Mini Home-Based Vital Sign Monitor with Android Mobile Application *(myVitalGear)*

Mas Azalya Yusof [1], Yuan Wen Hau [2]
[1,2] *UTM-IJN Cardiovascular Engineering Centre, School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia,* 81310 UTM Johor Bahru, Johor, Malaysia.
[1]masazalya@yahoo.com, [2] hauyuanwen@biomedical.utm.my

***Abstract*— Frequent vital sign monitoring could help to reduce loss of life due to early detection of vital sign abnormality, especially to elderly people and patients with chronic disease or infectious disease. It helps to enable prompt medical action for early prevention measurement. This paper proposes a portable and mini home-based vital sign monitor, named *myVitalGear*, which can measure heart rate using electrocardiogram (ECG), body temperature and blood oxygen saturation (SpO_2) accurately. In this system, a high precision DS18B20 temperature sensor is used to measure body temperature. Analog heart rate monitor sensor with AD8232 chip is used to obtain ECG for heart rate measurement and heart rhythm abnormality detection. In addition, MAX30100 pulse sensor is used for SpO_2 measurement. Arduino Nano microcontroller is used as the master controller of this system to acquire and process all the vital signs measured by aforementioned sensors. The system also consists of light emitting diode (LED), LCD and buzzer as the status indicator. A mobile application is also developed with this system to display the vital sign measurement, and sending of notification message and user location to the healthcare provider if any abnormality is detected. Results has shown that the system able to provide vital sign measurement with accuracy of 99.8%, 98% and 99.5% for heart rate, SpO2 and body temperature, respectively.**

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

I. INTRODUCTION

Health care technology development and rapid advancement in these recent years not only result in longer life span in worldwide but at the same time, increase complicated and critical health state. World population aging are rising thus escalate the proportion of older adults compared to the entire population. United Nations reports that the ratio is believed to increase twofold between 2007 and 2050, attain two billions by 2050 [1].

As aging problem become one of the critical points, the requirement for treatment in hospital and home rise cautiously. However, the main disadvantages of long term and full-time care need aid of workforce and financial initiatives [2]. Other than that, frequently, worsen health condition and clinical state are the result of vital signs measurement variation [3]. As a result, continuous vital signs continuous monitoring especially in critical patients are very crucial. Unluckily, it is very tedious yet expensive to remain at the hospital for post medical treatment and for recuperation purposes [4]. In addition, having to stay at the hospital is one of the terrifying experience, since patients and family must endure the main obstacles such as costly charge, being far from home and family members, as well as being restricted to move around [5]. According to another survey carried out in United States, 30% of those who are more than 65 years old conveyed that instead of getting into nursing home, they would “rather die” [1].

Besides the rising of world population aging issues, cases of chronic diseases, such as cardiovascular diseases, also keep increasing around the world. For instance, numbers of death in remote area caused by coronary artery diseases are elevated, where 91% of the patient which 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 suffered from 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 in Japan and around 1.3 to 4.6 million people in India also experience the same illness [6]. These numbers can be alleviated through efficient electrocardiogram (ECG) monitoring at home as an early precautionary measure.

On the other hand, one of the main factors for mortality of children under five years old worldwide is pneumonia. There is 151.8 million cases of pneumonia in developing countries is reported every year, with additional 4 million cases in developed countries [7]. 8.7% of all cases are severe and considered as life-threatening. 15 countries worldwide are listed with high disease burden, which India is on the top with 43 million new pneumonia cases every year [8]. Pneumonia had caused 920,136 deaths of children under the age of 5 in 2015, which is 15% of all deaths of children of that age. It also contributes to 24.8 cases per 10,000 adults in USA [9]. One of the main reason which contribute to these numbers is inadequate exposure of early recognition of this severe disease’s sign from home [10]. As a result, a frequent home-based monitoring of blood oxygen saturation (SpO_2)

978-1-5386-2471-5 ©2018 IEEE

measurement which is the main sign of pneumonia is important to reduce the number of deaths due to this disease.

In certain developing countries like Malaysia, another factor that lead to high rate of mortality is dengue. Cases of dengue fever in Malaysia keep increasing drastically from year of 2000 to 2014 which is from 32 cases out of 100,000 population to 361 cases out of the same number of population [11]. In addition, there are many infections incidence that are correlated with occupation due to participation in high risk working place or job scope through contact, airborne, sexually or oral [12]. Tuberculosis, Psittacosis, Hepatitis B, Hepatitis C, Melioidosis and Malaria are some of the occupational infections incidence worldwide. These infections will lead to a life-threatening condition if not effectively treated. Since the main symptom of these infections as well as dengue incidence is fever with elevated body temperature, thus an early preventive measurement step by frequent body temperature monitoring can reduce the risk.

Based on the aforementioned discussion, home monitoring is one of the best solutions to enable remote monitoring of the health condition of elderly at home, as well as the early detection of certain chronic diseases and infectious diseases. This paper presents a portable and high accurate mini home-based vital sign monitor which can measure human vital signs of SpO_2, ECG and body temperature based on Arduino Nano technology with Android-based mobile application support and auto alarm system.

II. Related Work

There are several vital sign monitor available in the commercial medical device market which offer basic human health status monitoring, but they also have some disadvantages. 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 costly thus not suitable for home user. It is also not portable hence cannot easily move around to various places for frequent vital sign monitoring. In addition, since these devices are mostly operated by healthcare professional, thus they normally have complex user interface design which is not feasible by elderly at home.

A home care telemedicine had been established by developing a wireless and affordable system using PIC 166C774A which enable patients to obtain their vital signs by their own [13]. ECG signal and blood pressure parameter are acquired, processed and sent to a remote computer for supervision purposes and information analysis by health care professionals. However, this homecare telemedicine has no alarm system to alert the user for any abnormal reading obtained. Another cost-effective, wireless ECG signal acquiring system for study and clinical interpretation which can be operated in Windows, Linux, or Mac OS is proposed by [14]. ECG data is displayed in real time and stored in text file for further post-analysis in MATLAB. However, this system only comprises of one vital sign, which may not sufficient or significant for clinical decision other than cardiovascular diseases.

A thorough combination of Information and Communication Technology (ICT) system is developed which targeted 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 directs the information to the Hospital Information System (HIS) automatically thus enable the physicians to have their patients in remoteness under control and whenever requisite, appropriate actions will be taken. This system applies few wireless and non-invasive biomedical sensors for signal acquisition, but some of the instruments such as blood pressure monitor and digital scale are bulky.

III. System Design And Development

Fig.1. shows the system architecture of the proposed home-based mini vital sign monitor, *myVitalGear,* which could acquire heart rate through electrocardiogram (ECG), blood oxygen saturation (SpO_2), and body temperature. The ECG is measured using three electrodes to obtain single Lead I ECG according to Einthoven's triangle arrangement. SEN0213 ECG sensor with AD8232 chip extracts, amplifies and filters small biopotential signals then effectively eliminate the noise to obtain ECG. DS18B20 temperature sensor is used to measure body temperature. It is a one-wire sensor which only require one data line for data transmission with the microprocessor [15]. MAX30100 pulse sensor is used to acquire SpO_2 reading by using photoplethysmogram (PPG) transmission method, a volumetric non-invasive measurement method that make use of single detection [16].

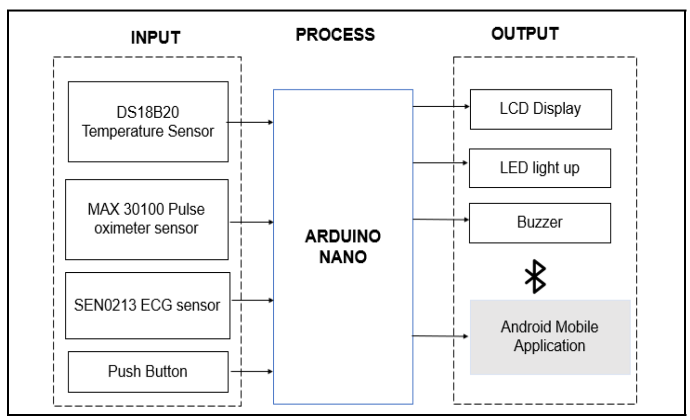

Fig. 1. System architecture of the project

These sensors reading are processed by Arduino Nano as the master microcontroller to produce both visual and auditory output to the users. A push button is used as the selector switch between the three different vital signs measurement and a 9v power adapter is used as the power supply. The result is displayed on the liquid crystal display (LCD) screen while the buzzer will alarm the user whenever abnormality is detected, and light emitting diode (LED) will light up based on the range of vital signs reading accordingly. LED is also used to indicate the standby mode of device. The result of real time vital sign measurement is also shown on the Android-based mobile application which is connected with the system using HC-05 Bluetooth module. The mobile application also functions to allow auto-send notification message whenever abnormality is detected. ProSim 8 Vital Sign Simulator is used for accuracy measurement and calibration.

A. Hardware Circuit Design and Assembly

Fig. 2 shows the printed circuit board (PCB) hardware circuit design of *myVitalGear*, which consists of the microprocessor, Arduino Nano board, SEN0213 ECG sensor board, potentiometer, two-way switch, buzzer, Bluetooth module HC-05 and female connectors which are placed inside the casing. Potentiometer is implemented to control LCD backlight adjustment. While, push button, LCD and two LEDs are placed on the casing surface for user interface. Only single push button is used for ease of operation, cleaning, and minimal system workflow which aids especially the elderly user to handle the device.

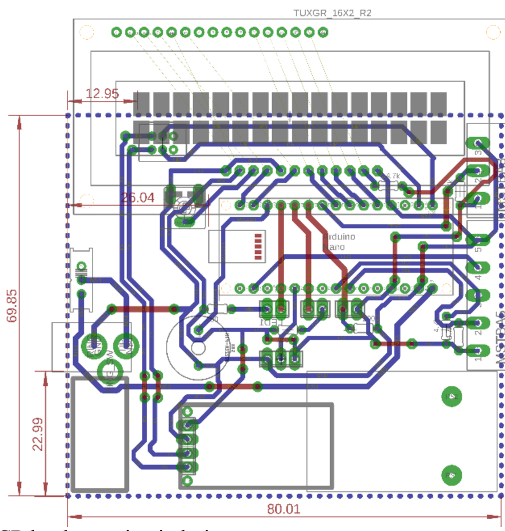

Fig. 2. PCB hardware circuit design

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. 3. They can be plugged in through the connector every time during vital sign measurement or removed to be kept when not in used. All of 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.

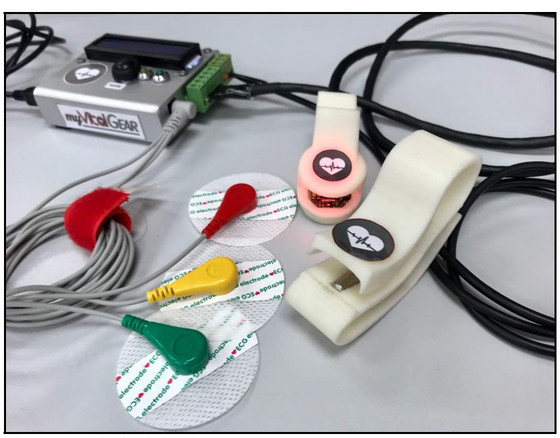

Fig. 3. Fully assembled of the device

For body temperature measurement, the time taken is 30 seconds, which is half of the time taken by oral digital thermometer. The patient needs to put his or her fingertip to the sensor which had been attached to the finger clip as shown in Fig. 4, and ensure that the surface of the finger in contact with the sensor is maintained for accurate measurement. The reading is slightly affected by the surrounding temperature, hence user is advised to take the measurement in normal room temperature.

Fig. 4. Body temperature measurement

After 30 seconds of measurement, a short beep will sound to indicate that the measurement is done. LCD screen will display the body temperature in both units, degree Celsius, ℃ and Fahrenheit, F. Patient can proceed to the next vital sign measurement by easily push the button to switch the modes of measurement. Fig. 5 shows the measurement of SpO_2 where the patient need to place his or her thumb on the sensor which is also attached to a finger clip, for ease of operation. This measurement only take 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 form of percentage. The reading is continuously monitored until patient changes to another mode.

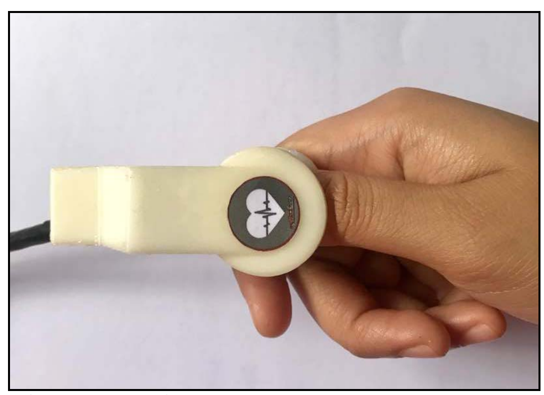

Fig. 5. Blood oxygen saturation measurement

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 electrodes of the ECG sensors are labelled with R, L and F. R electrode is attached to right arm and L to the left arm, both electrodes are attached on the palm side of the wrist to obtain Lead I ECG. While, the reference electrode labelled as F, is attached to the right leg, above the ankles to reduce interference. This connection of electrodes follows Einthoven's triangle rule. A few precaution steps must be taken during electrode placement, such as ensuring each pad positioned at the right side, minimize body movement, use new pads instead of recycled one, and applying conductive paste to the electrodes in order to reduce noise during ECG signal acquisition. Fig. 6 shows the complete top-level system flowchart.

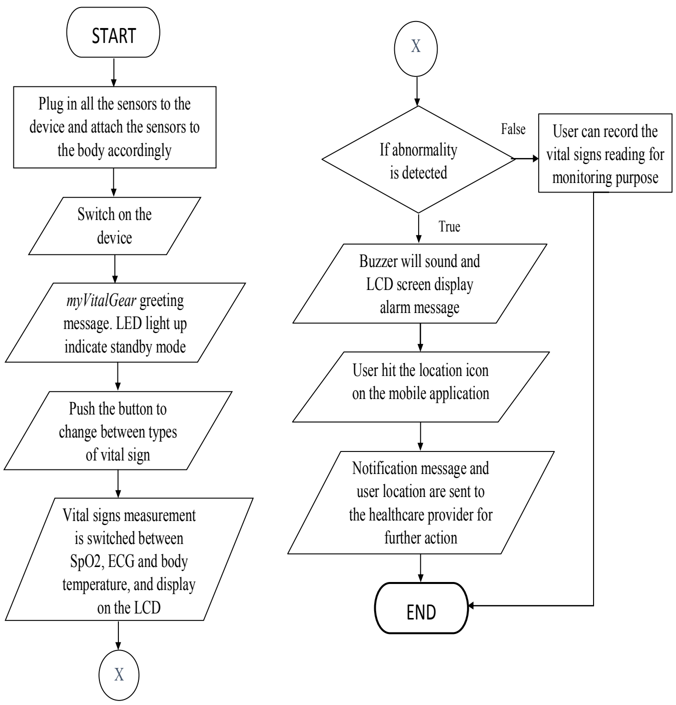

Fig. 6. Top-level system behavioural flowchart

B. *Android* Mobile *Application Development*

Fig. 7(a) depicts the home page of the developed mobile apps of the proposed *myVitalGear* device, as the name stated at the top of the screen. This page consists of the description of the device and the application for user information. User can tap the NEXT button to proceed. Once the user proceeds to the next page, a notification bar will appear to remind the user to enter the contact number of his or her healthcare provider or immediate guardian according to the user practical condition. Fig. 7(b) 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. Contact number that is previously filled in the box to save the number. User can begin measuring the vital signs by activating the vital signs sensors. Fig. 7(c) 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 range according to the Table I, it 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.

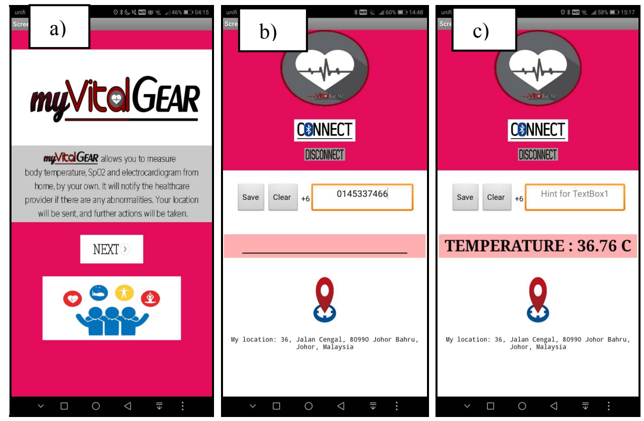

Fig. 7. (a) Home screen of the mobile application (b) Second page interface of the mobile application (c) Temperature measurement is displayed on the screen

TABLE I. NORMAL RANGE OF VITAL SIGN MEASUREMENT

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

IV. RESULTS AND DISCUSSION

This section presents the result and discussion in terms of functionality verification and measurement accuracy. During the functionality verification, ProSim 8 Vital Sign Simulator is used for accuracy measurement and calibration.

A. *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. 8 to Fig. 10 show the measurement snapshot of user heart rate based on electrocardiogram (ECG), oxygen saturation (SpO_2) and body temperature, respectively. The vital sign measurement that display on mobile apps is presented in Fig. 7(c). Fig. 11 shows the snapshot of short text message (SMS) sample received on guardian's mobile phone in case any abnormality is detected.

Fig. 8. Heart rate measurement output display

Fig. 9. SpO_2 measurement output display

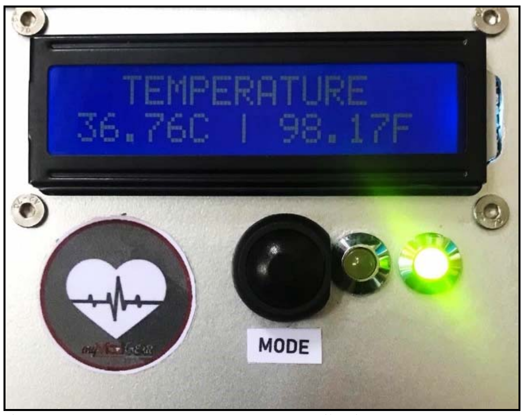

Fig. 10. Body temperature measurement output display

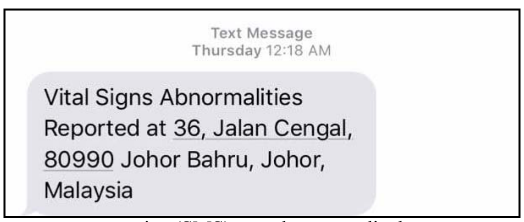

Fig. 11. Short message service (SMS) sample output display

It can be observed that the device has successfully displayed the output of vital sign reading of ECG, body temperature and SpO_2, respectively, on the LCD screen and on the mobile apps in real time. In case of any abnormality is detected, an SMS notification will be sent to the guardian or healthcare provider for further prompt medical action.

B. Accuracy Performance Analysis

There are three vital signs measurement accuracy test have been conducted which are heart rate using ECG, body temperature and SpO_2 measurement. ProSim 8 Vital Signs Simulator is used to test the accuracy of heart rate using ECG and SpO_2 reading, whereas Rossmax thermometer is used for body temperature accuracy testing. For each vital sign measurement, few testing data has been measured and the average accuracy is calculated.

For the heart rate accuracy analysis, it is carried out by setting the heart rate reading on the ProSim 8 simulator 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 compared with the ProSim8 patient simulator. Result shows that only 1 bpm error is incurred for eight reading. The alarm function for all range of reading is behaved correctly according to the design specification.

For body temperature measurements accuracy analysis, 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. Results show that there is minor measurement difference which is at most ± 0.09 °C.

SpO_2 accuracy performance test is carried out by comparing the reading using *myVitalGear* with the pre-set reading on ProSim 8 Vital Sign Simulator. Eight different readings are tested and benchmarked. The result shows a larger error presents when the pre-set value is in abnormal range of SpO_2 reading, anyhow the readings only show ±1% error in normal range.

By using accuracy mathematical formula as shown in (1), the overall accuracy of vital sign measurement of *myVitalGear* is calculated and summarized in Table II.

$$\text{Accuracy (\%)} = |\text{(theoretical value} - \text{experimental value)}| \,/\, \text{theoretical value} \times 100\% \qquad (1)$$

TABLE II. TABLE OF VITAL SIGN MEASUREMENT ACCURACY

Vital Signs	Accuracy (%)
Heart Rate	99.4
Temperature	99.7
Oxygen Saturation (SpO2)	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 due to the reason of SpO_2 implemented acquisition algorithm.

V. CONCLUSION

This paper has presented a portable and high accurate mini vital sign monitor, named *myVitalGear*, that designed for home-based monitoring which can measure the human vital signs of oxygen saturation (SpO_2), electrocardiogram (ECG) and body temperature based on embedded Arduino Nano technology. The mini vital sign monitor is integrated with an Android-based mobile application with simple user interface to display real-time vital sign monitoring result and auto-send notification in case of any abnormality is detected.

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, the 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

There are a few limitations and drawbacks that presented in this device which can be improved 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 are in high power consumption. As part of the future improvement, a suitable and efficient power source need to be revised for the design enhancement.

Besides, the accuracy of the device can be further improved in the future. For instance, some precautions and preparations of ECG and body temperature measurement need to be practiced for optimized vital sign reading. Whereas for SpO_2 measurement, a few improvements on the data acquisition algorithm need to be done for more accurate reading. Besides, 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 system specification enhancement.

ACKNOWLEDGMENT

This research is supported and funded by Ministry of Higher Education (MoHE) Trans-Disciplinary Research Grant Scheme (TRGS) with Grant no. TRGS/1/2015/UTM/02/3/3 (UTM vote no. R.J130000.7845.4L842) and Universiti Teknologi Malaysia Research University Grant with Vote No. Q.J130000.2545.16H83.

REFERENCES

[1] L. Liu, E. Stroulia, I. Nikolaidis, A. Miguel-Cruz, and A. Rios Rincon, "Smart homes and home health monitoring technologies for older adults: A systematic review," *Int. J. Med. Inform.*, vol. 91, pp. 44–59, 2016.

[2] N. V. S. Monitoring, "Kl Detecting Receiving / Sensing r-," vol. 1, no. 19, 2009.

[3] S. Saponara *et al.*, "Remote monitoring of vital signs in patients with Chronic Heart Failure: Sensor devices and data analysis perspective," *2012 IEEE Sensors Appl. Symp. Proc.*, no. September, pp. 1–6, 2012.

[4] H. Mansor, M. H. A. Shukor, S. S. Meskam, N. Q. A. M. Rusli, and N. S. Zamery, "Body temperature measurement for remote health monitoring system," *Smart Instrumentation, Meas. Appl. (ICSIMA), 2013 IEEE Int. Conf.*, no. November, pp. 1–5, 2013.

[5] P. Mendoza, P. Gonzalez, B. Villanueva, E. Haltiwanger, and H. Nazeran, "A Web-based vital sign telemonitor and recorder for telemedicine applications.," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, vol. 3, pp. 2196–9, 2004.

[6] G. Savarese and L. H. Lund, "Epidemiology Global Public Health Burden of Heart Failure," pp. 7–11, 2017.

[7] O. Access, "Risk factors of severe pneumonia among children aged 2-59 months in western Kenya: a case control study," vol. 8688, pp. 1–13, 2012.

[8] M. Ghimire, S. K. Bhattacharya, and J. P. Narain, "Pneumonia in South-East Asia Region: Public health perspective," *Indian J. Med. Res.*, vol. 135, no. 4, pp. 459–468, Apr. 2012.

[9] C. Cilloniz, I. Martin-loeches, C. Garcia-vidal, A. S. Jose, and A. Torres, "Microbial Etiology of Pneumonia : Epidemiology , Diagnosis and Resistance Patterns."

[10] R. Article, "Review Article Childhood pneumonia in developing countries," vol. 8, no. 2, 2013.

[11] C. P. G. Management, D. Infectionadults, and T. Edition, *CPG Management of Dengue Infection In Adults (Third Edition) 2015 1*. 2015.

[12] V. K. E. Lim, "Occupational infections," vol. 31, no. 1, pp. 1–9, 2009.

[13] R. Isais, K. Nguyen, G. Perez, R. Rubio, and H. Nazeran, "A low-cost microcontroller-based wireless ECG-blood pressure telemonitor for home care," *Proc. 25th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (IEEE Cat. No.03CH37439)*, vol. 4, pp. 3157–3160, 2003.

[14] M. A. Ahamed, M. Asraf-Ul-Ahad, M. H. A. Sohag, and M. Ahmad, "Development of low cost wireless ECG data acquisition system," *Proc. 2015 3rd Int. Conf. Adv. Electr. Eng. ICAEE 2015*, no. December, pp. 72–75, 2015.

[15] U. Interface, R. Only, and O. Port, "DS18B20 Programmable Resolution 1-Wire Digital Thermometer DS18B20 Programmable Resolution 1-Wire Digital Thermometer Absolute Maximum Ratings," vol. 92, pp. 1–20.

[16] O. Satav, S. Shinde, and S. Kamble, "Smart Phone Based SpO2 Monitoring System," vol. 1, no. 2, pp. 216–221, 2017.