Towards Estimations of Continuous Cardiac Output with Impedance Cardiography: a Pilot Study

Chao-Ting Liu

Institute of Biomedical Engineering,
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: dfr1507@gmail.com

Po-Hsun Huang

Institute of Computer Science and Engineering,
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: sdk58927@gmail.com

Tzu-Chien Hsiao

Department of Computer Science, Institute of Biomedical Engineering,
Biomedical Electronics Translational Research Center
National Chiao Tung University
Hsinchu, Taiwan R.O.C.
e-mail: labview@cs.nctu.edu.tw

Abstract—**Impedance Cardiography (ICG) is a non-invasive method to estimate the cardiac output, which is very helpful for the prognosis of cardiovascular disease and the diagnosis of disease. By applying a stable high-frequency and low-intensity current to the human, we can measure the impedance variation of the human body, and, therefore, get the ICG signal to judge the possible characteristic points and estimate the cardiac output. The measurement of ICG in long-term care is limited due to the cost involved and the need for professional evaluation. For this reason, in this paper, we develop an impedance signal measurement system suitable for long-term care. We use a modified circuit system and LabVIEW software to detect the impedance variation of the human body and the characteristic points of ICG. At present, our preliminary results have been able to detect possible points B and C, for the detection of point X. We need to compare and confirm these results using Electrocardiography (ECG). In the future, we will use the feature points detected by this system to estimate the cardiac output and develop it into a portable instrument for long-term care**.

Keywords-Impedance Cardiography (ICG); Cardiac Output (CO); Stroke Volume (SV).

I. INTRODUCTION

In recent years, cardiovascular diseases have seriously affected people's health and have led to an increase in mortality [1]. Therefore, the prediction and management of cardiovascular diseases become very important. In the past, it has been proposed that cardiac output can be estimated by thermal dilution [2], however, this is not an option for long-term monitoring because it is an invasive method.

Impedance Cardiography (ICG) is a non-invasive, continuous, easy and accurate method to evaluate left ventricular stroke volume and cardiac output [3], and it is also suitable for long-term monitoring of cardiac activity. In the past, other non-invasive evaluation methods have been proposed to measure cardiac output, such as Doppler ultrasound [4]. Although the measurement results are accurate, Doppler ultrasound is not suitable for long-term care because of the high cost and the need for professional analysis.

The principle of ICG instrument is to apply a constant low current (1mA-5mA) and high frequency (50kHz-100kHz) signal to the outer electrode by means of four electrodes placed, then Ohm's law is used to measure the voltage signal of the external electrode to estimate the chest impedance of human body [5]-[7]. The cardiac output can be evaluated by the characteristic points and the method proposed by Kubicek [3][8].

Cardiac output is the volume of blood entering the aorta from the left ventricle every minute, and stroke volume is the volume of blood ejected from the left ventricle in each systole. Cardiac output is the product of cardiac stroke and heart rate [9], as (1).

$$CO = SV \times HR \qquad (1)$$

Cardiac output is important information to evaluate cardiac health, and ICG is a simple way to evaluate cardiac output.

The typical waveforms of impedance variation (delta Z), ICG and Electrocardiography (ECG) are shown in Figure 1 [10].
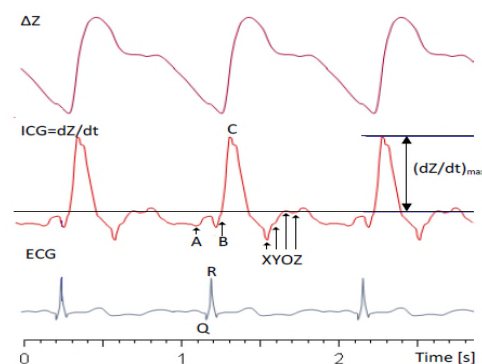

Figure 1. Impedance variation, ICG typical signal and ECG signal

A typical ICG can distinguish the following characteristic points [11]:

TABLE I.   CHARACTERISTIC POINT

Characteristic point	description
A	This point is related to atrial contraction.
B	Corresponding to the opening of the aorta, this point occurs at the zero crossing point before ((dZ/dt)max), which is an important information to judge the pre-ejection period (PEP) and Left Ventricular Ejection Time (LVET).
C	((dZ/dt)max): This point is the maximum amplitude of this signal, which can reflect the maximum speed of impedance change, which is related to the maximum ejection speed of the heart.
X	Corresponding to aortic closure, it is the most negative point of ((dZ/dt)max) signal, occurring after point C.
Y	Corresponding to pulmonary artery closure.
O	It is related to mitral valve opening and volume change in diastolic period.
Z	This point is related to the third heart sound after the O point.

The time relationship between the characteristic points of ICG and ECG signal is as follows [11]:

TABLE II.   CHARACTERISTIC PERIOD

Characteristic period	Description
Q-B	Q point in the ECG and B point in the ICG (the opening of the aortic), which is the pre-ejection period (PEP).
Q-C	Time interval between Q point in ECG and ((dZ/dt)max)in ICG, which can be used to calculate the heather index for cardiac contract.
B-X	The time interval between the opening of the aorta and aortic closure. This segment is the Left Ventricular Ejection Time (LVET), which is the ICG signal feature.

After obtaining these characteristic points and time interval relations, we can estimate SV by Kubicek's method [3][8][12] and then evaluate the Systolic Interval and activity of the heart.

$$SV = \frac{\rho L^2}{Z_0^2} \times LVET \times \frac{dZ}{dt}(max)$$

(2)

where ρ is the blood resistivity of human body in Ω-cm, L is the distance between two sensing electrodes in cm, Zo is the basal impedance in Ω, (dZ/dt)max is the maximum value of impedance change in Ω/s, and $LVET$ is the Left Ventricular Ejection Time in s.

We have made a preliminary introduction to our research. In Section 2, we will show our system design and experimental process. In Section 3, the results of the experiment are shown. In Section 4, we discuss the problems we are facing at present. In Section 5, we summarize our current research results and contributions.

II. MATERIAL AND METHOD

A. System Description

ICG circuit system is mainly divided into three blocks (1) transmitter (2) receiver (3) software Layer. Figure 2 is the framework diagram of the ICG circuit system; Figure 3 is the ECG framework and position of electrode corresponding to the body.

(1) Transmitter

First of all, we use a 12V lead-acid battery as the DC power supply of the oscillator which can produce stable frequency, and then connect the Voltage Controlled Current Source (VCCS) circuit to make the sinusoidal signal output stable current [7]. In order to ensure safety, we design an additional voltage limiting circuit as the protection circuit, and then apply the stable current signal to the outer electrode of the four electrodes.

(2) Receiver

Then, we receive the voltage signal of the human body from the inner electrode, using ad633 as an instrument amplifier, and use 60kHZ and 90khz band pass filter of 8 orders as filtering signal. Finally, we use NI USB-6210 to do ADC and input the signal into the computer.
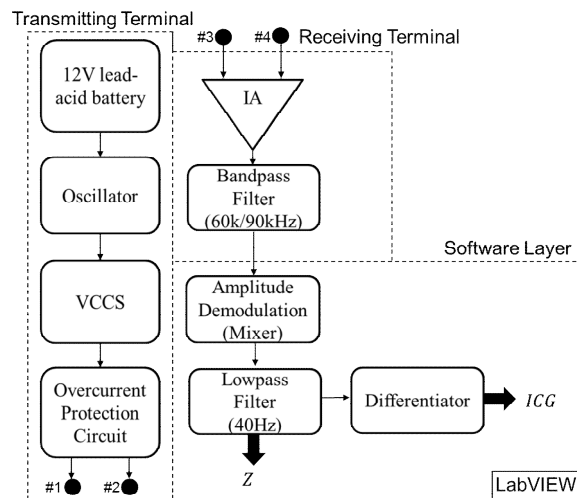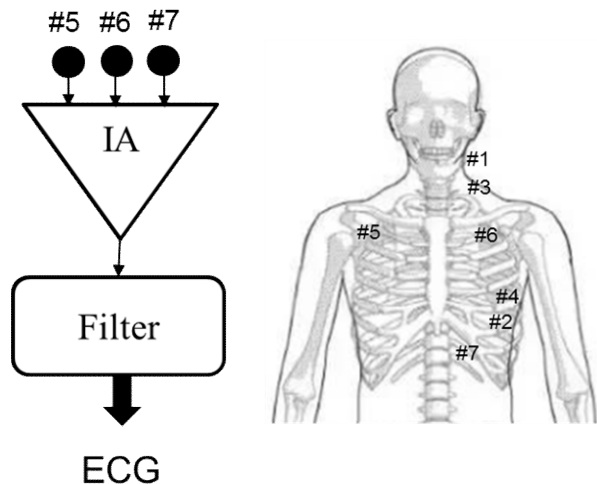

Figure 2. Framework diagram of ICG circuit system

Figure 3. ECG and position of electrode corresponding to body

(3) Software Layer

We use LabVIEW as software layer and analysis, the received signal is demodulated by mixer. Then we use 8 order's 40 Hz low pass filter to get the modulation signal (delta Z). Then, we use the obtained modulation signal (delta Z) do differential and multiplied by a negative sign to obtain the ICG signal [13].

The following is the process of mixer:

- Demodulated by mixer

$$X_{Carrier} = V_C \cos(2\pi f_C t) \qquad (3)$$

$$X_{AM} = V_{AM}(1 + m\cos(\pi f_m t))V_C \cos(2\pi f_C t) \qquad (4)$$

(3) multiplying (4) → (5)

$$X_{Out} = \frac{V_{AM}V_C^2}{2} + \frac{V_{AM}V_C^2}{2}\cos(2\pi f_m t) +$$

$$\frac{V_{AM}V_C^2}{2}(1 + m\cos(2\pi f_m t)\cos(2(2\pi f_C t))) \qquad (5)$$

(5) through a 40Hz low pass filter → modulation signal

where $X_{CARRIER}$ is the carrier signal, V_C is voltage amplitude of carrier signal, f_C is the frequency of carrier signal, X_{AM} is modulated signal, V_{AM} is voltage amplitude of the modulated signal, f_m is the frequency of modulation signal, t is time.

B. Subject data collection and experiment process

This research's data was extracted from one subject; no history of cardiovascular disease was in this subject.

Before the experiment, the electrodes should be placed first as shown in Figure 3. Four electrode positions required for ICG: Lead 1 is placed on the left upper neck. Lead 2 is placed 3 cm below lead 1. Lead 3 is placed at the point where the xiphoid is cut to the left of the chest. Lead 4 is placed 3 cm below lead 3 [6]. The positions of the ECG electrode (Lead 5-7) are as shown in Figure 3.

The experimental procedure is: first, let the subject rest for 3 minutes to measure the baseline, and then do 30 seconds of rhythmic breathing to acquire ECG and ICG signal.

III. RESULT

Figures 4 and 5 show the signals when we measure only the ICG of the subjects. Figures 6 and 7 show the signals when we measured the ECG and ICG of the subjects at the same time.
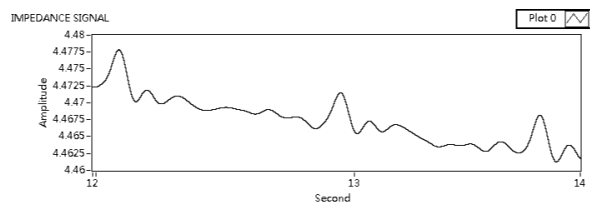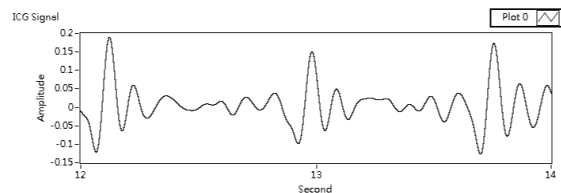

Figure 4. Impedance variation (delta Z)

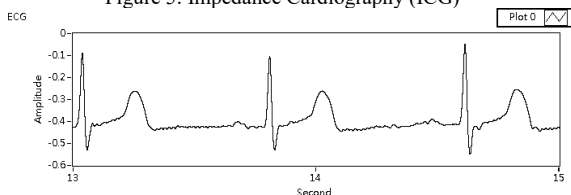Figure 5. Impedance Cardiography (ICG)

Figure 6. ECG signal (Simultaneous measurement with ICG)
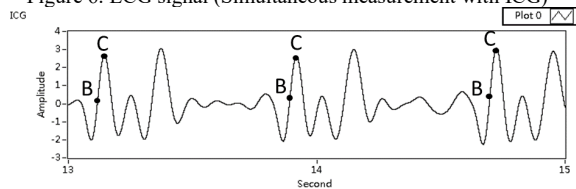

Figure 7. ICG signal (Simultaneous measurement with ECG)

The change of human body impedance was shown in Figure 4. The maximum impedance can be observed in each cardiac cycle. From the three cardiac cycles in Figure 5, we can observe the ICG that obtained by letting delta Z do differential and multiplied by a negative sign.

Figure 6 is the ECG signal measured with ICG at the same time. Figure 7 is the ICG signal measured with ECG at the same time. We may determine the possible point B and point C, and the interval between point C of ICG is similar to the RR interval of ECG. But point x cannot be accurately determined. We need to find out the possible x point by comparing ICG with ECG.

IV. DISCUSSION

By comparing the signal characteristics of Figure 4 and Figure 5 with those of previous papers, we can detect

possible B and C points, but we cannot accurately determine x points. Therefore, we hope to get possible x points by comparing with ECG signals.

According to [5] [11], we can confirm point B of ICG from point R of ECG. By comparing Figures 6 and 7, we can see that point B (when the aorta is opened) does occur after point R of ECG, and point C occurs at the highest point after point B, so point B and point C may be correct. Then, we can compare the x-point of ICG by the end of the T-wave of ECG [11] [14]. From Figures 6 and 7, we may find that at the end of the T-wave of ECG, the X point corresponding to this time is almost the most negative value after zero crossing, so this is the possible x point.

Although it is possible to detect the possible feature points of ICG through the simultaneous measurement of ECG and ICG, there are still several deficiencies in this study. First of all, there is the problem of signal coupling in the measurement. It can be seen from the ICG signal that the influence of ECG signal-coupling may affect the judgment of feature points. Second, the number of subjects is too small, there is only one subject at present, it is necessary to measure the data of multiple subjects for comparison, which can increase the reliability of signal and feature point detection

Finally, the problem of signal distortion will affect the judgment of feature points; the circuit design can be modified to increase the stability of the instrument.

V. CONCLUSION

This study shows that the impedance variation and ICG may be detected by the modified circuit, despite the fact that the possible characteristic points of ICG can be detected at present. However, there are still several deficiencies that have not been resolved, so it is impossible to accurately estimate cardiac output. In the future, we will solve these deficiencies, so as to estimate the accurate cardiac output, and then develop into portable instruments, which will help long-term care for the tracking and diagnosis of diseases.

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