# Health Care System at Home with Blood Oxygen Test

Zhi Xuan Yeap, Kok Swee Sim, and Teck Kiang Kho
Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, Melaka, Malaysia
Email: zhixuanyeap@hotmail.com, {kssim, tkkho}@mmu.edu.my

*Abstract*—**Health care system with blood oxygen test (BOT) at home is useful for patients who need to do blood oxygen test at hospital or clinic frequently. Therefore, a health care system with noninvasive BOT at home which is able to communicate with the doctor or health care personnel is useful. This paper introduces how the pulse oximeter is connected to computer and how to build a health care system with BOT which can give accurate results as compared to device Nonin Go2. Besides, the communication between applications such as how to handle the bytes to be sent or to be received is introduced. TCP/IP is selected as the communication protocol. Several tests such as t-test, line regression test, and Bland-Altman graph test is conducted to evaluate the accuracy of the results read and displayed in this health care system. This system uses a CMS 50D+ model pulse oximeter from CONTEC.**

*Index Terms*—**health care system, blood oxygen saturation, blood oxygen monitoring system**

## I. Introduction

### A. Abbreviation

In this paper, estimated blood oxygen taken from using pulse oximeter is called SpO2. There are several short forms using in Table II, which is the protocol of pulse oximeter. SS means signal strength, E1 means error of searching time out, E2 means device not connected, S1 means hear beat sound, SG means SpO2 graph, HB means heart beat graph, E3 means device error, SP means searching pulse, PR means pulse rate, Sp means SpO2 value, and Sy means synchronization bit.

Human body consists of 7 % of blood. The blood is made up of 55% of plasma and 45% of cells. Blood cells can be categorized into three types, erythrocytes (red blood cells), thrombocytes (platelets) and leukocytes (white blood cells) [1]. Among these blood cells, red blood cells act as the transport to carry oxygen between organs. Therefore, red blood cells play an important role to human body [2].

There are several ways to measure the blood oxygen saturation. Arterial Blood Gases (ABG) test is the most common way to measure blood oxygen in hospital. This measuring way has some disadvantages. Normally, the test takes blood sample from artery. Patients suffer bruise and painful while taking the blood sample [3]. Therefore, a noninvasive method is discovered by Aoyagi before 1972. This method uses the light absorption characteristic of oxyhaemoglobin and deoxyhaemoglobin to estimate the blood oxygen saturation. This method is called as pulse oximetry.

A software is requested to communicate with the pulse oximeter and the result is able to send to doctor for monitoring purpose. This may help the people who need to monitor their blood oxygen saturation frequently without travelling to hospital. This system uses CONTEC CMS 50D+ pulse oximeter to measure the blood oxygen saturation. The result will send to server through internet by using TCP/IP protocol telnet port, port 23. Telnet port is chosen as it is not easy to be blocked and it is popular. The patients' details are to be stored in a data base. This data base is saved as ".csd" file type. Every transmission is encrypted with advance encryption standard (AES) and/or SHA-1 [4]. SHA-1 is a one way encryption technique that the encrypted messages are not able to be decrypted

## II. Set up of the System

A block diagram of the blood oxygen monitoring system is shown in Fig. 1.

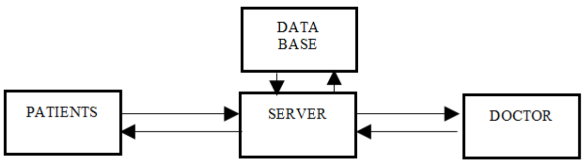


Figure 1. Block diagram of blood oxygen saturation monitoring system in home.

This blood oxygen saturation monitoring system consists of three applications which are the software for patients (monitoring system for patient), a server and software for doctors (monitoring system for doctor). These applications are created with Visual Studio 2013 C sharp (c#) language. Patients log in to the "monitoring system for patient" and measure the pulse rate and oxygen saturation. Results are sent to doctors. Doctors log in the "monitoring system for doctor" and monitor the result of the patients. Server reacts to the request which sent by patients and doctors by recognized the "header".

The system adds a header "1" to indicate the server that the patient requests to log in. Header "2" is to indi-

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cate the server that the patient requests to register a new account. Header "3" is to indicate the server that the patient requests to update the data. Header "4" is to indicate the server that the doctor requests to log in. Header "5" is to indicate the server that the doctor requests to access patient information. Header "6" is to indicate the server that the doctor requests to search patient details using key words. Header "7" is to indicate the server that the doctor requests to add comment on patients' result.

Every transmission of string uses a similar format which is separated by "," and end with ";". For example, "information1, information2, information3,…;". The string will be encrypted with AES [5] and converted to bytes before sending between server and users. There is a problem that the server and user application will keep sending null spaces after the information byte is ended. Therefore, a slicing algorithm is needed to exclude the spaces after the information bytes. Every byte to be transmitted will be added with ending characters "34" at the end of bytes. "3" is the control character means "end of test" and "4" is the control character means "end of transmission" in ASCII. However, "34" can be replaced with other ASCII control characters in this system. From the tests that have done, one ending character is not enough to be the signal of "end of transmission" as the center of bytes to be transmitted may contain the same characters. The failure is caused by the system which identifies the decrypted message as the ending character. A solution is came out which is using two ending character. Within 20 transmissions of different bytes, none of them has error occur. Therefore, two ending characters are used to identify the "end of transmission". After the "3" is detected in the transmission string, the system will check on the next character. If the next character is "4", it is mean that this is the end of transmission. If the next character of "3" is not the '4", means that it is just one of the character among the transmission string.

The communication between pulse oximeter and computer is a main part of this project. The protocol of the pulse oximeter CONTEC CMS 50D+ has been discovered. Putty software is used to store the received bytes and Hexeditor is used to translate the byte to hexadecimal code. From the observation on the results of Hexeditor, the device is designed to send 5 bytes as a group. Each bit inside the bytes has its own identity. The transmission protocol on how the device sends information to computer is shown in Table I.

TABLE I. TRANSMISSION OF PROTOCOL OF PULSE OXIMETER

| | $1^{st}$ bit | $2^{nd}$ bit | $3^{rd}$ bit | $4^{th}$ bit | $5^{th}$ bit | $6^{th}$ bit | $7^{th}$ bit | $8^{th}$ bit |
|---|---|---|---|---|---|---|---|---|
| $1^{st}$ Byte | SS1 | SS2 | SS3 | SS4 | E1 | E2 | S1 | Sy |
| $2^{nd}$ Byte | SG1 | SG2 | SG3 | SG4 | SG5 | SG6 | SG7 | Sy |
| $3^{rd}$ Byte | HB1 | HB2 | HB3 | HB4 | E3 | SP | PR8 | Sy |
| $4^{th}$ Byte | PR1 | PR2 | PR3 | PR4 | PR5 | PR6 | PR7 | Sy |
| $5^{th}$ Byte | Sp1 | Sp2 | Sp3 | Sp4 | Sp5 | Sp6 | Sp7 | Sy |

From Table I, SS1 to SS4 are the four bits to indicate the signal strength. E1, E2, and E3 are three bits to indicate error bit as shown in the abbreviation. SG1 to SG7 are bits to indicate the SpO2 graph and HB1 to HB4 are to indicate the heart beat graph. The most important information is the fourth byte and fifth byte, which is PR and Sp. PR1 to PR8 means the pulse rate value and Sp1 to Sp7 means the SpO2 value.

The first byte will indicate if the pulse oximeter sends the true measured value. From trial and error process, if the first byte equals to "85" in hexadecimal which, the next four received values is useless as the pulse oximeter is not ready yet. The example of error bytes is shown in Fig. 2. If the first byte is not equal to "85", further checking is needed to be done. The fourth byte should not be "133" as well. If fourth byte is equal to "85", it means that it is not the real fourth byte but the first byte of the next group. The bytes is checked until the first byte is not equal to "85" and the fourth byte and fifth byte contains a value, the pulse rate and SpO2 can be extracted from the raw data and shows on graphic user interface GUI. The target bytes of data are shown in Fig. 3.

```
000012e0  59 0b 52 61 c5 55 0a 53  61 c5 4f 09 53 61 85 49  |Y.Ra.U.Sa.O.Sa.I|
000012f0  09 53 61 85 43 08 53 61  85 3e 07 53 61 85 39 07  |.Sa.C.Sa.>.Sa.9.|
00001300  53 61 85 34 06 53 61 85  30 06 53 61 85 2d 05 99  |Sa.4.Sa.0.Sa.-..|
00001310  99 99 99 53 61 85 2b 05  99 99 99 53 61 85 2a 05  |...Sa.+....Sa.*.|
00001320  99 99 99 53 61 85 29 05  99 99 99 99 53 61 85 2a  |...Sa.).....Sa.*|
00001330  05 53 61 85 2a 05 99 99  99 99 99 99 99 99 85 2a  |.Sa.*.........*|
00001340  05 99 99 99 53 61 85 2a  05 99 99 99 99 99 53 61  |....Sa.*......Sa|
```

Figure 2. The error 5 bytes of data from pulse oximeter

```
00002420  16 02 58 61 94 14 02 58  61 94 13 02 58 61 94 11  |..Xa...Xa...Xa..|
00002430  02 58 61 94 0f 01 58 61  94 0e 01 58 61 94 0d 01  |.Xa...Xa...Xa...|
00002440  58 61 94 0c 01 58 61 94  0b 01 58 61 94 0a 01 58  |Xa...Xa...Xa...X|
00002450  61 94 09 01 58 61 94 08  01 58 61 94 07 00 58 61  |a...Xa...Xa...Xa|
```

Figure 3. Target 5 bytes of data from pulse oximeter

## III. FINDING AND DISCUSSION

A comparison test is done to justify that the measurement of this device whether it is accurate by comparing the measurements from the system with U.S. branded pulse oximeter Nonin Go2 as reference. Nonin Go2 is the only brand of pulse oximeter which applied PureSAT Technology. 47 samples are used. For the rest of this paper, "x" is the measurements from Nonin Go2 device and "y" is the measurements from CONTEC CMS 50D+ device. HR is the heart rate or pulse rate values and SpO2 is the blood oxygen saturation percentage. Three tests are tested. Scatter diagram, Bland-Altman diagram and range of limit of agreement are used in the test [6].Correlation coefficient (r) is calculated. r is the mean of the multiply of $x^*$ and $y^*$. Furthermore, T-test is tested. In this rest of this paper, x is used to indicate Go2 and y is used to indicate 50D+. In order to do the T-test, a null hypothesis has to be made. The null hypothesis is claimed that mean values of y system is almost equal to x device with confident level alpha that equal to 0.005. Three parameters are obtained as output. The h is the null hypothesis, p is the probability that the observed samples are extreme or equal to reference samples, ci is the critical range. A right tailed test is used as the mean values are larger than zero.

Two scatter diagrams are drawn (shown in Fig. 4 and Fig. 5). Points are concentrated and a straight line can be drawn. Therefore, a hypothesis can be claimed that the y axis values are almost equal to x axis values [7]. From the scatter diagram Fig. 5, points are concentrated and straight line can be drawn. The relationship between y and x is said to be strong relating.

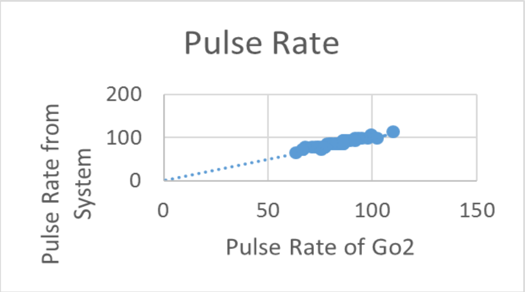


Figure 4. Scatter diagram of pulse rate

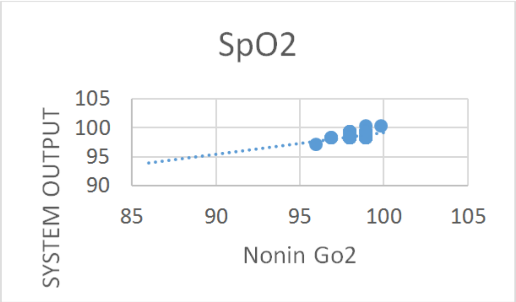


Figure 5. Scatter diagram of SpO2

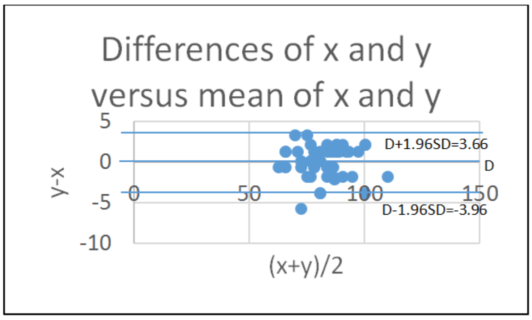


Figure 6. Bland-Altman diagram of pulse rate

Bland-Altman diagram is plotted in Fig. 6 and Fig. 7 [8]. Mean of differences of x and y (D) and standard deviation of differences between x and y (SD) is calculated with (1) and (2). The mean of differences of heart rate D is equal to -0.1489 and standard deviation of difference SD of heart rate is equal to 1.9458. Mean $\tilde{x}$ of Go2 device is equaled to 83.4894. Standard deviation $\sigma_x$ of Go2 device is equaled to 10.0019. The mean difference D of SpO2 is 0.2340 from the system and standard deviation of difference SD is equaled to 0.7418. The mean $\tilde{y}$ is equal to 83.3404, and standard deviation $\sigma_y$ is equal to 10.0645. From Fig. 6, almost all the points are fall between the lines of agreement which are -3.96 to 3.66. A conclusion can be made that the result of y device is accurate as x device. From Fig. 7, all the points are lied between ranges of limit of agreements. The values shows that the result from y system is accurate enough to replace x device.

$$D = \frac{\sum(y-x)}{\text{no of samples}} \tag{1}$$

$$SD= \sqrt{\frac{((x-y)-(\widetilde{x-y}))^2}{\text{no.of samples}-1}} \tag{2}$$

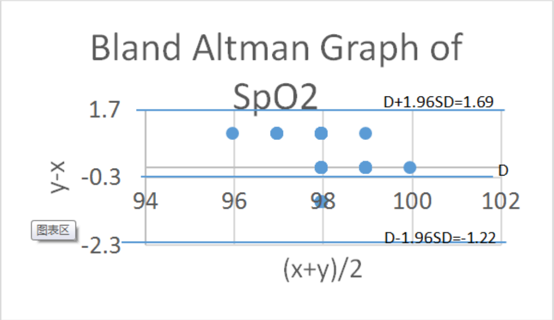


Figure 7. Bland-Altman graph of SpO2

Correlation coefficient can be calculated by taking the average of multiplying (3) and (4).

$$x^* = \frac{(x-\tilde{x})}{\sigma} \tag{3}$$

$$y^* = \frac{(y-\tilde{y})}{\sigma} \tag{4}$$

The correlation coefficient is equal to 0.9571. The stronger the linear association between two devices, the highest the correlation coefficient. The highest correlation coefficient is equal to 1. Therefore, we can conclude that the pulse rate measurements from x device can be replaced by the pulse rate measurements of y system.

In this T-test, h value is equaled to 0 and shows that the null hypothesis cannot be rejected. Next, p is get from the output. The p-values is equal to 0.6969 and this proved that the null hypothesis is claimed with doubt is small. The ci ranges get from the output are -1.0891 to infinity. The range is overlapped with the zero axis, so the hypothesis cannot be rejected. Correlation coefficient of SpO2 is equal to 0.9232. 0.9232 is closed to 1. Therefore, we can conclude that by knowing the value of x, y values can be predicted with very small differences. Lastly, T-Test is performed. h equal to 0, p equal is to 0.0164 and ci range (-0.1143 to infinity) is overlapped with zero, we can conclude that the null hypothesis is accepted.

## IV. Conclusion

A health care system at home with BOT is designed to measure pulse oxygen. The result can be monitored by doctor or health care personnel and the results are accurate by comparing to Nonin Go2 device. With the aid of this system, blood oxygen saturation can be monitored without going to hospital. This system helps to save cost and time of travelling to hospital. Besides, this system helps patients who have difficulties to move to monitor their blood oxygen at home.

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**Zhi Xuan Yeap is b**orn at Penang Malaysia on 1991. She is studying bachelor of engineering (Hons.) electronics majoring in telecommunications at Multimedia University (MMU) Melacca, Malaysia. She has been worked as an Electrician Assistant for 3 months on year 2010. At the same time, she worked as a Hostel Warden at Jit Sin Independent High School. She resigns later to continue her studied as an engineer at MMU Melacca. In 2013, she worked as an Internship at Hercules Machinery Gases.

**Kok Swee Sim** is the Professor in the Faculty of Engineering and Technology (FET) at the Multimedia University of Malacca, Malaysia. His main areas of research are IC failure analysis, application of SEM, noise quantization, biomedical engineering and image processing. He has been working in the industrial and teaching line for more than 20 years. Ir. Prof Dr. Sim Kok Swee is an Associate Fellow for Malaysia Academic Science Malaysia, Senior panel for Engineering Accreditation Council and Malaysian Qualifications Agency (MQA), Fellow Member of The Institution of Engineers, Malaysia (IEM), Senior Member of Institute of Electrical and Electronics Engineers (IEEE). He is heavily involved in IEM as Melaka State committee member, secretary, vice chairman, IEM Multimedia University student chapter advisor, the Institution of Engineering and Technology (IET) MMU student chapter

**Desmond Teck Kiang Kho** is a Lecturer in the Faculty of Engineering and Technology (FET) at the Multimedia University of Melaka, Malaysia. His main areas of research are Digital Signal Processing, Wireless Communications, Biomedicine, and Image Processing. He received his First Class Diploma in Electronics and Electrical from Inti College Sarawak, Malaysia and First Class Honours Bachelor of Engineering Degree in Electronics Engineering majoring in Telecommunications and M. Eng. Sc. in Telecommunications Engineering from Multimedia University (MMU), Malaysia. He has industrial working experience as engineer which involved in yield enhancement process and testing process of wafer fabrication operation at 1st Silicon (Malaysia) Sdn. Bhd.