Design and Development of a Wireless Pulse Oximeter System

Abhishek Ekhare
Department of Instrumentation and Control, College of Engineering, Pune. Maharashtra, India.
abhishek.ekhare@gmail.com

Uttam Chaskar
Department of Instrumentation and Control, College of Engineering, Pune. Maharashtra, India.
umc.instru@coep.ac.in

Abstract—**Pulse oximetry is a superior technique of quickly measuring the patient's blood oxygen saturation level (%SpO2) and sphygmo (pulse rate). Photoplethysmography is the vol- umetric measurement of a tissue, obtained by optically illu- minating the skin surface and measuring the changes in light absorption by the tissue. A photoplethysmogram (PPG) is often obtained by using a pulse oximeter, which is conventionally used to calculate oxygen saturation, pulse rate, blood pressure and cardiac output. If the pulse oximetry results are transferred wirelessly to a remote location like computer or cellphone, quick action can be taken to provide oxygenation to the patient and any untoward incident can be averted. This paper presents the design and development of wireless system for remotely monitoring a patient's blood oxygen saturation levels and pulse rate. The data is continuously transmitted to computer front-end as well as an sms is sent to the cellphone in case of emergency conditions like (%SpO2) falling below 90% or pulse rates below 60 or above 150. The Global System for Mobile Communication (GSM) is used as the wireless module. The system was tested on real-time patients and performed satisfactorily. The results obtained are also presented in this paper.**

Keywords-Pulse oximetry; blood oxygen saturation level; hemoglobin; hypoxia; carboxyhemoglobin; sms.

I. INTRODUCTION

The core concept behind pulse oximetry is the variation of the absorption of photons travelling through a blood speci- men at different wavelengths [1]. This variation is related to the presence of hemoglobin in the blood specimen. A pulse oximeter is essentially a portable, non-invasive monitoring of oxygen saturation which enables prompt recognition of hypoxemia. Pulse oximetry basically measures oxygen satu- ration (%SpO_2) i.e. the percentage of hemoglobin saturated with oxygen [2], [3]. Pulse oximetry has been recommended as a standard for care of every general anaesthetic. The device provides valuable data regarding blood oxygenation and this information is obtained continuously, non-invasively and easily. A sensor containing two LEDs (infrared and red) and a photodiode is placed on a thin part of the patients anatomy, such as a finger or ear pinna. The two LEDs are paired and placed on the opposite side of the photodiode such that as they alternately transmit light through the anatomy, the photodiode acts as a light detector, generating an analog electrical signal for each wave length proportional

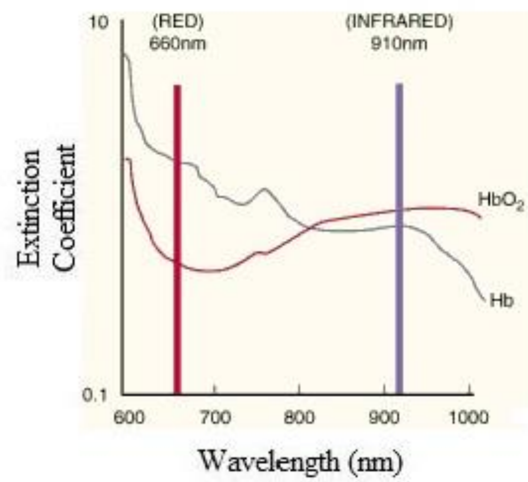

Figure 1. Graph of hemoglobin extinction.

to the amount of photons which have not been absorbed or scattered [2]. The pulsatile component of each signal is used to generate similar arterial pressure waveforms which, because of the difference in hemoglobin extinction coeffi- cients discussed, can be compared to deduce the proportion of oxyhemoglobin in the patient's blood and thus give an accurate estimation of their oxygen saturation.

The basic principle of oximetry is based on Beer- Lambert's law which states that there is a logarithmic dependence between the transmission of light through a substance and the product of the absorption coefficient of the substance and the distance the light travels through the ma- terial (i.e., the path length). Oxygen saturation is measured by passing red and infrared light alternatively through the tissue containing pulsating flow of blood (e.g. finger tip or ear lobe) and measuring the absorption of red and infrared light by the pulsating blood [4]. Pulse oximeter is based upon two physical principles. First, the light absorbance of oxygenated hemoglobin (HbO_2) is different from that of deoxygenated hemoglobin (Hb) at the oximeters two wavelengths, as shown in Fig. 1. Second, the absorbance at both wavelengths have pulsatile (AC) component, which

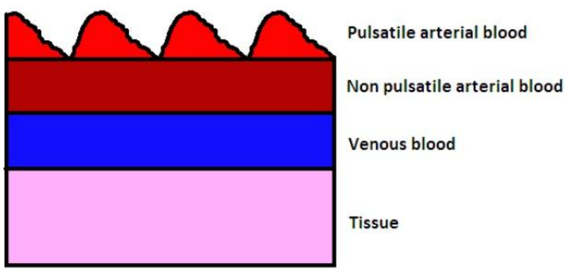

Figure 2. Absorption of light by various components of blood.

is the result of fluctuating volume of arterial blood between the source and detector. The output light at each wavelength consists of two components. The first component varies with pulsation of the blood. The second is large, constant light output level. This is the light that passes through the tissues without being absorbed or scattered. This is the light that passed through the tissues without being absorbed or scattered [5]. These are referred to as the AC and DC components respectively as shown in Fig. 2.

The use of wireless technology in healthcare has proved to be a boon to patients. Medical condition of a patient can be quickly conveyed to the concerned personnel wirelessly over long distances and timely actions can be taken to avert any untoward incident. One of the particular interst of use of wireless technology in medical field is to remotely monitor vital parameters of the patient [6]. The impact of wireless technology in healthcare has proved to be enormous and its usage is rapidly spreading [7]. Among the main benefits of incorporating mobile technologies into the field of medical care the authors of [8] point out also that mobile solutions have been shown to help:

- improve patient safety.
- decrease the risk of medical errors.
- increase physician productivity and efficiency.

Blood oxygen saturation level (%SpO_2) is an important vital parameter as far ar patient monitoring is concerned. Inhalation of certain gases like carbon monoxide can cause decrease in blood oxygen saturation levels. Carbon monoxide mainly causes adverse effects in humans by combining with hemoglobin to form carboxyhemoglobin (HbCO) in the blood. This prevents hemoglobin from releasing oxygen in tissues, effectively reducing the oxygen-carrying capacity of the blood, leading to hypoxia [1]. Reduced supply of oxygen to vital organs can lead to organ failure. Most importantly, reduced oxygen supply to brain can be fatal. Another area of interest to monitor (%SpO_2) is concerned with anesthetists. The oxygen saturation in blood is a vital sign for anesthetists to judge the extent of anesthesia administered to the patient. Morever, patients below 90% SpO_2 are not permitted to undergo surgery.

Pulse rate is another important vital parameter. Adminis-

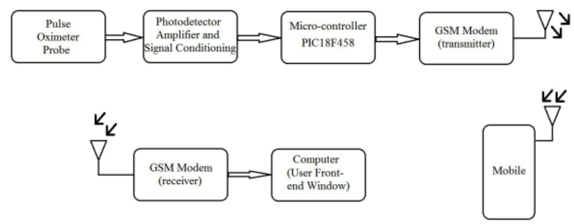

Figure 3. Block diagram of wireless pulse oximeter

tering certain medicines can lead to high or low pulse rates. The normal range for %SpO_2 is above 90% and for pulse rate between 60-100 for adults. If conditions like rapidly falling or increasing pulse rate and %SpO_2 are communicated to the concerned personnel (physician,nurses etc), life-saving actions like administering medicines to stabilize pulse rate or providing oxygen can be taken. Most of the personnel use cellphones. Morever, the network of cellphones is vast and the number of cellphone users have increased since the past decade. Sending an sms to the cellphone of the physician is a conveinent way of alerting him about the detoriating condition of the patient [9].

II. METHODOLOGY

Fig.3. shows the block diagram of the complete wireless pulse oximetry system. The system consists of the probe which houses the R and IR LEDs, the transistor driving circuit to drive the LEDs, the sample and hold circuitry to demultiplex the signal, the signal conditioning and amplification circuit and the PIC18F458 microcontroller. The microcontroller drives the transistor network and subsequently the LEDs with a 1 KHz square wave alternating between zero and five volts. The transistor network is designed to simplify the process of toggling between the infrared and red LEDs of the probe which are reverse biased and thus require a bipolar signal to change. Given that the microcontroller is limited to positive voltage, the transistor network utilizes two output ports of the microcontroller to generate the necessary bipolar signal. That is, a positive or negative difference in voltage across the LED terminals is determined by the port chosen for output by the PIC. This scheme offers a

work-around for high frequency time multiplexing used in commercial pulse oximeters such that the infrared and red signals may be processed individually. The Nellcor DS-100 series pulse oximeter probe was used as the sensor [10]. A suitable signal conditioning and amplification circuitry was designed to extract the pulse oximetry signal [4]. The PIC18F [11], [12] series microcontroller was used. GSM modem was interfaced on the transmitter as well as receiver side (computer). The cellphone itself acted as a receiver to receive incoming emergency sms [9].

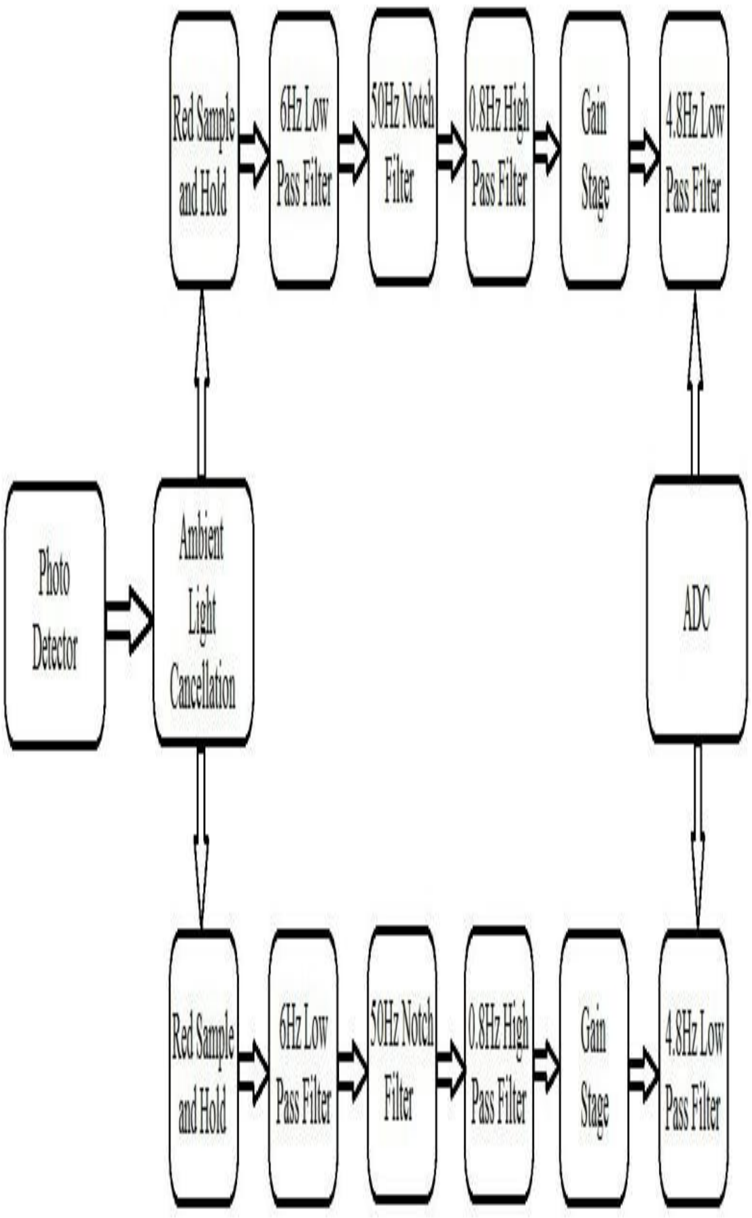

Figure 4. Block diagram of signal conditioning circuitry

A. Pulse Oximeter Probe

The Nellcor DS-100 series pulse oximeter probe is used as the sensor. The probe consists of two LEDs i.e. red(660nm) and infrared(940nm) and a photo detector. The probe is of transmittance type with the LEDs and photo detector on opposite sides [10].

B. Signal Conditioning Circuitry

Fig.4. shows the block diagram of signal conditioning circuitry. The output of photodetector from the probe is given to the signal conditioning and amplification circuitry, which consists of numerous filters and amplifiers. The first filter is a low pass filter with a cut-off frequency ($\mathbf{f}_0$) of 6Hz designed to eliminate high frequency noise. The filter cut frequency of 6Hz is calculated using (1), by selecting the appropriate values of resistor and capacitor.

$$f_0 = \frac{1}{2\pi RC} \quad (1)$$

The second filter is a 50Hz notch filter. The purpose of this filter is to eliminate the 50Hz power-line interference. The notch filter is designed as a passive filter in the twin-T configuration. The notch filter is referenced to Vcc/2 to add an offset voltage. The third filter is a 0.8Hz high pass filter. The desired cut-off frequency is calculated using (1). This filter separates the DC component of the signal. The fourth filter is a first order active 6Hz low pass filter that also provides a gain of 31. The cut-off frequency of this filter is set by calculating the value of components using (1). The values of components are calculated using Equation (3) to set the desired gain of 31. The fifth and last one is a 4.8 Hz low pass filter. The cut-off frequency of this filter is also calculated using (1). The last stage is an active amplifier with variable gain to adjust the amplitude of the derived photoplethysmogram [10]. The values of components are calculated using (2). The result at this point is a noise-free photoplethysmogram. This photoplethysmogram is further fed to the microcontroller.

C. Microcontroller

The PIC18F45550 Microcontroller includes 32kb of internal program memory, 2048 bytes of RAM area and an internal EEPROM of 256 bytes. A 13-channel 10-bit A/D converter is also included within the microcontroller, making it ideal for real-time systems and monitoring applications [11], [12]. All port connectors are brought out to standard headers for easy connect and disconnect. In- Circuit program download is provided, enabling the board to be easily updated with new code and modified as required, without the need to remove the microcontroller.

D. Wireless Module

GSM MODEM provides full functional capability to serial devices to send SMS and data over GSM Network. The GSM MODEM is avaliable in 300/900/1800MHz frequency bands. It requires less than 3.5mA current during the idle mode. The GSM MODEM supports popular "Attention (AT)" command set so that users can develop applications quickly. Some of the common AT commands are:

- AT-Attention Command. Alerts GSM module for communication.
- ATZ-Reset Command. Resets the GSM module.
- AT+CMGF-Sets SMS input mode as text mode.
- AT+CNMI-Sets the SMS indicator format.
- AT+CMGS-Sends text message.
- AT+CMGR-Receives text message.

This product provides great feasibility for devices in remote location to stay connected which otherwise would not have been possible where telephone lines do not exist. The patient parameters are continuously transmitted to the computer front end. Whenever the safe range of the blood oxygen saturation or pulse rate of the patient is violated, the programmed microcontroller interfaced with GSM MODEM sends an alert sms to the doctors mobile number specified deploying wireless technology.

III. RESULTS

The results obtained after testing the system are presented here. The system was tested with real-time subjects, and results for various subjects were documented. Fig.5. shows the output at the final stage of the signal conditioning and amplifying circuit. This signal is the desired interference and noise-free photoplethysmogram. Fig.6. shows the sms received on the cellphone in case of emergency.

IV. CONCLUSION AND FUTURE WORK

A prototype pulse oximetry monitoring system, based on ready to use, off-the-shelf components has been developed and tested. This low priced and easy to set system allows healthcare personnel to monitor a patients oxygen saturation (%SpO_2) and sphygmo (pulse) signs from a remote location without requiring the physician to be physically present to take the measurements. The system can be used for routing vital sign information to a central location within the hospital

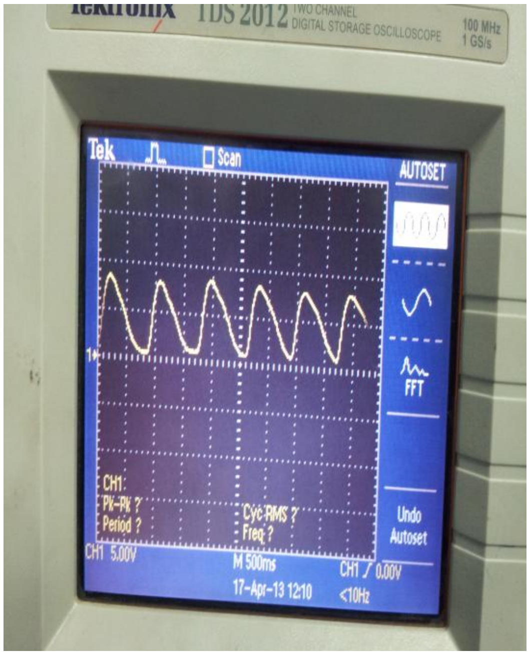

Figure 5. Pulse oximeter wavefrom.

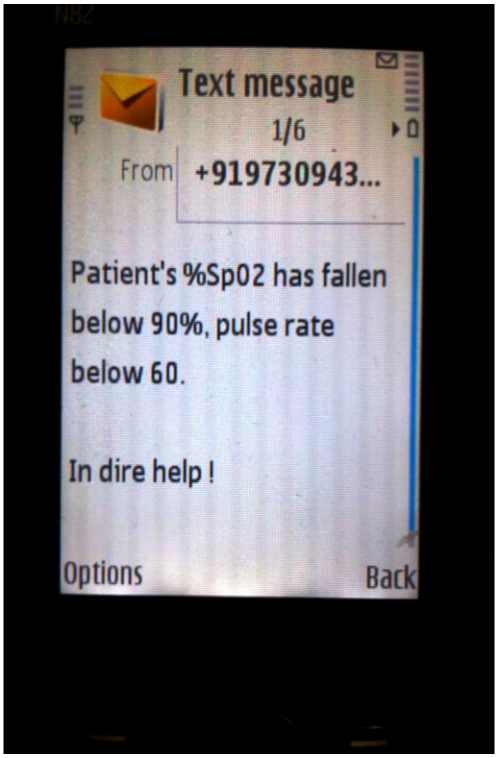

Figure 6. SMS received on cellphone in case of emergency.

premises as well as in applications that require monitoring from within a patients home. The mobile nature of the system allows ambulatory patients the freedom to move around the hospital when practical while remaining constantly monitored. Preliminary tests showed that the $\%SpO_2$ and pulse rate measurements for six patients were accurate when compared to traditional measurement methods. The major value of this wireless pulse oximeter system is the detection of disorder of the patients who are located in the remote areas or in travel and are not in a position to report to the doctor for immediate treatment. An alert SMS can be transmitted using the GSM technology to the doctors and advises can be sought for saving the life of the patient. So far we have developed a model for enhancing the mobility of doctor alone and in future we will extend the prototype to more vital patient parameters like ECG, heart rate, body temperature and by providing mobility to both doctor and patient.

ACKNOWLEDGMENT

The authors are deeply grateful to Medion Healthcare Pvt. Ltd. for encouraging and sponsoring the project, providing labs and necessary equipments which were required for the smooth progress and completion of the project.

REFERENCES

[1] J. G. Webster, Design of pulse oximeters. CRC Press, 2002.

[2] Y. Mendelson and J. C. Kent, "Variations in optical absorption spectra of adult and fetal haemoglobins and its effect on pulse oximetry," Biomedical Engineering, IEEE Transactions on, vol. 36, no. 8, pp. 844–848, 1989.

[3] J. G. Kim, M. Xia, and H. Liu, "Extinction coefficients of hemoglobin for near-infrared spectroscopy of tissue," Engi- neering in Medicine and Biology Magazine, IEEE, vol. 24, no. 2, pp. 118–121, 2005.

[4] R. Gupta, S. Ahluwalia, and S. Randhawa, "Design and development of pulse oximeter," in Engineering in Medicine and Biology Society, 1995 and 14th Conference of the Biomedical Engineering Society of India. An International Meeting, Proceedings of the First Regional Conference, IEEE. IEEE, 1995, pp. 1–13.

[5] H. Lim and J. Lee, "Tissue oxygenation using the near- infrared and red," in [Engineering in Medicine and Biology, 1999. 21st Annual Cnf. and the 1999 Annual Fall Meeting of the Biomedical Engineering Soc.] BMES/EMBS Conference, 1999. Proceedings of the First Joint, vol. 2. IEEE, 1999, pp. 809–vol.

[6] K. Lorincz, D. J. Malan, T. R. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, M. Welsh, and S. Moul- ton, "Sensor networks for emergency response: challenges and opportunities," Pervasive Computing, IEEE, vol. 3, no. 4, pp. 16–23, 2004.

[7] J. Park, "Healthcare information technology: Are you plugged in?" document available at: http://www. surgicenteronline. com articles/341feat1. html.

[8] R. Sokullu, M. A. Akkas, and H. E. Çetin, "Wireless patient monitoring system," in Sensor Technologies and Applications (SENSORCOMM), 2010 Fourth International Conference on. IEEE, 2010, pp. 179–184.

[9] R. Sukanesh, S. Rajan, S. Vijayprasath, N. Aishwarya, and P. Angela, "Intelligent wireless mobile patient monitoring system," in Communication Control and Computing Tech- nologies (ICCCCT), 2010 IEEE International Conference on. IEEE, 2010, pp. 540–543.

[10] S. Lopez, "Pulse oximeter fundamentals and design," Freescale semiconductors, RTAC Americas, Guadalajara, Mexico, Tech. Rep. AN4327 Rev.1, September, 2011.

[11] M. A. Mazidi, R. McKinlay, and D. Causey, Pic microcontroller and embedded systems. Prentice Hall, 2009

[12] "Pic 18fxx8 data sheet,"Microchip Technology Inc, U.S.A.

[13] A. Huch, R. Huch, V.Kö nig, M.Neuman, D.Parker, J. Yount, and D. Lubbers," Limitation of pulse oximetry,"The Lancet, vol. 331, no. 8581, pp. 357-358,1988

[14] J. E. Sinex, "Pulse oximetry: principles and limitations," The American journal of emergency medicine, vol. 17, no. 1, pp. 59–66, 1999.

[15] M. Brown and J. Vender, "Noninvasive oxygen monitoring." Critical care clinics, vol. 4, no. 3, pp. 493–509, 1988.

[16] J. Welch, R. DeCesare, and D. Hess, "Pulse oximetry: instrumentation and clinical application," Respir Care, vol. 35, no.6, pp. 584-597, 1990