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Detection of Breathing and Heartbeat by Using a Simple UWB Radar System

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***Abstract*—We present the development on an ultra-wideband (UWB) radar system and its signal processing algorithms for detecting human breathing and heartbeat in the paper. The UWB radar system consists of two (Tx and Rx) antennas and one compact CMOS UWB transceiver. Several signal processing techniques are developed for the application. The system has been tested by real measurements.**

***Index Terms*—UWB radar application; wavelet; empirical mode decomposition, breathing monitoring; heartbeat detection.**

I. Introduction

Ultra-wideband (UWB) radars are widely used in different applications, such as through-wall tracking and detection [1], medical monitoring instruments [2], life detection [3], industry processing monitoring [4], etc. Several distinct advantages make UWB radar systems attractive: i) good time domain resolution and therefore accurate tracking and positioning; ii) strengthened target recognition; iii) robust immunity to passive jamming; iv) relatively low cost.

In this paper, a simple compact UWB radar system [5] is applied to the application of breathing and heartbeat detection. An experimental vibration system with a known frequency is set up as an emulating model for heartbeat in order to develop signal processing algorithms. Based on the experiment data and true human measurements, several signal processing algorithms, such as wavelet, empirical mode decomposition, are explored and implemented. Promising results are achieved.

II. System Calibration

System calibration is applied to clarify the system property and identify potential interferences that could compromise the measurements, such as temperature effect and jamming. The results conclude that the interferences could have significant impact on measurements of minor movement such as human heartbeat. Thus, adjustments corresponding to these have been done on the further experiment environment setups, including discarding data collected during heat up period and performing measurements in electromagnetic shielded environment.

III. Breathing Moniteroring

The setup for breathing detection is as shown in Fig. 1: two Vivaldi antennas are placed in parallel with d_a = 12 cm, and one person is sitting in a chair with a distance d_{obj} = 24 cm between the chest and the outer edge of the antennas.

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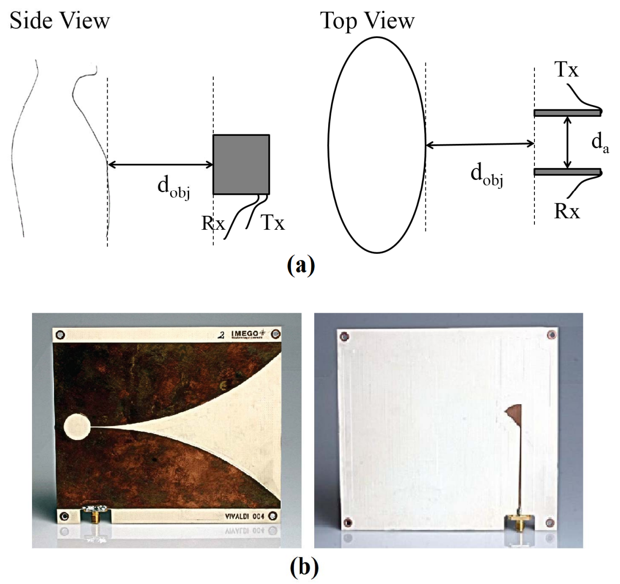

Figure 1. Experimental setup of breath detection (upper) and the Vivaldi antenna (lower).

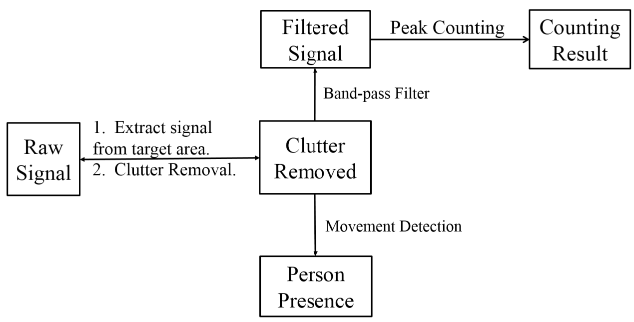

Figure 2. Signal processing procedure diagram for breath detection.

In the experiment phase, measurements have been done for 60 seconds continuously. Then the collected raw data has been processed following the procedure in Fig. 2.

As depicted in Fig.2, based on the distance between the human and the antennas, it is possible to extract signal from the area that covers the human's position. Then, by applying singular value decomposition method to remove the reflection from the static objects in the signal (please refer to [1]), an enhanced clutter-removed signal is obtained. The clutter-removed signal is been further processed in order to do the movement detection as well as the breath signal reconstruction.

A differential phase method is applied here for movement detection: for two identical signals with a time delay, the time delay could be obtained by Fourier Transform [1].

Suppose s_1 and s_2 are identical signals with a phase shift:

$$s_2(\tau) = s_1(t - \tau) \quad (1)$$

By applying Fourier Transform we have:

$$S_1(\omega) = S_2(\omega)\, e^{-j\omega\tau} \quad (2)$$

Where τ is the time shift between two consecutive measurements, which is positive when the patient is exhaling and negative when inhaling. Therefore:

$$S_1(\omega) / S_2(\omega) = e^{-j\omega\tau} \quad (3)$$

Thus, the angel of $S_1(\omega) / S_2(\omega)$ could be obtained by:

$$\text{angel} = -j\omega\tau \quad (4)$$

Since human breath is a slow periodic movement, the statistical distribution of the reflection from the breathing chest is centered at a low frequency. Fig. 3 is the comparison of the movement detection results with and without presence of a person. The breathing can be detected by a simple Generalized Likelihood Ratio Test (GLRT).

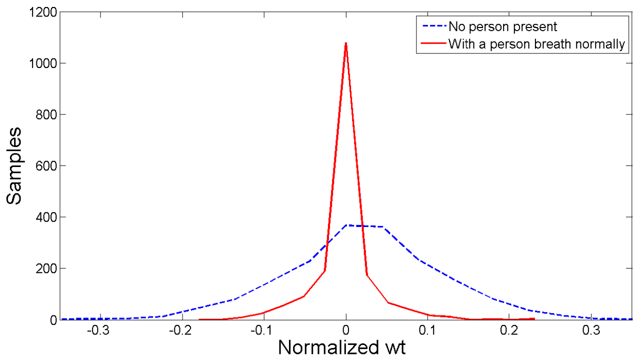

Figure 3. Signal extracted for movment detection.

Results from one minute continuous measurements can be found in Fig. 4. After preliminary processing, the breathing and heartbeat signals are assumed to be additive as shown in Fig. 4. The 'envelop' is considered as the breathing signal and the higher frequency components is the heartbeat.

IV. HEARTBEAT DETECTION

First, human heartbeat movements are emulated by using a vibrating corner reflector, as shown in Fig. 5. The experimental setup contains a function generator, a vibrator, a corner reflector, and our UWB system. To rule out jamming from other sources in order to develop and test signal processing (SP) algorithms in the early stage of the work, the experimental setup, except the desktop computer, was placed inside a magnetic shielded (MS) room. Different signal processing (SP) techniques, including band-pass filtering, empirical mode decomposition (EMD) and wavelet packets, are explored and applied to different scenarios, as shown in Fig.6.

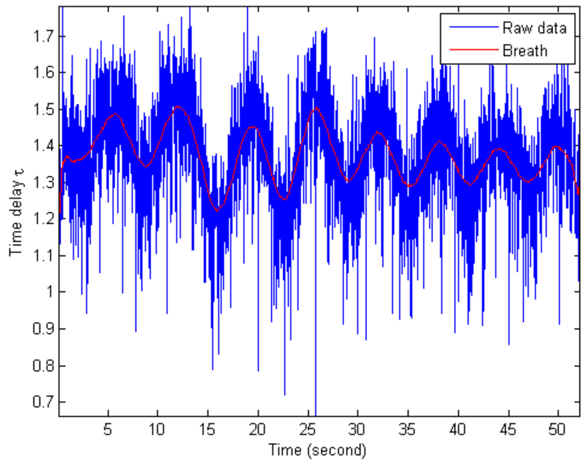

Figure 4. Breath signal reconstruction from measurements during 55 seconds.

Figure 5. Experimental setup of vibrating corner reflector.

The result of a moving metal plate with 1.5 Hz frequency is shown in Fig. 7. Although the reconstructed signals share high similarity in frequency domain, the signal processed by the FIR1 filter contains side lobes with higher amplitude. However, it can be used as a complementary approach in later experiments.

Then, the tested approaches are applied to the detection of human heartbeats with the same setup as breathing detection presented in Fig. 1 (a). The only difference is all measurements are done in MS room like the simulation experiment above in order to rule out Jamming. An adjusted signal processing flow was used, as shown in Fig.8.

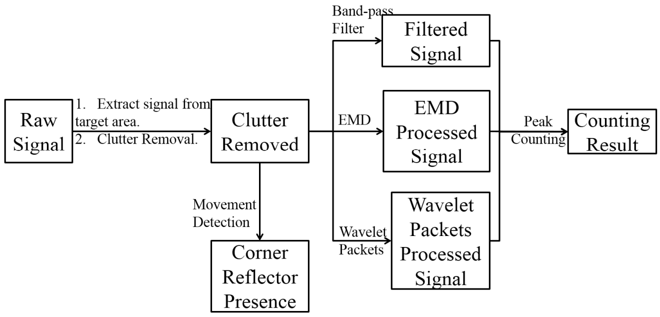

Figure 6. Signal processing procedure diagram for corner reflector movment detection.

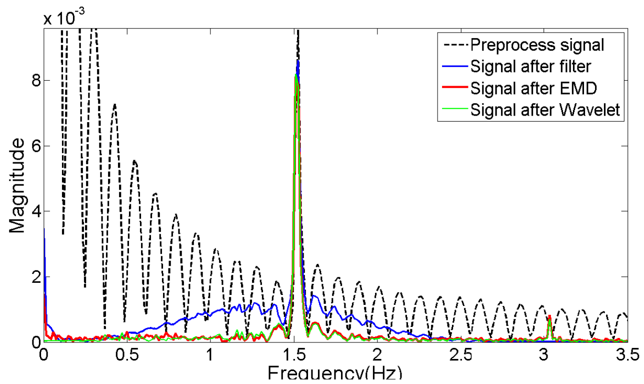

Figure 7. The results of signal of one sample with 1.5 Hz movement processed in the frequency domain.

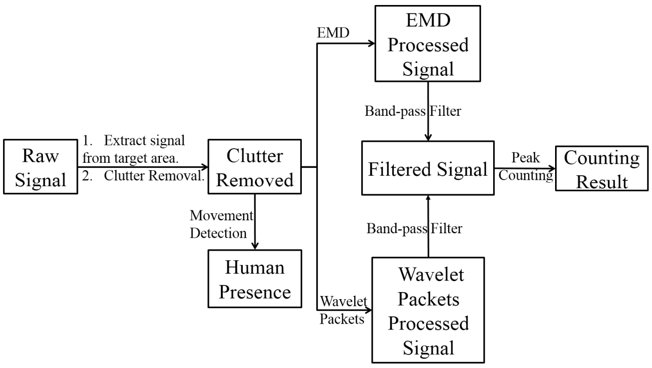

Figure 8. Signal processing procedure diagram for heartbeat detection.

As depicted in Fig. 8, two methods are applied to the clutter removed signal: EMD and Wavelet Packets. EMD is a nonlinear technique that can decompose a signal into finite components known as Instantaneous Mode Functions (IMF), which was developed by N.E. Huang in 1998. Specifically, the algorithm used in this paper achieves the target signal s(t) decomposition by the following steps [6] :

- Find all minima and maxima extremes and plot a curve for each set by using cubic spline interpolation, which are the blue and red curves respectively.
- Compute the mean values between the maxima and minima curves, and make a residual curve r(t) which is the pink one in the figure.
- Get the detail known as IMF by d(t) = s(t) − m(t).
- Repeat the process above on the residual r(t) until it fits the stopping criteria.

The stopping criteria can be defined based on the requirement of the analysis. In this project, an existing library is used for calculation which defines the calculation stops once all condition below are satisfied [7]:

- For each point, $mean_{Amplitude}(t) < 0.5 * amplitude(t)$;
- mean of $bool_{criteria}(t)$ less than 0.05;
- There are less than two extremes in the curve.

where

$$mean_{Amplitude(t)} = abs(max_{Amplitude}(t) + min_{Amplitude}(t))/2 \quad (5)$$

$$amplitude(t) = abs(max_{Amplitude}(t) - min_{Amplitude}(t))/2 \quad (6)$$

$$bool_{criteria}(t) = (mean_{Amplitude}(t)/amplitude(t)) > 0.05 \quad (7)$$

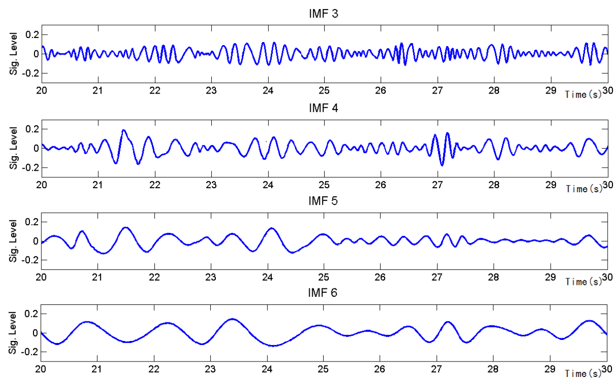

Figure 9. Four IMFs that decomposed from the clutter removed signal, which are used for heartbeat signal reconstruction.

Fig. 9 shows four IMFs that are decomposed from the clutter removed signal. By combining them together, a rough reconstructed heartbeat signal could be obtained [8].

Another technique is the wavelet decomposition. The wavelet decomposition is a technique for decomposing time series with different scales and times. [9] By using Wavelet transform, a signal could be divided into two parts: Signals in lower frequency (refereed as A, which stands for 'Approximation coefficients') and higher frequency (referred as D, which stands for 'Details').

By using wavelet packets, the wavelet transform is first applied to the original signal to get A and D. Then the transform is applied again on both A and D and their outcome respectively. Hence, this analysis will produce a binary tree with root node on the top of the tree and *2n* on the *n*th level of the tree. By doing this, the frequency components can be selected according to our interests.

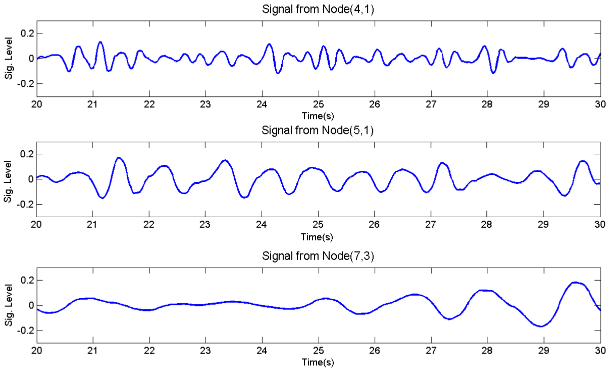

Figure 10. Three sub signal that decoposed from the clutter removed signal, which are used for heartbeat signal reconstruction. Node (4, 1) indicates the node is the 1st node on the 4th level of the binary tree.

Fig. 10 shows three nodes that are decomposed from the clutter removed signal. In order to reconstructed heartbeat signal, we can combine all signals from nodes that are within our interest frequency range.

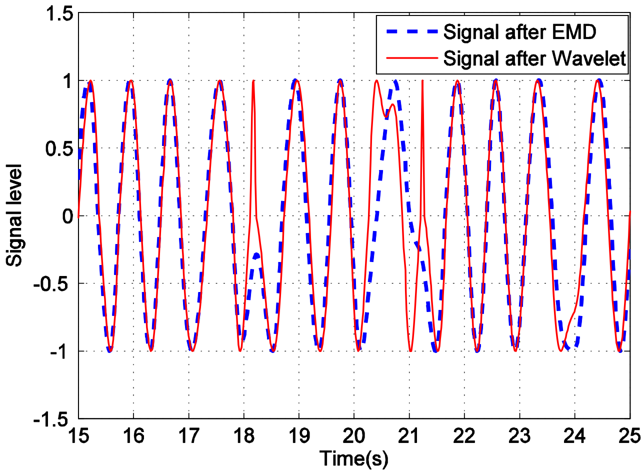

Figure 11. Heartbeat signal reconstruction from continuous measurements.

In the reality, the breathing and the heartbeat signals are additive together in the receiving signals, as shown in Fig. 4. The 'envelop' is considered as the breathing signal and the higher frequency components is the heartbeat which is of our interest. By applying EMD and wavelet packets methods, both the breathing and the unwanted components with higher frequencies than the heartbeat are sufficiently suppressed. One example of the reconstruction results in time domain is shown in Fig. 11. We can see that the outcome of both methods share high similarity on their shapes and synchronized at their peaks.

V. CONCLUSIONS

In this work, possible applications are implemented and tested using one UWB radar chip. Breath detection is one of the most promising possibilities for patient monitoring in an open area or even through a wall due to its penetration ability. From the experiments using the corner reflector and measurements of real heartbeats, we conclude that it is possible to detect small movements with ±0.5mm amplitude using the radar system. The wavelet packets and EMD methods are applied to suppress clutters and interference and the heartbeats are reconstructed by periodic sinusoid.

Although there are many previous studies focusing on certain vital signs [8] or signal to noise and clutter ratio improvement [10], but with the performance of current system, by combining different signal processing methods, the system can achieve effective measurement both off-line and in real time with less power and smaller antennas. Therefore, better mobility is achieved.

As future work, more radar modules can be utilized simultaneously to achieve better resolutions in two or three dimensions for ranging and tracking applications. By using the correlation between the signals from different radar modules, a higher signal to noise ratio could be obtained.

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