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A New Algorithm for Detection of Heart and Respiration Rate with UWB Signals

Mehran Baboli, *Student Member IEEE*, Olga Boric-Lubecke *Senior Member, IEEE*, Victor Lubecke, *Senior Member, IEEE*

Abstract— **Proposed is a detection algorithm for physiological monitoring with Ultra Wide Band (UWB) radar. This new algorithm is based on detection of movement energy in a specified band of frequency using wavelet and filter banks. One of the advantages of this algorithm is its ability to detect heart and respiration rates of a subject in an environment containing other motion. The heart movement is detected with the accuracy of 95% and respiration with the 100%. This algorithm has a repeatability of 93% which is a significant characteristic of the method.**

I. INTRODUCTION

Ultra Wideband (UWB) radar has high spatial resolution and the use of UWB signals has been suggested for medical applications [1]. Monitoring vital life signals gives us valuable information from the patient. In recent years, new non-contact methods using Doppler radar have been presented to detect the heart and respiration rate of a subject [2-4] to overcome limitations of existing contact measurement methods, especially during long-term monitoring and in situations where contact measurement is infeasible (such as for a fetus and persons buried under debris). Radar frequency of operation must be selected based on the time resolution and penetration requirements for measuring heart beats. The radiation power should be within the authorized FCC limits. UWB waves are one of the best choices because of low transmitting power and wide frequency band characteristics. In this paper, heart and respiration rate are detected using UWB waves. In published literature [5-7], the frequency of heart and respirations has been calculated using Fourier transforms. In this method, it is assumed that all of the objects in the test environment are static except the thorax of the target. The thoracic motion is detected through changes in the phase of the reflected signal stemming from changes in path length as the subject approaches towards and recedes from the antenna. In previous work [8] respiration rates have been determined using the wavelet transform. Respiration rate was detected in an static environment. The dependence of the method to the transmitted pulse is one of the limitations. In [9] the heart beating frequency has been detected using correlation. First, the static part of the channel has been omitted using the averaging, then with the aid of cross correlation of the transmitted and received wave the dynamic part of the channel has been detected so as calculate the movement frequencies using the Fourier transform. The important drawback of these methods like the previous ones is the assumption of the static environment and the proposed methods in these papers cannot work properly when other frequency moving objects are present in the patient's neighborhood.

One the main challenges in remote monitoring is compensating for extraneous motion. Existing methods, both UWB and Doppler radar, cannot effectively detect heart and respiration rates when the environment contains other periodic motion [5-9]. The only suggested method is to attach a tag to the target [10-11] which has some inconveniences for the person and complicates the system. In this paper an algorithm is proposed to distinguish two periodic sources of motion with different frequency, based on filter banks.

II. METHODOLOGY

A. Experiment setup

For detecting the heart and respiration rate, a burst of ultra wide band pulses are radiated to the thorax in a time division Δt according to Fig.1 The reflected signal is received and stored in a matrix. The separation between the transmitting and receiving antenna is d_1. The transmitter and receiver distance from the target are d_2 and d_3 respectively. d_4 is the antenna distance from the earth.

The sampled version of the reflected signal has been placed in a row of the matrix. Total number of matrix rows are equal to the total radiation time of the UWB signal (T), divided by the time division (Δt) and number of the columns are proportional to the sampling rate in the receiver (S). A sample of the transmitted pulse in the transmitter and also a sample of the receiver pulse in the receiver are depicted in Fig.2 and Fig.3.

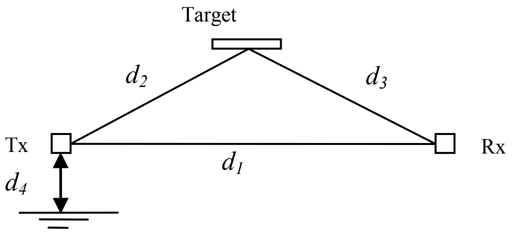

Fig.1. Measurement setup. Pulson P210 transducers are used as UWB radar. A wired figure-Pressure pulse sensor and the respiratory effort belts are used as a reference for comparison.

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Mehran Baboli is a PhD student at the Electrical Engineering department of University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: Baboli@Hawaii.edu).

Olga Boric-Lubecke is with Department of Electrical Engineering at University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: olga@ieee.org).

Victor M. Lubecke is with Department of Electrical Engineering at University of Hawaii at Manoa, Honolulu 96822 USA (e-mail: lubecke@hawaii.edu).

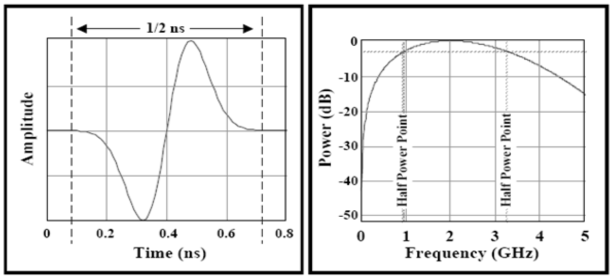


Fig. 2. A sample of the transmitted pulse in time and frequency domain

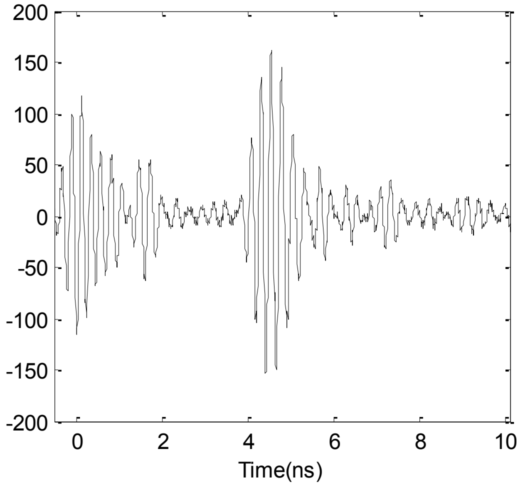


Fig. 3. A sample of the received waveform in the receiver

Table 1. The UWB transmitter specifications

Band width (10 dbm radiated)	3.2 GHz
Center Width	4.7 GHz
EIRP	12 dbm

The specifications of the transmitter and receiver antennas used in the test are presented in Table 1.

B. Algorithm

Multiresolution signal analysis and filter bank have been used in the fields of computer vision and signal processing. We use wavelet and filter bank idea in breaking down of the frequency into component frequency at different resolutions to ignore other periodic frequencies that are not in the same range of the heart rate.

First the static part of the channel is omitted (Fig.4). [5]. Next the wavelet packet transformation is applied on the data.

The wavelet transform is defined as [12]

$$T_{m,n} = \int_{-\infty}^{\infty} x(t) \frac{1}{a_0^{m/2}} \psi\left(a_0^{-m} t - nb_0\right) dt \qquad (1)$$

$$\psi_{m,n}(t) = \frac{1}{\sqrt{a_0^m}} \psi\left(\frac{t - nb_0\, a_0^m}{a_0^m}\right) \qquad (2)$$

Where ψ is the mother wavelet, m is related to dilation and n is related to the translation. a_0 is the step parameter of dilation, constant and greater than 1, b_0 is the location parameter that should be selected greater than zero [12].

Using the wavelet transform the signal can be decomposed in the time domain with different scale and time. In other words, the wavelet transform is time/scale decomposition. As the wavelet can be written in filter form, any scale can be related to a frequency band. A filter of the scale τ_j is approximately a band pass filter in the $[1/2^{j+1}\ 1/2^j]$. Every scale is named a transform level. So in the jth level of the transform, the frequency band [0 ½] is divided to 2^j band with equal length. The wavelet packet for j=3 is depicted in Figure 4. It is shown that the frequency band is divided to $2^j=2^3=8$ equal band. The energy in every band can be calculating conveniently. The sum of the energy of the frequency banks in each level is the same.

From the theory of the wavelet transform and filter banks, every wavelet divides signal in the frequency domain to a high and low frequency, a high pass and a low pass filter. After j transforms levels, the frequency band length is calculated as follows [12]:

$$f_s = \frac{1/2}{2^j} \times f \qquad (3)$$

Where, f is the highest frequency of the signal and is calculated considering the Nyquiest frequency from $f=1/\Delta t$ that Δt is the time distance between consequent transmitted pulses. The signal length is divided by two in every wavelet transform. Assuming a signal with a length of $N=2^n$ sample after j transformation level, the signal level will be 2^{n-j}. Assuming 2^m sample for the base function (mother), the signal should have at least 2^m samples for a correct transform, therefore in the jth level we have $2^{n-j} \geq 2^m$ samples, where n is at least $n=m+j$

After calculation the wavelet transform for each column of the received matrix, the energy of each frequency bands in the last transform level is calculated the maximum value is stored as an index of the column in the array E. The column in which E reaches to its maximum value is the location of desired motion. In case of having simultaneous periodic movement, by comparing the energy of desired frequency band in each column and finding the maximum, we can detect the column which contains the data of our target. The flowchart of the proposed algorithm is shown in Fig 5.

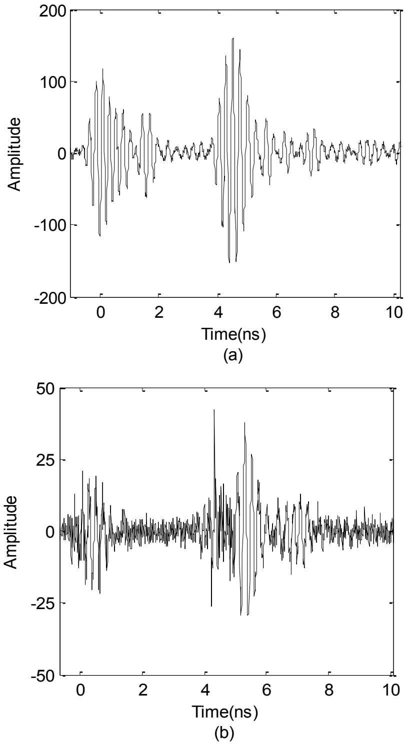
III. RESULT

The tests are done in this distance

d_1 = 1m, $d_2 = d_3 = d_4$ =1m

t = 100 ms

The result obtained with the daubechie (db8) as the mother wavelet base function. The function and its scale have been shown in Fig 6.



(a)

(b)

Fig. 4. a) The signal received b) The sample after the stationary data

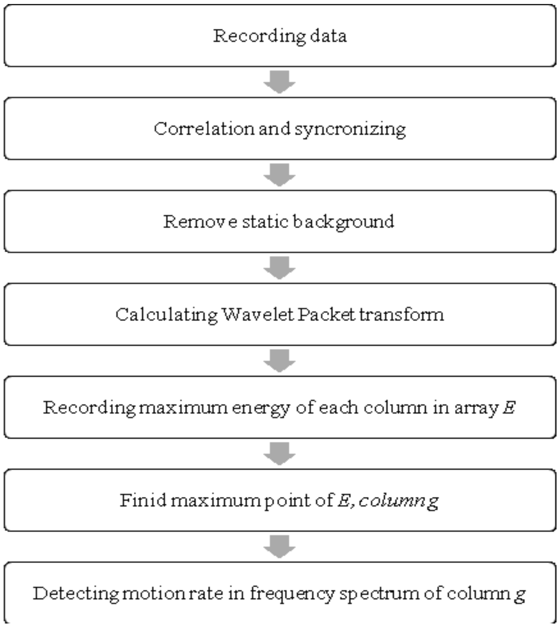


Fig. 5. The Proposed detection algorithm has 7 steps. It is capable of detecting heart and respiration rate in an environment that contains other periodic motions.

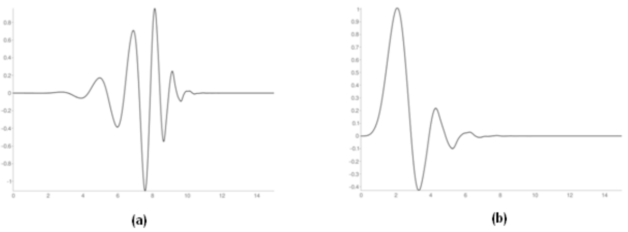


Fig. 6. Daubechie 8 wavelet

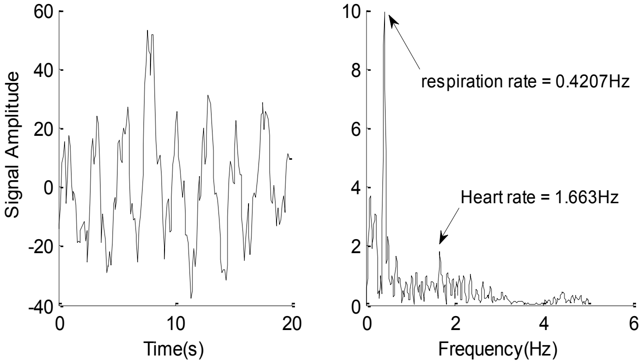
In the environment 1 that the only heart and respiratory is motion in environment the result can be illustrated in Fig. 7.

In both experiments a wired figure-Pressure pulse sensor and a respiratory effort belts are used as a reference to compare the heart and respiration rate data obtained from UWB radar.

Fig. 7 shows the results of the algorithm in frequency and time domain. In this experiment, target is located 1m away from the antennas. The direct measurement of respiration rate is 0.45Hz, which means 27 breaths per min. As shown in Fig. 4, the estimated rate using proposed algorithm is 0.4525Hz, or 27.15 breaths/min.

Fig. 8 shows the results applying the algorithm in [5] and our proposed algorithm when other motions exist in the environment which has a periodic motion in 3 Hz. For this experiment, contact measurement device shows a rate of 0.37 Hz for respiration rate, while the estimated rate by the proposed method is 0.38 Hz. As shown in Fig.8 other algorithm cannot detect the desired motion since the other movement has bigger amplitude.

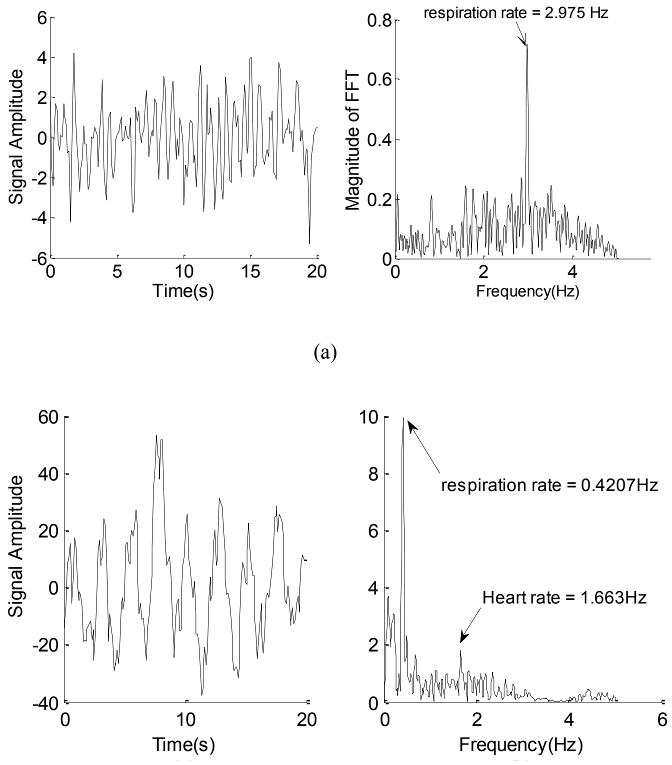
In the Fig. 8, 9 three dimensional Fourier transforms are shown. This figure shows another periodic movement in the environment, but the algorithm, can discriminate this movement from the other periodic movements.



(a)

(b)

Fig. 7 Heart and respiration rates measured with UWB system when there is no other periodic motion in the environment (a) The signal in the column g that has the maximum energy in the range of heart rate [.6 2]. (b) Frequency spectrum of column g. It has two peaks which are related to respiration rate and heart beats respectively.



(a)

(b)

Fig. 8. The comparison between (a) the result of algorithm presented in [5] and (b) the result of the proposed algorithm when there is another motion in the environment.

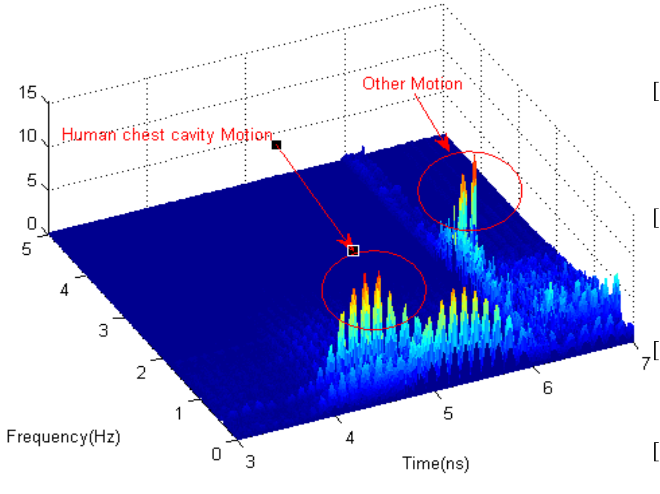


Fig. 8 The spectrum of received matrix in 3D format when another motion is in the environment. As shown in Fig.7 the proposed algorithm is still able to detect the respiration rate and heart beats of the target.

IV. CONCLUSION

In this paper, a new algorithm is proposed based on the energy in the movement frequency to detect the heart and respiration rate using the wavelet transform and filter banks. The results show the high accuracy of the method. The most important feature of the algorithm is its robustness against the periodic movement in the environment. It can detect heart beat and respiration rate even if another movement exists in the environment.

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