A new method for vital sign monitoring using IR-UWB radar

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Abstract. Quadrature Demodulation IR-UWB radar is a new form of impulse-radio Ultrawide Band (IR-UWB) radar and it can improve the resolution of distance measurement. This paper focuses on a new method for vital sign – specifically breathing rate and heart rate – from the phase of recorded I/Q signals, using Quadrature Demodulation IR-UWB radar. The results of the experiment show that a better estimation of heart rate can be got from such a new method based on the phase difference.

1. Introduction
IR-UWB radar transmits pulse impulse series at a certain frequency. The pulse series is transmitted by the antenna and reaches the measured object through the channel.[1]-[2] The measured object will reflect the pulse back to the receiving antenna of the radar. Pulse impulse signal is simple so that it can be transmitted without modulation, which is helpful to make the radar device simplified to reduce difficulty in producing the radar. The receiving signal is \( y(t) = \sum \delta(t - nT_s - t_{11}) \ast h(t) \), therefore the distance between radar and measured object is \( d = t_{\text{11}} \cdot c/2 \), where \( c \) is the speed of light, \( t_{\text{11}} \) is the time difference between the radar transmitting pulse and receiving echo. So, if the radar is setup appropriately, we can get the distance between human’s chest and the radar every time when radar transmits a pulse. With it, the distance changes because of breath and heartbeat can be recorded to estimate the breathing rate and heart rate[3]-[8].

The Quadrature Demodulation IR-UWB radar can Quadrature Demodulation the signal to improve the resolution of distance measurement[9]-[10]. Therefore, the tiny movement of human’s chest is easier to get, so that the estimation of heart rate can be more accurate.

The paper is organized as flows. Section 2 presents a new signal processing method of the radar. Experiment result is in Section 3. At last, the conclusion discusses in Section 4.

2. Signal Processing method
The following figure is the steps of signal processing.
Figure 1. Diagram of Signal processing

Using the changes of phase signal can get the distance of a higher resolution. To get the phase signal, we should use Analog-to-digital conversion (ADC) on the receive reflection at first, and then Quadrature Demodulation the digital signal. We can put the signal received in a pulse repetition cycle, and transform the signal into frequency domain using fast Fourier transform (FFT). By dropping the DC component and negative spectrum component, and then using inverse Fourier transform to get the I/Q signal, also called the phase signal.

The breathing rate range from 8 beats/min to 45 beats/min, that is 0.133 Hz - 0.75 Hz. The range of heart rate is between 45 beats/min - 150 beats/min, that is 0.75 Hz - 2.5 Hz. So, the pulse repetition frequency (PRF) should be set to at least 2.5 \times 4 = 10 Hz. The frequency response of first order difference filter at the 10Hz sample rate shows in the figure 2.

Figure 2. The frequency response of first order difference filter

Coincidentally, the frequency response below 0.133 Hz is very low, and the frequency response in 0.133 Hz - 0.75 Hz is lower than -3 dB while 0.75 Hz - 2.5 Hz is between -3 dB and 3 dB. So that use such a filter can filtrate the response signal due to the little movement of human body. It can also control the harmony causing by breathing due to the radio between breathing rate and the heart rate is 1:4[11]. In conclusion, it can make the heartbeat signal easier to be detected.

After Quadrature Demodulation, the distance change $\Delta d$ should be calculated as
\[ \Delta d = \frac{\lambda \Delta \phi}{2 \pi} \]

where \( \Delta \phi \) the weighted average of the phase difference,

\[ \Delta \phi = \frac{\sum_{i=1}^{n} w_i \cdot \arg(\Delta k_i)}{\sum_{i=1}^{n} w_i} \]

where \( \Delta k_i \) the single-phase difference,

\[ \Delta k_i = y[n, x_i] \cdot y[n, x_{i-1}] \]

and the weight \( w_i \)

\[ w_i = \text{Im} (\Delta k_i) \frac{|y[n, x_i]|}{\max(|y[n, x_i]|)} \]

where \( y[n, x_i] \) is the signal matrix of the radar, in which \( n \) represents different pulse repetition cycle, \( x_i \) represent different range bin, which also means the time after a pulse impulse have been transmitted.

After getting the distance change, it will be transformed into frequency domain. The peak in range 0.133Hz-0.75Hz represents its corresponding frequency is breathing rate, while the corresponding frequency of the top between 0.75Hz-2.5Hz means heart rate.

3. Experiment results

The impulse-radio Ultrawide Band (IR-UWB) radar used in this work is Acconeer XR112, which provides flexible pulse repetition frequency (PRF), and measurement distance while it is low energy consumption. It generates a pulse with a central frequency of 60Ghz, which is in an unauthorized frequency band so it can be easily used in an actual product. As the figure 3 shows, in this experience, a healthy adult male sit still at about 30cm from the radar antenna and the PRF=10Hz. The measurement distance is from 18cm to 120cm. We use an electrocardiograph (ECG) HealForce PC-80B as a reference sensor of heart rate at the same time.

![Figure 3. Experiment setup](image)

The figure 4 and figure 5 show the normalization frequency response of distance with difference and without difference.

![Figure 4. with difference](image)
![Figure 5. without difference](image)
From the result, we can get that the estimate of the heartbeat is 71 beats/min while the heart rate result from reference sensor is 75 beats/min.

We can define a signal-to-noise ratio (SNR) to quantify the results, the SNR is given as below [12]:

\[
\text{SNR} = 10 \log \frac{\int_{f_{min} - B/2}^{f_{max} + B/2} \left| P(f) \right| df}{\int_{0}^{\infty} \left| P(f) \right| df - \int_{f_{min} - B/2}^{f_{max} + B/2} \left| P(f) \right| df}
\]

where B represents the resolution of the frequency, \( P(f) \) represents the frequency spectrum at frequency \( f \). \( f_{max}-f_{min} \) represents the maximum frequency and the minimum frequency. The SNR of heart rate with phase difference is -21.5161 dB, comparing to -25.7739 dB without phase difference. We can get an SNR improvement for heartbeat signal is 4.2578 dB. Higher SNR makes it easier to get an accurate estimation of heart rate especially in a complex environment.

4. Conclusion

Comparing the results with phase difference and without phase difference, we can conclude that the heart rate estimation result is better with phase difference. But the result is got from short distance from the radar to human body and need do more to find the result in the longer distance.

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