Among this numbers, 8.7% of all cases are considered as life-threatening and severe cases. 15 countries worldwide are listed with high disease burden, which India is on the top with 43 million new pneumonia cases every year [10]. It also contributes to 24.8 cases per 10,000 adults in USA as developed countries [11]. In developing countries like Malaysia, it is reported by Department of Statistics that the principle cause of death for female is pneumonia which involves 4,637 occurrences (14.0%) in 2016 [8]. Insufficient exposure of early detection of this severe disease's symptoms at home become one of the main causes in which contribute to these amount of numbers [12]. As a result, continuous monitoring of blood oxygen saturation (SpO_2) measurement which is the main sign of pneumonia is very important to decline the amount of deaths caused by this disease.

Another factor that causes the high mortality in certain developing countries in Southeast Asia and Latin America is dengue fever. Cases of dengue fever in Malaysia keep increasing drastically from year 2000 to 2014, which the number arises from 32 cases to 361 cases out of 100,000 population [13]. In addition, there are many incidences of infection diseases are correlated with occupation due to high risk working place or job scope through contact, airborne, sexually or oral [14]. Tuberculosis, Psittacosis, Hepatitis B, Hepatitis C, Melioidosis and Malaria are some of the occupational infectious diseases worldwide. These infections will lead to a life-threatening condition if not treated effectively. As the main symptom of dengue and these infections is fever with elevated body temperature, thus an early preventive measurement procedure by continuous body temperature monitoring can help to minimize the risk.

Based on the aforementioned issues, it can be observed that home-based vital sign monitoring is one of the promising solutions to enable remote monitoring of the health condition of elderly at home, as well as the early detection and prevention of certain chronic diseases and infectious diseases. These cause the home-based vital sign monitoring system which allow the patients to stay at home but always under health care surveillance is in great demand, as it is very convenient for both persistent and stable patients, allows the patients to be administered from home with affordable cost and easy service, reduce the risk of hospital disease infection and increase beds vacancy in the hospitals. This paper presents the design of a miniaturized and portable home-based vital sign monitor which can measure human vital signs of ECG, SpO_2, and body temperature accurately based on Arduino Nano technology with Android-based mobile application support and auto alarm system.

The rest of this paper is organized as follows. Section 2 presents related works in vital sign monitor design. Section 3 describes the design of the proposed home-based vital sign monitor design in terms of hardware circuit and biomedical sensors, the embedded software development, as well as the mobile app development targeted for Android-based smart phone. Section 4 presents the system functionality verification result and accuracy performance analysis. This paper is concluded in Section 5 with suggestions for future work.

2. Related Work

There are many commercial vital sign monitors available in the medical device market which offer basic human health status monitoring, unluckily they have some limitation to the layman home users. For example, the hospital grade vital sign monitor such as CARESCAPE VC150 model from GE Healthcare, can measure few basic vital signs simultaneously, but this model is large, bulky and cost expensive which is not suitable and not affordable by most of the home user [15]. It is also heavy duty and not portable hence it is difficult to carry around to different places for vital sign monitoring. In addition to that, these high end models generally require costly maintenance service to ensure its lifetime last longer. Furthermore, since these devices are mostly targeted for healthcare professional, thus they usually equipped with complicated user interface design which is not practical for layman user especially elderly at home.

A mini and affordable pulse oximeter is proposed by [16] which able to measure SpO_2 and pulse rate using photoplethysmography (PPG) signal. As very limited vital signs can be measured using this proposed work, a solid clinical interpretation will not able to be made through the limited measurements acquired. Though this work applies moving average algorithm to filter high frequency noise and low pass filter to remove motion artefacts, this work does not have significant high accuracy and stability, in which patients' movement will very much influence its measurement accuracy performance. In addition to that, if there is any vital sign abnormalities are detected by this system, there is no alarm to alert the caregiver to take further action as well as prompt medical action by healthcare provider.

Another cost-effective, wireless ECG signal acquisition system for study and clinical interpretation which can be executed in different operating system such as Windows, Linux, or Mac OS is proposed by [17]. Arduino Uno is utilized as the microcontroller and the ECG signal is wirelessly transmitted through Bluetooth to any laptop or desktop which connect with a Bluetooth dongle. The ECG data could display in real time and stored in a text file for further post-analysis in MATLAB. The system is battery powered thus it is portable and able to obtain 22 hours of online ECG data continuously. However, this system only acquire single ECG vital sign, hence it may only suitable for cardiovascular diseases screening but not significant enough for solid clinical decision of other infectious diseases such as dengue fever.

Other than that, a wireless vital signs monitoring system is proposed by [18] to measure systolic and diastolic blood pressure, ECG signal and human body temperature by implementing biomedical sensors and Arduino UNO as microcontroller with wireless communication. Patients are wirelessly monitored inside their home by using this system. However, the wireless sensor is prone to RF interference which become the main drawback of this system.

A home care telemedicine has been established in [19] by developing a wireless and cost-effective system using PIC 166C774A which allow patients to obtain their vital signs by themselves. This system able to acquire ECG signal and blood pressure vital sign parameter, process and transmit to a remote computer for the purpose of information analysis and clinical supervision by healthcare professionals. In another work proposed by [5], the researchers utilize World Wide Web (WWW) capacity to access patients' vital signs detail information through the Internet using web-page for real-time patient tele-monitoring. It is an economical computer-based vital sign telemonitor and recorder system infrastructure with a convenient graphical interface for healthcare personnel interpretation. However, both of these telemedicine framework are lack of the auto alarm feature to alert the user if any abnormal reading or measurement is acquired.

A patient monitoring system based on Information and Communication Technology (ICT) is developed which aimed for the chronic heart failure patients to acquire their vital signs including non-invasive blood pressure (NIBP), ECG, SpO_2, and weight on daily basis at home [3]. It transmits the information to the Hospital Information System (HIS) automatically thus allow the physicians to monitor their patients in remoteness under control and carry out suitable medical action whenever necessary. This system implements few wireless and non-invasive biomedical sensors for signal acquisition, but several instruments such as blood pressure monitor, and digital scale are quite bulky. Besides, this system is not suitable for remote monitoring at rural area where the internet infrastructure is not well established.

This section has reviewed existing commercial devices and many related works on vital signs monitoring, including wearable monitor, wireless vital signs monitoring, telemedicine as well as bedside monitoring. All of them have their own advantages and practicality but at the same time, present some disadvantages and drawbacks such as cost expensive, lack of auto alarm triggering, and limited vital sign acquisition for significant clinical interpretation. These drawbacks become the main motivation of invention of *myVitalGear* as one of the proposed solution to overcome the aforementioned issues, which will be discussed in detail in the following sections.

3. System Design and Development

Fig. 1 shows the top level system architecture of the proposed home-based vital sign monitor, named *myVitalGear* where Arduino Nano board is chosen as the microcontroller and the hardware implementation platform. The *myVitalGear* consists of three biomedical sensors to acquire input vital sign parameters, a push button, and few output peripherals as status indicator. It also connects with a HC-05 Bluetooth module to enable wireless data communication with a mobile app targeted for Android smartphone.

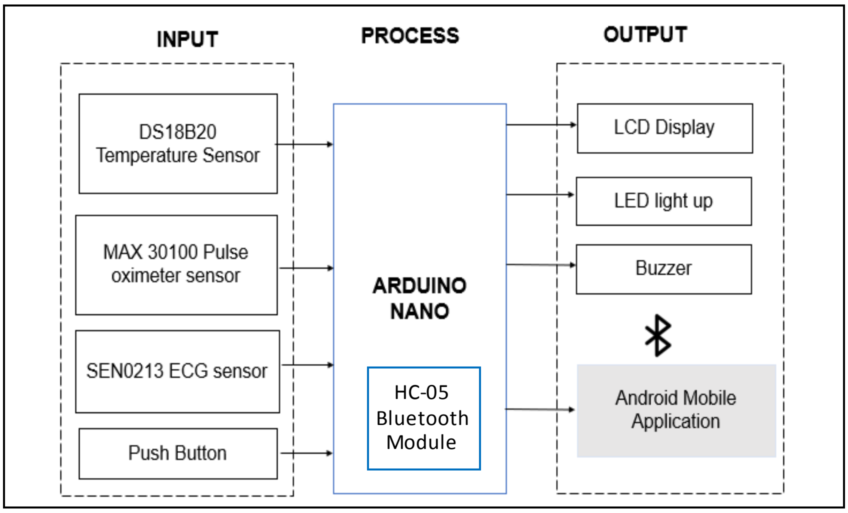

Fig. 1 - System architecture of *myVitalGear*

Based on the three biomedical sensors, this device able to acquire few vital sign parameters in terms of ECG, SpO_2, body temperature and heart rate. The SEN0213 ECG sensor with AD8232 chip is responsible to acquire and amplify small biopotential input raw ECG signal which shows the electrical activity of the heart. This sensor has high signal gain with DC blocking capabilities, built in low pass filter, internal RF and electromagnetic interference filter, hence could effectively remove the noise to obtain clean ECG signal. In this system, the single Lead I ECG data could be acquired from patient in real time by using three electrodes according to the Einthoven's triangle arrangement.

DS18B20 temperature sensor is a single-wire sensor which only requires one data line for data transmission with microprocessor to measure body temperature [20]. It can measure the range of temperature from -10°C to 85°C with ±0.5°C accuracy, hence provide a stable and high accurate body temperature measurement. This sensor is also very sensitive to temperature change, thus the time taken for body temperature measurement can be reduced and increase the efficiency of vital signs monitoring. As the sensor need to be in persistent and proper contact with the skin, it is attached to a flexible finger clip which enable the fingertip to be attached for stable temperature measurement. The temperature measurement requires 30 seconds for stable reading, which is half the time taken by oral digital thermometer which normally take 60 seconds to complete a measurement.

MAX30100 pulse sensor is selected to acquire heart rate signal and SpO_2 reading based on photoplethysmogram (PPG) transmission method, a volumetric non-invasive measurement method that make use of single detection [21]. The PPG signal is acquired by irradiating two different wavelengths of light through the tissue and compares the light absorption characteristics of blood under these wavelengths. This sensor consists of two LEDs, a photodetector, optimized optics, and low-noise analog signal processing, as well as a built in 50Hz filter [22]. When only infrared LED is on, only pulse rate is being measured. In order to measure oxygen saturation, both red and infrared LEDs need to be turned on. MAX30100 sensor is attached on a finger clip, which can fit the thumb to allow easy and simple measurement. Patient's thumb will be put on the red and infrared LED which are located on the surface of the sensor. The clip opening is designed to be flexible in order to fit average size of user's thumb.

These sensors reading are processed by Arduino Nano as the master microcontroller to produce both visual and auditory output to the users. Arduino Nano board is chosen as the microcontroller of this device due to its wide range of capabilities, from fundamental and ordinary tasks up to advanced application. It is equipped with ATMega328 8-bit microcontroller which consists of fourteen digital pins, eight analog pins as well as GND and VCC power pins, sixteen MHz ceramic resonator, an ICSP header and one reset button. It also equips with Mini-B USB port and power jack port. Its memory capacity comprise of 2kb SRAM, 1kb EEPROM and 32kb flash memory [23]. It consists of digital and analog input output (I/O) pins that can be interfaced to various expansion boards, shields and other circuits thus allowing it to receive inputs from ECG signal acquisition and conditioning circuit, pulse oximeter circuit and also body temperature acquisition circuit. Arduino Nano is utilized in this system for ADC conversion, signal analysis and serial communication. It receives the inputs from ECG, pulse oximetry and heart rate as well as temperature sensors attached to the patient. The readings are then processed, extracted, analyzed and interpreted by Arduino board to produce readable and understandable output. The output is displayed on the LCD screen, with simple interface for easy understanding by home user especially for elderly people. The LED will light up accordingly to indicate the range of the acquired reading and notify the user through the buzzer when any abnormal reading is obtained. The standby mode of this device is also indicated by using LED. A push button is acted as the selector switch between these three different vital signs measurement and a 9v power adapter is used as the power supply.

In addition of on-device result display using LCD and LED, the result of real time vital sign measurement could also be displayed in an Android-based mobile application which is connected with *myVitalGear* via HC-05 Bluetooth module. Bluetooth communication is one of the most suitable communication technologies to integrate both mobile apps and the proposed *myVitalGear* vital sign monitor due to its efficient short-range wireless communication for information exchange between devices, low cost and low power consumption [24]. The mobile application also functions to enable auto-send notification message whenever vital sign abnormality is detected. Short Message Service (SMS) enables short message to be transferred and exchanged between two mobile phones and can be simply performed by layman who is not proficient in using computer [25].

3.1 Hardware Circuit Design and Assembly

Fig. 2 shows the printed circuit board (PCB) hardware circuit design of *myVitalGear*, which comprises of the Arduino Nano microcontroller board, SEN0213 ECG sensor module, potentiometer, two-way switch, buzzer, HC-05 Bluetooth module and female connectors which are placed inside the casing. SEN0213 ECG sensor is connected to the analog pin, DS18B20 temperature sensor is connected to the digital pin and MAX30100 pulse sensor is an I2C component, thus connected to SDA and SCL pin of the Arduino board. A two-way switch is used to allow the connection between TX and RX pin of Arduino and HC-05 to be connected and disconnected every time the program need to be uploaded into the system. A slide switch is used to switch the system on or off. Potentiometer is used to control the LCD backlight intensity. Only single push button is used as the selector switch for ease of operation, cleaning, and minimal system workflow which aids especially the elderly user to handle the device. The push button, LCD and two LEDs are placed on the casing surface for simple user interface.

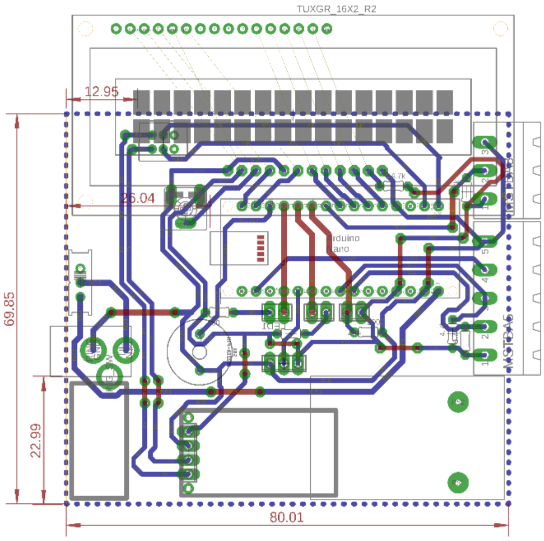

Fig. 2 - PCB hardware circuit design

Fig. 3 shows the casing design which is fabricated to house the PCB and all of the aforementioned components. Its dimension is 850mm x 750mm x 230mm. LCD screen, two LEDs and a push button are the components that placed at the top surface of the casing. The green connector is placed at the right side of the casing for the sensor's connection, whereas for the left p art of the casing, there will be ports for mini-B USB, power adapter, and two-way slide switch.

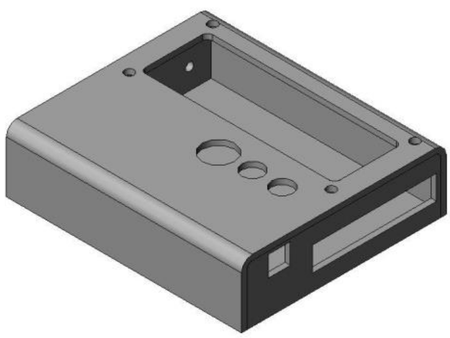

Fig. 3 - Casing design

The sensors used for measuring the body temperature, ECG and SpO_2 are separated from the main body of the device as shown in Fig. 4. They can be plugged in through a green screw pluggable connector (Fig. 5) every time during vital sign measurement and easily be removed when they are not in use. All the sensors are connected at the right side of the device, while power adapter or mini-B USB to supply power are connected at the left side of the device.

Fig. 4 - Fully assembled of the device

Fig. 5 - Green pluggable connector

By placing fingertip to the sensor which had been attached to the finger clip as shown in Fig. 6(a), the patient can acquire his or her body temperature after 30 seconds for stable body temperature measurement. For acquiring accurate body temperature measurement, the patient should ensure that the surface of the finger is always in contact with the sensor. Since the reading is slightly affected by the surrounding temperature, user is advised to take the measurement in normal room temperature to avoid any possible temperature measurement inaccuracy.

A short beep will sound after 30 seconds of body temperature measurement to indicate that the measurement is completed. LCD screen will display the body temperature in both units of degree Celsius (℃) and Fahrenheit (F). Push button is pressed by the user to proceed to switch the modes of measurement for next vital sign measurement. Fig. 6(b) shows the proper method of SpO_2 measurement where the patient needs to place his or her thumb on the sensor which is also attached to a finger clip, for ease of operation. This measurement only takes a few seconds and the surface of the thumb in contact to the sensor must also be retained for a stable precise reading. The result of the measurement is displayed on the LCD screen, in the unit of percentage (%). The reading is continuously monitored until patient changes to another mode.

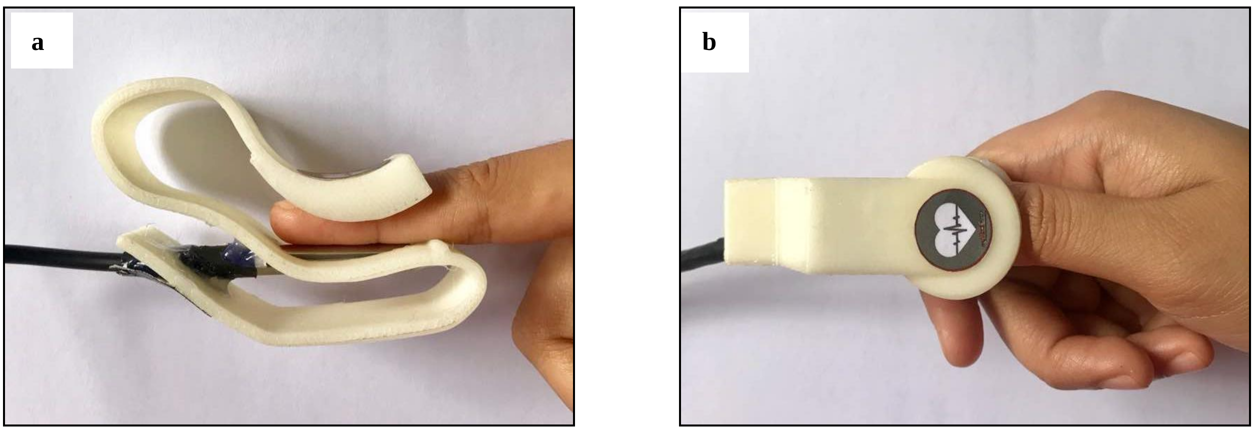

Fig. 6- (a) Body temperature measurement; (b) Blood oxygen saturation measurement

Lastly, patient can monitor his or her heart rate and R-R interval through ECG monitoring in the unit of beat per minute (bpm). Three ECG electrodes are labelled as R, L and F, respectively. Electrode R and electrode L is attached to right arm and left arm, respectively. Both electrodes are attached on the palm side of the wrist to obtain Lead I ECG as shown in Fig. 7. The reference electrode labelled as F, is attached to the left leg, above the ankles to reduce interference. This connection of ECG electrodes follows Einthoven's triangle rule [26]. A few precaution steps must be taken during electrode placement, such as ensuring each pad positioned at the right side, minimize body movement to reduce motion artefact, use new electrode pads instead of recycled one for better connectivity, and apply conductive paste to the electrodes in order to reduce noise during ECG signal acquisition.

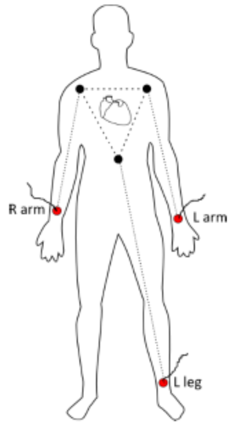

Fig. 7 - ECG electrodes placement according to Einthoven's triangle [27]

3.2 Embedded Software and Android Mobile Application Development

Fig. 8 shows the top-level system behavioural flowchart of the proposed *myVitalGear* vital sign monitor, which mainly based on the execution of the embedded software running at ATMega328 microcontroller, as well as Bluetooth wireless communication with mobile app running on an Android mobile phone. The embedded software is developed in C language in Arduino IDE and carry out the functionalities of three vital signs acquisition and processing (ECG, SpO_2 and body temperature), transmit the acquired reading to mobile app via Bluetooth wireless communication, displayed the measurement result on the LCD screen, as well as control status indicator such as LED and buzzer. On the other hand, the mobile application functions to display the same vital sign measurement in real time, as well as auto-send notification message whenever vital signs abnormalities are detected.

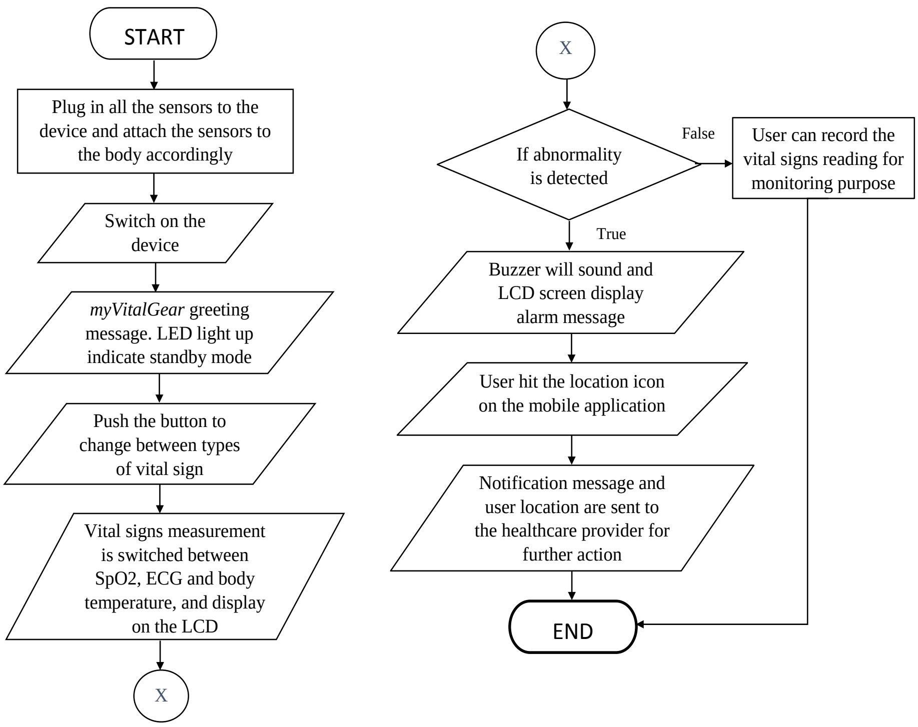

Fig. 8 - Top-level system behavioural flowchart

MIT Apps Inventor 2 is used to develop the Android-based mobile application to be integrated with the *myVitalGear* device. It consists of two parts which are Designer and Blocks. Designer allows the user to edit the user interface, customize the layout, add medias, animation, sensors and many more. User can edit the added components and properties of each components. Blocks layout which give the user a platform to customize and program the apps including the control, logic, math, text, colors, variables and so on. Two screens are developed and integrated with the system. It can be connected to the system through Bluetooth and scanning QR code to be tested on the mobile phone. When the mobile application is finalized, it is built into .apk file and installed into Android mobile phone as a standalone application.

The main function of the *myVitalGear* is to display the vital sign measurement in real time and send notification message with user's location if any abnormality is perceived. Fig. 9(a) depicts the home page of the developed mobile apps, as the name of *myVitalGear* is stated at the top of the screen. This page consists of the description of the device and the application for user information. Once the user taps the NEXT button to proceed to the next page, a notification bar will be popped up as shown in Fig. 9(b) to remind the user to enter the contact number of his or her healthcare provider or immediate guardian according to the user practical condition. The user could press OK to proceed. Fig. 9(c) shows the GUI layout of the second page to ready for the vital sign measurement. Firstly, the user need to connect to the Bluetooth to interact with the *myVitalGear* device. The information of contact number that is previously filled in the text box will be save automatically. User can begin measuring the vital signs by activating the *myVitalGear* vital sign monitor. Fig. 9(d) shows the example of temperature measurement result displayed on the screen where the same case will go to SpO_2 and ECG measurement, respectively.

Whenever any abnormality of vital signs is detected as out of the normal reference range according to the Table 1, the user will be notified by beeping alarm in the device. The user can directly hit the location icon located at the bottom of the screen to automatically send a notification message to the contact number saved previously either to the healthcare provider or the caregiver. User's location will also be sent together for further prompt medical action to be taken.

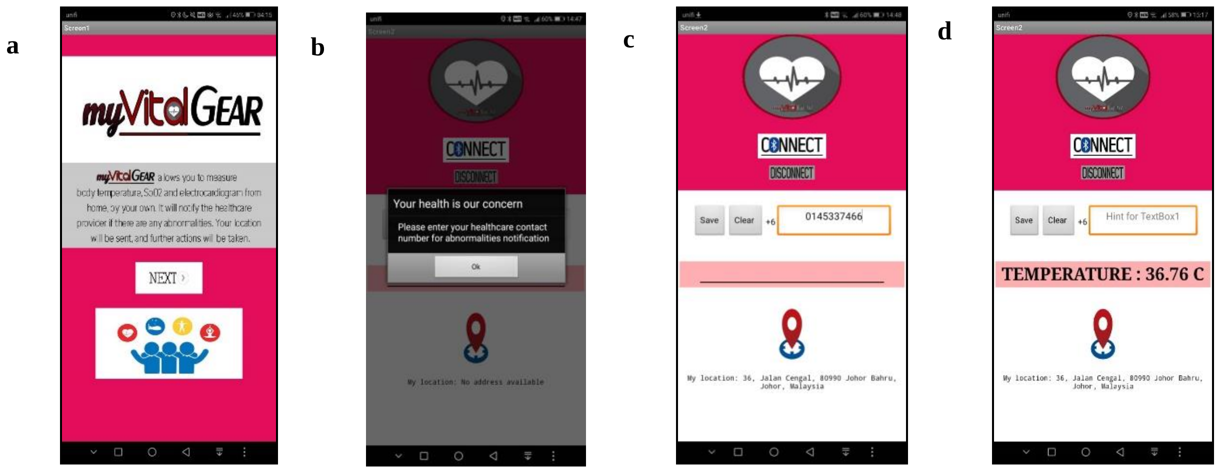

Fig. 9 - (a) Home screen of the mobile application; (b) Notification pop-up message; (c) Second page interface for vital sign measurement; (d) Temperature measurement result display

Table 1 - Normal range of vital sign measurement

Vital Signs	***Normal Range***
Temperature	35°C (95F) - 37°C (98.6F)
SpO_2	95% - 100%
Heart Rate	60 bpm – 100 bpm

4. Results and Discussion

This section presents the result and discussion in terms of functionality verification and measurement accuracy performance. During the system functionality verification and accuracy performance validation process, Rossmax thermometer as shown in Fig. 10 is used to test and calibrate the measurement of body temperature. It is a very accurate oral digital thermometer, with ±0.1°C accuracy for temperature between 35.5°C to 42°C and ±0.2°C accuracy for body temperature less than 35.5°C and more than 42°C. On the other hand, ProSim 8 Vital Sign Simulator as shown in Fig. 11 is used as the functional verification tools to calibrate and test the measurement of SpO_2 and ECG. ProSim 8 is an 8-in-1 patient simulator which can simulate ECG, non-invasive blood pressure (NIBP), oxygen saturation (SpO2), cardiac output, invasive blood pressure (IBP), respiration as well as temperature. However, since the temperature probe of the simulator is not compatible with the device produced in this proposed device, this simulator is only utilized to test SpO2 and ECG measurement.

Fig.10 - Rossmax oral digital thermometer

Fig. 11 - ProSim 8 Vital Sign Simulator

4.1 System Functionality Verification

The system output consists of three vital sign measurements which display on the LCD screen, depends on the mode of measurement. Fig. 12(a) to Fig. 12(c) display the measurement snapshot of user's heart rate based on electrocardiogram (ECG), oxygen saturation (SpO_2) and body temperature, respectively. Fig. 12(d) shows the snapshot of short text message (SMS) sample received on guardian's mobile phone in case of any abnormality is detected.

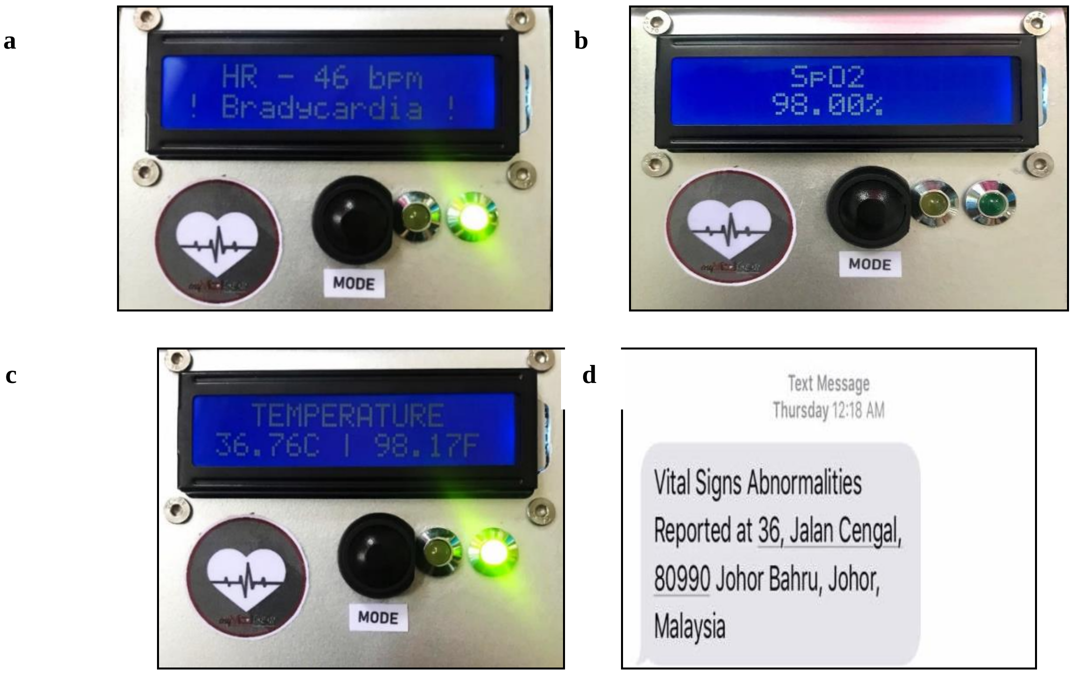

Fig. 12 – (a) Heart rate measurement output display; (b) SpO_2 measurement output display; (c) Body temperature measurement output display; (d) Short message service (SMS) sample output display

It can be observed that the device has successfully displayed the output of vital sign reading of ECG, SpO_2 and body temperature, on the LCD screen, respectively. The same measurement reading is also successfully displayed on the mobile apps in real time as shown in Fig. 9(d). In case of any abnormality is detected, an SMS notification together with the user's location is also successfully sent automatically to the guardian or healthcare provider for further prompt medical action.

4.2 Accuracy Performance Analysis

There are three accuracy performance test have been conducted to validate the measurement accuracy of body temperature, SpO_2, and heart rate using ECG signal, respectively. For each vital sign measurement, few testing data has been measured and benchmarked with the associated verification tool, and the average accuracy is finally calculated.

For body temperature measurements accuracy analysis as shown in Table 2, twenty measurements from different subjects acquired at different time are recorded. For each measurement, body temperature is measured using *myVitalGear*, in both Celcius, °C and Fahrenheit, F. The body temperature reading is then compared with commercial Rossmax thermometer as shown in Fig. 13 for performance benchmarking. The Rossmax thermometer took 60 seconds for body temperature measurement, while the *myVitalGear* took only 30 seconds to complete a measurement. Results show that there is minor measurement difference which is at most ±0.09 °C.

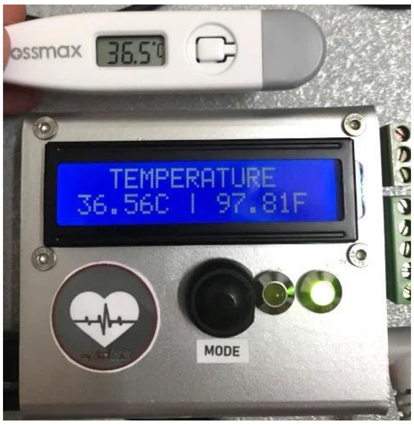

Fig. 13 - Body temperature measurement testing

Table 2 - Table of body temperature reading accuracy test.

NO	*Rossmax TG100 Thermometer (60 sec)*	*myVitalGear (30 sec)*	
	Celcius (°C)	**Celcius (°C)**	**Fahrenheit (F)**
1	36.5	36.50	97.70
2	36.3	36.38	97.48
3	36.4	36.49	97.68
4	36.7	36.70	98.06
5	36.9	36.88	98.02
6	36.7	36.75	98.51
7	36.5	36.53	97.75
8	36.5	36.50	97.70
9	36.5	36.49	97.68
10	38.9	38.85	101.93
11	38.9	38.88	101.98
12	38.7	38.75	101.75
13	38.5	38.50	101.3
14	36.6	36.65	97.97
15	36.5	36.58	97.84
16	37.0	37.10	98.78
17	36.9	36.87	98.37
18	36.9	36.90	98.42
19	36.4	36.43	97.57
20	36.3	36.26	97.30

For SpO_2 measurement accuracy analysis, SpO_2 tester in ProSim 8 is configured to intended value varied from 30% up to 100% saturation. Fig. 14 shows MAX30100 pulse sensor which is attached to the finger clip is being tested, and the measurement reading is compared with the pre-set SpO_2 reading on the simulator. Eight different readings are tested and benchmarked as shown in Table 3. The result shows that there is a larger error presents which contributes to about 3-5% error when the pre-set SpO_2 value is configured in abnormal range. However, the measurement only show ±1% error when the SpO_2 is configured in normal range.

Fig. 14 - Oxygen saturation measurement testing

Table 3 – Table of Oxygen Saturation Reading Accuracy Test

ProSim8 Vital Signs Simulator (%)	***myVitalGear* (%)**
80	85
85	88
90	91
92	93
94	95
96	97
98	98
100	99

For the heart rate measurement accuracy analysis, ECG electrodes is connected to the ProSim 8 simulator, according to the Right (R), Left (L) and reference leg (F) electrodes as shown in Fig. 15. Heart rate on the ProSim 8 simulator is configured varied from 40 beats per minute (bpm) up to 120 bpm, which covers the range of bradycardia, normal and tachycardia. The measurement result generated by *myVitalGear* is recorded and benchmarked with the ProSim8 patient simulator. Result shows that only 1 bpm error is incurred for eight readings as shown in Table 4. The alarm function for all range of reading is behaved correctly according to the design specification.

Fig. 15– Electrode placement for ECG measurement testing

Table 4 - Table of heart rate reading accuracy test

ProSim8 Vital Signs Simulator (bpm)	*myVitalGear* (bpm)	Condition	Alarm
40	40	Bradycardia	On
45	45	Bradycardia	On
50	51	Bradycardia	On
55	55	Bradycardia	On
60	61	Normal	Off
65	65	Normal	Off
70	69	Normal	Off
75	74	Normal	Off
80	80	Normal	Off
85	84	Normal	Off
90	89	Normal	Off
95	95	Normal	Off
100	100	Normal	Off
105	105	Tachycardia	On
110	111	Tachycardia	On
115	115	Tachycardia	On
120	121	Tachycardia	On

Based on accuracy mathematical formula as shown in (1), the overall average accuracy of vital sign measurement of *myVitalGear* is calculated and summarized in Table 5.

$$Accuracy\ (\%) = \frac{|(theoretical\ value - experimental\ value)|}{theoretical\ value} \times 100\% \quad (1)$$

Table 5 - Table of Vital Sign Measurement accuracy

Vital Signs	Accuracy (%)
Heart Rate	99.4
Temperature	99.7
Oxygen Saturation (SpO_2)	98.1

The device shows high accuracy of heart rate and body temperature measurement which are 99.4% and 99.7%, respectively. The accuracy of oxygen saturation reading is slightly lower compared to other two vital signs, but still achieve at least 98% of average accuracy.

5. Conclusion

This paper has presented a miniaturized, portable and high accurate vital sign monitor, named *myVitalGear*, which is designed to serve home-based monitoring of human vital signs measurement in terms of oxygen saturation (SpO_2), heart rate using electrocardiogram (ECG) signal, and body temperature based on embedded Arduino Nano technology. The *myVitalGear* device is integrated with an Android-based mobile application with simple user interface to display vital sign monitoring result in real-time and auto-send notification in case of any abnormality is detected. Measurement accuracy analysis has also be conducted on all three vital sign measurement with convincing performance where average accuracy is at least 98% and above.

This device eases the continuous monitoring of vital signs to indicate patient's physiological state at home. It is also user-friendly and easy to use especially for the elderly with simple user interface. The electrode and sensors are for personal use at home and not share with other patient, thus can reduce the risk of hospital infection. Other than that, long distance travelling and long waiting time at the hospital can be avoided through home monitoring. Patient is able to monitor his or her health state frequently for early abnormality detection thus reduce risk of chronic and infectious disease. If any vital sign abnormalities are observed which can lead to life-threatening condition, patients or caregiver can directly notify the healthcare provider for further prompt medical action. As a result, this device is completely assembled to enable home monitoring as well as preventive measurements for any abnormalities occurrence, thus reduce the risk of chronic and infectious disease.

However, there are few limitations and drawbacks that presented in this device which can be the room of improvement in the future. Firstly, the device is powered by 9v power adapter due to the biosensors, liquid crystal display (LCD), as well as the HC-05 Bluetooth module which consume a lot of power. This causes the continuous long hour monitoring cannot be carried out if low battery capacity is provided. Besides, the integration of battery in the design will increase the size of the device as well as the device cost. As a result, a suitable and efficient power source need to be revised for the design enhancement as part of the future improvement. In addition to that, the accuracy of the device can be further improved in the future, such as some precautions and preparations of ECG and body temperature measurement need to be practiced for optimum vital sign reading, as well as data acquisition algorithm for SpO2 measurement need to be carried out for more accurate reading. Moreoever, certain useful functions such as vital sign measurement storage for data tracking and logging purposes, more vital sign abnormalities classification, and use of wireless sensors can also be included for systemspecification enhancement in the future.

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