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Continuous Measurements of ECG and SpO_2 for Cardiology Information System

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***Abstract*— This paper presents a low-cost method to continuously measure patient's electrocardiogram (ECG) signal and blood-oxygen saturation (SpO_2) level. Hardware implementations of the designed ECG conditioning circuit and pulse oximeter are based on the use of commercially available devices. A user-friendly graphical user interface has been developed by using LabVIEW program to display and record incoming measurements. From the measured ECG curve and the pulse oximeter data, the heart rate and %SpO_2 can be determined, respectively. In addition, the adjustable high/low heart rate and low %SpO_2 alarm limits are provided for users. If the obtained heart rate exceeds the preset settings and %SpO_2 level falls below its alarm limit, the audible alarms will be turn on. The probe-off alarm for measuring SpO_2 level is also included. Resulting signals of all patients being continuously monitored can be transferred to a Central Monitoring Station and a Cardiac Center via local area network (LAN) in a hospital for diagnosis by experts later. To verify the performances of the proposed measurements, experimental results from measuring reference ECG waveforms and %SpO_2 levels are given.**

***Index Terms*—Electrocardiogram, ECG, Pulse Oximeter, SpO_2, Cardiology Information System.**

I. Introduction

As an area of medical informatics, the aim of a CARdiology Information System (CARIS) in a hospital is to achieve the best possible support of cardiac patient care and administration by electronic data processing [1]-[3]. An electronic patient record has become an essential tool to support patient care in recent years [4]-[6]. The ability to access all information obtained in the cardiac function lab such as electrocardiogram (ECG) signal and blood-oxygen saturation (SpO_2) level anywhere through the hospital network has been shown to greatly enhance daily routine of cardiologists.

In order to develop the low-cost biomedical instrument providing the ability of record storage in digital format for CARIS, the continuous measurements for monitoring and recording ECG and SpO_2 data via LAN system have been proposed in this paper. The design technique falls into two parts: hardware and software. The hardware realizations of ECG conditioning circuit and pulse oximeter have been constructed on printed circuits. Measured signals by ECG conditioning circuit and pulse oximeter are fed to a computer through a USB data acquisition module. The software written in LabVIEW program has been developed in close contact with the prospective users. The performances of the proposed measurements were tested at the Biomedical Instrument Calibration Unit, Siriraj Hospital, Bangkok, Thailand. The BIO-TEK multiparameter and SpO_2 simulators were employed to generate reference ECG curves and %SpO_2 levels, respectively. Test results demonstrating close agreement with reference signals are also presented.

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II. Proposed Measurement Description

A. Proposed Measurement Concept

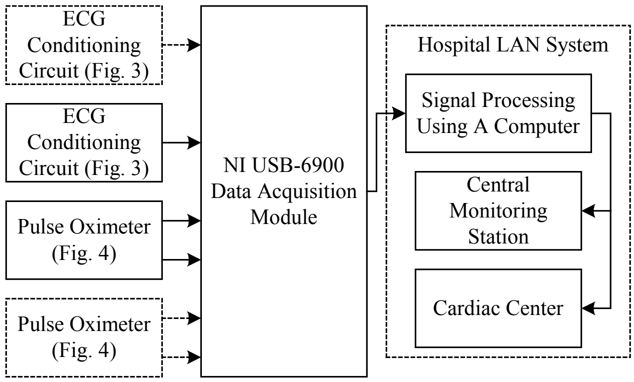

Fig. 1 Proposed measurement concept.

Fig. 1 shows the proposed measurement concept for monitoring and recording ECG and SpO_2 data. The ECG conditioning circuit is employed to perform on measured ECG signal. The pulse oximeter using finger-type probe is connected to indirectly measure the SpO_2 level. Acquired signals by ECG conditioning circuit and pulse oximeter are sent to the computer by using the NI USB-6009 data acquisition module, which provides the maximum sampling rate of about 48kS/s. Furthermore, the NI USB-6009 module supports 8 analog-input channels, other ECG conditioning circuits and/or pulse oximeters then can be connected synchronously. The measured signals are processed by the developed software written in LabVIEW program. The heart rate and %SpO_2 level can be obtained. Resulting data can be transferred to the Central Monitoring Station and the Cardiac Center, where cardiologists want to see patient's cardiology information, via hospital LAN system.

B. Hardware Design of ECG Conditioning Circuit

Fig. 2 illustrates the normal ECG waveform [7], which

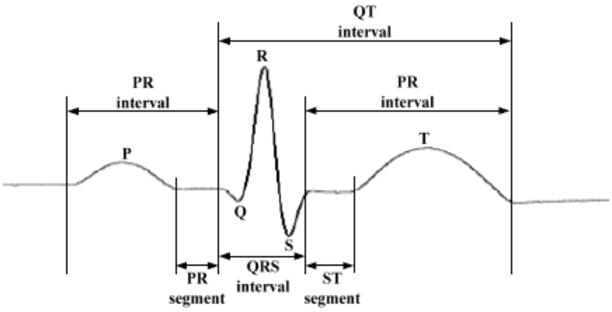

Fig. 2 Composition of the ECG signal.

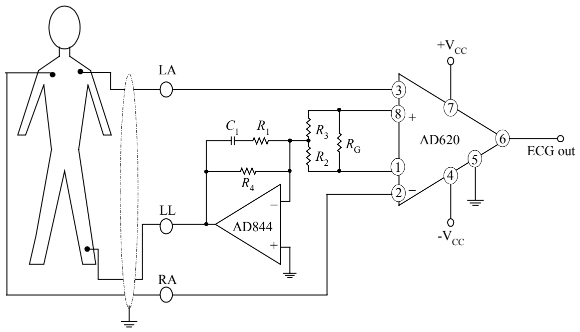

Fig. 3 Designed ECG conditioning circuit.

consists of a P wave, a QRS complex, and a T wave. These various parameters are useful for diagnosis and health monitoring. The designed ECG conditioning circuit as shown in Fig. 3 is based on the use of the AD844 high-speed opamp and AD620 high-accuracy instrumentation amplifier to sense and amplify detected signals from electrodes. The voltage gain of signal amplification G can be given by

$$G = \frac{R_2 + R_3}{R_G} + 1 \quad (1)$$

If the circuit parameters C_1 = 0.1μF, R_1 = 10kΩ, R_2 = R_3 = 24.9kΩ, R_4 = 1MΩ, and R_G = 143Ω were chosen, then the voltage gain G is about 349.

C. Hardware Design of Pulse Oximeter

Pulse oximetry is a simple non-invasive method of monitoring the percentage concentration of haemoglobin saturated with oxygen, termed oxyhaemoglobin, to the total heamoglobin concentration. The percentage oxygen saturation in the patient's blood as measured by the pulse oximeter, %SpO_2, can be stated as [8]

$$\%\mathrm{SpO_2} = \frac{\mathrm{HbO_2}}{\mathrm{Hb} + \mathrm{HbO_2}} \times 100\% \quad (2)$$

where HbO_2 and Hb denote oxyhaemoglobin and de-oxyhaemoglobin, respectively.

The designed pulse oximeter using finger-type probe is depicted in Fig. 4. The light emitter with red (with wavelength of 600-750nm) and infrared (with wavelength 850-1000nm) LEDs and the TCS-230 photodetector are opposite of each other with the measuring site in-between. The timing control constructed by using 89C2051 microcontroller generates the 1kHz control pulse signals R_1, R_2, IR_1, and IR_2, where the signal R_1 is the complement of IR_1 whereas the signal R_2 is the complement of IR_2. The On and Off states of the red and infrared LEDs are controlled by the signals R_1 and IR_1, respectively. The alternative burst of red and infrared light can then pass through the site. Absorption at these wavelengths differs significantly between HbO_2 and Hb as shown in Fig. 5 [9], therefore from the ratio of the absorption of the red and infrared light, the %SpO_2 level can be expressed as [10]

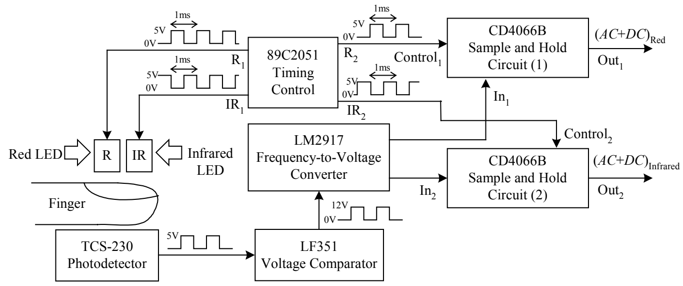

Fig. 4. Designed pulse oximeter using finger-type probe.

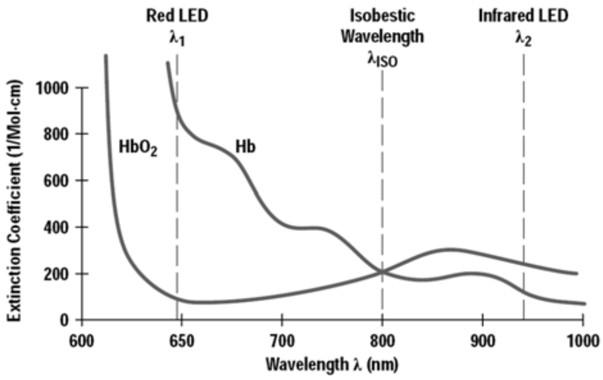

Fig. 5. Absorbtion spectrum of Hb and HbO_2.

$$\%\mathrm{SpO_2} = K \times \frac{(AC/DC)_{\mathrm{Red}}}{(AC/DC)_{\mathrm{Infrared}}} \quad (3)$$

where K is proportionality constant, which can be considered by calibration results, and AC and DC are the changing and static components of the transmitted red and infrared signals that pass through the measuring site and are received at the photodetector. The AC and DC components of the received light are manipulated by operations of the LF351 voltage comparator, LM2917 frequency-to-voltage converter, 89C2051 timing control, and the CD4066B sample and hold circuits for further processing.

D. Software Design

To continuously display and record the measured ECG and SpO_2 data, the graphical user interface on the computer screen has been developed by using LabVIEW program.

Fig. 6 shows the block diagram of measured data processing. To cancel noise elements embedded in the measured ECG and AC and DC components of the transmitted red and infrared signals, the 30Hz and 40Hz Butterworth-lowpass filters are employed, respectively. The adjustable alarm limits for detecting high/low heart rate and

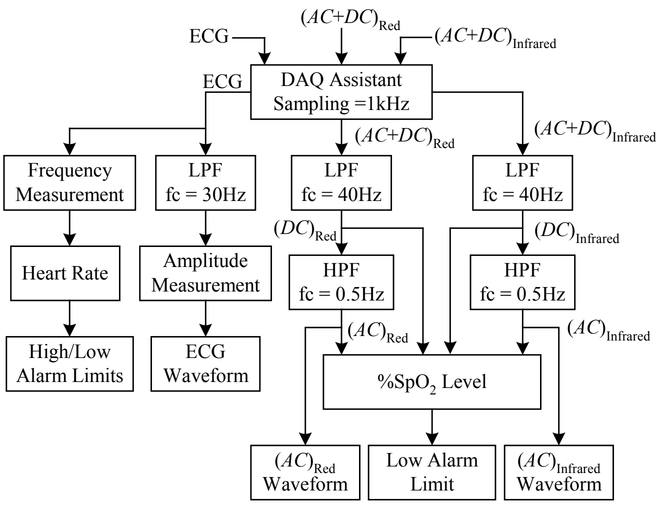

Fig. 6 Block diagram of measured data processing.

low $\%SpO_2$ events are provided. The pulse oximeter probe-off alarm is also included. From the frequency measurement of the obtained ECG signal, the heart rate can be determined. If the heart rate exceeds the preset limits, the audible ECG alarm will be turn on to alert users. For pulse oximeter data processing, the *AC* and *DC* components of the transmitted red and infrared signals can be separated by using the 0.5Hz Butterworth-highpass filters. The $\%SpO_2$ level can be calculated by using (3) and then compared with the appropriate setting value. The acceptable normal ranges from 95% to 100%. If the $\%SpO_2$ level falls below its low limit, the SpO_2 alarm will be active. Based on the use of Web Publishing Tool of the LabVIEW program, the resulting data in digital format from the proposed measurements can be easily transferred to the Central Monitoring Station and the Cardiac Center via hospital LAN system.

III. Experimental Results

To verify the performances of the proposed measurement system, the BIO-TEK multiparameter (Lionheart 3) and SpO_2 (Index 2 Series) simulators were used to generate reference ECG waveforms and $\%SpO_2$ levels, respectively. From calibration results, the constant K = 98.5 can be obtained for calculating $\%SpO_2$ level as shown in (3).

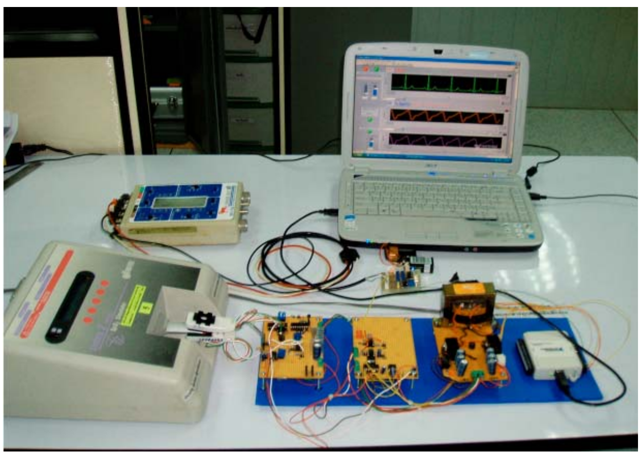

Fig. 7 Overall connections of the proposed system.

TABLE I
Measured Results for Six Different Values of Heart Rate

Heart Rate (bpm)	Measured Value (bpm)					Average	Average Error
	1st	2nd	3rd	4th	5th		
120.0	120	120	120	120	120	120.0	0%
100.0	100	99	100	101	100	100.0	0%
90.0	90	90	90	90	90	90.0	0%
80.0	79	80	80	79	80	79.6	0.50%
60.0	61	60	60	60	61	60.4	0.67%
40.0	40	40	39	40	41	40.0	0%

TABLE II
Measured Results for Six Different Values of $\%SpO_2$

$\%SpO_2$	Measured Value (%)					Average	Average Error
	1st	2nd	3rd	4th	5th		
100.0	99	100	100	99	100	99.6	0.40%
98.0	98	97	97	98	99	97.8	0.204%
94.0	93	94	95	94	94	94.0	0%
90.0	89	91	90	91	92	90.6	0.67%
84.0	83	84	85	84	85	84.2	0.23%
80.0	80	79	81	80	81	80.2	0.25%

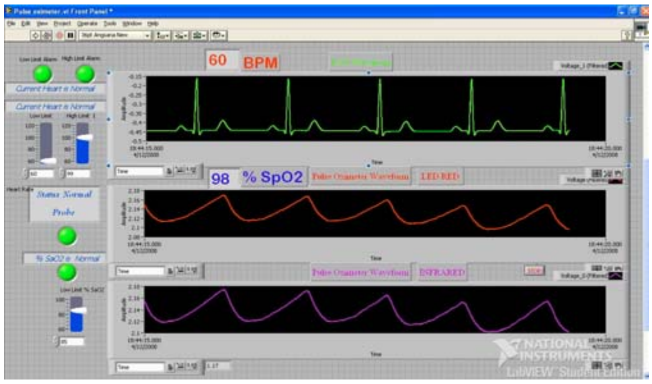

Fig. 8 Sample of developed LabVIEW window.

Figure 9. Transmitted data via LAN system.

Fig. 7 shows the overall hardware connections of the proposed system for experiment setup. Measured results for six different values of heart rate (i.e. 120 bpm, 100 bpm, 90 bpm, 80 bpm, 60 bpm, and 40 bpm) are summarized in Table 1. To test the repeatability, the measurement was repeated five times for each heart rate value. From Table 1, it is clearly seen that the maximum error of about 0.67% is obtained. Table 2 summarizes the experimental results from five repeat measurements for six different values of $\%SpO_2$ level, i.e. 100%, 98%, 94%, 90%, 84%, and 80%. From Table 2, it can be observed that the maximum error is about

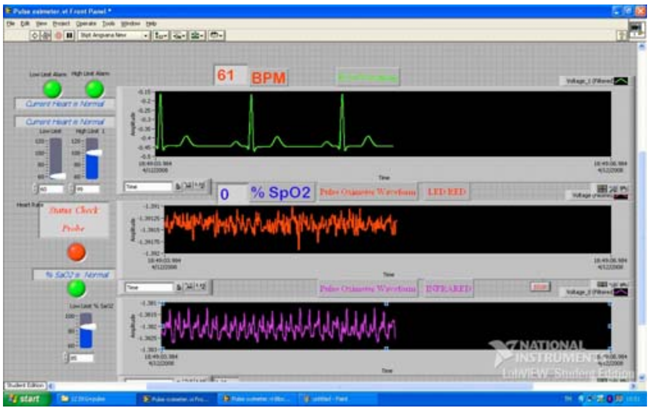

Fig. 10. Probe-off alarm and warning message.

0.67%. Fig. 8 shows a sample of the developed LabVIEW window for monitoring ECG signal, heart rate, %SpO_2 level, ECG alarm, SpO_2 alarm, probe-off alarm, and AC components of received red and infrared signals.

To test the ability to access the measured data via the network, Fig. 9 shows the transmitted data by using the LabVIEW Web Publishing Tool. When the finger-probe for measuring SpO_2 has dislodged, the probe-off alarm and warnning message will be displayed as shown in Fig. 10.

IV. Conclusion

In this paper, the low-cost biomedical measurement system with the ability of record storage in digital format has been presented. The hardware implementations using commercially available devices and the software written in LabVIEW program for continuously monitoring and recording ECG and SpO_2 data have been described. The proposed measurement system has to provide the possibility to access the measured data at different locations via LAN. To demonstrate the accuracy and repeatability of the proposed measurements, the experimental results are given.

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