Radar Life Signal Processing Algorithm Based on Improved EEMD

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Abstract. Non-contact measurement of human vital signs is of great significance to the construction of smart homes and hospitals. The vital signal extracted from the FMCW radar contains a lot of noise. In order to reduce the noise impact and improve the life signal detection results accuracy, Ensemble Empirical Mode Decomposition (EEMD) algorithm is studied, and a new method based on the combination of EEMD and Translation Invariant Wavelet Transform (TIWT) is proposed. This method firstly decomposes the original signal using EEMD to obtain several Intrinsic Mode Function (IMF) components, and then changes the arrangement order of IMF by Translation Invariant Wavelet Transform to change the position of the singularity in the whole signal to reduce or eliminate the oscillations. Finally, signal screening is completed and life signals are reconstructed. Experiments show that, the proposed method has better detection accuracy in detecting vital signs collected by radar.

1. Introduction
Cardiopulmonary information, as two major criteria for human health evaluation, is of great significance for understanding the state of the body [1-2]. Compared with non-contact methods such as infrared thermal imaging technology and camera analysis, radar-based non-contact life signal detection results are more stable and less susceptible to ambient thermal radiation, light and other environmental factors[3]. It is the key to a variety of applications, such as sleep monitoring, remote patient monitoring, driver safety assistance system, etc[4-6].

In practice, the random noise in radar acquisition of vital signs is smooth, nonlinear, commonly used filter is difficult to effectively solve the problem of harmonic interference, and the frequency band containing the vital signal will be filtered out [7], Zhaohua Wu et al. proposed the EEMD algorithm. This algorithm added white Gaussian noise and filled the whole time-frequency space with the characteristics of binary filter banks of EMD, thus solving the modal mixing problem [8]. In the processing of low and medium frequency signals, different signals plus noise may lead to different mode numbers. Liu Zhenyu et al. proposed the ICEEMDAN algorithm, which was applied in the classification and detection of radar life signals [9]. However, the proposed correlation did not enhance the periodicity of signals, and only extracted the two components with the largest correlation for reconstruction, and the results still had large errors.

Based on this, this paper proposes an integrated empirical mode decomposition and shift-invariant wavelet processing method (TI-EEMD). Research by changing the sequence of signals, the position of singularities in the whole IMF component is changed, so as to reduce or eliminate the possibility of vibration radar life signal noise, improve the applicability of the EEMD algorithm in the processing of...
radar vital sign signals, and reduce the measurement error of the algorithm in the short and medium distance.

2. Radar life detection algorithm of eemd
FMCW radar transmitting antenna sends frequency-modulated continuous wave to the space, and generates echo signal after touching the target, which is received by the receiving antenna. In other words, the received signal can be regarded as the delay of sending signal [10].

During radar sampling, singularities are easy to appear in the sampled signals, causing problems such as signal discontinuity and skipping distortion. Through analysis, the implementation process of radar vital sign detection algorithm (TI-EEMD) based on translation invariant wavelet and empirical mode decomposition is proposed. The steps are as follows:

Step 1: In the initial signal, white noise with an expectation of 0 and constant power spectral density is added to form the signal to be processed;

Step 2: The signal to be processed is taken as a whole and decomposed by empirical mode decomposition.

Step 3: Repeat the first step and the second step for a total of m times, and each time the white noise conforming to the new normal distribution is added.

Step 4: do integrated average processing for IMF components, so as to solve the problem that IMF components are affected by adding white noise.

Then the translation and reconstruction of the intrinsic modal function are carried out:

Step 1: Take each component of the IMF as the overall signal, and then cycle shift the signal separately.

Step 2: After displacement processing, the contradiction of discontinuity points may appear in the signal. The optimal displacement at one point may lead to poor results at another continuous point. Therefore, it is necessary to adopt the multi-average method for the processed signal.

Step 3: Complete signal spectrum calculation and signal reconstruction.

The selection principle of signal reconstruction is based on the frequency classification of respiration and heartbeat. The reconstructed signal is converted into time frequency to obtain signal frequency, which is used for data comparison. The method effectively eliminates the signal noise, ensures the single scale feature of the decomposition mode, and carries on the nonlinear processing to the signal model, and improves the data detection accuracy.

3. Experimental analysis
3.1. Algorithm Simulation
In order to verify the feasibility and advantages of the TI-EEMD algorithm, the simulation test of the algorithm was carried out first. Adult normal respiratory rate 0.20 ~ 0.33Hz; The normal heart rate is 1.00 ~ 1.33Hz[11]. Assumptions vital signs parameters of the target under test as shown in table 1, due to the radar acquisition of vital signs information also includes all kinds of noise, therefore, in order to simulate the indoor noise radar signal interference, joined the white noise in the simulation signal, this helps to further test algorithm is practical, after the simulation signal is shown in figure 2.

| The specific value   |
|---------------------|
| Heart rate(Hz)      | 1.3     |
| Heart amplitude(m)  | 0.001   |
| Breathing rate(Hz)  | 0.3     |
| Breathing amplitude(m)| 0.005  |
The frequency diagram after waveform reconstruction is shown in Fig.3 and Fig.4. EEMD algorithm can also complete the separation and reconstruction of life signals, but the obtained results differ greatly from the actual simulation data. The error of heartbeat frequency was 28.46%, and the error of heartbeat amplitude was 39.17%. The overall effect was not ideal. Compared with the actual simulation data, the respiration rate error is 3.3%, and the respiration amplitude error is 0.14%. The error of heartbeat frequency was 1.54%, and the error of heartbeat amplitude was 13.5%. Compared with the EEMD algorithm, the TI-EEMD algorithm was significantly improved in the processing of simulated life signals, indicating that the algorithm was feasible and effective for processing life signals.

3.2. Experiment and comparison

In order to further verify the feasibility of the experiment and compare it with the ICEEMDAN algorithm, the testers wore photoelectric heart rate products during the radar test, and the measured data can be used for reference. To reduce the randomness of the experiment, a total of three testers were selected. The details of the tester are shown in Table 2.

| The tester | gender | age | height(cm) | weight(kg) |
|------------|--------|-----|------------|------------|
| A          | male   | 25  | 175        | 72         |
| B          | male   | 24  | 179        | 68         |
| C          | female | 24  | 164        | 51         |

In the process of experimental data collection, the radar is placed next to the computer, and the tester is sitting in front of the radar sensor, and basically remains stationary. Each tester carried out 2 groups of experiments. In the first group, the distance between the tester and the radar was 0.5 meters. In the second experiment, the two were separated by 1.0 meters, and each experiment lasted for 20 seconds.
Table 3. Experimental results at 0.5 meters.

|                | A  | B  | C  |
|----------------|----|----|----|
| The reference rate (Hz) | 1.183 | 1.017 | 1.433 |
| EEMD measures heart rate (Hz) | 1.069 | 0.897 | 1.261 |
| TI-EEMD measures heart rate (Hz) | 1.170 | 1.031 | 1.472 |
| EEMD error (Hz) | 0.114 | 0.120 | 0.172 |
| TI-EEMD error (Hz) | 0.013 | 0.014 | 0.039 |

Table 3 and Table 4 respectively show the error between the heartbeat signal extracted by the tester at 0.5m and 1.0m by EEMD and TI-EEMD method and the reference value. In the two experiments, the error of female subjects was larger, and it was believed that the respiration amplitude of female subjects was lower than that of male subjects, and they were more likely to be interfered by respiratory harmonics.

Table 4. Experimental results at 1.0 meters.

|                | A  | B  | C  |
|----------------|----|----|----|
| The reference rate (Hz) | 1.033 | 1.016 | 1.200 |
| EEMD measures heart rate (Hz) | 0.857 | 0.852 | 0.967 |
| TI-EEMD measures heart rate (Hz) | 1.055 | 0.978 | 1.155 |
| EEMD error (Hz) | 0.176 | 0.164 | 0.233 |
| TI-EEMD error (Hz) | 0.022 | 0.038 | 0.045 |

Compared with EEMD and ICEEMDAN algorithms, as shown in Table 5, the overall average error of the data obtained by TI-EEMD algorithm is improved compared with both EEMD and ICEEMDAN algorithms. Among them, the results processed by EEMD algorithm have the largest error and the worst stability. As can be seen from Table 6, the data of EEMD and ICEEMDAN algorithms fluctuated greatly in the measurement process and lacked robustness. In these three experiments, the robustness of TI-EEMD was improved. Compared with EEMD and ICEEMDAN algorithms, heart rate standard deviation increased by 0.021 and 0.020 on average. The experimental results show that the vital sign information collected by the radar based on this method has a high consistency with the reference data.

Table 5. Comparison of EEMD, ICEEMDAN, TI-EEMD experiments.

| Distance (m) | methods | Maximum error (Hz) | Minimum error (Hz) | The average error (Hz) |
|--------------|---------|--------------------|--------------------|------------------------|
| 0.5          | EEMD    | 0.172              | 0.114              | 0.135                  |
|              | ICEEMDAN| 0.130              | 0.000              | 0.040                  |
|              | TI-EEMD | 0.039              | 0.013              | 0.022                  |
|              | EEMD    | 0.233              | 0.164              | 0.191                  |
| 1.0          | ICEEMDAN| 0.120              | 0.000              | 0.050                  |
|              | TI-EEMD | 0.022              | 0.045              | 0.035                  |

Table 6. Standard deviation of EEMD, ICEEMDAN, TI-EEMD heart rate experiment.

| Distance (m) | EEMD  | ICEEMDAN | TI-EEMD |
|--------------|-------|----------|---------|
| 0.5          | 0.030 | 0.038    | 0.012   |
| 1.0          | 0.045 | 0.036    | 0.022   |
4. Conclusion

In this paper, a radar vital signs detection and extraction algorithm based on TI-EEMD is proposed. The simulation results show that the proposed algorithm can effectively process the simulated vital sign signals, and the performance of the proposed algorithm is verified by comparing the actual measurement with other algorithms. The results show that this method can effectively suppress clutter and is more suitable for extracting vital signals from the original signals of FMCW radar. With the increase of the measurement distance, the interference of the space environment interference antenna radiation will increase, affecting the accuracy of the results. In the future, we will focus on the improvement of the hardware and software system, so as to realize the medium and long distance detection.

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