The Application of the Hilbert-Huang Transform in Through-wall Life Detection with UWB Impulse Radar

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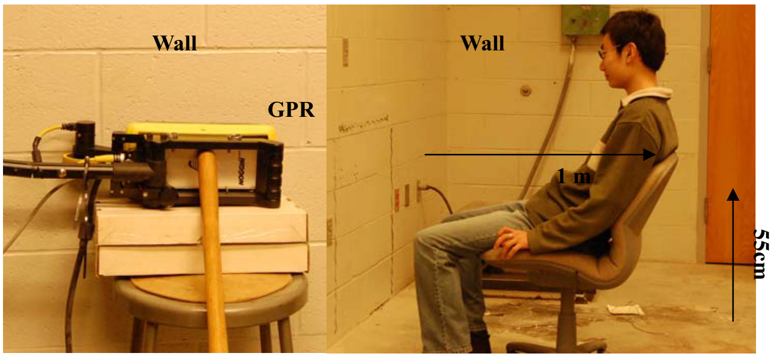
Abstract— Hilbert-Huang Transformation (HHT) is a powerful tool for nonlinear and non-stationary data analysis. In this paper, a dataset using an ultra-wide (UWB) impulse radar system with central frequency of 1 GHz was collected for life motion detection behind a cinder block wall. To extract the information of life motions such as breathing and heartbeats from the raw data, we first applied the empirical mode decomposition (EMD), the first step of HHT to decompose the signal (background signal included) into a family of the intrinsic mode functions (IMFs). We then apply Hilbert spectral analysis (HSA) to get the frequency spectra of different IMFs. After dividing by the spectrum of the background radar record (equivalent to de-convolving the background record in the time domain), we found that breathing appear as a spectral peak at 0.2–0.4 Hz and heart beating appears as 1.0–1.2 Hz. This is coinciding with real condition. Our preliminary results show that the HHT technique provides significant assistance in signal processing for the detection of human targets behind opaque obstacles.

1. INTRODUCTION

Hilbert-Huang Transformation (HHT) is a novel digital signal processing technology based on the combination of the empirical mode decomposition (EMD) and the Hilbert spectral analysis (HSA). It is designed specifically for analyzing nonlinear and nonstationary data [1]. In this paper we first design a through-wall life detection experiment and then using HHT to analysis the dataset collected by ultra-wide band (UWB) impulse radar system. Our effort contributes to the research of live human beings detection, the one is becoming increasing important in modern society. Its purpose is to identify life-being located behind the obstacle, which has significant meaning on the application of military, rescue operations under conditions of extraordinary situations or other related field. In common condition, even a person stays quietly without doing anything can still appear to have tiny movement caused by breath and heart beat. These displacements can be captured by EM wave detection. Some research shows that UWB impulse radar system was efficient of capturing human breath and heart-beat movement [2, 3]. Based on these, E. Zaikov explored an experiment using UWB radar for trapped- people detection [4]. In which the tiny breath and heart-beat movement was easily submerged by noise when people was motionless. By applying HHT preliminary into analysis, Ram M. Narayanan [5] presented the results with several potential breath-signal peaks in frequency domain in 0.4–0.8 Hz. However real breath signal still can not be localized; at the same time the extraction of heart beat, only 1–2 mm chest movement related, is failed to achieve. Here we are striving to overcome these difficulties.

2. EXPERIMENT DESIGN

The through-wall human cardioasperation detection experiments were conducted in a laboratory with ciderbrick walls (no reinforced steel bars) as shown in Figure 1. The Ground Penetration Radar (GPR) (Sensors and Software 1-GHz Nuggins system) is used as the UWB impulse source and receiving system. The recording time window length for each recording trace is chosen to be 16 ns, long enough for the radar waves to be reflected from an object in the air within 2-meter radius. GPR is located with its antenna closely stick to one side (Figure 1(a)) of the wall. On the other side of the wall, a chair is put in front of the wall, the distance between which and wall is set to be 1 meter. The subject we choose has good health condition with average heart beat frequency 1.05–1.2 Hz (65–72 beats/min). The distance between subject's cardiac and ground floor is measured to be 55 cm, when he is sitting in the chair. Taking this as a reference, the location of GPR is set to validate that both antenna and the cardiac stay in same horizontal line (Figure 1(b)).



(a) (b)

Figure 1: Photos of experiment setup. (a) and (b) are device set on two sides of the wall, the location of GPR is set to validate that both antenna and the cardiac stay in same horizontal line.

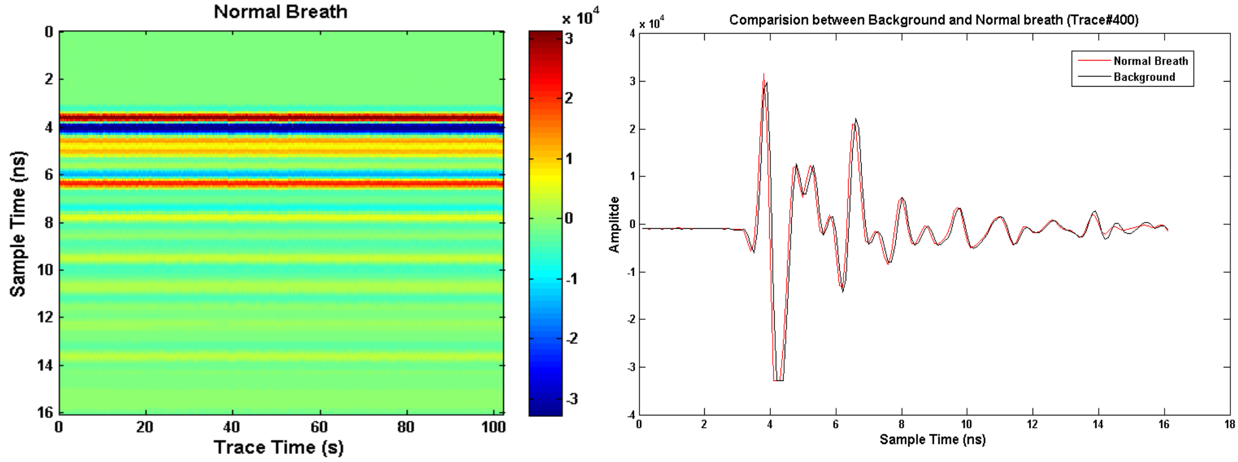
The GPR system collected 1 recording trace per 0.1 sec, with 8 stacking to minimize the random error. At the beginning of the experiment, subject is absent; data with the 1024 recording traces (nearly two minutes) is collected by GPR as a background reference signal. It will be used in data analysis later. After that, subject is asked to sit peacefully on the chair with his shoulders and back tightly against the back of the chair to stop body displacement. Now we collect data in three statuses: normal breathing, holding their breath, and repeatedly speaking the words "one, two, three". The breath frequency of normal breath and speaking are measured to be around 0.2–0.4 Hz (12–24 times/min) and 0.4–0.5 Hz (24–30 times/min) respectively. And for breath holding, breath frequency can be seen as 0. For the first and the third status the total number of recording traces is well above 1024, for about 2 minutes. For the status of holding breath the number of recording traces is less than 256, i.e., generally less than 30 seconds.

3. HHT DATA PROCESSING AND RESULT ANALYSIS

3.1. Empirical Mode Decomposition (EMD) and Back Ground De-convolution

In experiment mentioned before, four datasets are totally collected: background signal, normal breathing, breath holding and speaking. Here taking dataset of normal breathing (Figure 2(a)) as an example, which is made of 1024 time traces. Each trace is generated from one pulse. Because the time period between two traces is 0.1 s, in X-direction the total measured time is 102.4 s. The Y-direction shows the length of each trace. 161 points is contained in one trace with the time window of 16.1 ns, so the time period between two points is 0.1 ns in Y direction. In Figure 2(a), with the existence of wall strong reflection appears from 0.3 ns to 0.7 ns. With the consideration of void velocity of EM wave and the distance of 1 m between wall and human, the reflection signal of human physiology movement should appear after 12 ns. This is also shown in Figure 2(b) precisely, taking the example of trace No. 400, when compare this trace between normal breath and background reference, obvious phase distortion appears after 14 ns. This is caused by reflection and velocity change when EM wave passing human body. Based on this, we only focus the dataset from 14 ns to 16 ns, which includes signal of breathing and heart beating. However, due to multiple refection from wall and test environment, data collected is too complex to recognize human physiology movement directly, which is a relative small portion submerged into complex background. If this complex signal can be divided into several simple patterns, the small target portion we concerned will be easier to be extracted.

Here we apply EMD, one step of HHT into data analysis. EMD sees a signal trace as a muster of many coexisting simple oscillatory modes with the same number of extreme and zero crossings, symmetric envelopes and significantly different frequencies. These modes are called intrinsic functions (IMFs). What EMD does is to separate those IMFs from the original signal one by one, until the residue is monotonic [1]. Now EMD is applied to the data with the sample time from 14ns to 16ns, and the same IMFs of different sample time are summated and averaged. By doing this, the signal noise ratio of signal is increased and the uncertainty of signal is reduced. At the same time, dataset of background reference is derived into IMFs as the same way as what mentioned before. After letting each IMF of normal breath de-convoluted by identical IMF from background, we derive the result of normal breath with 7 IMFs included (Figure 3).



(a) (b)

Figure 2: (a) is the dataset of normal breathing, in which X-axis represents different traces from No. 1 to No. 1024, and the time period between two traces next to each other is 0.1 s. Y-axis shows the length of each trace. 161 points is contained in one trace with the total time window of 16.1 ns. (b) is one trace plot for trace No. 400 from the datasets of both normal breath (red) and background (blue). Phase distortion appears after sample time of 14 ns.

From IMFs of normal breath (Figure 3), we can find out that EMD always extract IMF from the highest frequency to lowest. The tiny peaks with relative high frequency appearing on IMF7 and IMF5 are totally coming from errors of de-convolution rather than EMD. Here the first component, IMF1 appears to have a similar shape of radio wave, and its frequency is much higher than any kinds of physiological movements. It may mainly relate to the carrier wave radiated from GPR, the same as IMF2. From IMF3 and IMF4, 9–13 peaks can be counted in every 10 seconds; this coincides with the frequency of heart beating (1.1–1.2 Hz). However, as the displacement caused by cardiac movement is tiny, distinct feature can not be identified in either IMF3 or IMF4. In IMF5 and IMF6, the movement with obvious amplitude and every two to three peaks in 10 seconds is clearly shown. We believe this is caused by breath movement (0.2–0.4 Hz), the most obvious movement in chest area. In IMF7, both amplitude and frequency is very low, this is not taking into consideration.

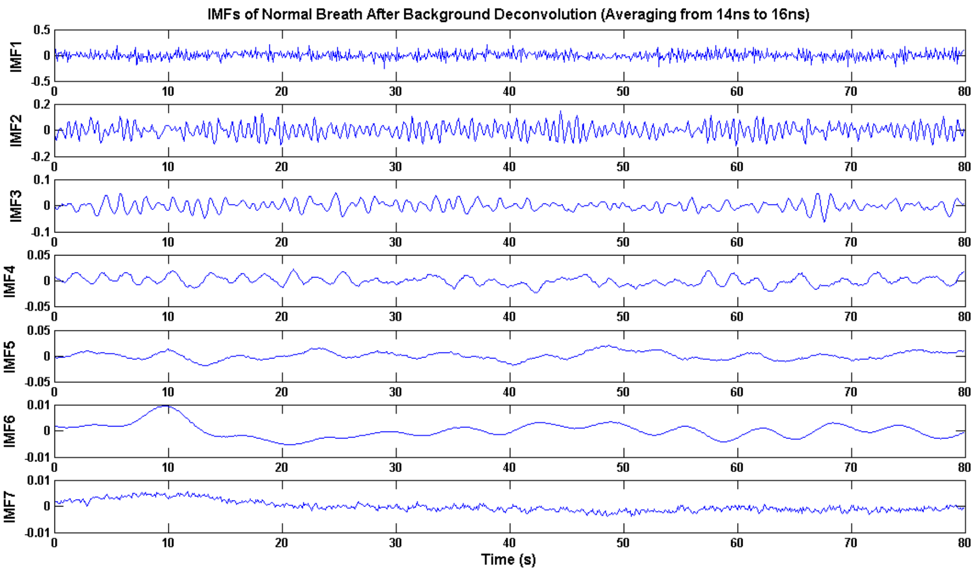


Figure 3: IMFs of normal breath after background de-convolution.

3.2. Hilbert Spectral Analysis (HSA)

EMD is the data processing approach used in time domain. It is not enough for further quantitative analysis for physiology features we concerned, especially for heart beating with tiny amplitude. So it is necessary to transform IMFs we derived into the spectrum of frequency domain. As to this point, traditional method used by most people before is fast Fourier transformation (FFT). But for non-stationary and instantaneous signal analysis, HSA, the other step of HHT, is a better solution than FFT. The principle of HSA is clearly shown in [Huang and Wu, 2008] [1]. Here we make a comparison between HSA and FFT by using original (without de-convolution) IMF 5 of normal breath and breath holding, the result is shown in Figure 4. It is clear that for both normal breathing and breath holding, the peaks derived by HAT are narrower and more identical than which derived from FFT. Another advantage coming from HSA is that the shape of the spectrum will not be significantly effected by the length of original trace in time domain. This can be seen from breath holding in Figure 4(b), in which the time window is only 256 points. After 0.3 Hz, compare to continuous fake peaks generated by FFT, spectrum of HSA is much more smooth and realistic.

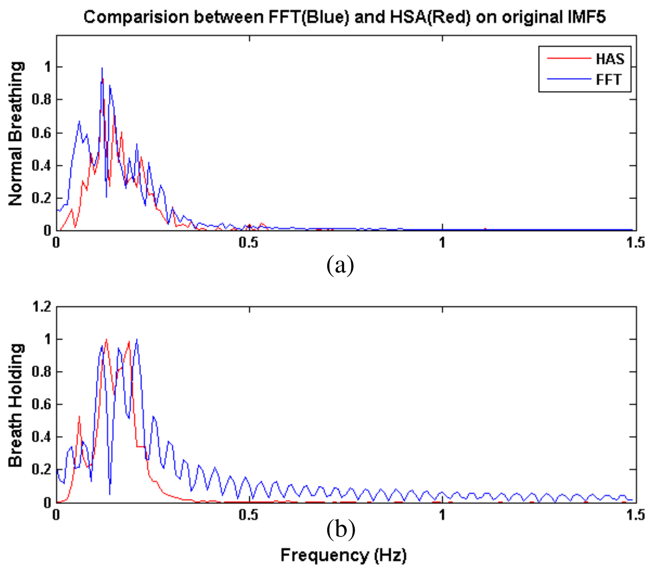
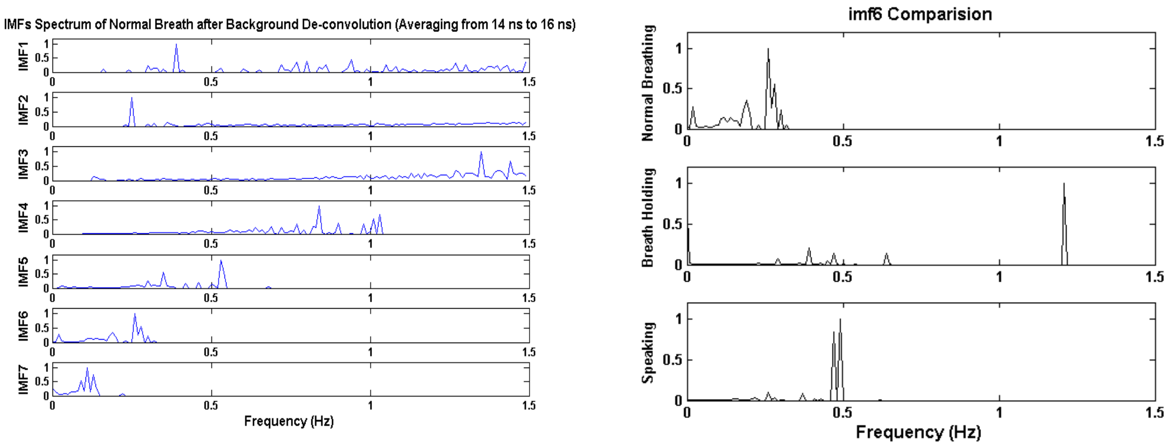


Figure 4: Comparison between FFT (blue) and HSA (red) spectrum of Original (without de-convolution) IMF5. (a) displays differences for dataset of normal breathing. (b) shows the condition of breath holding.

By using HSA on IMFs shown in Figure 3, we get frequency spectrum of 7 IMFs shown in Figure 5(a). Note that in IMF 4 obvious peak appears around the location of 1.05 Hz. We believe this can be seen as the feature of subject's heartbeat. Frequency component with large amplitude of 0.3 Hz is observed in IMF 2, 6 and IMF 1, 3, 4, 5, 7 with tiny peak. This may relates to human breathing. Besides these, there are still others peaks appear in different IMFs, the prediction of the origin can come about harmonic frequency, suppose the frequency of heart beating and breathing are 1.1 Hz and 0.3 Hz respectively. The production of these two movements will produce new frequency of 1.4 Hz and 0.8 Hz. This can explain the peaks appear in IMF3 and IMF4. If the harmonic wave is strong enough, it may effect on the original wave to produce secondary harmonic wave, such as the peak of IMF5 in 0.5 Hz. This prediction is waiting for further validation.

3.3. IMFs Compare among Normal Breathing, Breath Holding and Speaking

After processing datasets of breathing holding and speaking in the same way illustrated in part 3.2 and 3.3, we get frequency spectrum of 7 IMFs for two statuses respectively. After making comparison among statuses for each IMF, we observe obvious differences on chest movement appear in IMF6 (Figure 5(b)). When compare with normal breathing, the frequency of 0.3 Hz disappear in the spectrum breath holding. This is believed to cause by the seizing of chest movement. On the contrast, the higher peak of breathing appears at 0.5 Hz at the spectrum of speaking shows that when people speak, both the amplitude and frequency of chest movement increase.



(a) (b)

Figure 5: (a) is frequency spectrum of 7 IMFs for normal breathing derived by HSA. Frequency component of breathing is obvious in IMF2 and IMF6, and heart beat can be seen in IMF4. (b) shows comparison on IMF6 among normal breathing, breath holding and speaking. With seizing chest movement, the frequency of 0.3 Hz, which coincides with breathing, disappears in the middle spectrum.

4. CONCLUSIONS

In this paper it proves that by using HHT, the combination approach of EMD and HSA, feature of human breathing and heart beating can be successfully extracted from datasets collected by UWB impulse radar system. For the frequency spectrum derived by HSA from different IMFs, distinct frequency relates to different physiology movement can be well recognized. After analysis, these components are highly coinciding with the real human movement. This shows the significant potential of HHT approach for through-wall life detection improvement.

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