Low-Cost MCU Solution for Measuring HRV using SpO2 Sensor

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***Abstract*--In this paper, a low-cost Heart Beat Variability (HRV) analyzer base on the principle of Photoplethysmography (PPG) is presented on an ultra-low power MCU platform. It is a non-invasive method of measuring the variation in blood volume in tissues using a light source and a detector. Base on the blood variation, the proposed HRV device will be able to calculate the heart beat rate, level of oxygenation and HRV data. In emergency, the specific information will be send back to the ICU center through the 3G-WCDMA interface, where caregivers can further analyze it and determine treatment methods.**

Keywords: Heart Beat Variability, PPG, SpO2, Wireless Sensor

I. INTRODUCTION

In this paper, a personal Heart Beat Variability (HRV) analyzer on an ultra-low power MCU is presented. Measuring the heart beat rate through the SpO2 sensor is a medical treatment for monitoring the patient in the hospital and supports the doctors in analyzing their situation without invasion using a probe that is placed on their fingers. In the SpO2 sensor, PPG probe uses two LEDs, visible infrared (660 nm) and infrared (940 nm), to sense the intensity for each LED light which transmitted through the finger as shown in Fig. 1. Since two LEDs are driven mutually at the specific frequency controlled by the MCU, it requires the H-bridge circuit to drive them as well as controls their intensity using the DAC interface. In each phase, the MCU takes the LED lighting input through an amplifier that already integrated on the MCU's ADC, after that we can track the AC component signal (the absorption by the arteries) which is necessary to track the heart beat rate [1-3].

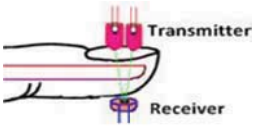

Fig. 1. The illustration of PPG method [4]

In Fig. 2, using the AC component provided by both visible infrared and infrared LEDs and the tracking algorithm, the peak-to-peak of the signal which corresponding to the heart beat will be tracked.

In this paper, the proposed system can acquire the raw data from the SpO2 probe before amplified and convert to digital signal using the MCU. After that, an infinite impulse response filter (IIR) will be used to track the AC component. This kind of data is past to the computer, here it is analyzed using Berger algorithm [5] and Fast Fourier Transform (FFT) to find the heart beat rate and HRV data [6-7].

This paper is organized as follows. Section II briefly introduces the concept of the proposed low-cost HRV analyzer. The experimental results are shown in Section III and Section IV concludes the paper.

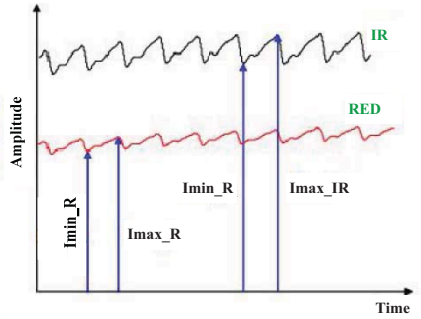

Fig. 2. AC component (RED) and tracked heart beat rate (IR)

II. SYSTEM ARCHITECTURE

This custom MCU board includes a Texas Instruments MSP430FG439 ultra-low power microcontroller, SpO2 sensor and H-circuit for driving SpO2 sensor as shown in Fig. 3(a). The MCU software includes the algorithm to take the information from the sensor to perform conditioning and processing before measuring the heart beat rate and HRV as shown in Fig. 3(b). The two LEDs are time multiplexed alternately, and the built in operational amplifiers of the microcontroller amplify the signal from the probe's photo diode and then it is converted to digital signal. The signal coming out of the amplifier contains a large DC component (caused by the lesser oxygen and scattered light), it is the signal that needs to be extracted to find the AC component. The DC filter is an IIR filter; it will add a small portion of the extraction result of the present input and the last output value to create a new output value.

The calculated heart beat rate data is sent back to the computer via UART communication. The software receives data and performs the fast HRV calculation based on the Berge algorithm. Fig. 4 shows the overall implementation

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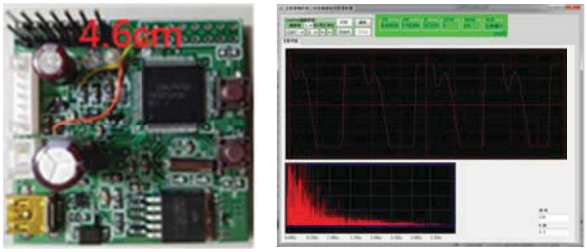
flow of the proposed low-cost solution for Measuring HRV using SpO2 Sensor.



(a) Custom PPG Board (b) HRV analyzed software

Fig. 3. Personal HRV analyzer based on an ultra-low power MCU solution.

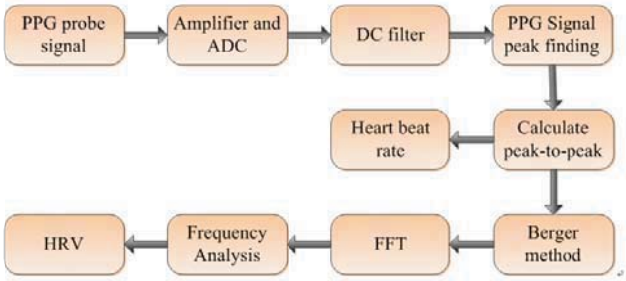


Fig. 4. Implementation of fast HRV algorithm.

Table 1. Comparison between PPG and ECG results.

TP ln(ms^2)		HF ln(ms^2)		LF ln(ms^2)		L/Hln(ratio)		RRI(ms)	
PPG	ECG	PPG	ECG	PPG	ECG	PPG	ECG	PPG	ECG
7.58	7.87	7.03	6.86	6.19	6.81	-0.83	-0.06	750	742
7.70	8.23	6.57	7.11	6.61	6.90	0.03	-0.21	732	726
7.56	7.71	6.89	6.45	6.13	7.03	-0.76	0.576	751	748
7.65	8.34	6.84	7.53	6.45	7.22	-0.38	-0.3	770	761
7.66	8.24	6.86	6.72	6.37	7.55	-0.49	0.825	780	777
7.42	7.81	6.93	6.39	6.72	6.59	-0.21	0.203	749	747
7.18	7.63	7.21	6.41	7.36	6.22	0.15	-0.19	744	740
7.33	7.48	7.04	6.66	6.8	6.15	-0.24	-0.52	755	748
7.54	7.66	7.10	6.24	5.8	6.75	-1.3	-0.51	763	754
7.07	7.08	7.44	6.15	6.7	5.92	-0.73	-0.23	746	741

III. Experimental Results

A. Custom HRV board

The custom board includes the microcontroller with the integrated analog amplifier and ADC, the 3.3V power supply and the H-bridge circuit to drive the SpO2 sensor. The microcontroller takes the input signal from the sensor and amplifies it, then pass to the ADC. The result is then past to the AC component tracking where the DC component (a result of the absorption by the body tissue and veins) is filter. The final result is send back to the computer for further analysis with the HRV analysis software via UART communication.

B. HRV analyzed software

The HRV analysis software is designed using the Visual C# language. It is responsible for taking the AC component value from the PPG board and performs the fast HRV algorithm. The procedure first uses the Berger method and then 1024-FFT. The software also displays the heart beat rate bases on the AC component value as shown in Fig. 3(b).

Table 1 shows the HRV measurement results between the proposed PPG based design and standard ECG device available in the consumer market [8]. The average difference between PPG and ECG are shown below: TP: 0.336%, HF : 0.615% and LH : 0.741%. The result meets our conventional expectation.

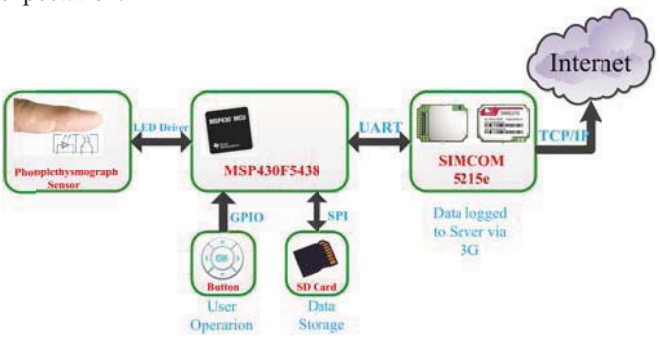


Fig. 5. Personal HRV analyzer

IV. Conclusion

The proposed low-cost personal HRV analyzer can perform the fast HRV analysis and oxygenation measuring with the acceptable accuracy on an ultra-low power MCU solution. In the future, when the sensor captured the patient data and found the HF/LF signal level not normal, it will notice the caregivers through the 3G-WCDMA communication interface as shown in Fig. 5. Therefore, the human resource of the ICU center can be reduced by using the proposed HRV device and improve the care quality for patients.

Reference

[1] Shao-Yen Tseng, Wai-Chi Fang, "An EKG System-on-Chip for Portable Time-Frequency HRV Analysis", *IEEE International Conference on Consumer Electronic,* pp.559-560, 2011.

[2] N. E. Almond, D. P. Jones and E. D. Cooke "High quality photoplethysmography signals from a laser Doppler flow meter: preliminary studies of two simultaneous outputs from the finger", *Journal of Biomedical Engineering,* vol.10, no.5, pp.458-462,1988.

[3] TI Single-Chip Pulsoximeter, http://www.ti.com/lit/an/slaa280a/slaa280a.pdf, 2007.

[4] Sang C. Suh and Varadraj P. Gurupur "Biomedical Engineering" 2011.

[5] Berger, R.D et. al, "An Efficient Algorithm for Spectral Analysis of Heart Rate Variability" *IEEE Transactions* on *Biomedical Engineering*, vol. 33, no. 9, pp.900-904, 1986.

[6] Chia-Ching Chou, Shao-Yen Tseng, Ericson Chua, Yaw-Chern Lee, Wai-Chi Fang, Hsiang-Cheh Huang, "Advanced ECG Processor with HRV Analysis for Real-Time Portable Health Monitoring", *IEEE International Conference on Consumer Electronic Berlin,* pp.172-175, 2011.

[7] Chao-Feng Chang, Yu-Wei Chuang, Chun-Sheng Lin, Chun-Kai Liao, Liang-Yu Shyu, and Wei-Chih Hu, "Analysis Natural Heart Rate Variability Using Photoplethysmography", *Journal of Advanced Engineering*, vol.5, no.3, pp.235-243, 2010.

[8] ECG device WG-MP-HRV-01, http://www.wegene.com.tw/cht/ WeGene Technology, 2002.