Design issues in vital sign monitoring through IR UWB radar

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***Abstract*—Measurement of respiration and heartbeat rate through IR UWB radar has been discussed; the main issues related to the extraction of heartbeat signal from the received signal are also described. An algorithm for estimation of heartbeat frequency from the received signal has been proposed. A notch filter bank is used to find the maximum peak frequencies in the observation frequency range of about 1Hz to 3 Hz. The heart rate may be estimated even if its magnitude is not the maximum in the specified range of frequencies. The main contribution of this paper is to differentiate the heart rate from the closely located respiration harmonics by adjusting the frequency resolution and notch filter bandwidth.**

***Keywords*—Vital Signs, Respiration Rate; Heartbeat Frequency; Notch Filter; Harmonics**

I. INTRODUCTION

IR UWB technology has a variety of applications due to robustness in harsh environment, accurate positioning and its higher penetration capabilities [1]. UWB is used in the medical applications because of its low power consumption [2] and larger spatial resolution [3]. Since UWB has larger bandwidth and lower power spectral density, therefore, it has smaller electromagnetic interference and Specific Absorption Rates [3].Vital sign monitoring is important in situations such as non-invasive patient monitoring, searching for people after natural disasters[3][4]. In [5-7] it is shown that UWB technology can estimate vital signs i.e. respiration and heartbeat rate and can be helpful in continuous health monitoring of a patient.

The respiration signal has larger amplitude as compared to the heart signal, therefore, it is relatively easy to estimate the respiration frequency by searching for the peak value in the Fourier Transformed received signal. The heart rate signal is lower in magnitude and it is located close to the second and third harmonics of the respiration signal; which makes it harder to estimate [2]. In order to differentiate the heart rate signal from respiration harmonics, the bandwidth of the notch filter should be as narrow as possible.

The received signals are stored in a matrix of size$(\mathrm{m} \times \mathrm{n})$, where m represents the number of samples in slow time, while n show the samples in fast time. First of all, we find the column by searching for maximum energy. Then FFT is applied to that column. The depth of the column $'n'$ shows the resolution of the pulses in the frequency domain. If the breathing harmonic and heart rate frequency are located closely, then the depth of column need to be greater so that it result in narrower pulses; and design of filter with narrow band becomes feasible. By increasing the depth of matrix and designing a narrowband notch filter, it becomes possible to differentiate between closely located breathing harmonic and heart rate.

II. PROPOSED ALGORITHM

After receiving the signal reflected from the human sitting in front of radar, it is passed through an averaging filter to remove the clutter; the breathing frequency is calculated from the maximum peak location of the received signal spectrum. Selection of number of samples for frequency calculation decides the bandwidth of the notch filter. The sampled signal is transformed to frequency domain by FFT function. The signal contains harmonics of breathing frequency and intermodulation components in the range of the heart signal frequency [2], therefore, it is necessary to sort out some method to extract heart signal from comparably stronger harmonic and intermodulation products.

Let 'N' represent the number of desirable maximum peak points and x_1 and z_1 be the received signal and its Fourier Transform respectively. 'M' represents the number of iterations. For each of the iteration, window for Fourier transform is changed in a sliding fashion. The novelty of this algorithm is that it selects 'N' peaks points as compared to a single peak point in the literature and it also counts the number of each peak point over 'M' iterations. Then it selects the heart rate on basis of maximum repetition and mean amplitude.

Algorithm: Heart Rate Estimation

Recursion: $k = 1 \dots M$

1. Find 'N' peak points:
2. Remove Breathing Harmonic Components:
Use a comb filter for removing all harmonics of breathing signal or use a bank of notch filters. The selection of bandwidth of notch filter is discussed in the next section.
3. Count the number of repetition of peak points through the 'M' iterations.
4. Measure the mean magnitude of all the peak points.
5. Select the heart rate among the mostly repeated components which has the largest mean magnitude.

This algorithm ignores those peak points which are not repeated even if their magnitude is greater than the heart component. The shortcoming of the previous algorithms is that only the peak magnitude is considered which may not always be the heart signal. But in the proposed algorithm even if the heart signal is not the maximum, it is stored in an array and checked if it repeats regularly for ‘M’ number of iterations then it is assumed as heart rate on basis of its repetition and mean magnitude.

In the proposed algorithm, we require notch filter bank for cancellation of the peak values in order to find the next peak value. The bandwidth selection for the notch filter is a critical issue as it can filter out two components simultaneously if the bandwidth is kept higher. The bandwidth is inversely related to the number of samples provided to the FFT function.

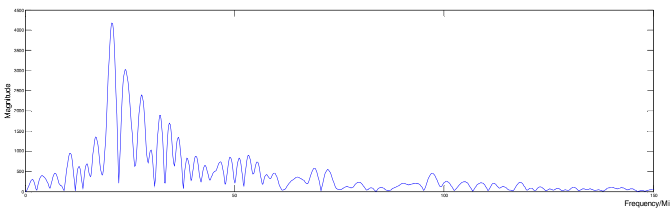

Fig. 1. Narrower pulses in frequency due to Larger Observation Samples

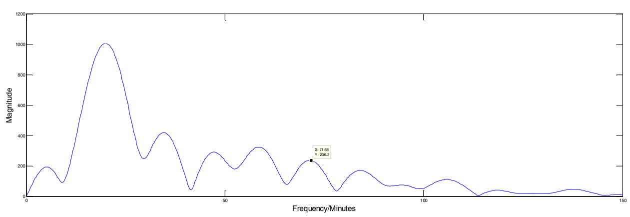

Fig. 2. Wider pulses in frequency due to Larger Observation Samples

For the spectrum of Fig. 3 the number of observation samples was 2000 while for the spectrum obtained in Fig. 4, only 500 samples were considered for FFT operation.

III. EXPERIMENTAL RESULTS

The effect of depth of the matrix on the pulse width is observed.

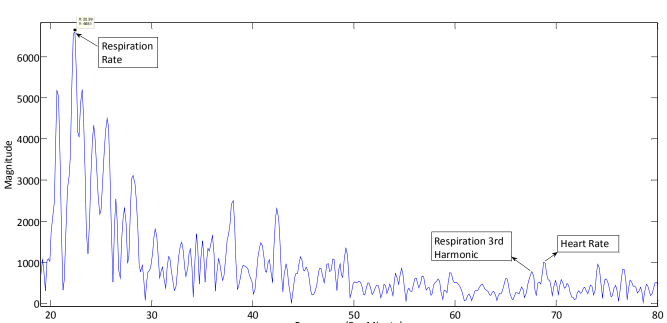

Fig. 3. Heart Rate and third Respiration harmonic are located closely

The bandwidth of the notch filter for cancelling the harmonics is kept 0.005-0.02 Hz and the depth of the matrix is varied over a range of 300 to 3000 and it shown better performance as the matrix depth is increased and filter bandwidth is decreased. The real heart rate value was 69.4489, while the value achieved by experiment was 69.0918 when the filter bandwidth was 0.01 Hz and number of samples used in FFT was 3000. When the notch filter bandwidth was changed to 0.03 Hz, it also cancelled the heart signal; and the wrong heart rate of 74 was detected. Therefore, the bandwidth of the filter for cancelling harmonics should be taken care of.

IV. CONCLUSION AND FUTURE WORK

In this paper, the design issues related to heart rate estimation are discussed. The depth of the matrix and bandwidth of notch harmonic canceller can be adjusted to differentiate between closely located heartbeat signal and harmonic of respiration signal. An algorithm is proposed for selecting the heart rate signal which may be sometimes weaker in magnitude than the breathing harmonics and intermodulation components. Furthermore, the variation of magnitude of intermodulation products also needs some investigation. Mathematical relationship between the bandwidth of Notch Filter and number of samples used in each FFT operation is also important for designing sharp Notch Filters for harmonic cancellation.

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