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IoT Health Monitoring Device of Oxygen Saturation (SpO2) and Heart Rate Level

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***Abstract*— People are normally suffering from body sickness such as heart disease, high blood pressure and diabetes when getting older. Thus, the health of elderly should be monitored to prepare for any emergency cases. This research presents a real-time monitoring system for elderly that is able to measure heart rate and Peripheral Capillary Oxygen Saturation Level (SpO2). The monitoring system is constructed using MAX30100 as front-end sensor and Node MCU (ESP8266) is used as microcontroller to collect and transfer the data to Cloud. Five healthy subjects have been chosen properly and their SpO2 and heart rate level are collected. All data undergone a few processes for validation such as segmentation and filtering. For SpO2, the data are computed to IR/RED variables. Then, the IR/RED are processed to get SpO2 ratio using empirically derived calibration curves in order to produce normal and abnormal results. For heart rate, a correlation test is conducted between the experimental reading with the reference reading. For the monitoring system, both SpO2 and heart rate data are combined to obtain the final classification of normal and abnormal. The result of the correlation test shows strong correlation value (rs=0.993). The percentage error is calculated between the developed system with a commercial oximeter which is resulted with less 3% and 1.03 % for SpO2 and heart rate, respectively. Based on the validation results, the monitoring system of SpO2 and heart rate is ready to be used. Also, the IoT system allows many authenticated users to monitor the patient condition.**

Keywords*— *IoT device, SpO2, Heart rate, MAX30100, monitoring device

I. Introduction

The aging population is increased in the last 10 years. This condition will continue for next 20 years as the life expectancies had increased and the rate of fertility is declined as well [1] [2]. Human body tends to get weaker when turned older. Therefore, most elderly people suffer from age-related sickness such as hypertension, heart failure, coronary artery disease, high blood pressure, diabetes and so on [3]. Heart rate, blood pressure, respiration rate, temperature and peripheral capillary oxygen saturation level (SpO2) are considered as the five most important vital signs of a human body. The SpO2 value is crucial as vital organs in the body may irreversibly damage when they are not supplied with enough amount of oxygen [4]. The lower SpO2 level in blood is a major cause of morbidity and may lead to death. Therefore, a wearable device is proposed to have a real-time monitoring SpO2 and heart rate of the elderly in order to prepare any emergency circumstances that involved with oxygen and heart rate.

There are a few related researches that can be referred during conducting this research, especially works regarding data processing of SpO2 and heart rate [5-6], development of IoT wearable healthy devices [7-8] and the use of MAX30100 [9-10]. Also, there are many reports regarding the use of IoT in healthcare such as Electrocardiogram (ECG) monitoring [11] and blood pressure [12]. Some reports introduced a few health parameters in one system [13].

This research is focusing on development of SpO2 and heart rate monitoring system based on Internet of Thing (IoT) application for the elderly people. The system made up of MAX30100 Pulse Oximeter and Heart-Rate Biosensor is used to monitor the peripheral capillary oxygen saturation level (SpO2) and heart rate of the elderly. The data measured will be stored and processed. The result of the data is authorized by the authenticated personnel and can be seen through web-based interface and can be analyzed by the medical professional.

II. Methodology

This research consists of four major works which is involved of development of SpO2 and heart rate monitoring with IoT system, data collection and validation, data classification of normal and abnormal level. Each work is described as below;

A. Development of SpO2 and heart rate monitoring with IoT system

At first, a complete circuit of Spo2 and heart rate sensing is fabricated. MAX30100 sensor is used as it can provide both data of SpO2 and heart rate [14]. NodeMCU ESP8266 is used as micro controller to connect the sensor and to obtain the data from user or patient [15]. Also, it can transmit the data to internet through its Wifi module. Fig.1 shows the block diagram of the developed healthcare monitoring system.

In general system, the data from the sensor is stored in database that created using Firebase. An application (Apps) as interface is created to enable the users to revise back the previous reading that has been measured. The Apps can only access by the authenticated person, which are the elderly, the elderly family members and the medical caretakers. With this system, the medical caretakers can real-time monitor the health condition of the elderly remotely. When the medical caretakers sensed that there is unusual reading or result that is beyond the threshold value, the doctors can notify the elderly people about their health condition.

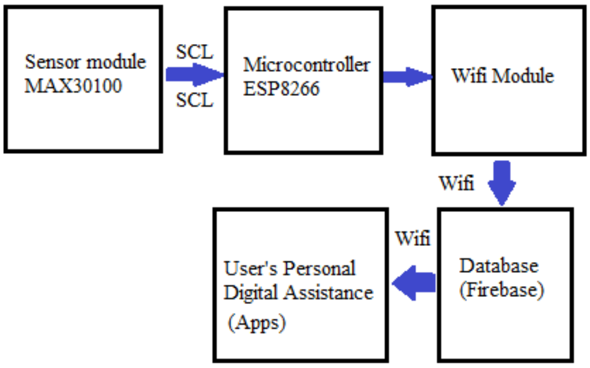

Fig. 1. Block Diagram of Healthcare Monitoring System

The MAX30100 sensor is an integrated pulse oximetry and heart-rate monitor biosensor module. It operates on a single 1.8 V low power supply and a separate 3.3 V power supply for the internal LEDs. The small physiological sensor is a complete system that is consisting of Red or Infrared (IR) Light Emitting Diode (LED), LED driver, photodetector or photodiodes, ambient light rejection, digital noise cancellation and data FIFO [14]. Fig. 2 shows the device.

Fig. 2. MAX30100 sensor

B. Data collection and validation

MAX30100 sensor provides a set data that consists of IR and RED of LED data for SpO2. These data are known as Photoplethysmography (PPG) signal. This sensor has come with a datasheet which is consisted of reference of healthy and unhealthy ranges [14]. Hence, five healthy subjects are considered for data collection and validation of the developed system. The collected data will be referred to datasheet reference and Health Regulation [4]. Table I and Table II shows the range of SpO2 and heart rate condition based on Health Regulation.

TABLE I. LEVEL OF SPO2 CONDITION

SpO2 reading (%)	Level
>=94	Normal
91 – 94	Mild hypoxemia*
86 – 90	Moderate hypoxemia*
< 86	Severe hypoxemia*

* Hypoxemia is defined as decreased partial pressure in blood and oxygen available to the body or an individual tissue or organ.

TABLE II. LEVEL OF HEART RATE CONDITION

Heart rate (bpm)	Condition
> 99	Abnormal
60 – 99	Normal
< 60	Abnormal

In order to ensure the data is correct and reliable, 30 seconds of duration is set for each time of data collection. The earlier data will be removed as it usually not stables as shown in Fig. 3. Then, the data are segmented into a few segments to ease the processing. For 30 seconds, almost 1000 data are collected for IR and RED. This will get around eight segments for one data set of PPG signal.

Next, the IR and RED data were used to calculate the ratio value of SpO2 level of the subject. Fig. 4 shows the IR and RED data of MAX30100. Equation (1) and (2) are used to calculate the ratio of SpO2, *R*, and SpO2 value [6].

$$R = \frac{AC_{RED} / DC_{RED}}{AC_{IR} / DC_{IR}} \quad (1)$$

$$SpO2 = 110 - 25\,R \quad (2)$$

Where *R* is the ratio, *AC* and *DC* are obtained from PPG signal. Fig. 5 shows measurement of *AC* and *DC* variables.

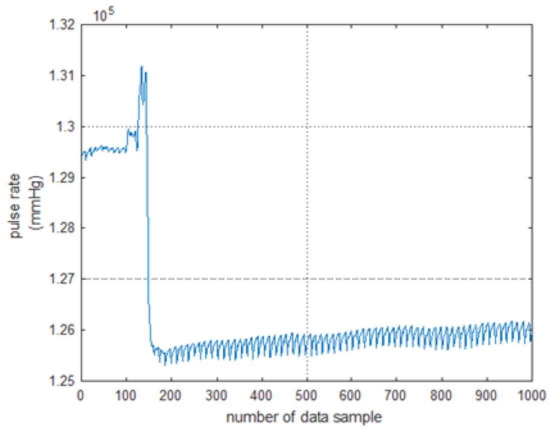

Fig. 3. The raw PPG signal

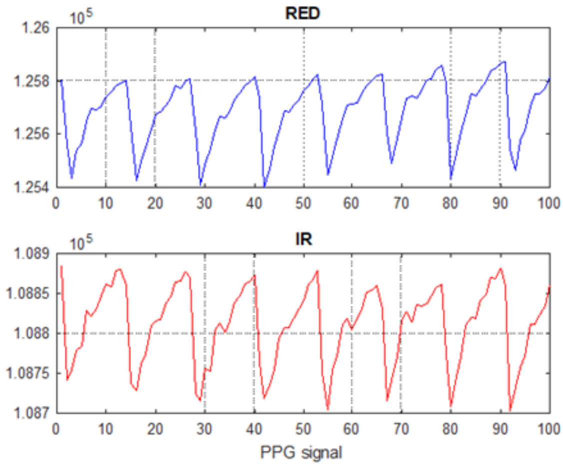

Fig. 4. The example of PPG signal

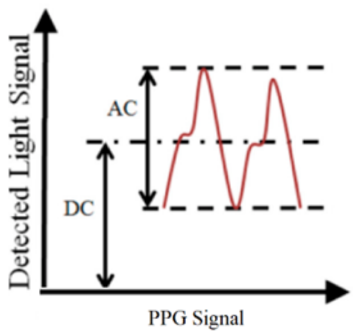

Fig. 5. *AC* and *DC* measurement from RED/IR signal [6]

There is a technique on how to get the AC and DC values. For each segment, peak values of PPG signal are determined. From the peak, make a range about 8 to 10 data with the peak become its median. The value of range is determined by progression of the PPG signal. The peak value is also considered as maximum value. Then, from the range, sort the range to get the minimum and medium value. After that, AC and DC can be calculated using (3) and (4).

$$AC = max - min \tag{3}$$

$$DC = median \tag{4}$$

Beside comparing the results of both of heart rate and SpO2 level to the guidelines, the data were also compared with the pulse oximeter that is available in recent market and it is used by medical staffs. The validation result is shown by comparing both data and they are presented using percentage error analysis. For this testing, the reading of heart rate and SpO2 are taken concurrently using the developed system and the commercial oximeter.

C. Classification of healthy and unhealthy

The classification of healthy and unhealthy condition is required to show at the final stage of the system in order to deliver the condition of patients to the caretakers or medical staff. At first, the classification of SpO2 and heart rate condition is made one by one, before they are combined using rule-based algorithm.

For SpO2 condition, a majority voting is used to determine the condition. Previously, there is a few segments for one data set. One data set means that when one reading is taken from the monitoring device. For the SpO2 classification, two conditions are set, normal and abnormal. Normal condition happens when SpO2 value is 95% and above as shown in Table I. Else, it is considered abnormal. Based on the SpO2 results from each segment, the majority results will take as the final result of SpO2 condition. The pseudo code of the classification is showed below;

```
Pseudo code of SpO2 condition classification
Get number of segments;
Get SpO2 values;
CtrH = 0; CtrU = 0;
for i=1: number of segments
   if segment(i) ≥ 95%
       CtrH = CtrH +1;
       #Spo2normal
   else
       CtrU = CtrU + 1;
       #SpO2abnormal
   end
end
if CtrH>CtrU
   SpO2 = normal;
if else CtrH<CtrU
   SpO2 = abnormal;
else
   SpO2 = undefined;
   #CtrH=CtrU
   #readagain
end
```

For heart rate classification, there will be three levels of condition as shown in Table II. Reading from MAX30100 is taken and classified using rule-based algorithm. The pseudo code is shown below;

```
Pseudo code of heart rate condition classification
Get bpm value;
if bpm < 60
   heartrate = abnormal_low;
if else bpm > 60 && bpm < 100
   heartrate = normal;
else
   heartrate = abnormal_high;
end
```

Final stage of classification also implemented rule-based algorithm. In this stage, it will determine the overall results that consists of SpO2 and heart rate reading. The pseudo code is shown as below;

```
Pseudo code of final classification
Get heart rate (hr) condition
Get SpO2 condition
if SpO2 = normal && hr = normal
   Healthresult = Healthy;
if else SpO2 = normal && hr = abnormal_low
    Healthresult = Unhealthy with heartrate
                   low;
if else SpO2 = normal && hr = abnormal_high
    Healthresult = Unhealthy with heart rate
                   high;
if else SpO2 = abnormal && hr = normal
    Healthresult = Unhealthy with SpO2 low;
else
    Healthresult = Undefined;
    #errorinreading
    #readagain
end
```

III. Results and Discussions

In this section, all results that obtained from this study are shown and discussed.

A. Practical use of MAX30100

There are some pre-cautions that required to be taken to get consistent, accurate and less noise of results or data when using MAX30100. The following are some of the pre-cautions when making circuit connections and taking readings;

- Devices must be soldered properly. It is not recommended to use bread-board.
- Connecting pins on the MAX30100 to the Arduino ESP8266 must be done carefully and in accordance with the specifications in the program.
- The most effective finger to take readings is the right middle finger [16]. But, there is report said fingertip is the effective finger [6].
- Finger should be closed and static while reading is taken [6].
- Readings intake is encouraged three times.

B. SpO2 results

As stated in methodology section, SpO2 results are computed using IR/RED LED dataset. From one dataset, it is filtered to remove the earlier data, divided into a few segments and computed to get ratios as well as SpO2 percentages. The ratios and SpO2 computation are based on empirical equation and SpO2 guidelines.

Table III shows an example of a dataset of IR/RED that have been computed and resulted with ratios and SpO2 percentages. For this dataset, eight segments have been obtained after filtering and segmentation process. Based on the segments, all ratios are above than 0.5 and the SpO2 percentages are above than 96%. As referred to SpO2 guidelines, 96% and above are indicated to be normal amount of oxygen in blood. Fig. 6 shows a plot that indicated a threshold (red line) of normal and abnormal results of SpO2. From the plot, all the SpO2 percentages can be seen located above the red line. This can be concluded that the dataset is a normal SpO2. This result is expected because the conducted experiment was dealing with healthy subjects only.

TABLE III. SPO2 RESULTS BASED ON A DATASET 1 OF IR/RED

No of segment	Ratio	SpO2 (%)
1	0.53	96.82
2	0.51	97.23
3	0.55	96.15
4	0.55	96.20
5	0.52	97.11
6	0.55	96.27
7	0.54	96.56
8	0.51	97.14

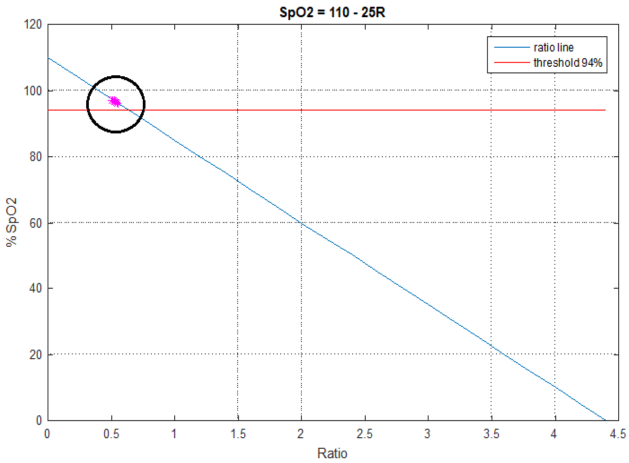

Fig. 6. The SpO2 against ratio results for a dataset 1

C. *Classification results*

For the monitoring system, there are three classifications that have been developed to get the condition of patient. All the classifications are constructed using rule-based algorithm and have been set according to required guidelines. But, for SpO2, it will go through a majority voting algorithm before classified using rule-based algorithm.

Table IV shows two initial results of SpO2 and heart rate classifications. The system has been tested using 100 datasets which are involved 50 normal and 50 abnormal datasets for both SpO2 and heart rate. Based on results, SpO2 resulted with 100% and 96% accuracy of normal and abnormal, respectively. For heart rate, both normal and abnormal resulted with 100% accuracy.

The main reason of SpO2 results are not obtained 100% accuracy is may due to the number of segmentation and calculation of AC and DC from IR/RED data. Hence, in order to ensure the reliability of the system, a few times of readings are required.

TABLE IV. RESULTS OF SPO2 AND HEART RATE CLASSIFICATION FOR 50 NORMAL AND 50 ABNORMAL DATASETS

Class	SpO2 (%)	Heart rate (%)
Normal	100	100
Abnormal	96	100

For final classification which is consisted of both SpO2 and heart rate, the datasets are still same with the individual classification of SpO2 and heart rate. The results for normal is 100% correct while abnormal is 98% correct. The inaccuracy of abnormal result is due to the same datasets as previous testing which the wrong classification in SpO2 has been brought to the final classification. Table V shows the results of final classification.

TABLE V. RESULTS OF FINAL CLASSIFICATION FOR 50 NORMAL AND 50 ABNORMAL DATASETS

Class	% accuracy
Normal/healthy	100
Abnormal/unhealthy	98

D. *Correlation heart rate of MAX30100 with commercial oximeter results*

For data correlation, the analysis method used is Spearman's Rank Correlation. The analysis is conducted to both the heart rate reading that is obtained from the experimental hardware device and the pulse oximeter device. Spearman's Rank Correlation is carried out to confirm and concluded that the heart rate reading obtained from the hardware device is strongly reliable.

Table VI presents the results obtained from Spearman's Rank Correlation. The Spearman's Rank Correlation coefficient (rs) is a test statistic that measures the strength of the statistical relationship or association between two samples or variables. The results show that the heart rate reading for dataset 1 to dataset 5 has positive linear relationship as the coefficient values for the data sets are all positive values. This indicates that as one variable increases, the other variable increases together. Moreover, the p-values for the data sets are lower than 0.05. This explains that the correlation between the experimental hardware device and the pulse oximeter device is statistically significant, as all the data sets show p-values are lower than 0.05. The relationship between the experimental reading and reference reading is strong correlation as rs-values are higher than 0.8 for all the data sets.

TABLE VI. SPEARMAN'S RANK CORRELATION RESULTS FOR HEART RATE DATASET 1 TO DATASET 5

Dataset	p-value	rs-value
1	0.00002	0.989
2	0.00002	0.985
3	0.00002	0.992
4	0.00002	0.993
5	0.00001	0.967

E. *Comparison between the developed system with commercial oximeter results*

The heart rate and SpO2 readings are presented in beats per minute (bpm) and percentage of oxygen level (%). Table VII shows the results of comparison between the developed system with commercial oximeter which are involved with five datasets of SpO2 and heart rate from five subjects. These results show that the percentage errors are less than 3%, and this is considered as low and can be acceptable.

TABLE VII. PERCENTAGE ERROR RESULTS OF THE DEVELOPED SYSTEM WITH A COMMERCIAL OXIMETER

No. of datasets	SpO2 (%)	Heart rate (%)
1	3.00	1.03
2	2.15	1.03
3	2.22	1.02
4	2.94	1.02
5	2.06	1.02

F. Real time performance with IoT

The heart rate and SpO2 of patient that are measured through the developed system are sent to the cloud service and stored in the database. In this system, the database that is used to store the measuring reading is Firebase, that is owned by Google. Then, the data are transmitted and display on the webpage interface that is created by using HTML 5 language through the Visual Code Studio IDE. The webpage can only access by authorized personnel, which are the patient, the patient's authorized family member, and also the medical professional.

Fig. 7 to Fig. 10 show the flow to access to the monitoring system. Fig. 7 shows the login page of the authenticated personals. This page is purposely developed to have secure system and particularly for the specific or authentical users. By using the same webpage, the patient, the patients' family members and the medical professional can sign up as one of the authenticated users. The sign-up page is as shown in Fig. 8. These users are only able to login to the health monitoring website and can access the patient's data. When the authenticated users have done creating the account, the authenticated credentials are stored directly in the Firebase. This can be seen in Authentication selection of the Firebase Project selected. The example of stored authenticated account can be seen in Fig. 9. The privacy of the users is protected as when the wrong email or password is keyed in, there will be a red-coloured error message shown on the webpage that stated "The email and password you entered don't match", as shown in Fig. 10. This authentication method which is email and password protected webpage only allowed the users. Thus, this purposed cloud system allows various authorised users to access the webpage and can monitor purposely for the health of the elderly securely.

Fig. 7. Login page of the authenticated personals

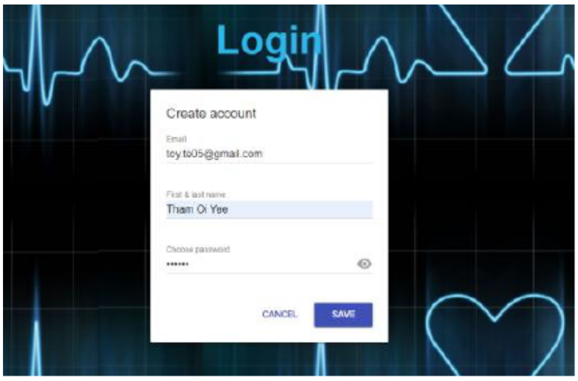

Fig. 8. Sign up page for authenticated users

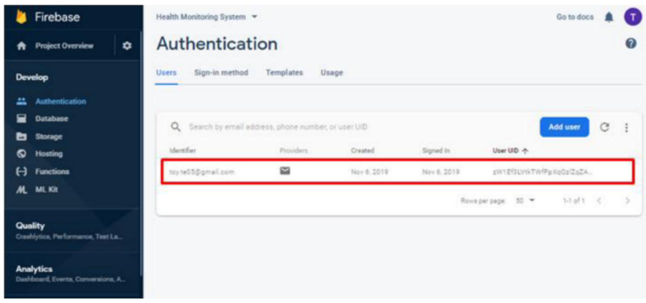

Fig. 9. Firebase authenticated credentials

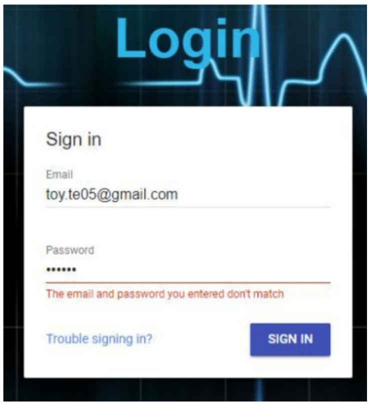

Fig. 10. Error message

Fig. 11 to Fig. 13 show that the heart rate and SpO2 reading that are measured from the monitoring device is able to transmit to the database for storage purpose and at the same time, the reading can be display real-time on the webpage created. Fig. 11 shows the webpage interface that is created to display the heart rate and SpO2 reading in real-time when the monitoring device is turned on. The reading will be updated continuously to the latest heart rate and SpO2 level. Besides, the previous heart rate and SpO2 reading is able to trace back by the user's family members and the medical professionals by click the "History" button. The previously readings are shown on the interface as shown in Fig. 12 and the medical professionals can monitor the health condition of the elderly user. At the same time, the heart rate and SpO2 reading are stored in the Firebase real-time database, which is shown in Fig. 13.

Fig. 11. Updated heart rate and SpO2 level

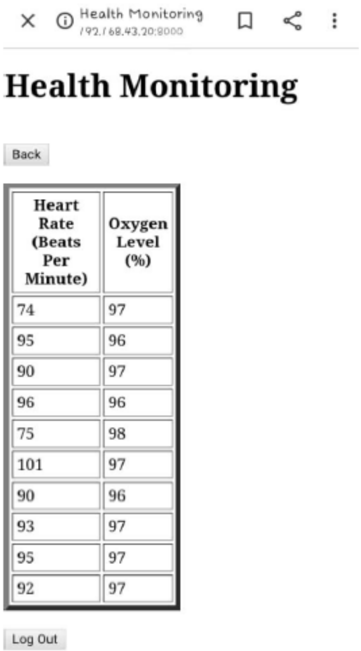

Fig. 12. Previous Heart Rate and SpO2 Level

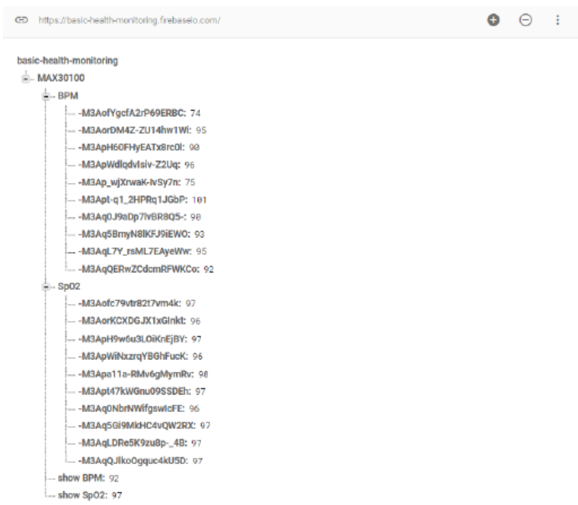

Fig. 13. Storage of heart rate and SpO2 level in Firebase

IV. Conclusions

The significance contribution of this project shows that the pulse oximeter device can be constructed using MAX30100 High-Sensitivity Pulse Oximeter and Heart-Rate sensor and NodeMCU. It is low cost and light device that is able to wear on the wrist, without causing burden. By implementing Internet of Things (IoT) application, the sensor readings are able to transmit to the users' personal device assistant (PDA) in real-time. Thus, this gives advantages on remotely monitor aspect. The real-time implementation system is also coming together with login section in which only the authorised personal can access the system. Therefore, this developed system's security guarantee can provide confidence to the users and also the healthcare and medical staffs.

References

[1] W. M. S. bin W. Ibrahim, S. H. binti M. Ashi, N. H. binti Othman, and S.F. binti M. Zukri, "Factors Leading to Malaysia Ageing Population," 2017. doi: 10.4324/9781315693606.

[2] B. D. Chung Hua, H. Fahmi, L. Yuhao, C. C. Kiong, and A. Harun, "Internet of Things (IOT) Monitoring System for Elderly," in International Conference on Intelligent and Advanced System, ICIAS 2018, 2018, no. January, pp. 1–6, doi: 10.1109/ICIAS.2018.8540567.

[3] W. Zhihua, Z. Yang, and T. Dong., "A review of wearable technologies for elderly care that can accurately track indoor position, recognize physical activities and monitor vital signs in real time." Sensors 17.2 (2017): 341. World Health Organization. "Pulse oximetry training manual." *Geneva: World Health Organization* (2011).

[4] S. Bagha and L. Shaw, "A Real Time Analysis of PPG Signal for Measurement of SpO 2 and Pulse Rate," *Int. J. Comput. Appl.*, vol. 36, no. 11, pp. 45–50, 2014.

[5] H. Lee, H. Ko, & J. Lee, "Reflectance pulse oximetry: Practical issues and limitations". *Ict Express*, (2016). *2*(4), 195-198.

[6] M. Hassanalieragh, A. Page, T. Soyata, G. Sharma, M. Aktas, and G. Mateos, "Health Monitoring and Management Using Internet-of-Things (IoT) Sensing with Cloud-based Processing : Opportunities and Challenges," in *2015 IEEE International Conference on Services Computing*, 2015, pp. 285–292, doi: 10.1109/SCC.2015.47.

[7] M. A. Saip and A. S. Mohamed, "Smart Health Monitoring and Controlling using Raspberry Pi3," *Int. Innov. Res. J. Eng. Technol.*, vol. 4, no. 1, pp. 24–28, 2018, doi: 10.32595/iirjet.org/v4i1.2018.70.

[8] J. Wan, Y. Zou, Y. Li, J. Wang, "Reflective type blood oxygen saturation detection system based on MAX30100." *2017 IEEE International Conference on Security, Pattern Analysis, and Cybernetics (SPAC)*. 2017.

[9] R. Strogonovs. "Implementing pulse oximeter using MAX30100." *Morf-Coding And Engineering* (2017).

[10] M. S. Hossain and G. Muhammad, "Cloud-assisted Industrial Internet of Things (IIoT) – Enabled framework for health monitoring," Comput. Networks, vol. 101, pp. 192–202, 2016, doi: 10.1016/j.comnet.2016.01.009.

[11] V. G. Bangera and V. Dhiman, "IOT based Smart Health Monitoring for Old Aged Patients," Int. J. Recent Trends Eng. Res., vol. 3, no. 5, pp. 431–437, 2017, doi: 10.23883/ijrter.2017.3246.uvyjc.

[12] G. A. Alonso, "Design of a Versatile Low Cost Mobile Health Care Monitoring System Using an Android Application," in 2015 Pan American Health Care Exchanges (PAHCE), 2015, pp. 1–4, doi: 10.1109/PAHCE.2015.7173334.

[13] "MAX30100 Pulse Oximeter and Heart-Rate Sensor IC for Wearable Health-Maxim Integrated," 2020. https://www.maximintegrated.com /en /products/sensors/ MAX30100.html (accessed Jul. 06, 2020).

[14] "Introduction to NodeMCU | NodeMCU," 2020.https://www. electronicwings.com/nodemcu/introduction-to-nodemcu (accessed Jul. 06, 2020).

[15] Basaranoglu, G., Bakan, M., Umutoglu, T., Zengin, S. U., Idin, K., & Salihoglu, Z. (2015). Comparison of SpO 2 values from different fingers of the hands. *SpringerPlus*, *4*(1), 561.