Study on New Method of Heart Disturbance Filtering on Measurement of Impedance Pneumograph

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Abstract. The graph of impedance pneumograph often occurred heart disturbance. In order to decrease the disturbance, some traditional hardware and software methods were used. But effects of the filters were limited for the small frequency difference between heart and lung. The paper gave a new filter theory that he art was acted as a variety capacitance, then heart disturbance was decreased by integration of variety capacitance. Test results showed that the new filter theory was feasible and satisfied the requirements of clinic measurement.

1. Introduction
Measurement of impedance pneumograph has been proofed available, and has got the conclusion that the impedance of thorax has a linear correlation with the vital capacity [1]. Because of the disturbance of heart and the scaling problem to the graph of impedance pneumograph of different person, this method was not applied. Biology impedance has more convenience than traditional measurement, especially to the sick into death patient and peculiar sickness such as SARS, so the key of impedance pneumograph applied is to solve these two problems. The aim of scaling is to get the accurate values on expiratory reserve volume, inspiratory reserve volume and inspiratory capacitance. For people with serious sickness in lung, the method of traditional facemask should be replaced by satisfying methods, such as impedance pneumograph and so on. So the first of those two problems, the disturbance of heart must be solved in priority. In the contrast experiment we find that effects of the filters which was composed of traditional digital filters and lowpass was limited to decrease disturbance of heart [1-4]. Because of the complexity of human body it is difficult to find out proper module to accurately describe the physical structure of thorax. So thorax can approximately be describe the commixing of resistance, capacitance and inductance. However, it is difficult to measure the values of impedance with breathing, the graph of impedance has wave disturbance. Generally speaking, the frequency of breath is about 0.4Hz, and the frequency of heartbeat is about 1.1Hz, In this condition, it is easy to understand the poor effect of traditional filtering.

This paper analyses the physical structure of heart, considering the beating heart as a variable capacitance, capacitance becomes larger on heart diastole, smaller on systole. Because of the periodicity of heartbeat, according to the electrical theory, take integral on capacitance in one period, thus can dissolve the heart disturbance. The experiment proofed that this method is available and effective.
2. Disturbance source

2.1. Theory of impedance pneumograph

Human body is constituted of muscle, blood, body fluid and fat. The thorax changes shape as people breathe. Considering the thorax as a network composed of resistance, capacitance and inductance, the ratio of inductance is the smallest, so the model of thorax constituted by a variable impedance network composed of impedance and capacitance. As figure 1, R and C are the variety of impedance and capacitance caused by the changing thorax. If \( Z \) is the vector sum of \( R \) and \( C \), \( \Delta z \) is the variety of impedance, \( \Delta v \) is the vital capacity, then \( \Delta z \) and \( \Delta v \) has a linear correlation.

\[
\text{Figure 1. Model of thorax.}
\]

2.2. Electrical characteristics of heart disturbance

According to the definition of capacitance, the blood flowing through the heart can considered as conductor. The variety of blood caused by heartbeat (is as) seems the insulation between the two poles plates of capacitance or as the position changing of the poles plates. So the heart can be regarded as a fast-change capacitance, and the thorax change caused by breathing can be regarded as a slow-change capacitance. By all appearances, thorax capacitance is far much larger than heart. The electrical module of figure 1 can be replaced by figure 2. Use \( C_f \) and \( \Delta c \) to represent the(oral) original \( C \), \( C_f \) equal capacitance caused by breath, and \( \Delta c \) equal capacitance caused by heartbeat. The \( u \) is the total value of \( R \) and \( C \), if we get the voltage on \( \Delta c \) and subtract from \( u \), we can get accurately graph of lung impedance.

\[
\text{Figure 2. New model of thorax.}
\]

2.3. Decrease heart disturbance

For the module showed in figure 1, put a 30-50kHz sine wave on thorax, the value of voltage \( (u) \) on the variety impedance caused by breath can be expressed as formulary 1

\[
u = I(R + C) = Z * I
\]

Comparing the graph of lung impedance got from formulary 1 with the graph got from lung breath recorder, as figure 3 (note), though the heart disturbance is large, the wave is actually the same result measured by lung breath recorder. In other words, formulary 1 is satisfaction in lung impedance measurement.

Conceiving of capacity \( C \) as two equivalent capacities, formulary (1) can be transformed into formulary (2). If the voltage of \( \Delta c \) can be subtracted from formulary (2) , the disturbance of the heart can be got rid of . Because the changes of lung impedance are continuous, so the voltage of lung impedance can be regarded as the last sample value plus the voltage generated by impedance change of thorax sampled interval. The thorax impedance changes can be regarded as two parts, one is breath in lung , the other is heartbeat.

\[
u = I(R + C_f + \Delta c) = u_f + u_{\Delta c}
\]

The voltage of the heart equivalent capacitance can be represented by formulary (3).

\[
u_c = \frac{1}{C} \int_0^t i(\xi)d\xi + u(C_{f0})
\]
Figure 3. The compared graph of wave.

If set the integral time exactly as the time of one heartbeat, due to the cycles of the heartbeat, the integral result of formulary (3) is zero. The other term of formulary (3) can be regarded as the integral of the equivalent capacitance of heart during the period from the beginning to the time \( t_0 \), that is, the integral time is \( 0 \sim t_0 \). Similarly, \( u_f \) can be represented by the last sample value plus the voltage generated by effective impedance change \( \Delta Z \) sampled in spacing interval. Formulary (4) shows that

\[
u_k = u_{k-1} + \Delta Z_{k-1}I\tag{4}
\]

Substitute (3), (4) to (2), then the sample value of the voltage can be represented by formulary (5).

\[
\begin{align*}
u_0 &= u_0 \\
u_1 &= u_0 + \Delta Z_0 I + \frac{1}{\Delta C_0} \int_0^t i(t)dt + u(c_0) \\
u_2 &= u_1 + \Delta Z_1 I + \frac{1}{\Delta C_1} \int_0^t i(t)dt + u(c_1) \\
u_n &= u_{n-1} + \Delta Z_{n-1} I + \frac{1}{\Delta C_{n-1}} \int_0^t i(t)dt + u(c_{n-1})
\end{align*}\tag{5}
\]

Where \( I \) is the output current from the signal source (constant current source). Suppose the first sample value is zero, \( u(c_m) \) is represented by (6). \( m, k \in (0,n) \).

\[
u(c_m) = \frac{1}{\Delta C_{m-1}} \int_0^t i(t)dt + u(c_{m-1})\tag{6}
\]

Calculating Derivate of formulary (5), all the items are constants except the integral item. Then we can get the equivalent capacitance \( \Delta C \) of the heartbeat by deriving the time at every sample point. Formulary (5) has given the expression of disturbance at every sample point. We can get the lung impedance value by subtracting the integral of \( \Delta C \) and the accumulated disturbance caused by \( \Delta C \). If it is represented by \( U_k \), \( k \in (0,n) \), the lung impedance without heart disturbance can be represented by (7).
\[ U_0 = u_0 \]
\[ U_1 = u_1 - \Delta t(u_1 - u_0) - u(c_0) = u_1 - \Delta u_1 \Delta t \]
\[ U_2 = u_2 - \Delta t(u_2 - u_1) - u(c_1) = u_2 - \Delta u_2 \Delta t - \Delta u_1 \Delta t = u_2 - (\Delta u_1 + \Delta u_2) \Delta t \]
\[ U_n = u_n - \Delta t(u_n - u_{n-1}) - u(c_{n-1}) = u_n - \Delta u_n \Delta t - \cdots - \Delta u_1 \Delta t = u_n - (\Delta u_1 + \Delta u_2 + \cdots + \Delta u_n) \Delta t \]  

(7)

3. Test results

According to the formulary (7), the key of getting rid of the heart disturbance is to decide the value of \( \Delta t \). Because of the difference of the measurement unit, we cannot substitute two sample intervals to the equation. Analyzing the formation mechanism of (7), the range of \( \Delta t \) is (0, 1). We select two groups, \( \Delta t \) differing in each group, from the sample data and filter wave through formulary (7). Because of the great amount of data, only list compared values in several breath cycles. See the Figure 4 and Figure 5.

By comparing the data in Figure 4 and Figure 5, there is an obvious decrease of heart disturbance though it still exists after filtering. And as \( \Delta t \) becomes large, the disturbance is diminished. Meanwhile the responding \( U_k \) also becomes small.

![Figure 4. \( \Delta t=0.6 \)](image)

![Figure 5. \( \Delta t=0.2 \)](image)
4. Conclusion
According to the physiological structure of the heart, the heart is regarded as a variety capacitance. Because of the periodicity of heartbeat, the integration of capacitance in a heartbeat cycle can remove the heart disturbance in theory. The feasibility of the above model has been tested by practically calculating acquired data.

The paper doesn’t give the principle over how to get $\Delta t$. Besides the upper reasons on the paper, these data are related closely to scaling standard of impedance graph. Only taking two parts jointly into consideration, can we decide the principle of getting $\Delta t$. The method has been described in this paper is significance for the capacitance charges or discharges periodically, especially clearing the disturbance in graph.

Note: The wave displayed in lung function machine is taken from the input end of the signal-show instrument of the lung function machine, differing by 180 degrees in phase from the acquired signal. We subtract a constant from the acquired value in order to compare them conveniently. Then display them in LabVIEW. There is a difference in the number of the breath cycle between two groups due to the acquiring time.

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