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A Research of Non-Contact Respiration and Heartbeat Signal Separation

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Abstract

The objective of this research is from radar life parameter monitoring system for respiration and heartbeat signal separation, therefore the characteristic parameters of respiration; heartbeat could be extracted to provide the basis for family care and disease prevention. This paper put forward a method to analyze the characteristics of the echo signal, improve adaptive filter harmonic combination of reference input signals for respiration. Home monitoring results for simulation experiment is proposed based on LMS adaptive harmonic cancellation algorithm for adaptive filtering. Conclusion in the home monitoring experiment can effectively separate the respiration and heartbeat signals.

Keywords: *biological radar, adaptive noise cancellation, least mean square (LMS)*

1. Introduction

By transmitting the electromagnetic wave, the biological radar can detect or test the life information. When the electromagnetic wave irradiation transmitted by the radar reaches to the human body's chest, it is reflected back when there is an obstacle. In this process, the micro-motion of the chest wall arising from the motion of breathing and heartbeat etc. is reflected back together with the echo signals. The biological radar combines the radar technology and the biomedical engineering technology effectively. This radar can penetrate into nonmetallic substances (brick walls, ruins etc.) without any electrode or sensor required to contact the life body. Thus, the biological radar can detect the life information (the breathing, the heart rate, the blood flow etc.), even in the very far distance [1]. But the radar's high detection sensitivity leads to the consequence that strong echo noises from the background and other motions are also mixed in the echo signals. In addition, the human life signs show characteristics: weakness, low frequency, and susceptibility to interference. Therefore, detecting the weak life information under the background of strong noise to obtain the signal parameters has been the technological challenge in the non-contact detection of the biological radar.

Since the 1970s, the non-contact detection method based on the biological radar have attracted more and more attention in the detection and monitoring of life information parameters [2-6]. According to the literature [7], in 1996, Micropower Impulse Radar (MIR) was developed by Lawrence Livermore National Laboratory (LLNL) in American Stanford University. MIR can detect the human signals of breathing and heartbeat. Moreover, by adopting the range gate technology, it can also realize the furthest restraint of the external environment interference. Furthermore, in 2005, Yan-Ming Xiao *et al* [8] remotely detected the micro-motion of the cardiopulmonary signs, employing the low power radar system in the Ka band. Then, the signals of breathing and heartbeat were obtained. In 2009, aiming at the radar monitoring technology of the cardiopulmonary signs, Morgan *et al* [9] proposed the signal processing method of the adaptive noise cancellation. This method can separate the signals of breathing and heartbeat in the measured thorax micro-motion. But Morgan *et al* limited their attention only to the simulation model and did not analyze the measured data.

Previously, this research group explored the separation and extraction of the biological radar signals of breathing and heartbeat. Adopting the adaptive processing method, Wang Haibin [10] conducted the adaptive filtering, taking the breathing signal extracted in the experiments as the noise reference signal and the echo signals as the original input signals.

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Then, he detected the heartbeat waveform from the echo signals. But as this algorithm requires higher correlation to the noise signals, the filtering effect was unsatisfactory. Yang Dong [11] adopted homomorphic filtering to process the echo signals. But the complex cepstrum boundary could not be analyzed clearly due to the uncertain echo signal components. In addition, Yue Yu [12] adopted the wavelet transform to conduct the filtering. But this algorithm is usually applied in the de-noising of time-varying signals and jump signals. Besides, the algorithm is complex, with poor real-time performance. Hence, the filtering effect was poor.

This research proposed an adaptive harmonic cancellation method based on LMS. The method took the combined harmonic of the breathing signal as a reference input signal of the adaptive filter to conduct the signal filtering processing.

2. The Adaptive Harmonic Cancellation Algorithm Based on LMS

2.1. The Model for the Adaptive Noise Cancellation

The algorithm schematic diagram was demonstrated in Figure 1. The first signal s was influenced by noise in the acquisition process. That is, the irrelevant noise n_0 was superposed in the original signals. Hence, $s+n_0$ constituted the original input signals of the adaptive noise canceller. But in the second signal acquisition process, the reference input signal of the adaptive noise canceller was instituted by n_1. The signal n_1 had no correlation with the first signal, but n_1 was correlated to n_0 in one way or another (with the correlation pattern unknown). Then, the noise n_1 was processed to obtain the signal output evaluation y that was close to n_0. Afterwards, y was subtracted from the original input signals. Thus, the obtained output value corresponding to the system $s+n_0-y$ was also the concerned first signal value [13-14].

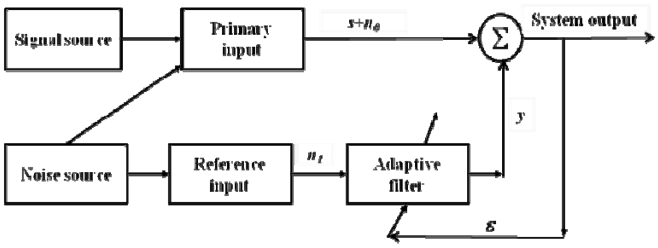


Figure 1. The Schematic Diagram of Adaptive Noise Canceller

2.2. The Modified Adaptive Harmonic Cancellation Algorithm Based on LMS

On the basis of the adaptive noise canceller, according to the research group's exploration in the prior period, the combined harmonic of the breathing signal was used as a reference input signal of the adaptive filter to improve the algorithm. Thus, the adaptive harmonic cancellation algorithm based on LMS was proposed.

For any periodic vibration function $f(x)$, if harmonic analysis is conducted, the harmonic expansion according to the flourier series is presented as follow:

$$f(x)=\frac{a_0}{2}+\sum_{k=1}^{\infty}(a_k\cos kx+b_k\sin kx) \quad (1)$$

So, the first item $\frac{a_0}{2}$ denotes the direct current component. The second item $k=1, a_1 \cos x + b_1 \sin x$ represents the fundamental component, while the third item $k=2, a_2 \cos 2x + b_2 \sin 2x$ is the second harmonic. Successively, the items after the second harmonic are called by a joint name: higher harmonic.

Thus, the model for the thorax motion caused by breathing was established as follow:

$S(x, n, \omega_0)$ represents the combined harmonic of the breathing signal. So,

$$S(a, n, \omega_0) = a_{2l+1} + \sum_{l=1}^{L} a_{2l-1} \cos(l\omega_0 n + a_{2l}) \quad (2)$$

The parameters in this formula: ω_0 denotes the fundamental frequency of the breathing signal, while $l\omega_0$ denotes the frequency of l th harmonic.

a_i refers to the vector of $[a_1, a_2, ...a_{2l+1}]^T$ and a_{2l} denotes the phase of l th harmonic. a_{2l-1} represents the amplitude of l th harmonic, while a_{2l+1} represents the direct current component of l th harmonic. Besides, the vector of $[a_1, a_2, ...a_{2l+1}]^T$ is generated by the random function. In addition, the harmonic order of breathing is denoted by L .

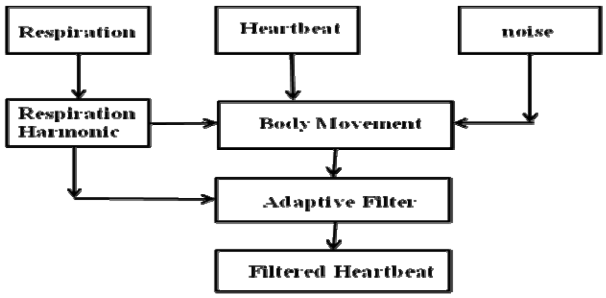


Figure 2. Adaptive Harmonic Cancellation Algorithm Based on LMS

The model for the thorax motion caused by the heartbeat signal was formulated as follow:

$$H(b, n, \varphi_0) = b_{2l+1} + b_{2l-1} \cos(\varphi_0 + b_{2l}) \quad (3)$$

The parameters in this model were shown as follows. φ_0 denotes the frequency of the heartbeat signal. b_i represents the vector of $[b_1, b_2, ...b_{2l+1}]^T$, setting $b_i = \frac{a_i}{20}$ according to the prior knowledge about the relation between the amplitude of the thorax motion caused by breathing and that caused by heartbeat.

The random noise model: random white noise with the variance of 1.25 was generated. The activity signal model was established as follow:

$$D(n) = S + H + noise \quad (4)$$

The combined harmonic of the breathing signal $S(x, n, \omega_0)$ was used as a reference input signal of the adaptive filter. The mixed activity signals $D(n)$ were taken as the original input of the adaptive filter. Then, the adaptive harmonic cancellation was conducted. Setting the output signal of the filter as $h^{'}$, the following equation can be obtained:

$$h^{'} = D - S \quad (5)$$

So, the error can be expressed as:

$$\varepsilon = H - h^{'} \quad (6)$$

Based on the LMS criteria, the filter parameters were adjusted adaptively to make ε^2 acquire the minimum value. Thus, we can obtain the optimal heartbeat signal output $h^{'}$ after the filtering.

3. The Simulated of Family Care of the Body Posture Experiment

3.1. The Hardware System of the Experimental Radar

In the experiments, the non-contact biological radar was used to detect and monitor cardiopulmonary signs. The experimental platform of corresponding system hardwares includes several modules: the radar transmitting and receiving module, the signal preprocessing module, the signal collecting unit, the signal processing and display module. Moreover, the working frequency of the radar was 35GHz and the transmit power was 1MW. In addition, the radar transmitted the microwave beam through the bilateral antenna array and the system gain was 17dB. Moreover, the polygraph produced by American BIOPAC Company was applied in the signal collecting and control unit.

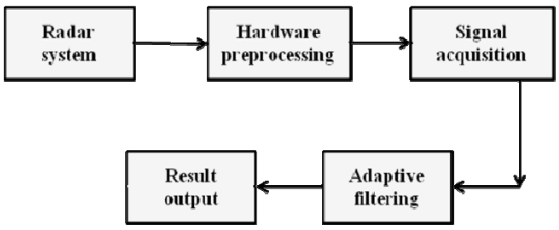


Figure 3. A Block Diagram of Non-Contact Bio-Radar Vital Signs Detection System

3.2. The Experiment Design

3.2.1. The Experimental Objects

16 healthy young man were chosen as experimental objects, their average ages among 24±4 years old, they were in good physical condition, no abnormal respiration and heartbeat feeling, no medical history. Before the experiments, the experimental objects had a good understanding of the means of the experimental signal acquisition and the radar work pattern in the life sign system based on the non-contact radar detection.

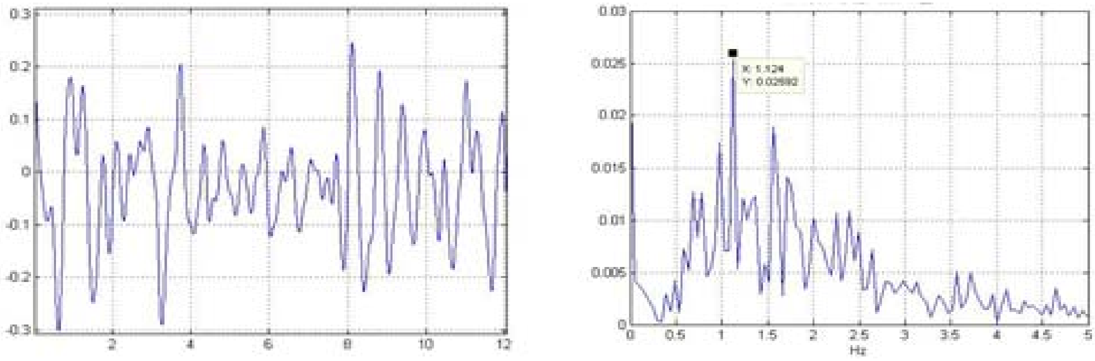
3.2.2. The Experimental Signal Acquisition Process of Respiration and Heartbeat

Experimental objects in sitting position, distance of radar detection and signal acquisition system in 4m, experimental process takes a deep breath type, taking a deep breath in the experimental object placed directly in front of a clock, set breathe once per 10 seconds. And inform the objects to avoid the shaking of the body during the process of data collection.

Respiration and body moving data from the radar and ECG amplifier synchronous acquisition of ECG signal by more than 16 channels physiological parameters recorder of A/D acquisition card input computer. Then, the data and the ECG were recorded and subsequent signal processing was conducted.

3.3. The Experimental Results and Discussion

3.3.1. The Body Movement Signal before the Filtering



(A) The Time Domain Graph (B) The Frequency Domain Graph

Figure 4. Filter Precursor Dynamic Signal Time and Frequency Domain Analysis

3.3.2. Harmonic Canceller by LMS Adaptive Filter Output After the Heartbeat Signal Spectrum and Synchronous Acquisition of ECG Signal Time-Frequency Diagrams

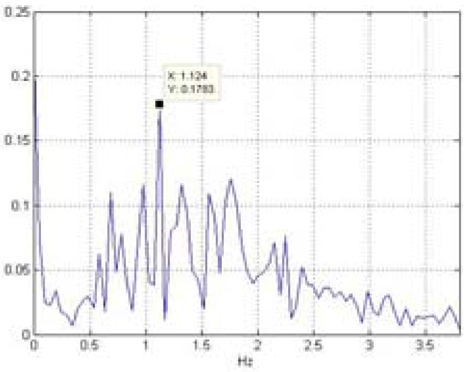


Figure 5. The Spectrum of the Filtered Signal

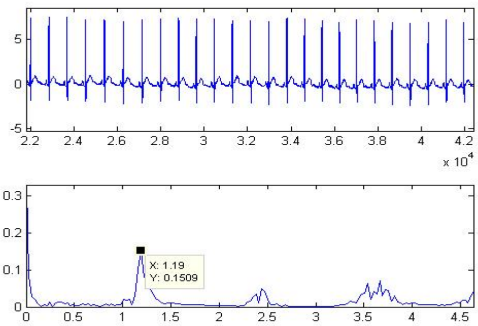


Figure 6. The Spectrum of the ECG Signal

Input dynamic signal waveform have burr, superposition with high frequency interference in the waveform. Input signal frequency domain graph shows at 1.124Hz signal amplitude is the largest, in the position of the 1Hz and 1.6Hz showed the amplitude is larger, at the same time, the signal noise mainly exist in the 1.5Hz to 4Hz frequency range.

Through adaptive filter processing, filtering after the original time domain signal superimposed on the body dynamic signal burr effect is smooth, periodic characteristics of the time domain waveform. Spectrum shown at 1.124Hz maximum amplitude, and position in 1Hz and 1.6Hz interference is suppressed, 1.124Hz, relative strengthening of energy. 1.5Hz to 4Hz frequency range of the noise is reduced but still exists.

Synchronous acquisition of ECG signal shows that the subjects of heart rate value is 1.19Hz, which confirmed after filtering the output signal spectrum in the 1.124Hz for a heartbeat signal. Suggests that by the algorithm can separate the heartbeat signals, calculating the heart rate and ECG signal frequency is consistent, and heartbeat signal outside the frequency signal amplitude was decreased, but the spectrum shows that the noise is still there. Heartbeat signals and ECG signal with the frequency of the error, error of 0.066Hz.

4.Conclusion

The non-contact monitoring system of the biological radar can detect the human life signs without direct contact with the human body. On this basis, the parameter characteristics of the signals are obtained. This can provide important basis for the clinical or home monitoring. Moreover, the abnormal body conditions can be timely estimated and the state of body health can be objectively reflected. In good experimental environment, the breathing signal can be separated from the activity signals through the filtering processing, when the experimental objects remain static. Due to the interference signals of breathing and body surface micro-motion, the spectral analysis on the activity signals in the echo signals shows the aliasing of higher harmonic of the breathing signal and the heartbeat signal. Therefore, the separation of the heartbeat signal becomes the technological difficulty. Based on the research group's experimental studies in the prior period, the radar echo signals were further analyzed. In the time domain, the micro-motion amplitude of the thorax caused by the breathing signal is larger, and the corresponding breathing signal is also stronger. In the frequency domain, the spectrum of the heartbeat signal is overlapped with the harmonic components of the breathing signal. Consequently, it is difficult to separate the breathing signal from the heartbeat signal effectively through the methods like simple filtering etc. Thus, it is in urgent need to investigate the effective signal separation algorithm. Only in this way can the heartbeat signal restrained and interfered by the echo signals of the breathing movement and body surface micro-motion be separated under the background of strong noise.

The adaptive filtering presents no clear requirements for the statistical properties of the noise and the signals. Thereby, according to the preliminary test characteristics of the original input signals, the parameter setting of the filter is adjusted adaptively to output the desired signals. Taking the higher harmonic of the breathing signal as the input signal of the adaptive filter, this research proposed the adaptive harmonic cancellation algorithm based on LMS. First, the simulated lying down experiments with the clinical monitoring was designed. Then, the activity signals collected in the experiments were processed using the adaptive harmonic cancellation algorithm. Thus, the signals after the filtering were obtained. Subsequently, the spectral analysis on these signals was conducted. The results obtained are in consistence with the ECG spectrum of synchronous acquisition. Besides, at this frequency point, the energy value of the signal reaches to the maximum. This fully illustrates that the signal obtained after the filtering is the heartbeat signal. Meanwhile, the signal spectrogram after the filtering reveals that the energy at other frequency points is restrained. Thus, the experiments show that the adaptive harmonic cancellation algorithm based on LMS can effectively separate the heartbeat signal from the activity signals obtained by the non-contact radar detection. Meanwhile, the corresponding parameter values are acquired. These results of the algorithm provide the reference basis for the clinical and home monitoring.

Acknowledgements

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