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Application of Empirical Mode Decomposition in Removing Fidgeting Interference in Doppler Radar Life Signs Monitoring Devices

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Abstract— **Empirical Mode Decomposition has been shown effective in the analysis of non-stationary and non-linear signals. As an application in wireless life signs monitoring in this paper we use this method in conditioning the signals obtained from the Doppler device. Random physical movements, fidgeting, of the human subject during a measurement can fall on the same frequency of the heart or respiration rate and interfere with the measurement. It will be shown how Empirical Mode Decomposition can break the radar signal down into its components and help separate and remove the fidgeting interference.**

I. INTRODUCTION

NON-CONTACT life sign monitoring using Doppler radar has recently been introduced to various applications including home monitoring and search and rescue operations[1][2]. Such a device is basically a Moving Target Indicator (MTI) working in the RF range that senses small physiological (caused by heart and respiration) movements of a human subject. This method works great for stationary human subjects since only the physiological motion is present in the field of view of radar, which simply translates to phase shift in the receiver and consequently appears as the AC part of the baseband output, while stationary objects in the background result in the DC part of the output signal. Due to the nature of the measurement method, any motion including the human subject's fidgeting during the measurement appears as interference in the radar's output signal. Similar problem exists for hand-held life sign monitoring devices, where mechanical hand-shake of the operator of the device appears as interference in the radar's output [3],[4]. In [3] and [4] the mechanical hand-shake problem has been discussed and simple solutions have been provided based on the prior knowledge of the interference. In this paper a similar method used in [4] is applied to clean up the radar's output for scenarios when the human subject is fidgeting while the measurement is being performed.

Empirical Mode Decomposition (EMD) introduced in [5] is used for breaking down the radar signal's output into its Intrinsic Mode Functions (IMFs). It will be shown that selecting the proper IMFs will result in removing the fidgeting interference.

II. SIGNAL ANALYSIS AND EMD

Fig. 1 shows the geometry and relative positions of a transceiver antenna and a human subject. R is the instantaneous radial distance of the transmitting antenna from the subject as depicted in Fig. 1. Radar's output after demodulation [6] yields the total motion which is subject's physiological motion and fidgeting in this case. EMD is used to decompose the demodulated radar signal into its two components: physiological motion and fidgeting. These two signals can be considered to be AM/PM modulated components of some fundamental frequency. Physiological motion has a periodic and narrowband signature. That is, the instantaneous frequency for heart and respiration varies slowly with time. This makes application of EMD feasible [8].

As it has been shown in [5] EMD can be used to find out the Intrinsic Mode Functions (IMFs) that constitute a signal. IMFs, denoted as $d_k[n]$, are functions for which 1) The number of exterma and the number of zero crossings are either equal or they differ at most by only one and 2) Mean value of two envelopes associated with the local maxima and minima are zero. In this paper EMD is essentially used as a filter bank [8]. IMFs of the demodulated radar signal are calculated using the sifting process on which EMD is based. Once the IMFs are obtained, the fidgeting signal will show up as an IMF and re-synthesizing the signal by combining only the desired components, results in removal of the fidgeting signal from the output.

III. MEASUREMENT SETUP

The radar used for these measurements has a single antenna mono-static configuration with I and Q outputs resulting from direct conversion of received RF signal. Setup diagram of the operating radar is depicted in Fig. 1. A HP83640B signal generator operating at 2.4 GHz was used as the signal source. RPS-2-30 splitters, ZFM4212 mixers from Mini-circuits and a Narda 4923 are also included in the

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design. The transmit CW microwave at the antenna input was measured to be 0 dBm. An ASPPT2988 antenna was used which has 8 dBi gain and 60 degrees beam-width. Finally, the I and Q mixers' outputs are low pass filtered and amplified by passing through a SR560 LNA (cutoff 100Hz, 40 dB gain) and are then recorded by a NI USB6259 16 bit data acquisition device to the PC at a sampling rate of 1kHz.

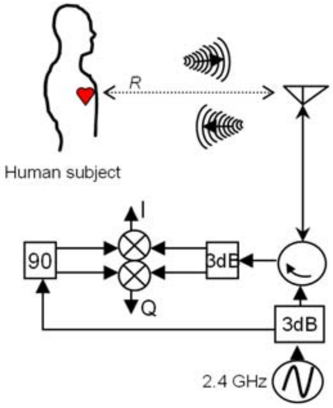

Fig. 1 Setup of the 2.4GHz doppler radar system for measuring life signs.

A chest band (Pneumotrace 1132 piezo electric respiration transducer) was used on the subject as a reference to log physiological respiratory motions of the subject. Also a UFI 1010 finger pulse sensor was used to record the subject's heart beat. Ultimately the radar's output will be compared with these signals which serve as a reference.

IV. RESULTS

In this section the results of the combined simulation/measurement will be discussed. As a proof of concept, physiological signals recorded using radar is contaminated with an interference of various amplitudes and frequencies. This signal is then processed using EMD and the steps discussed in the previous section to retrieve the heart signal. Fig. 2 depicts the finger pulse reference and the radar heart signals for measurements of a subject at rest zoomed in a 30s time interval.

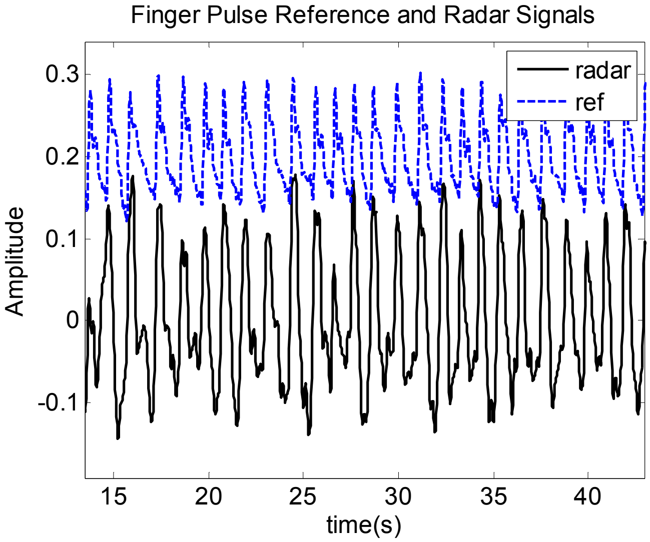

Fig. 2 A sample of finger pulse reference and radar signals. Both showing the heart beat pulses.

As it can be seen in Fig. 2, peaks in the trace obtained form the radar follow those of the reference well. The next step is to add interference content to the finger pulse reference signal. A sine modulated Gaussian signal centered at a frequency close to that of the frequency of heart (0.96Hz) has been used. This type of waveform has broader frequency content than a single sine wave and has the benefits of a transient signal. Fig. 3 depicts one of the interference signals used in these simulations in time and frequency domain (Gaussian width of 6s and centered at 1.13Hz). This interference signal is then added to the demodulated radar signal and the combination is shown in Fig. 4 together with the reference heart signal obtained from the finger pulse sensor. Empirical Mode Decomposition is then applied to the resulting signal and IMFs are calculated in Fig. 5 (using codes from [9]). As it can be seen in Fig. 5, IMF 1 shows the fidgeting signal. Correlation of IMFs and the reference and fidgeting signals is calculated and tabulated in Table I. Visual inspection together with results from Table I lead to identifying IMF 1 as the fidgeting signal. IMF 1 can then be removed by simply combining the other IMFs. Results are shown as the red trace in Fig. 4. Comparing the fidgeting removed trace with the reference heart signal shows that fidgeting has been effectively removed.

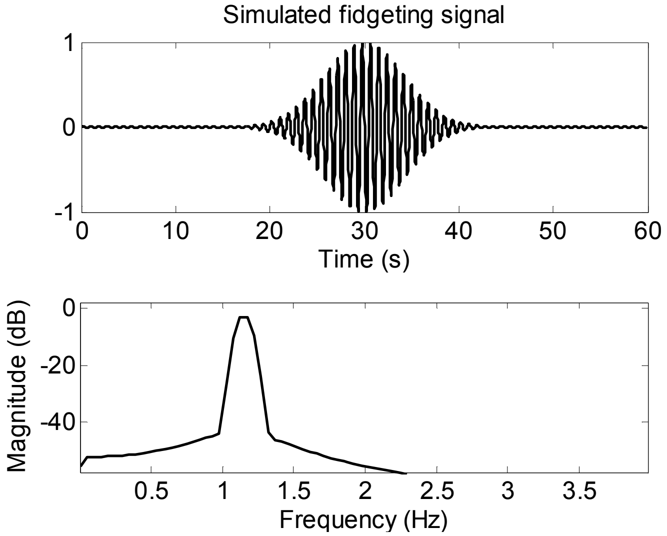

Fig. 3 The Sine modulated Gaussian signal used as the interference in time and frequency domain.

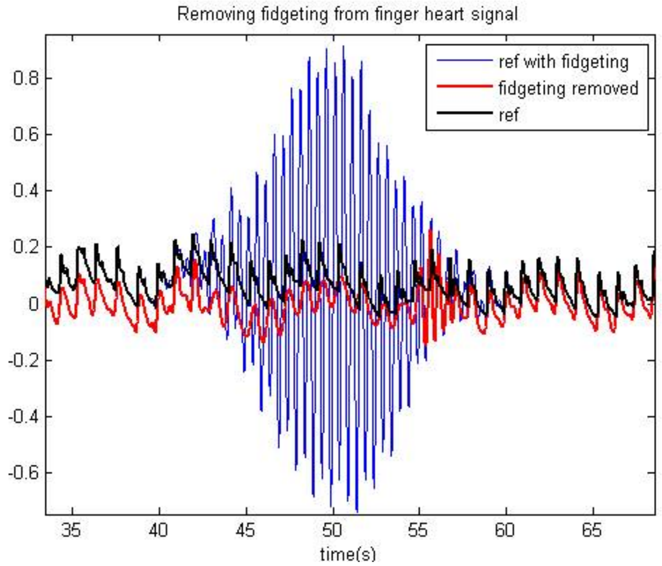

Fig. 4 Fidgeting signal super imposed on the heart signal obtained from radar together with the fidgeting removed trace.

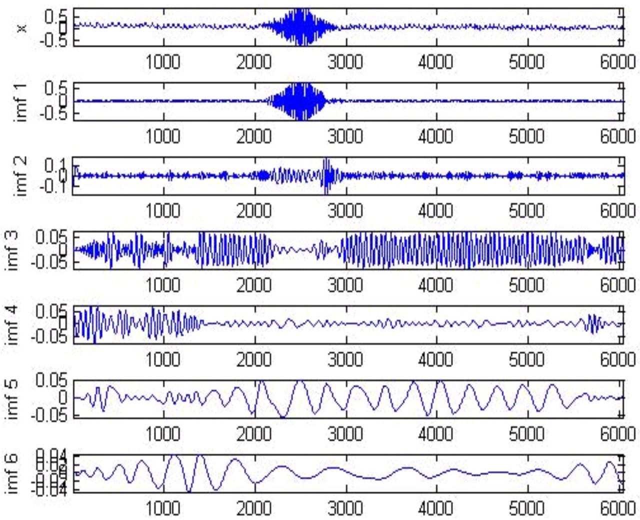

Fig. 5 Mixed fidgeting and heart signals (x) and its first 6 IMFs. As it can be seen, the fidgeting interference occurs at about t=40s.

TABLE I

CROSS CORRELATION OF EACH OF THE IMFS AND THE FIDGETING SIGNAL

IMF1	185.0
IMF2	2.9
IMF3	0.1
IMF4	0.02
IMF5,6,7,8,9	0.00

In the meantime use of a band pass filter for removing the fidgeting interference has been evaluated. The cut-off frequency for the lower and the higher frequencies are set at 0.5 and 1.15 Hz respectively. Fig. 6 show the results of using the band pass filter (as a simple signal processing tool) compared to that of the EMD. As it can be seen the band pass filter is unable to correctly remove the interference caused by fidgeting while EMD can produce results that correspond to the finger pulse reference.

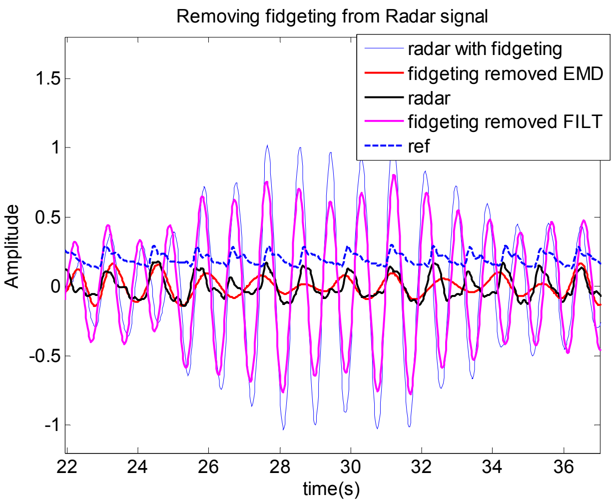

Fig. 6 Removing the fidgeting interference using both EMD and filtering. Emphasizing the fact that only filtering cannot remove this type of interference while EMD is effective.

V. CONCLUSIONS

One limitation of a wireless life sign monitoring device is its sensitivity to non-physiological motions of the human subject and in general any background motion. This type of interference, referred to as fidgeting here, once occurring at the same frequency band as that of physiological motion can be very difficult to remove using simple filtering techniques rendering heart and respiration rate estimation impossible. EMD has been known to decompose a specific signal into its mode functions. This property can help in separating components that are generated from different sources but happen at the same frequency. In this paper EMD was applied to removing simulated fidgeting motion from the physiological motion obtained from the radar signal. The method has been shown to be effective even when the fidgeting interference is occurring very close to the heart beat of the human subject and simple filtering methods cannot yield the desired separation. This method can be later generalized to remove interference of the same type from background objects.

ACKNOWLEDGEMENT

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