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Design of a Photoplethysmographic Sensor for Biometric Identification

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Abstract: Photoplethysmographic (PPG) signals contain rich personal information that can be used to distinguish individual subjects. This paper discusses the design of an analog amplification circuit for PPG signals to remove the DC component of the signal. By adding an amplifier bias-adjusting circuit, a high signal-to-noise ratio AC signal can be acquired from the raw PPG signal. This hardware improvement results in better signal quality and makes identification data-processing easier.

Keywords: biometric identification, photoplethysmographic (PPG) signal, signal-to-noise ratio.

1. INTRODUCTION

Photoplethysmographic (PPG) signals provide a noninvasive, easy to use, and accurate methodology to obtain valuable physiological information such as blood oxygen saturation, heart rate, and blood flow [1]. The optical parameters of blood and its components depend on many factors. PPG signals reflect the pulsatile action of arteries through the interaction between oxygenated-hemoglobin and photons. These photon-tissue interactions should present a unique pattern for each individual. The feasibility of applying PPG signals as a biologic discriminant has been preliminarily studied [2]. However, the parameters used in this approach did not fully use information contained in PPG signals.

PPG signals oscillate with the heart cycle period, due to the rhythmical increase and decrease in the tissue blood volume, resulting in a periodically changing transmission of light [3]. While the absorbance of some tissues (e.g., bone, muscle) is a constant and can be termed as the DC component of the PPG signal, the absorbance of arterial blood pulsations can be considered as an AC component [4]. But the AC component, which contains each individual's unique information, is only a very small portion of the whole signal. Therefore, an effective amplification circuit is critical to extract desired information from the AC signal.

In our previous study [6], an optical probe consisting of an infrared LED was used in a PPG sensor to collect data for identification usage. The system uses a simple architecture, where a National Instruments' DAQ-card directly sampled and converted analog signals into digital values. A MATLAB program analyzed PPG signal consistency and discriminability. However, the signal acquired from the analog circuit was very noisy, making it difficult to extract useful information from these data. To improve the PPG signal quality, several modifications were made to the original circuit. These circuit changes enhanced the capability to classify the PPG signals. This paper examines these circuit modifications and compares the quality of the signals from the old and new sensors.

2. METHODS

2.1 Hardware Modification

Figure 1 presents the analog signal amplification circuit that has been modified. Part A is adapted without major changes from an existing circuit [6], where a light feedback loop is used to maintain the intensity of the light absorbed by the photodiode constant. At the output of this feedback loop, the raw PPG signal is available from the emitter of transistor Q1. This raw PPG signal, due to its tiny AC amplitude, cannot be directly used by a microprocessor with

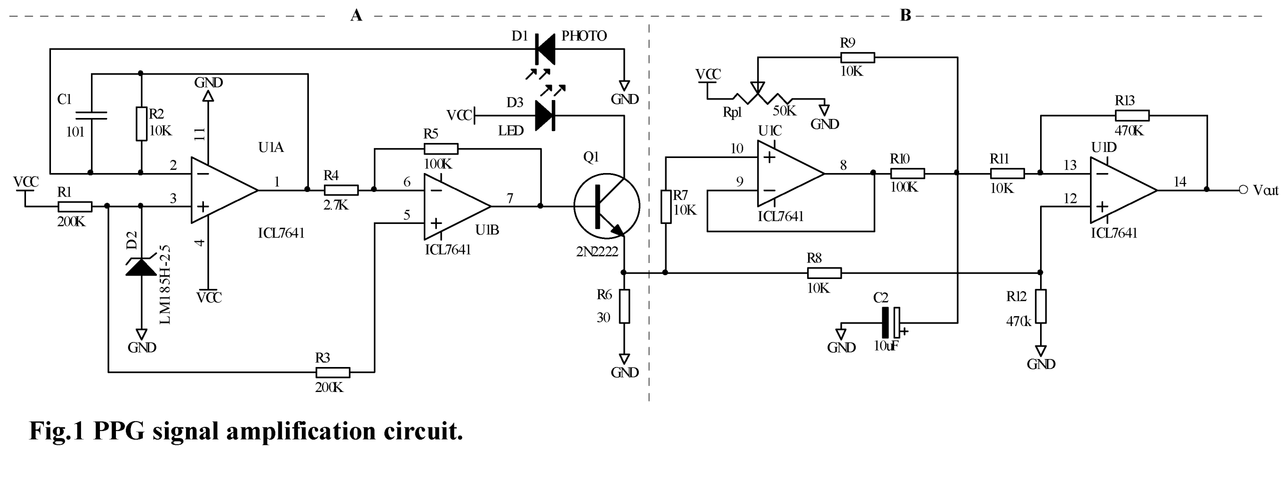


Fig.1 PPG signal amplification circuit.

limited ADC (analog-digital conversion) resolution. Therefore, an effective signal conditioning mechanism is needed to amplify the AC component.

Part B is the improved signal conditioning circuit to amplify the desired AC component of the PPG signal. The general idea is to obtain large AC amplitude by first reducing the DC portion from the raw signal and then amplifying the resulted difference (AC). Specifically, op-amp U1C works as a voltage follower to duplicate the original PPG signal without attenuating it. The output of op-amp U1C is first filtered with a low-pass RC network to obtain the DC component. The low-pass filter (R10 and C2) has a time constant of one second, which is approximately equal to the frequency of the PPG signal (heart rate). The filtered DC component is subtracted from the original PPG signal. The difference (desired AC component) is then amplified by op-amp U1D. PPG pulses with large an AC amplitude can then be measured at the output of op-amp U1D. Please note that, in the schematic, an adjustable DC bias circuit (Rp1 and R9) is added to make the circuit more flexible (especially for debugging purposes). This DC voltage is superposed to the PPG DC component from the filter to compensate the signal loss from the filtering process.

Figure 2 shows the printed circuit board and two optical probes (one works in a transmission mode; the other in a reflectance mode) used in the experiments. The transmission probe is an off-the-shelf finger clip (Dolphin 2010) made by Nellcor (A, top left). While it is convenient to mount the clip to the finger, the signal picked up from the finger is very sensitive to any small movements of the muscle/joints of the fingers, hand, wrist, elbow, and shoulder. In addition, the shape of the waveform varies with the relative position between the finger/hand and the heart. Acquiring signals from less moveable body locations may prevent these issues. Therefore, a reflectance probe was built (B, top right). This probe uses an infrared emitter with a wavelength of 940 nm and a photodiode whose peak sensitivity is at 940 nm. Both the LED and detector are placed on the same side of the tissue, allowing the reflectance probe to work for a wider range of body locations (e.g., forehead, temple) than its transmission counterparts.

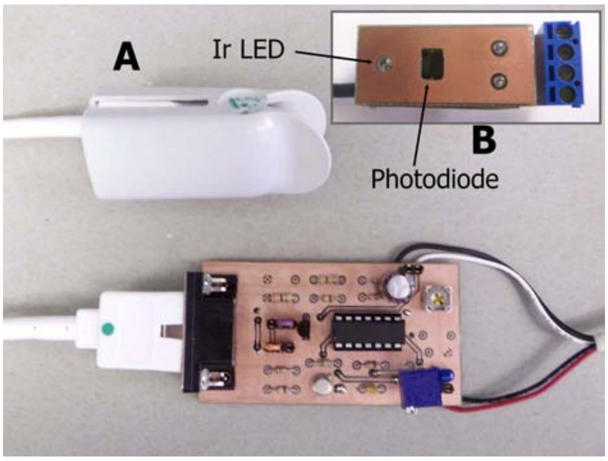


Fig. 2 The finished hardware PCB board and the sensors.

2.2 Data Acquisition

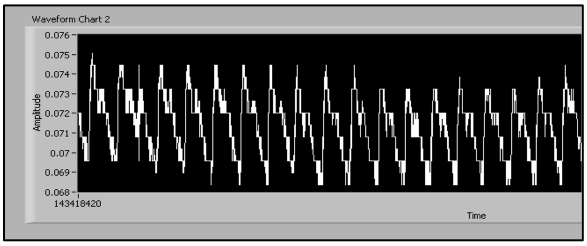
The processed AC PPG signal is sampled (A/D conversion) by a National Instrument's 6062E DAQ-card, and the data are collected by a LabVIEW Virtual Instrument (VI). This VI is designed with the following features and functionalities:

1) Setting up the data acquisition parameters: These parameters include the sampling rate, sampling mode, physical channel, and the range of the input signal. These parameters can be easily changed from the front panel.
2) Signal filtering: The DAQ-card samples at a rate of 100 kHz; this allows us to use arithmetic average to filter out high frequency noises, yet still maintain subtle information contained in the PPG signal, which is critical for identification applications.
3) Waveform display: The front panel of the VI displays the PPG waveform and its historical record with a chart.
4) Data collection and storage control: Two switches on the front panel are used to fully control data recording (save data in memory) and storage (save data as spreadsheet files). This feature helps us exclude those noisy data resulting from subject movements at the beginning of a data collection process and save only high quality data.

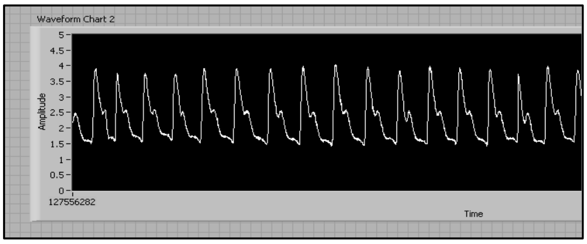
Saved data are analyzed by a MATLAB program. After loading the data from a spreadsheet file, the MATLAB program first takes 1^{st}- and 2^{nd}- order derivatives of the PPG waveforms; it then extracts the attributes from these derivatives to perform statistical discriminant analysis for individual identification. The attributes used in this processing include time intervals between maximum/minimum points and inflections points from the 1^{st}- and 2^{nd}-order derivatives (see [5] for more information about the steps of this analysis).

3. RESULTS

Figure 3 compares the signals acquired from the original and improved circuits. The waveform in the after-modification case is much cleaner and the amplitude has been significantly increased by the modified circuit. In this figure, the peak-to-peak value is increased from 0.01V to 2.5V. Subsequently, the signal-to-noise ratio has been improved about 250 times. Again, of critical importance, the waveform contains all the subtle variations of the pulses which can be potentially used for identification purposes.



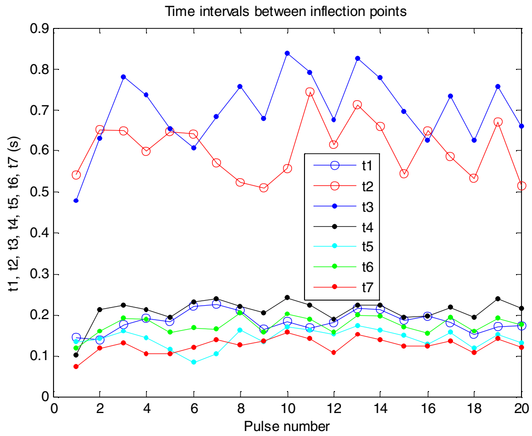
A. Before modification



B. After modification

Fig. 3 Comparison of output PPG signal sampled from the original and improved amplification circuit.

To more clearly demonstrate the improvement of the modification, time intervals extracted from one of the datasets have been plotted as shown in Figure 4. Figures 4A and 4B display data collected before and after the circuit modification, respectively. The curves in Figure 4B are smoother than those in Figure 4A and better present the consistency of the attributes for a subject. The data summarized in Table 1 numerically demonstrate that the signal has been greatly improved. The standard deviations of all the time intervals after the circuit modification are much smaller than those before the modification. From the comparison of PPG waveforms and the time intervals consistency, the output PPG signals have a great improvement in stability, amplitude, and signal-to-noise ratio.



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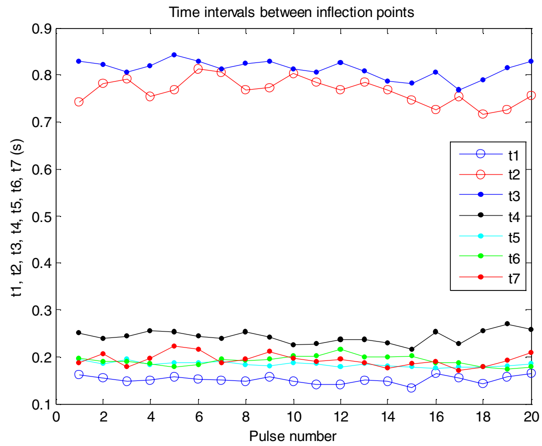

B. After modification

Fig.4 Comparison of time intervals between maximum/minimum points and inflection points.

4. SUMMARY

This paper has examined the problem of collecting PPG signals in order to discriminate between individuals. It presents a PPG sensor circuit design that can provide high signal-to-noise ratio and keep all the identification information. This results in an enhanced ability to generate good datasets for biometric identification research. To further investigate PPG signal applications in this area, we plan to extend our current work and:

1) Identify the optimal light wavelength that can obtain the best discrimination performance between different subjects.
2) Develop advanced discrimination algorithms to minimize false identification.
3) Test the system and the algorithms with a large subject population.

Table 1 Comparison of Statistical Features Before and After Circuit Modification.

		T1	T2	T3	T4	T5	T6	T7
Mean (s)	Before	0.1796	0.616	0.6999	0.2091	0.141	0.1746	0.1243
	After	0.1515	0.7663	0.812	0.2426	0.1841	0.1915	0.1937
STD (s)	Before	0.0247	0.06881	0.08692	0.03011	0.02348	0.02203	0.01988
	After	0.007845	0.02676	0.01895	0.01317	0.005141	0.01029	0.01369
%	Before	13.57	11.17	12.42	14.4	16.65	12.62	15.99
	After	5.18	3.49	2.33	5.43	2.79	5.37	7.07

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