Development of a Pulse Oximeter for E-Health Applications

Thai M. Do, Nam P. Nguyen, and Vo Van Toi

Abstract

The oxygen plays crucial role in our life. Especially, the brain and heart have a variety of sensitive with limited oxygen in the blood. If the limited oxygen which is called hypoxia in human body happens in several minutes, the human will be died immediately. Therefore, the pulse oximeter is compulsory for research and development. In this paper, we designed a new pulse oximetry which has a special function called telemedicine and a software program in the server for obtaining results of this device by using HL7 Standard. In this way, the patients can be supported and treated from far a distance. Indeed, it can be called a system of Internet of Thing (IoT) in health cares. By means of calibrating with SpO_2 FLUKE simulator, the Tele-Pulse Oximeter works effectively as our expecting, and the result of patients on the server software is received accurately as well. In the near future, this device has a vast potential in Vietnam E-Health system.

Keywords

Pulse oximeter • Telemedicine • Oxygen saturation

1 Introduction

Telemedicine is the use of telecommunications and information technologies in order to supply clinical health care from a distance. It helps eliminate distance barriers of doctors and patients, and it also can improve access to medical services in distant rural communities [1]. Nowadays, Telemedicine is more captivated by scientists. Due to its efficiency, Telemedicine has been used in huge variety of home health care which is health services delivered to patients' homes in part by telecommunication devices such as smartphone, tablet, and etc. [2]. In additionally, Telemedicine is very useful because it can save lives in critical care and emergency situations [1]. Especially, the government of Viet Nam focuses on improvement of health care ability in Viet Nam's hospitals. With this new method, it can help to reduce the workload of central hospitals, and the doctor can take care of many patients at the same time immediately.

Oxygen is very important in our lives. People always need it to breathe and live. Therefore, the monitoring of saturation oxygen in blood is necessary with the patients concerning with a problem of limited oxygen. In this paper, we introduce a design for Telemedicine of home healthcare for monitoring oxygen saturation in the blood which includes hardware and software of having a capability of transmitting data over the internet. This device allows patients to measure SpO_2 index on their finger at home using a non-invasive technique continuously.

2 Designing of the Tele-Oximeter System

Home Tele-healthcare services for oxygen saturation measurement are based on Client-Server architecture [3]. Therefore, it contains server applications that receive in-coming SpO_2 results from the clients and then storages into database. The device client is responsible in real-time for measuring SpO_2 and heart rate from patients and transmitting them through internet; The data of SpO_2 are packed in HL7 international standard. This system is shown in Fig. 1.

2.1 Implement Hardware of the Tele-Oximeter in Client Side

In the client side, it contains hardware devices of a pulse oximeter having a special function with sending the SpO_2

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V. Van Toi et al. (eds.), *7th International Conference on the Development of Biomedical Engineering in Vietnam (BME7)*, IFMBE Proceedings 69, https://doi.org/10.1007/978-981-13-5859-3_12

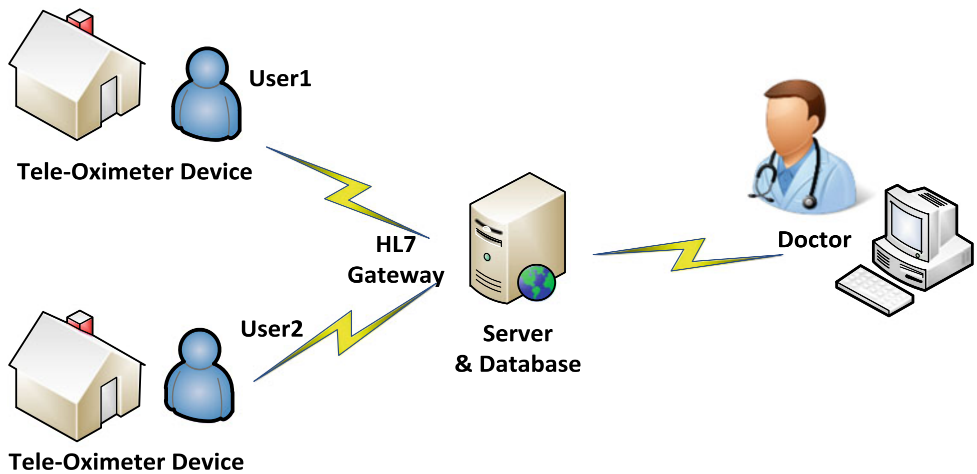


Fig. 1 Demonstrated a Tele-oximeter system including server and client side

index and heart rate via Wi-Fi communication to a central server. It is called the Tele-Oximeter. The firmware in this device is programmed to measure blood oxygen saturation level (SpO_2) and Pulse rate using of non-invasive method. This approach is based on altering intensity of light of Red and Infrared LED which transmit through tissue. This signal is obtained in arterial blood pulse and it is called photo-plethysmography(PPG) [4].

Principal of measuring SpO_2 index.

The SpO_2 index is calculated from monitoring the percentage concentration of hemoglobin saturation with oxygen which is called oxyhaemoglobin, to the total haemoglobin concentration. The pulse oximetry has a foundation of spectrophotometric measurements of alternatives in blood color; oxygenated blood is typically red. In contrast, deoxygenated blood is dark blue coloration. In the visible, the optical property of blood (between 400 and 700 nm) and near-infrared (between 700 and 1000 nm). The special regions concern strongly with the amount of oxygen concentration in the blood [5]. The graph of haemoglobin light absorption is shown in Fig. 2.

In Fig. 2, it is illustrated the absorption process of two light wavelengths transported through blood. This process depends on whether Hb(haemoglobin) is bound to oxygen in blood [4]. The Hb reaches a higher optical absorption coefficient in the red line of spectrum some 660 nm when comparing to HbO_2. In addition, the region of near-infrared of spectrum is around 940 nm, and the optical absorption of Hb is less than HbO_2 [5].

The light absorbance of haemoglobin solution is determined by the Beer-Lambert's Law, by using the below formula:

$$I_t = I_0.e^{-\alpha cd} \tag{1}$$

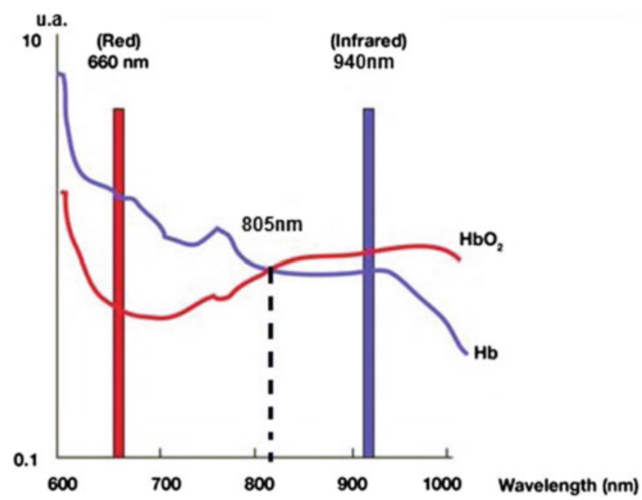


Fig. 2 Oxygenated versus de-oxygenated blood light absorption at different wavelengths [5]

where: I_t is the transmitted light intensity, I_0 is the incident light intensity, α is the specific absorption coefficient of the sample, c is the concentration of the sample, and d is the path length of light transmission.

By using two different wavelengths, Red and infrared, the ratio of absorption of these light wavelengths is made use of determining the fraction of saturated haemoglobin. Because of different optical attenuation at hemoglobin and deoxy-haemoglobin. The pulse oximeter is usually to use the light with wavelengths: 660 nm(R) and 940 nm(IR). The measure of oxygen concentration can be calculated in Eq. (2).

$$SpO_2 = \frac{H_bO_2}{HbO_2 + Hb} * 100 \tag{2}$$

By means of calculating R/IR, called "ratio of ratios", It has a concerning with SpO_2 concentration. This ratio is calculated in the following equation:

$$\frac{R}{IR} = \left(\frac{AC_R/DC_R}{AC_{IR}/DC_{IR}}\right) \tag{3}$$

In the Eq. (3), the "AC" component is described the pulsatile part of PPG signal, and the "DC" component is concerned with venous blood, skin, and tissue. Both of signals are shown in Fig. 3.

With normalization for both Red and infrared wavelengths, the component signal due to venous blood and surrounding tissues does not influence to the measurement of SpO_2. Consequently, the ratio of ratios can be concerned with SpO_2 index as shown in Fig. 4.

This algorithm is performed with the help of altering one of the two intensity of transmitter LEDs until the DC components of the red and infrared signals are equal as Fig. 4. The ratio of ratios is simplified in the below formula (4) [6]

$$\frac{R}{IR} = \left(\frac{AC_R}{AC_{IR}}\right) \tag{4}$$

Because of correlation between SpO_2 and SaO_2, the SpO_2 index can calculate by using the relationship of estimation in SaO2 and Ratio (R/IR). It is shown in the Eq. (5)

$$SaO_2 = A - B.(R/IR) \tag{5}$$

The constants A and B in the Eq. (5) derived practically during calibration by correlation between Ratio of Ratios and SaO2. This process is demonstrated in Fig. 5.

Hardware Design of the Oximeter device.

In this project, we designed the Tele-oximeter device for keeping track of SpO_2 index and heart rate supporting for hypoxia patients who suffer from limiting oxygen in the blood. In terms of hardware diagram in this device, the microcontroller with ARM-32 bit architecture is taken advantage of controlling the system of device. With the help of ARM cortex-M3 technology, it has enough performance for calculating the algorithm of SpO_2 index. In Fig. 6, it is illustrated for diagram of hardware design. In detail, the AFE4490 IC is utilized for key solution of SpO_2 measuring. With using SpO_2 Nellcor sensor and DB9 connector, signals in the device become better and calculating of results is more reliable.

From Fig. 6, There are three data connections in the oximeter device: GPRS, WiFi, and Bluetooth. The SpO_2 index and heart rate after measuring will be sent to a server by using wireless communication as GPRS or WiFi. In terms of configuration for users, the Bluetooth interface is utilized, and it is also used for transferring data of PPG signals into Personal Computer. All information of configuration such as username, user ID, and etc. will be saved in a ROM IC. In regarding to display results, the LCD 20 * 4 is made use of showing these results.

In related to controlling LED (Red and infrared) and receiver (Photodiode), the AFE IC can change LED current by means of an H-bridge configuration capable of driving up to 150 mA. In Fig. 7, the photodiode circuitry in the AFE can amplify currents less than 1uA with resolution 13 bit [5].

Sensor of SpO_2.

In this device, we chose SpO_2 Sensor via a DB9 connector and accompanied by a standard of Nellcor Company. In detail, the rules of connector are named in the pins demonstrated in Fig. 8.

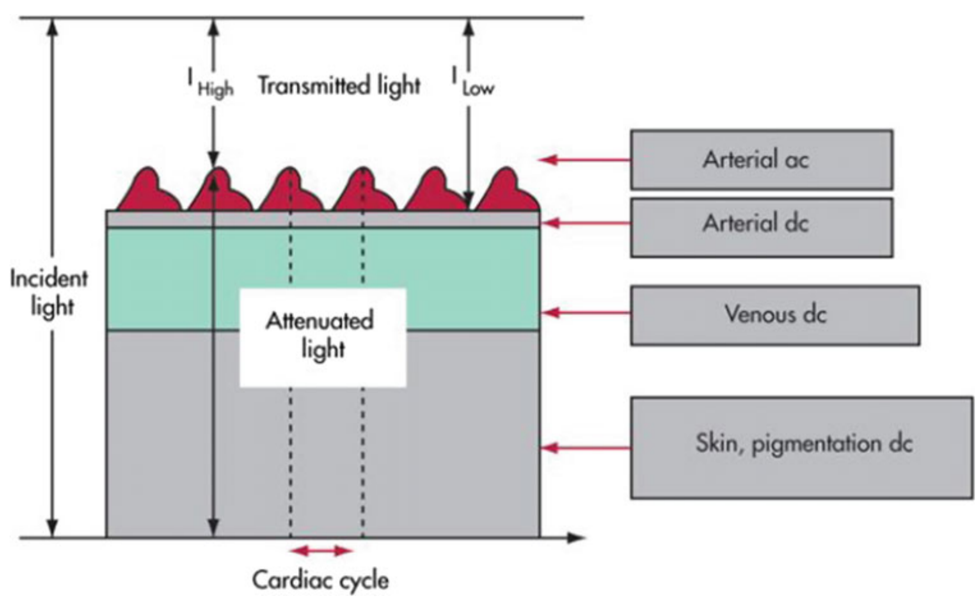


Fig. 3 Variations of light attenuation by tissue [5]

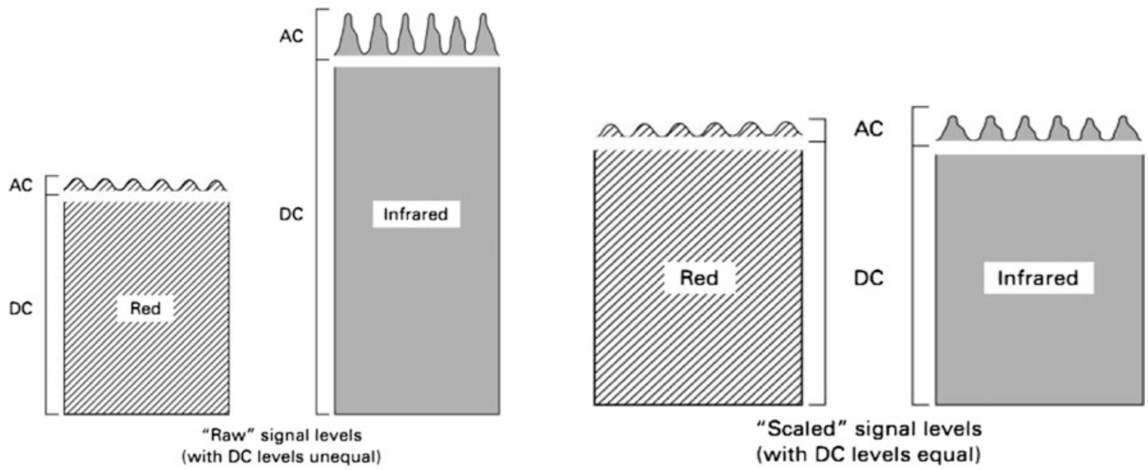


Fig. 4 Normalization of R and IR wavelengths to eliminate the influences of DC components [6]

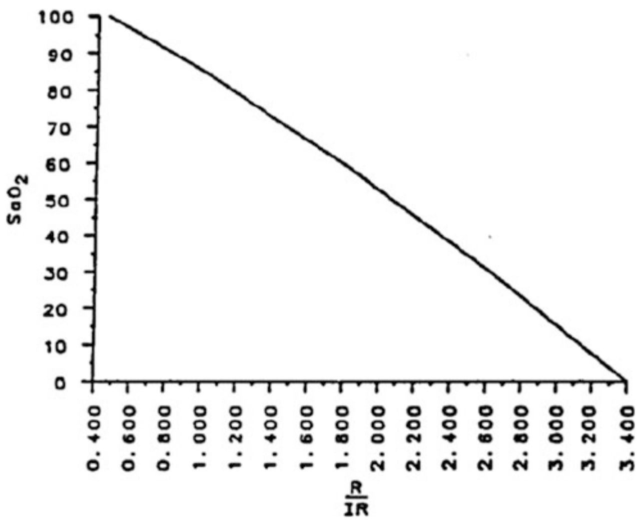


Fig. 5 Empirical relationship between arterial SaO2 and normalized (R/IR) ratio [5]

Digital signal processing in the SpO_2 device.

Because there is a huge amount of noise in received photodiode signals, the techniques of digital filter are applied to eliminating the noise. The processing data flow is displayed in Fig. 9.

In the acquisition of data, the AFE IC is configured with 1 ms period span of interrupt for collecting data. When time of ADC conversion finishes, ADC_RDY pin of AFE IC have a pulse that indicates the completion of ADC conversion. This pin is connected to an external microcontroller. With external interrupt, the MCU is programmed to read data of PPG signals with 1 ms. Then, these signals are limited with a FIR Filter for removing noise signals, and the IIR Filter is used for eliminating a DC component in the PPG signal. In order to reducing effect of DC components in calculating Ratio R/IR, an algorithm of DC correction is developed. It means that MCU have to manipulate the intensity of LED in transmitter side until the difference of DC component in Red and infrared is lowest.

2.2 Develop Software Programs for Collecting Directly Data and Central Server Side

The software program in the server will collect all data sent from the Tele-Oximeter and it stores these data in the database of patients. Every physician has an account and password to access this database. In addition, they also view the graph of measured results over time. Because of the access permissions of system, the doctor can only see the results of their tracking. The platform software programs are capable working on Personal Computer, smartphone, and website. With the help of these software programs, the doctor can easily take care of the patient from a distance. Even though, they can also give guidelines related to treatment or diagnosis for the patient.

3 Results of Experiment

We consider designing of the SpO_2 device with high compatibility for customers, because our target is that we want to manufacture mass-production of this device. Therefore, it is mandatory designing with small, comfortable, and reliable. In regards to the calibration, we make use of Simulator Fluke Index 2 for finding the relationship of SpO_2 value and ratio of R/IR. The process of calibration is shown in Fig. 10.

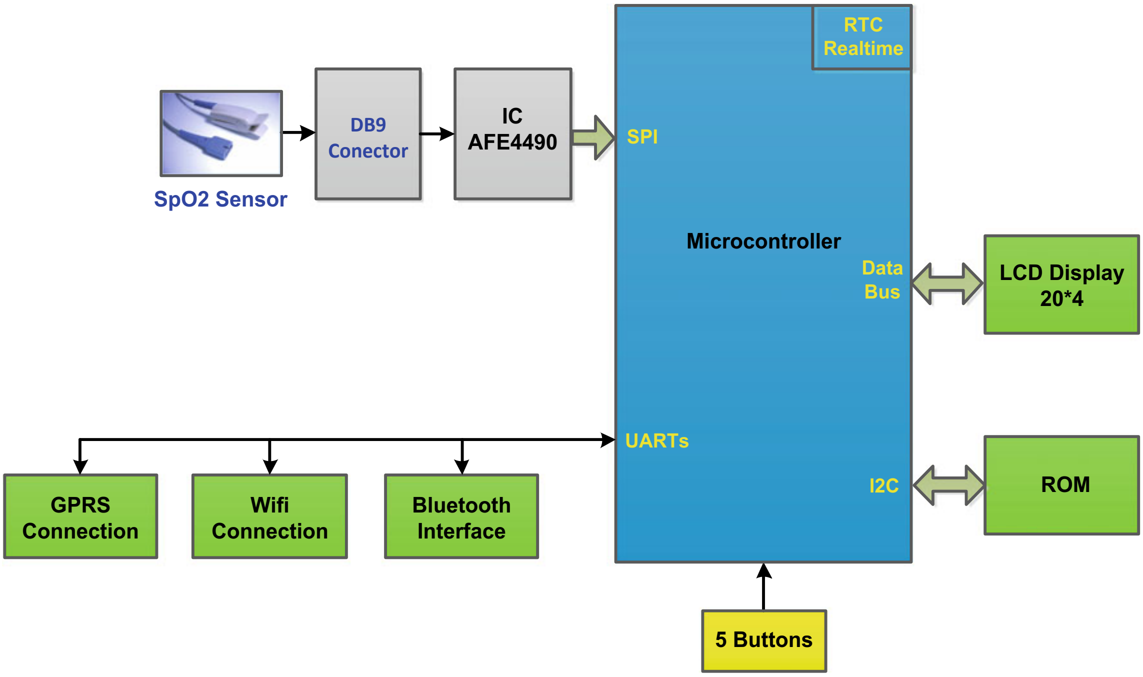
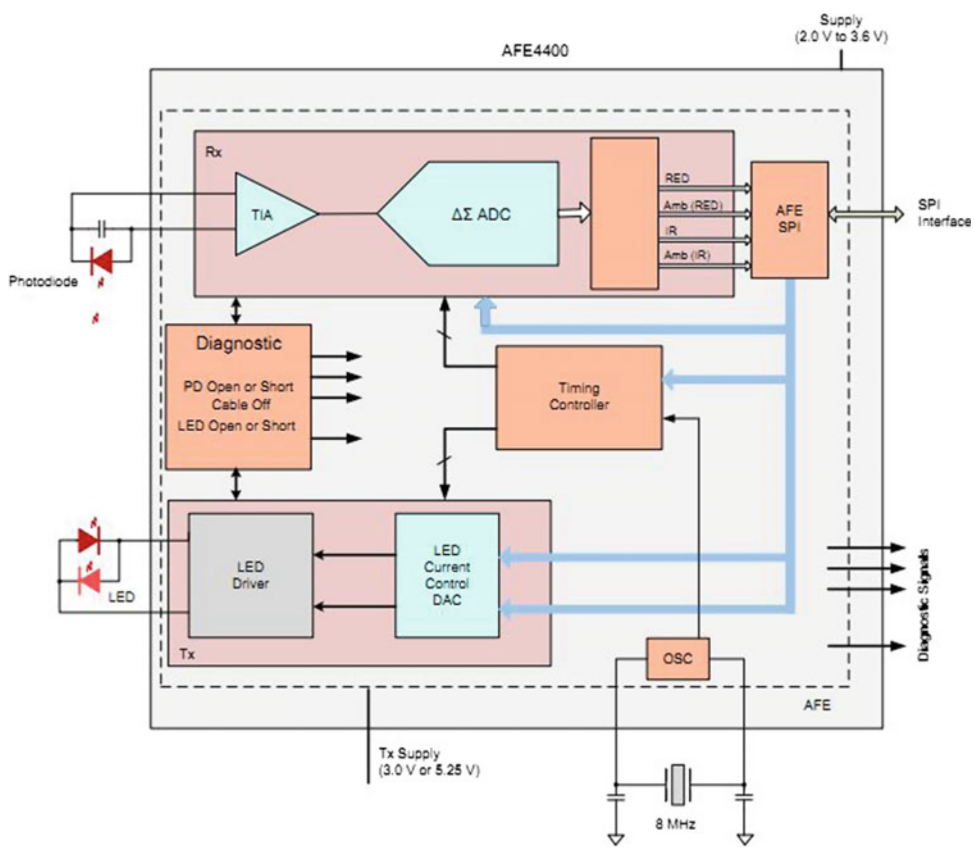


Fig. 6 Diagram of the designed Tele-oximeter device

Fig. 7 Simplified diagram of AFE4490 IC [7]



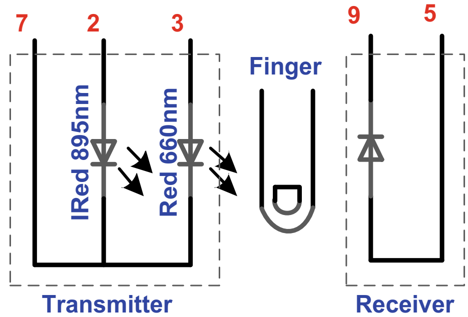


Fig. 8 Insight schematic of SpO_2 Nellcor

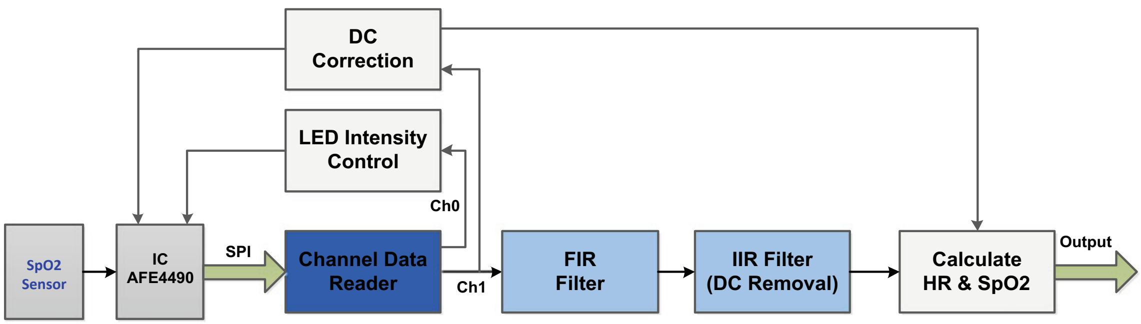
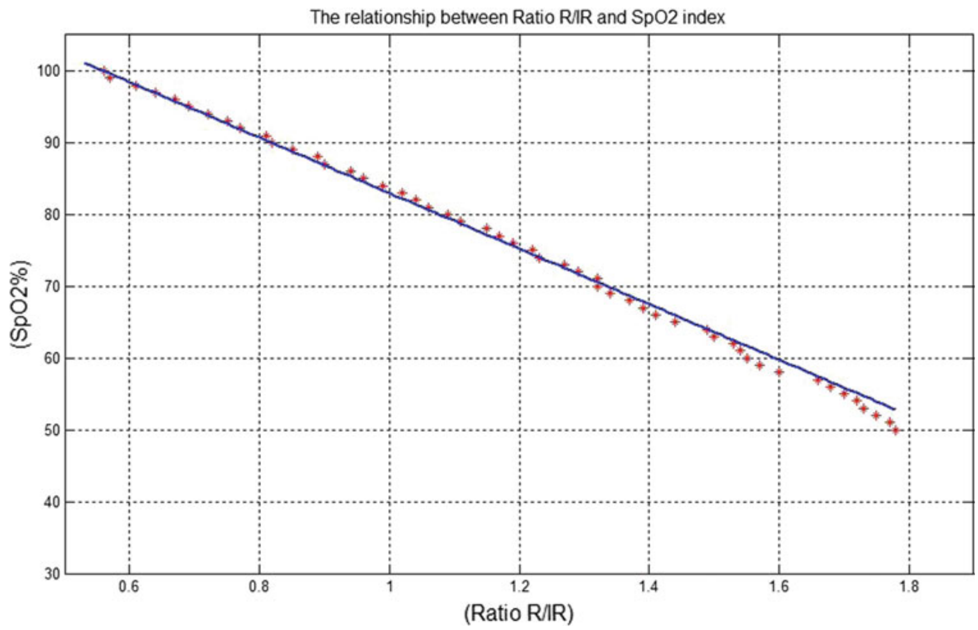


Fig. 9 The data flow and digital processing in the oximeter device

Fig. 10 Calibrated the SpO_2 device with Simulator Fluke Index 2

Because the Simulator of Fuke Index has oxygen simulations with saturation levels from 50 to 100%, and each of steps is with 1%, we investigate this range of SpO_2 value and calculate ratios of R/IR. Then, the slope of relationship is estimated with a linear function of −38.68. This function of blue line is displayed in Fig. 11.

Fig. 11 The relationship between ratio R/IR and SpO_2 value



In regarding to comparing with FLUKE Simulation index 2, we utilized the Tele-Oximeter device to measure with the range saturation lever of Simulator. These results are presented in Fig. 12.

As results in Fig. 12, with a range from 100% reducing to 73%, we can easily see that

The error of oxygen saturation is lower than 1%. With the range of 73 and 50%, the error is reached up 2%. Explaining for this result is cause of the first range of relationship between Ratio of R/IR and SpO_2 saturation more linear than the other described in Fig. 11.

Beside the SpO_2 device is implemented and designed for a cyber-medical system, the software program running on PC is also developed for acquiring PPG signals of Red and IRed; The communication of this transmission is Bluetooth interface. All information as Ratio, heart rate, and etc. are also gained such as Fig. 13.

In Fig. 14, we developed two software program for an e-health system, the first case of a is software on server side by obtaining data from the Tele-oximeter device using HL7 standard and then saving these data into a database. On the other hand, the other software on client side is to access the server to display SpO_2 index and heart rate.

To prove the quality of our device, we carried out an experiment of measuring on human subjects. With comparing with the results of Nonin SpO_2 device in Table 1, we can draw some conclusions that the errors of SpO_2 are pretty precise with ±1% as well as heart rate with around ±2 bpm.

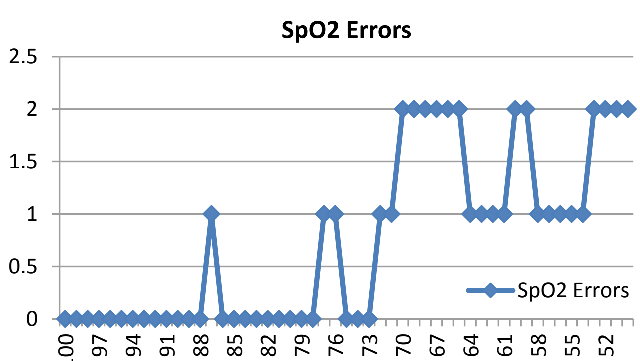


Fig. 12 The errors when calibrating with FLUKE Simulator Index 2

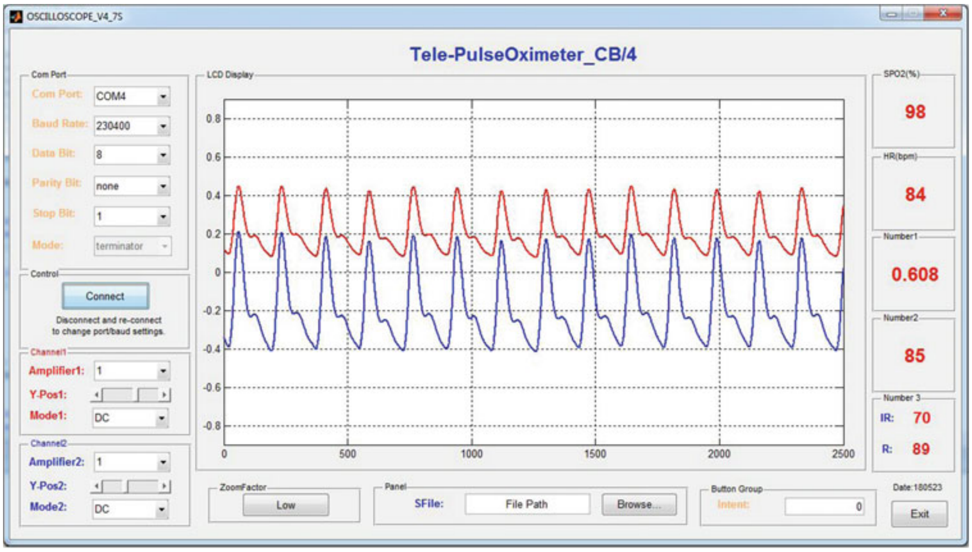


Fig. 13 A software program in order to collect data of PPG signals and SpO_2 results in MATLAB

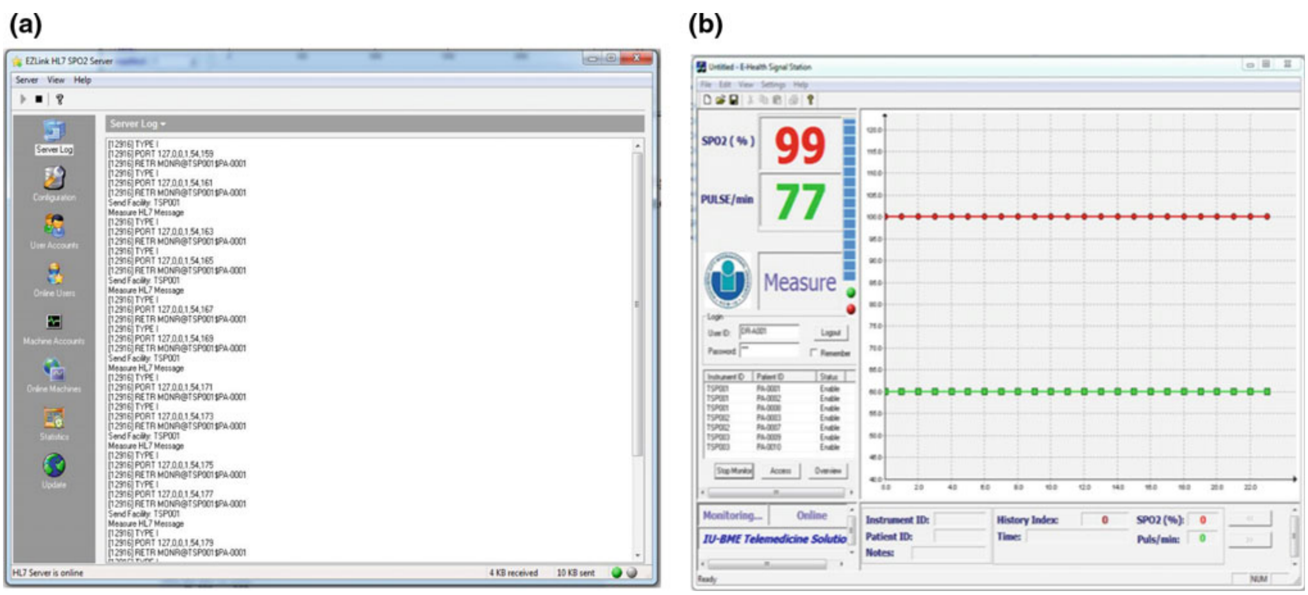


Fig. 14 Administrator and client software program: **a** on server side, **b** on client side

Table 1 Errors of measurement between a Nonin device and the Tele-Oximeter

Person	Nonin SpO_2 device		The tele-oximeter		Error (%)	Error (bpm)
	SpO_2 (%)	Heat rate (bpm)	SpO_2 (%)	Heat rate (bpm)		
1	98	73	99	71	1	2
2	98	78	99	77	1	1
3	98	70	98	72	0	1
4	98	88	99	87	1	1
5	98	75	99	75	1	0
Maximum error					*1*	*2*

Because it is difficult for us to find the patients with hypoxia, the range of low SpO_2 saturation not verified effectively in human subject experiments. So, This will be studied in the future.

4 Conclusions

In this paper, we developed a pulse oximeter which is called Tele-Oximeter. This device is compulsory for the people suffered from diseases of hypoxia due to having telemedicine functions. In regarding to software, we developed some programs on server and client side for telemedicine system, and a software program running MATLAB to plot PPG Signals on PC. Consequently, the errors when comparing with simulator Fluke index 2 is less than ±1% in the range 100% down to 73, and ±2% in the range of 73–50%. With respect to performing a human subject experiment, we have just studied on the good healthy subject; the results are pretty accurate with ±1% for SpO_2 saturation and ±2 bpm for heart rate. Although the number of human subjects is small, we will increase numbers of sample subjects and testing on real diseases of limiting oxygen saturation in the blood in the future.

Conflict of Interest The authors declare that they have no conflict of interest.

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