

Towards estimations of continuous cardiac output with impedance cardiography: a pilot study

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Resume of the presenter

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➢ Publication:

- C.-T. Liu, P.-H. Huang, and T.-C. Hsiao, “Towards estimations of continuous cardiac output with impedance cardiography: A pilot study”, 12th International Conference on e-Health, Telemedicine, and Social Medicine (eTELEMED), Valencia, Spain, Nov. 21-25, 2020.(Accepted for Oral)

➢ Award:

- 2017 Certified LabVIEW Associate Developer (CLAD, 100-317-22466)

Outline

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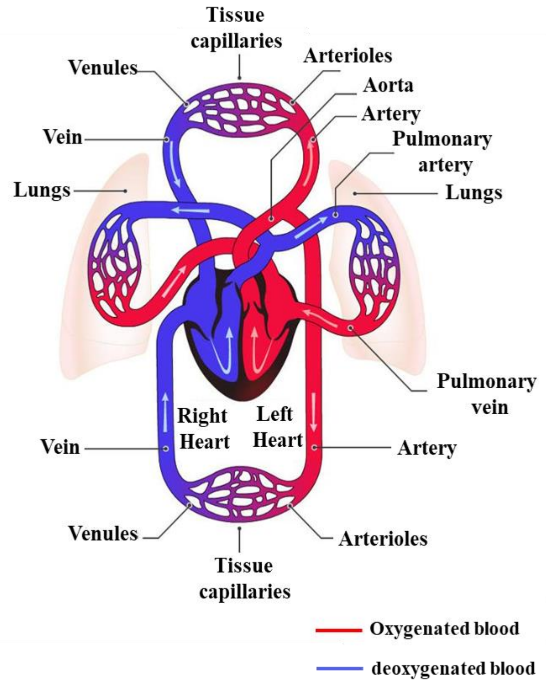
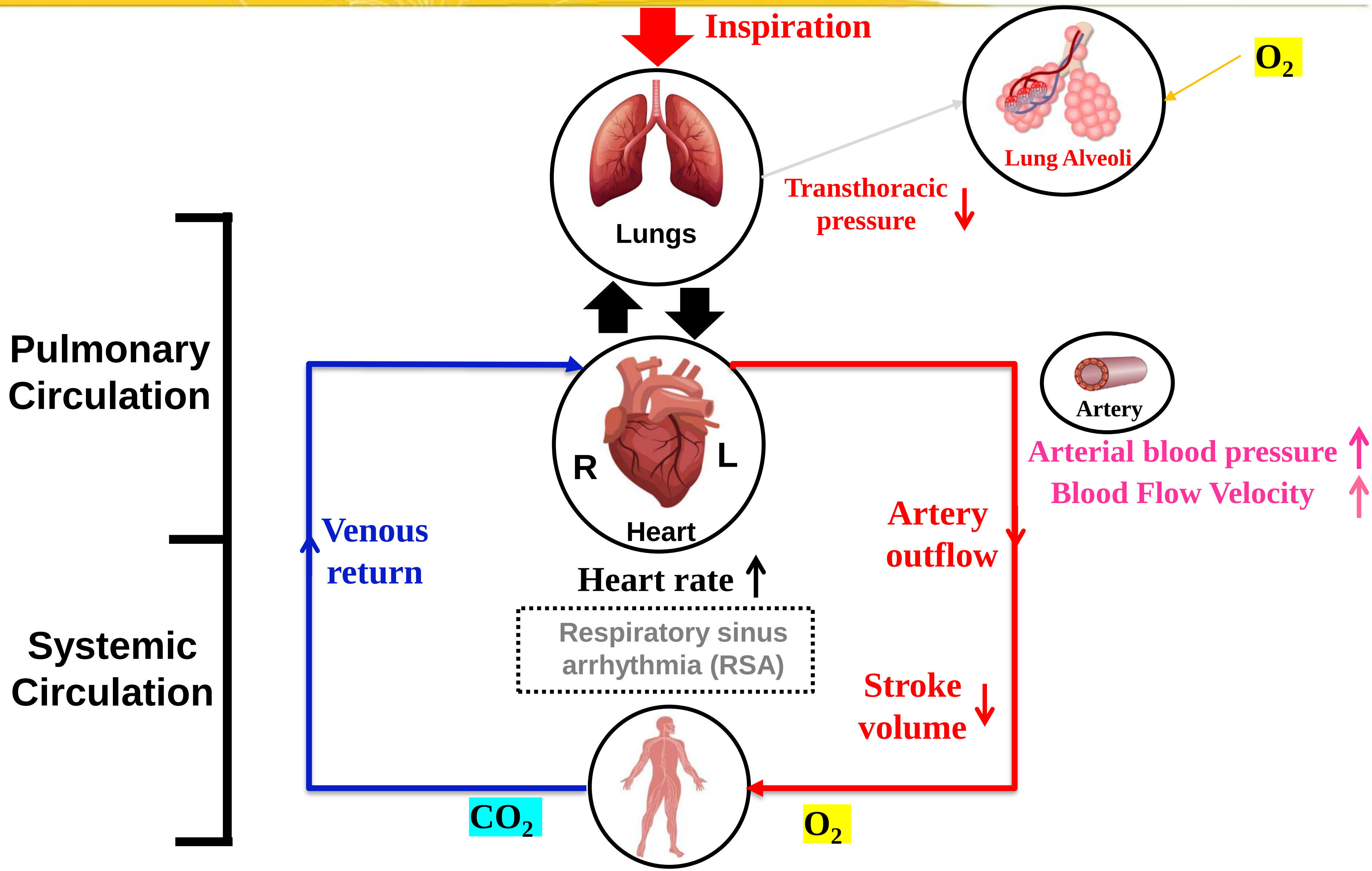
Hemodynamics

- **Hemodynamics** is the study of blood flow and circulation between tissues and organs, the circulatory system can be divided into systemic circulation (Heart to Tissue) and pulmonary circulation (Heart to Lung).



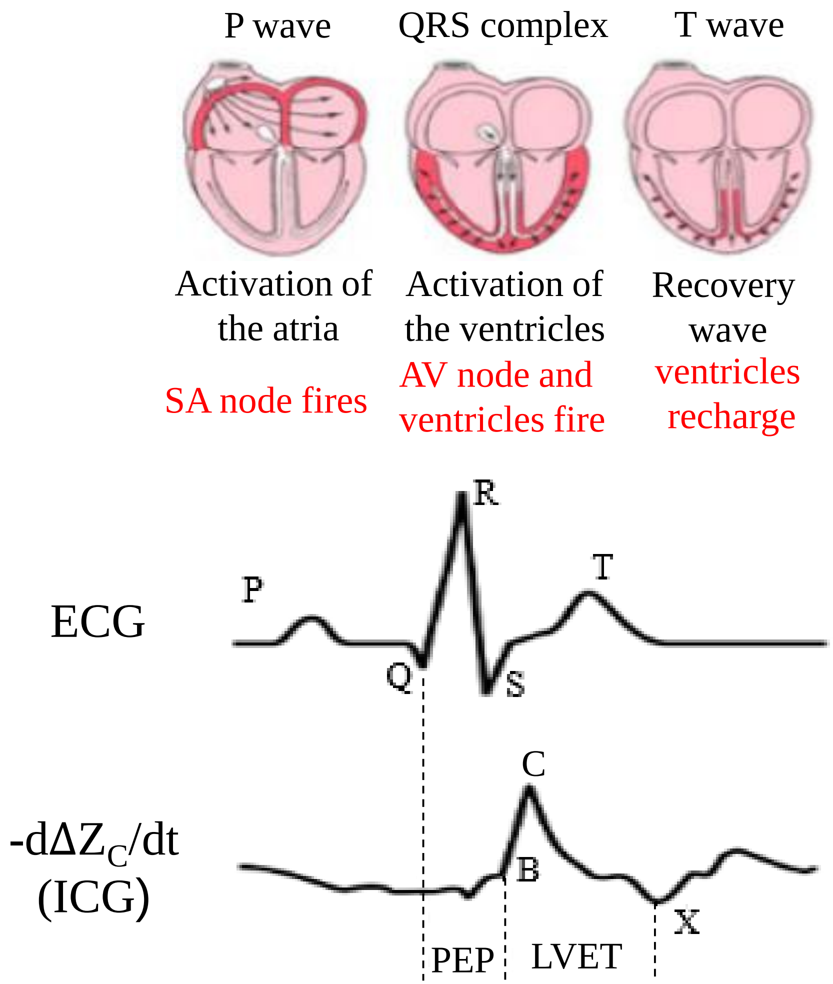
- Hemodynamic parameters
  - **Blood oxygen saturation (SpO2) -** by pulse Oximeter
    - Evaluate blood oxygen content
  - **Partial pressure of oxygen (PO2) -** by withdrawing blood
    - Evaluate gas exchange function of pulmonary
  - **Blood pressure (BP) -** by sphygmomanometer
    - The pressure exerted by blood on the vessel wall
    - Arteriopathy: atherosclerosis, hemangioma, aortic dissection
  - **Stroke volume (SV)** – by Impedance cardiography (ICG) and Doppler ultrasound (Non-invasive)
    - Evaluate cardiac contractility and cardiac regulation function
  - **Cardiac output (CO)** – by Pulse induced contour cardiac output (PiCCO) and Pulmonary artery catheter (PAC) (Invasive)
    - Evaluate cardiac pumping performance by long-term CO observation.

Cardiopulmonary interactions



Impedance cardiography (ICG)

- During heart beating, the corresponding relationship between ECG and ICG, as well as the important characteristic points and intervals.



($Z=Z_0+\Delta Z_C+\Delta Z_R$, Z_0=basic impedance;
ΔZ_C= impedance change caused by cardiac cycle;
ΔZ_R= impedance change caused by respiratory)

Point	**Description**
B	Corresponding to the opening of the aortic valve.
C	$(dZ/dt)_{max}$: This point can reflect the maximum speed of impedance change, which is related to the maximum ejection speed of the heart.
X	Corresponding to the closure of the aortic valve.

Period	**Description**
Q-B	The time interval between Q wave and the opening of the aortic valve is called pre-ejection period (PEP).
B-X	The time interval between the opening and closing of the aortic valve is called left ventricular ejection time (T_{LVE}).

- Berntson, G. G., et al., “Cardiovascular psychophysiology”, 2017.
- https://www.mdpi.com/1424-8220/20/7/2033/htm

History from CO to SV measurement

Non-invasive (SV)

Doppler ultrasound

SV = CSA $\int v(t)dt$

CSA = $\frac{\pi D^2}{4}$, D:aortic diameter.

- **Huntsman (1983).** Doppler ultrasound measures aortic diameter and aortic blood velocity**.** SV is determined by Blood velocity (v) and the cross-sectional area of the lumen (CSA).
- **Feigenbaum (1967).** propose ultrasound can be used to measure left ventricular stroke volume.

Electrical cardiometry

$$SV = \bar{V}_{EPT}\left[\frac{(dZ/dt)_{max}}{Z_0}\right]^n T_{LVE}$$

n is an exponent which is <1.

- **Schmidt (2005).** SV is estimated by the volume of electrically participating tissue ($\bar{V}_{EPT}$) derived from the body mass and height and aortic blood velocity during left ventricular ejection.
- **Bernstein and Osyka (2001)** proposed electrical cardiometry.

Bio-impedance

$$SV = \frac{L^3}{4.25}\frac{\delta}{Z_0}T_{LVE}\left(\frac{dZ}{dt}\right)_{max}$$

$$SV = \rho\frac{L^2}{{Z_0}^2}T_{LVE}\left(\frac{dZ}{dt}\right)_{max}$$

- **Bernstein (1986)** modified SV equation. ($\delta = \sqrt{(BMIp/24\ kg\ m^{-2})}$ where BMI_p = patient body mass index (kg m^{-2}), 24 kg m^{-2} = ideal BMI.)
- **Kubicek (1974)** estimate SV by using the maximum change of impedance and Left ventricular ejection time (T_{LVE}). (ρ= static specific resistance of blood ; L = the measured thoracic length between voltage sensing electrodes); Z_0 = base impedance; $(dZ/dt)_{max}$ = the maximum change of impedance.)
- **Kedrov (1949)** Firstly measuring the electrical impedance change.

Invasive (CO)

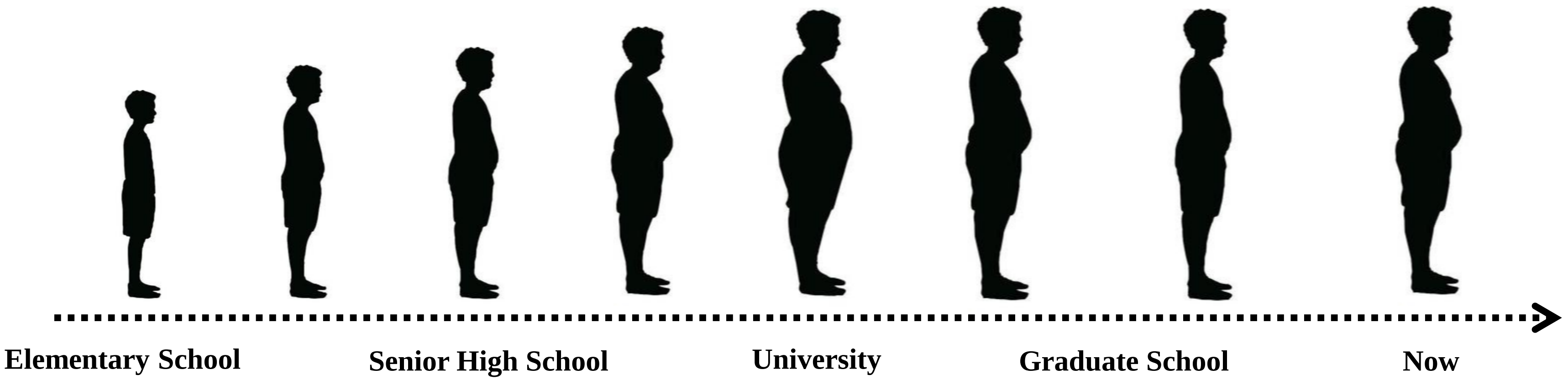
- **Fegler (1954)** proposed the thermodilution (TD) of CO determination.
- **Hamilton (1927)** used dye dilution method to calculate CO in humans.
- **Stewart (1897)** used Solution dilution method to obtain CO measurement for dogs.
- **Fick (1870)** defined CO measurement as estimating the amount of liters pumped by the heart in mins.

1870 Invasive Method **1948** Bio-impedance **1967** Doppler Ultrasound **2005** Electrical Cardiometry

Motivation

- Because I often participated in marathon or Triathlon competitions with the laboratory, with the change of body shape, I began to realize that when the intensity of exercise I could load increased, the change of respiratory rate also slows down during the exercise, I understood that **there's a connection between respiration and the mechanism of the cardiac.**
- In the laboratory, I was exposed to the physiological signal of impedance cardiography (ICG), which can monitor cardiac output and condition of cardiac health, let me be curious **if ICG can be used to understand the changes of breathing and heart pumping during exercise**.

- **Growth process:**



Objective

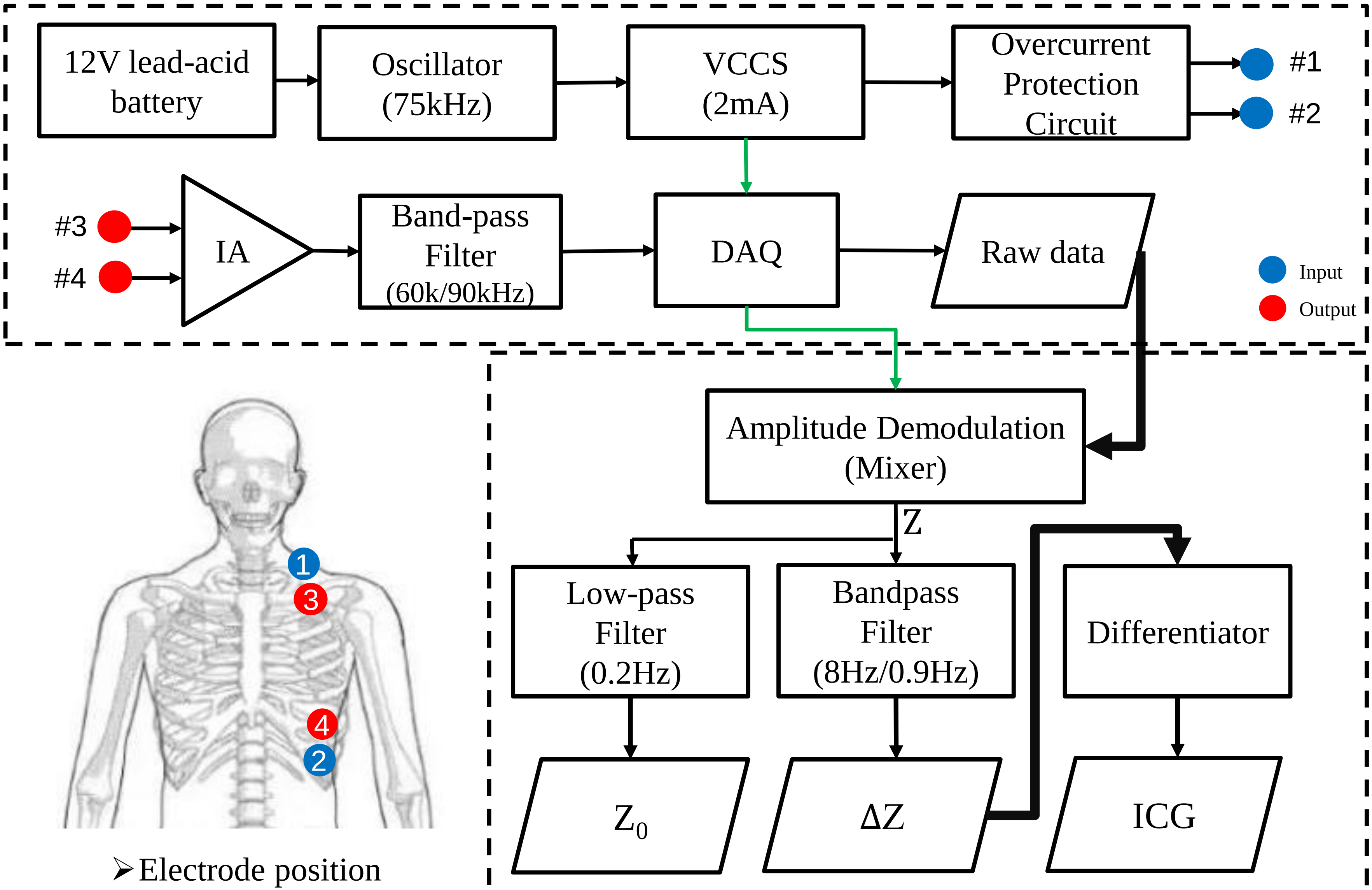
➢ Hypothesis:

1. ICG is a suitable way to estimate SV and get the original signal.
2. The physiological phenomenon of respiration can be reflected on ICG signal.

➢ Objective:

1. Designing ICG measurement system and obtain ICG raw data.
2. Calculating the stroke volume during exercise by our systems.
3. Observe respiratory signal from ICG signal.

The block diagram of ICG system



- Electrode position

Howland current pump circuit:

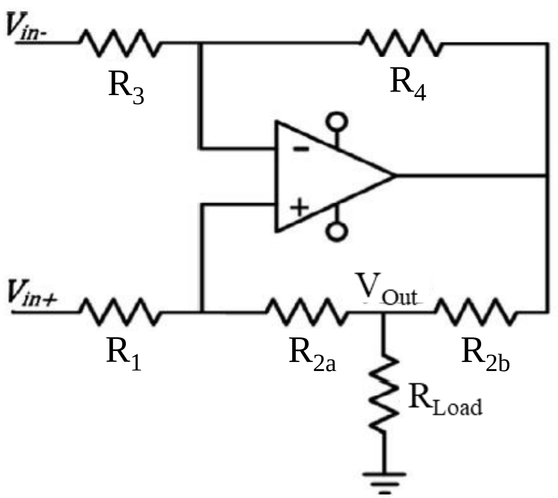


Figure.3. Howland current pump circuit

$$I_{\text{out}} = \frac{1}{R_{2\text{b}}}\frac{R_4}{R_3}\left(\frac{R_{2\text{a}}+R_2\frac{R_3}{R_4}}{R_{2\text{a}}+R_1}V_{\text{in}+} - V_{\text{in}-}\right) + \frac{R_4R_1 - R_2R_3}{R_3R_{2\text{b}}(R_1+R_{2\text{a}})}V_{\text{out}}$$

Where R_2 is the sum of R_{2a} and R_{2b}. If the following relationship is assumed,

$$\frac{R_2}{R_1} = \frac{R_4}{R_3}$$

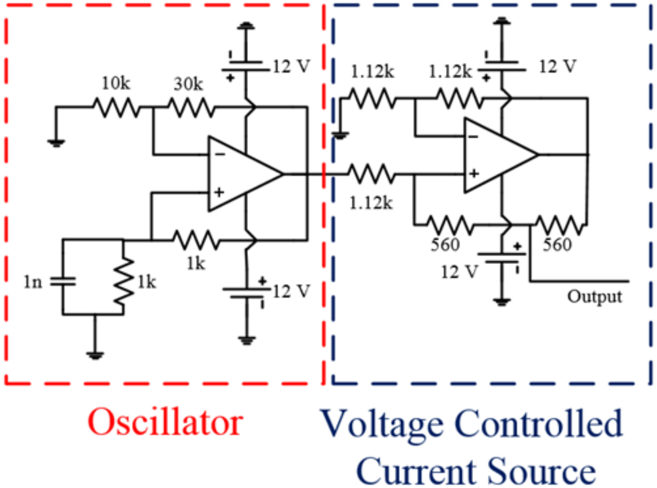
$$\frac{I_{\text{out}}}{V_{\text{in}+} - V_{\text{in}-}} = \frac{1}{R_{2\text{b}}}\frac{R_4}{R_3} = \frac{1}{R_{2\text{b}}}\frac{1-\beta_{\text{fb}}}{\beta_{\text{fb}}}$$

Where $\beta_{fb} = \frac{R_3}{(R_3+R_4)}$; and the circuit becomes a voltage to current converter with differential inputs.

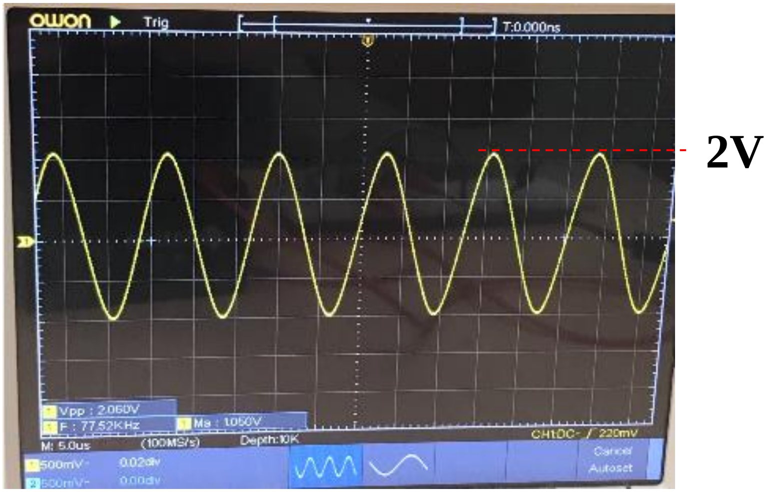
Mahnam, A., Yazdanian, H., & Samani, M. M. (2016). Comprehensive study of Howland circuit with non-ideal components to design high performance current pumps. Measurement, 82, 94-104.

Simulating signal

Simulating signal:

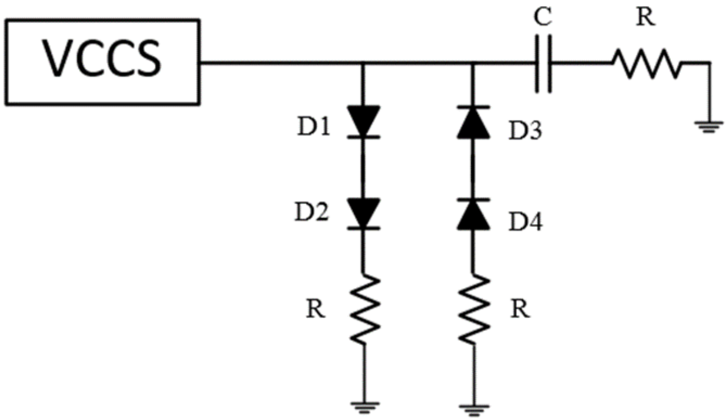


Load (1000 ohm):



Protection circuit :

- ➢ The protection circuit is set with **diodes**.
- ➢ Based on the characteristics of diodes, if the signal flowing through the human body **exceeds the set voltage**, it will pass through the diode and lead into the **ground**.



Amplitude demodulation

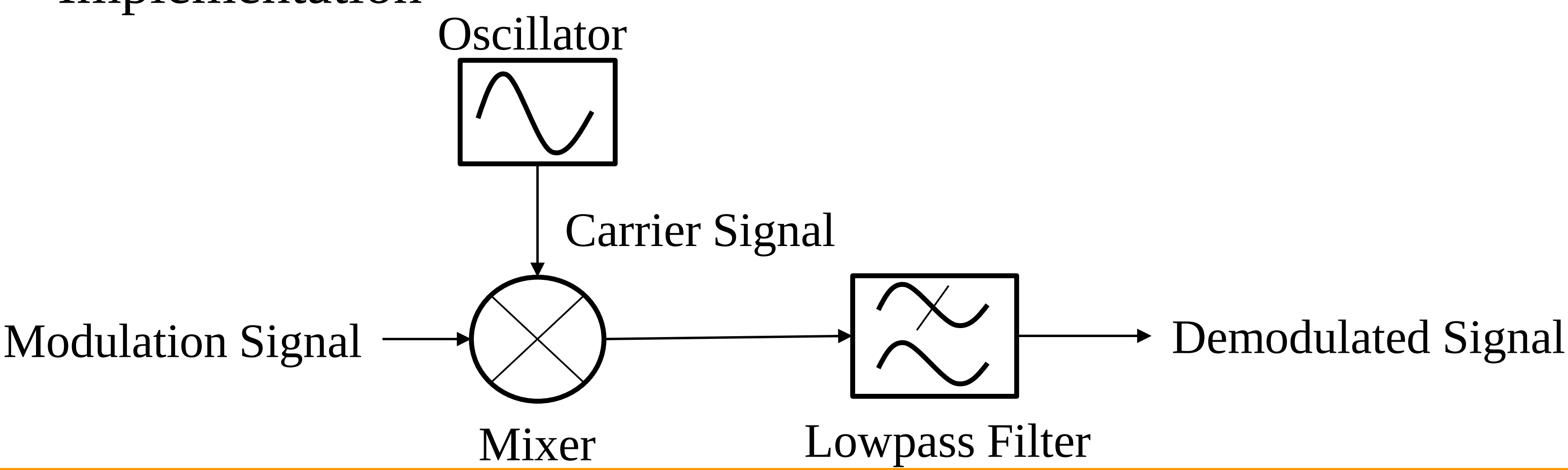
■ Synchronous detector

By inputting the AM modulated signal and the AM carrier to the multiplier, the original signal and the the carrier and its harmonics can be obtained.

$$\begin{cases} x_c = V_c \cos(2\pi f_c t) \\ x_{AM} = V_{AM}(1 + m\cos(2\pi f_m t))V_c \cos(2\pi f_c t) \end{cases}$$

$$x_{out} = \frac{V_{AM}V_c^2}{2} + \frac{V_{AM}V_c^2}{2} m\cos(2\pi f_m t) + \frac{V_{AM}V_c^2}{2}(1 + m\cos(2\pi f_m t))\cos(2(2\pi f_c t))$$

■ Implementation



Experiment procedure

➢ Data Acquisition

- **Ambu® Sleepmate RIPmate™ Inductance Belts**
- **Biomedical Sensor Pad**
- **NI USB-6210**
- **NI Elvis**
- **ICG Measurement Circuit** (Power Supply:12V battery, Output Current:1.8mA)

Inductance Belts

Biomedical Sensor Pad

NI USB-6210

NI Elvis

➢ Procedure

(Except training stage, others are totally spontaneous breathing.)

Baseline (3 min) → **Training (6/12/20/30-cycle paced breathing)** (5 min) → **Resting** (1 min) → **Biking** (5 min) → **Resting** (3 min)

Signal processing_ICG

Step 1: Pre-Processing

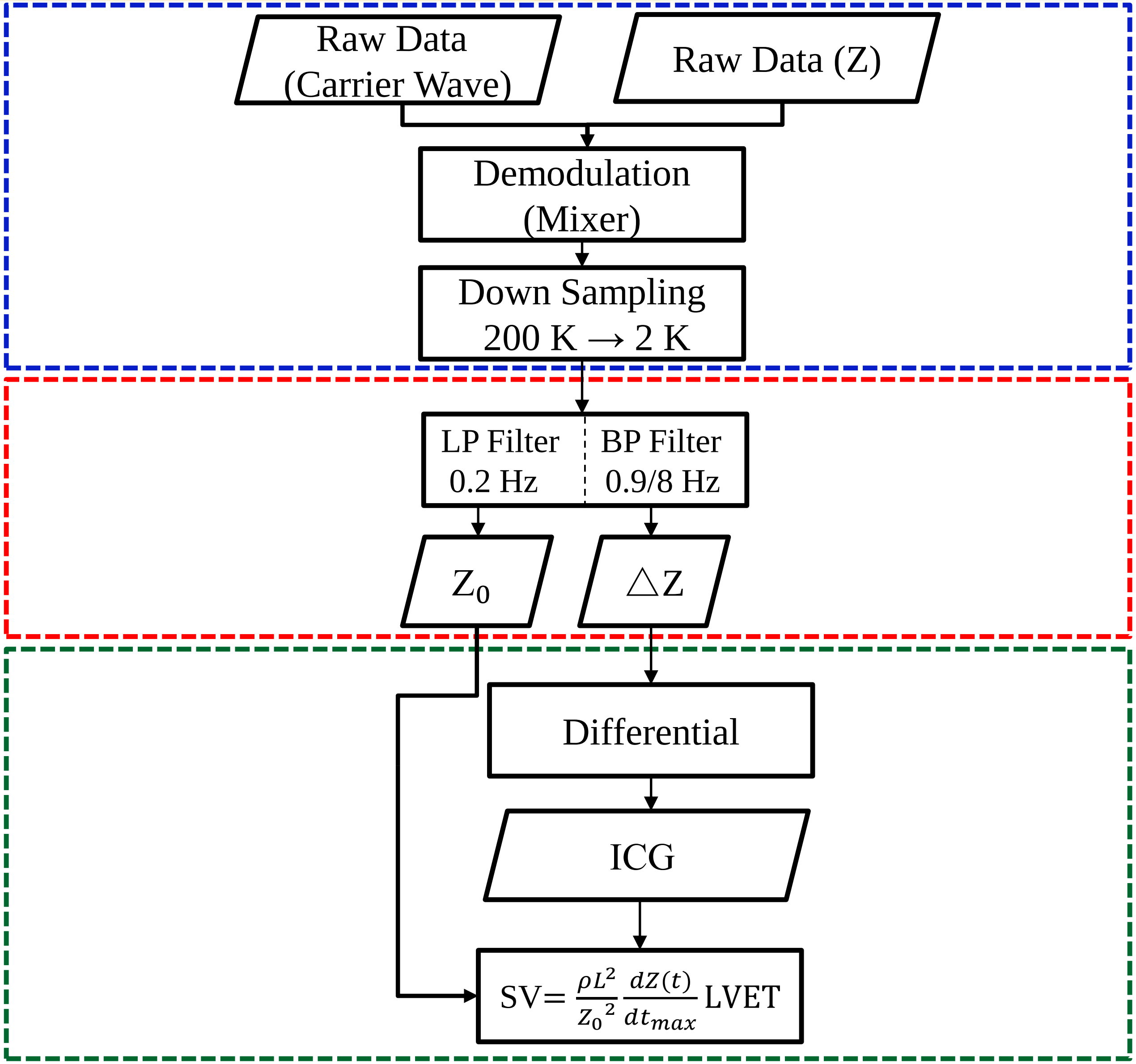
- Demodulation of AM modulation signal and down sampling point

Step 2: Decomposition

- Extract intrinsic characteristics from data.

Step 3: Signal Processing

- ICG was obtained and calculated the stroke volume (SV).



Signal processing_respiratory signal

Step 1: Pre-Processing

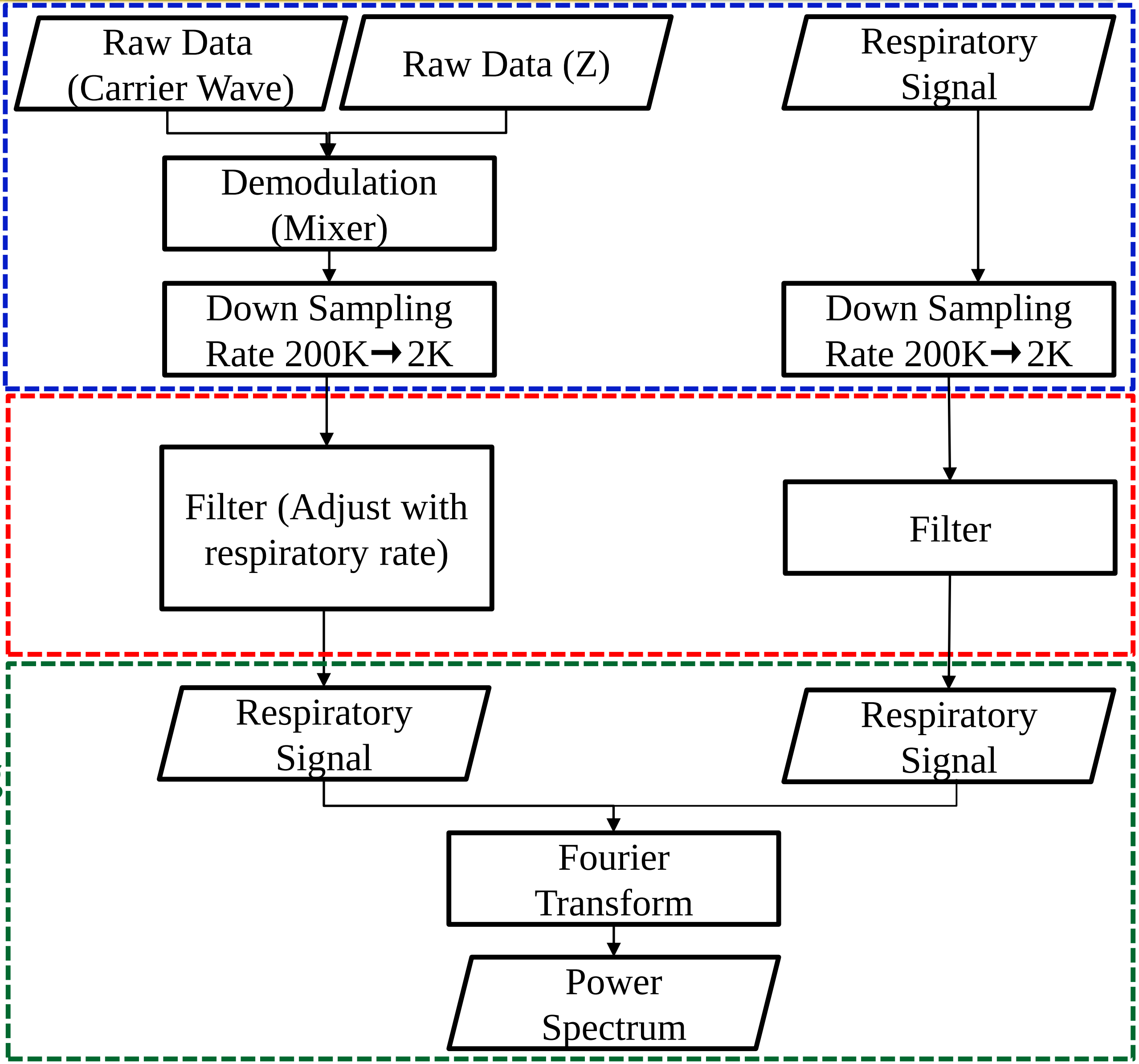
- Demodulation of AM modulation signal and down sampling point

Step 2: Decomposition

- Extract intrinsic characteristics from data.

Step 3: Signal Processing

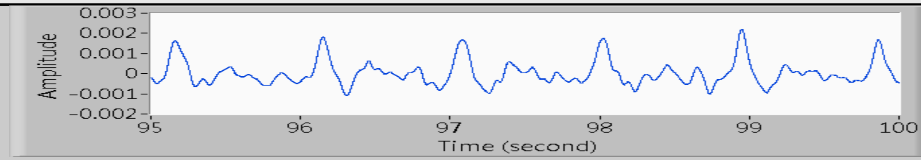
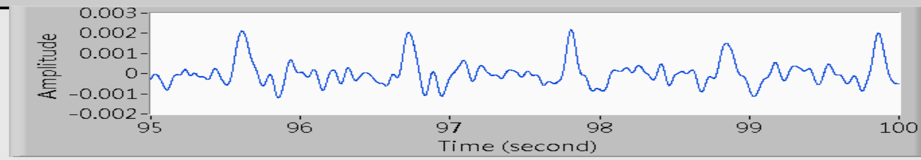
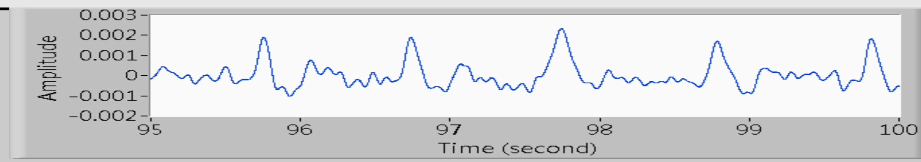
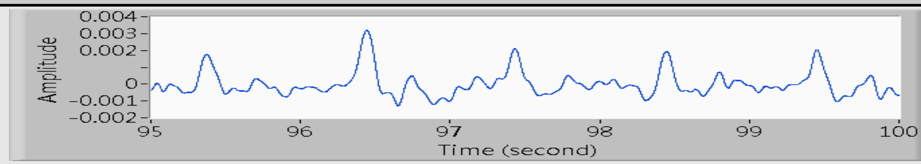
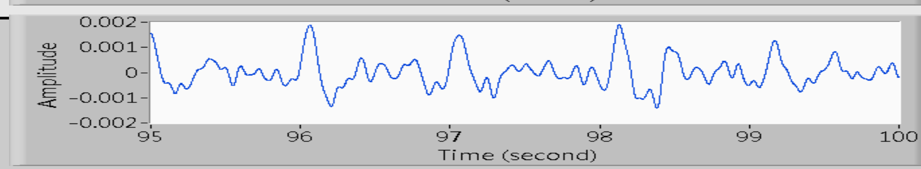
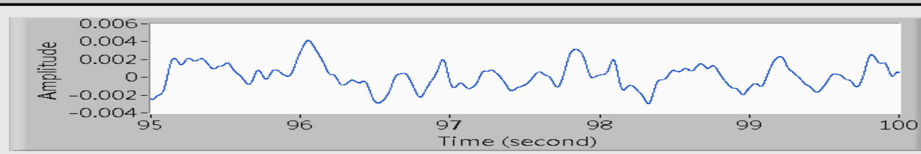
- The power spectrum of individual respiratory signals were compared.



Result :

Preliminary result

#Subject1

Stage	ICG signal	SV (ml)
Baseline		57
6-cycle breathing		54
12-cycle breathing		61
20-cycle breathing		64
30-cycle breathing		66
Biking		76

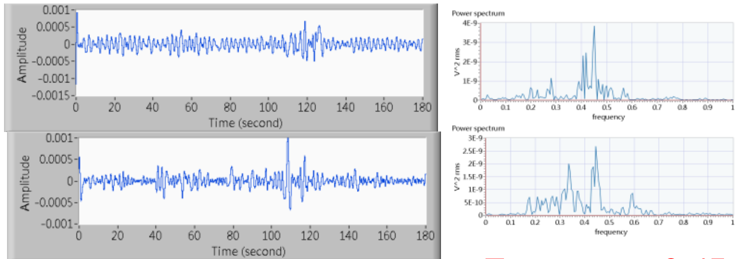
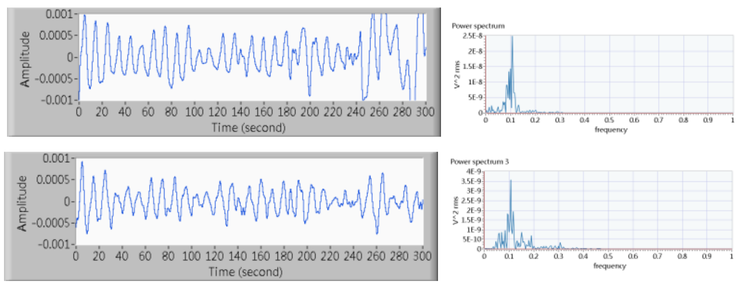
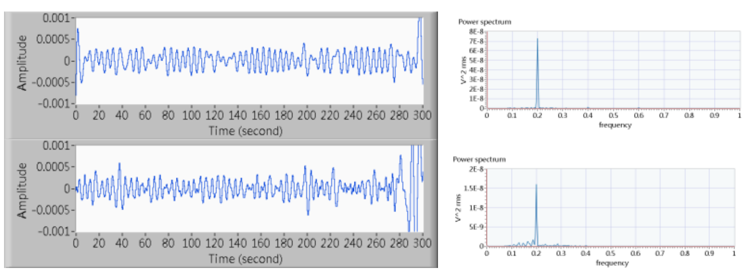
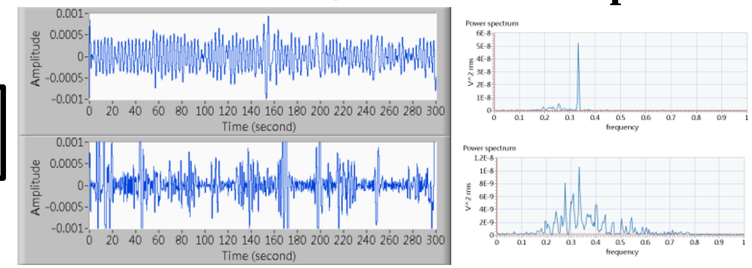
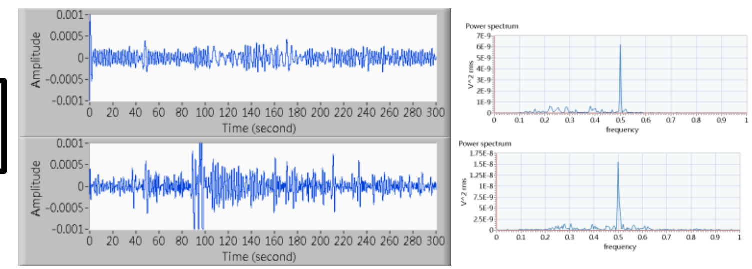
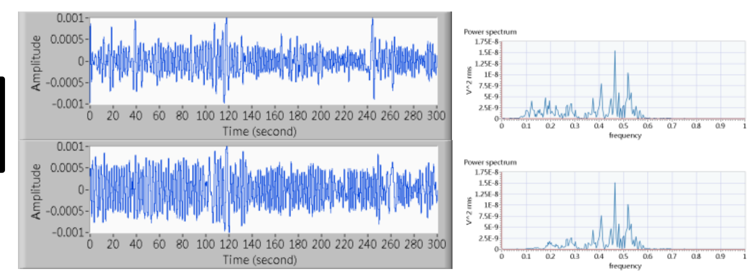
Result :

Respiratory signal

Upper: ICG

Lower: RIP

#Subject1

Stage	Respiratory signal	Power Spectrum
Spontaneous breathing		Frequency: 0.45
6-cycle breathing		Frequency: 0.1
12-cycle breathing		Frequency: 0.2
20-cycle breathing		Frequency: 0.33
30-cycle breathing		Frequency: 0.5
Biking		Frequency: 0.45

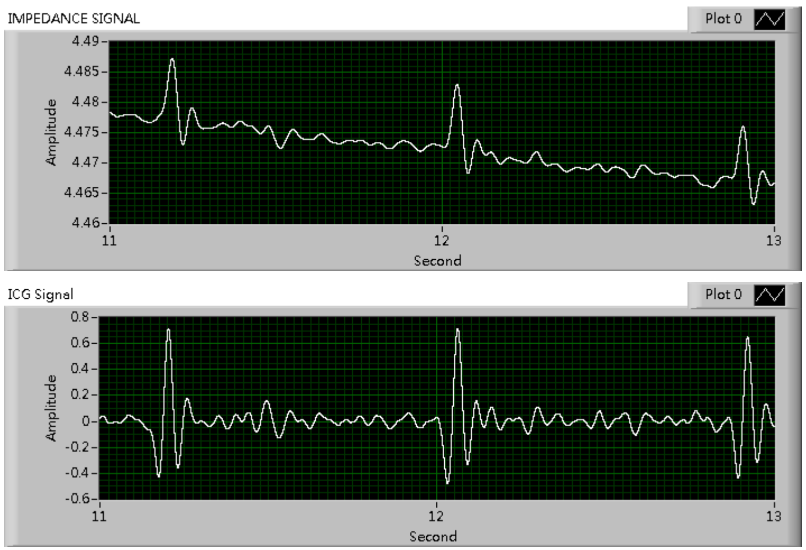
Discussion

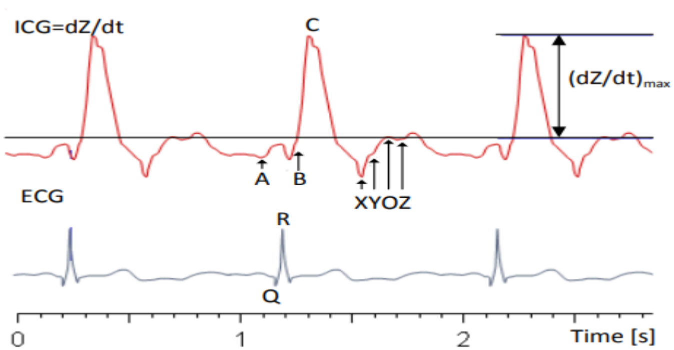
- ICG & ECG signal
- Estimation of SV during exercise

Discussion :

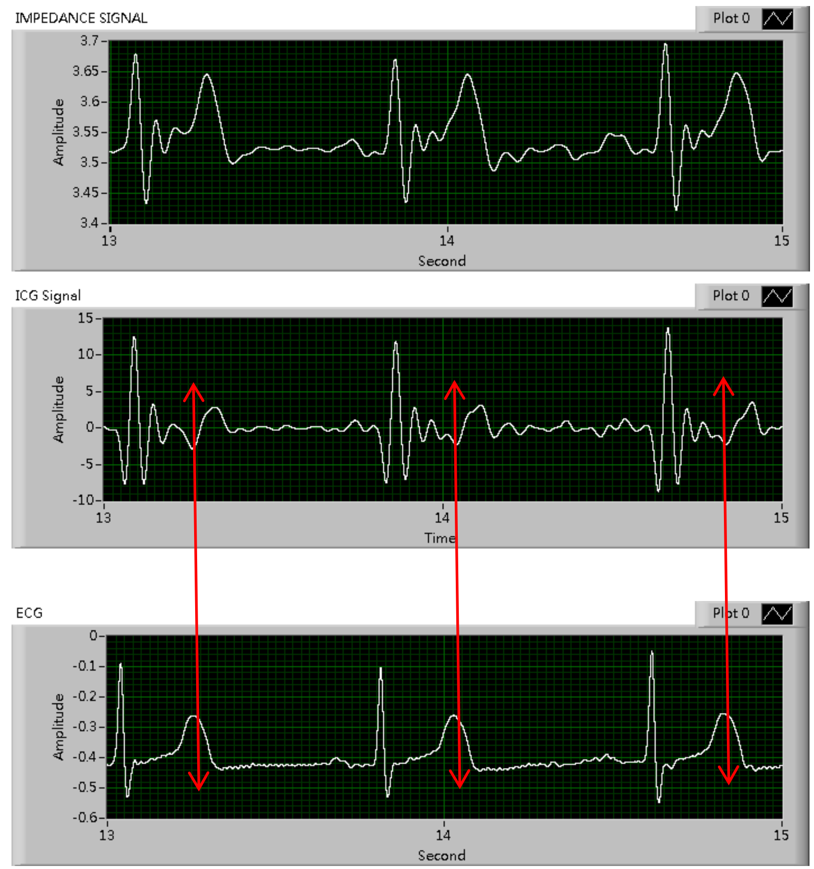
ICG & ECG signal

Only measuring ICG





Simultaneous measuring ICG and ECG



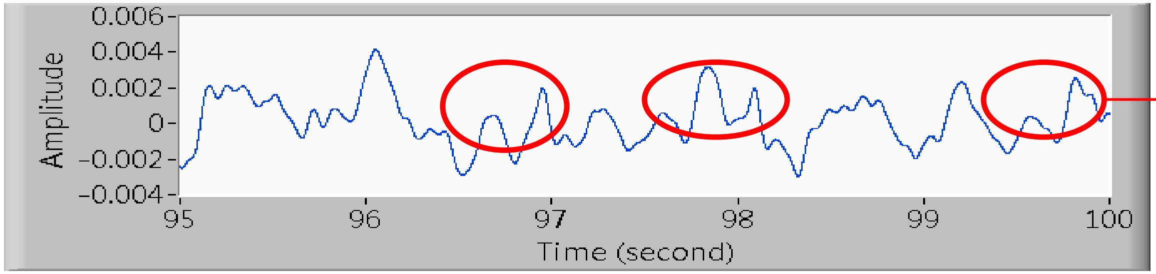
- When ICG and ECG signals are measured at the same time, the signals will affect each other.
- We can deal with this problem by the T-wave ratio of ECG to the x-point of ICG.

- J. Malmivuo and R. Plonsey, "Principles and applications of bioelectric and biomagnetic fields," Oxford University Press, 1995.

Estimation of SV during exercise

#Subject1

- **Estimation of SV during exercise:**



The feature points of ICG can not be identified accurately.

- In ICG measurement during motion, the signal will be affected by motion artifact and respiratory, resulting in the influence of feature point discrimination.
- The traditional signal processing method of ICG is filter. The filter has the problem of phase shift.
- We think that other signal processing methods can deal with this problem, and improve the signal distortion caused by motion artifact and respiratory, so as to improve the accuracy of SV estimation.

Conclusion & Further work

- This study shows that the impedance variation and ICG may be detected by the modified circuit, and can further estimate the SV.
- In the past studies, it was also pointed out that there was a certain relationship between the heart beating process and the respiratory mechanism. We made empirical studies through the way of paced breathing and biking.
- However, the current measurement results in the process of motion are also affected by the influence of motion artifact and respiratory, resulting in the signal feature points can not be clearly identified in some cases.
- In future work, we hope to estimate SV more accurately during exercise by signal processing, such as Empirical Mode Decomposition (EMD).

Thanks for your attention

Q & A

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