EXTRACTION OF BREATHING FREQUENCY OF HUMAN BEING HIDDEN BEHIND THE WALL USING DIFFERENT SIGNAL PROCESSING TECHNIQUES

[1] Abhay N Gaikwad
[2] Kalpesh S Dongre
[1]Professor, [2]Associate Professor
[1,2]Department of Electronics and Telecommunication Engg.,
[1,2] Babasaheb Naik College of Engineering, Pusad
Maharashtra, India

Abstract : Extraction of breathing frequency of human being who is hiding behind the wall is addressed in this paper. Breathing frequency information is extracted using two different signal processing techniques i.e., Fast Fourier transform (FFT) and Hilbert Huang transform (HHT). The major problem in extraction of breathing signal frequency is weak signal to clutter ratio. To improve the signal to clutter ratio, Singular Value Decomposition (SVD) is used. Experimental setup using Stepped-frequency continuous wave (SFCW) radar system is used to extract breathing signal of human being entrapped behind a plywood wall. After improving signal to clutter ratio, detection and location of breathing signal is obtained using standard deviation. Experimental results show successful detection of breathing signal of human being as well as extraction of breathing frequency using both FFT and HHT signal processing techniques.

IndexTerms - Fast Fourier Transform (FFT), Hilbert-Huang Transform (HHT), Life sign, Standard deviation (SD), Singular value decomposition (SVD), Step Frequency continuous wave (SFCW).

I. INTRODUCTION

The extraction of life signs of human being trapped under earthquake rubble or collapsed buildings using microwave based radar is an emerging technology [1]-[7]. The trapped victim under such circumstances cannot make movement and only way to detect the presence is to extract life sign as early as possible. Accurate and early detection of human vital signs is important to reduce loss of life. Change detection algorithm was used for detecting life sign of human [8]. Life detection algorithm using step frequency continuous wave (SFCW) radar is developed in [9-10]. In [11], they have proposed the life sign detection algorithm for SFCW radar in which multi-periods and filters are used to extract the micro-vibrations parameter of the life targets. Remote detection of human vital sign is investigated using SFCW based radar system [4]. In this paper various factors such as effect of varying thickness of the obstacles, human subject postures, status of breathing, position of radar antenna relative to human subject's chest, as well as the length of survey times are studied. In [12], multiple input multiple output processing for detection of walking person from a SFCW based system are presented.

One of the main problems in detection of life sign is strong reflection of wall and antenna air coupling. These reflections are unwanted and are called as Clutter. Different clutter reductions techniques are used like background subtraction method, range gating, moving average reduction technique, notch filtering and singular value decomposition (SVD) [12-20].

Differential image formation has been proposed to mitigate clutter i.e., strong reflection of the front wall and detect the human behind the wall [12]. Clutter reduction technique using Independent Component Analysis (ICA) described in [13] which is used to mitigate reflections due to wall for detections of static objects.

SVD has been used by researchers working in through wall radar detection to remove wall clutter to detect behind-the wall static targets [17]. In [17], SVD is applied on the data collected by taking measurements at different antenna positions, where as in this paper; we have applied SVD on data measured at same antenna location. Though wall and target reflections reside in many *Eigen* images, the significant or dominant *Eigen* images are obtained from first few *Eigen* value. Since our aim is to improve signal strength, removal of significant wall reflection using most significant singular values is carried out. In [18], SVD has been used for life sign extraction of more than one target but it is used after taking fast Fourier transform (FFT) of correlated signal. In our work we are proposing use of SVD for clutter reduction in earlier stage i.e., before applying FFT algorithm.

In [19], since FFT based method is not suitable for non stationary and non linear signal, authors proposes empirical mode decomposition (EMD)- Hilbert Huang transform (HHT) method for detection of breathing as well as other motions. On the basis of specific literature survey on SFCW based radar; it is observed that no one has applied EMD- HHT technique for extraction of life sign signal on experimental data. The objective of proposed paper is to extract life sign signal using FFT and HHT signal processing algorithm from the data which is collected experimentally using SFCW radar system.

Organization of paper is as follows. Section II describes about methodology in which experimental setup and radar system parameters used for data collection is included. It also describes the theory in signal processing algorithms i.e., FFT and HHT methods which are used for extraction of life sign. Results obtained through Experiments are presented in Section III. Section IV gives final concluding remarks.

II. METHODOLOGY

The methodology adopted in this paper is to collect the data using SFCW radar first for the person behind the opaque material. After data collection, analysis using signal processing techniques i.e., FFT and HHT for detecting life sign is carried out. For data collection, experimental setup is explained in section *A* and signal processing techniques are described in section *B.*

A. Experimental Setup

To extract life sign of human subject hiding behind plywood wall an experimental setup is developed which is shown in Fig.1. SFCW based radar system in a mono-static mode was used with the help of Vector Network Analyzer (VNA) and single antenna as shown in Fig.1. Calibration of VNA is done by standard one port calibration process i.e., Open Short Matched before reflection parameter S_{11} is measured in frequency range from 1 GHz to 3 GHz. The total numbers of scans or observations that were carried out are 1024. Data is collected by using VBA Macro program and is transferred to PC for further processing using MATLAB software.

The obstacle is plywood wall of 12 mm thickness. Distance between antenna and wall is maintained at 46 cm while distance between wall and human being is fixed at 58 cm. The total distance from antenna to target is 105 cm. The other radar parameters set for experimentation are shown in Table 2.1.

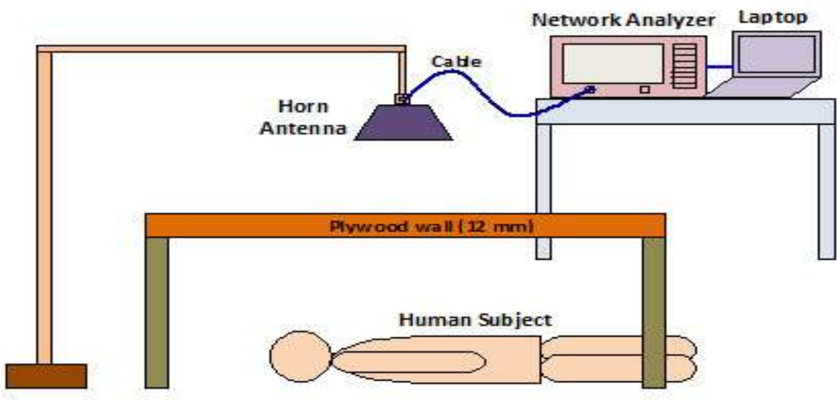


Fig. 1. Experimental Setup

Table 2.1 Radar Parameter for Experimentation

Sr. No.	Radar Parameter and specifications	
	Parameter	**Specification**
1	Operating frequency range	1 GHz to 3 GHz
2	Radiated Power	0 dBm
3	Number of Frequency points	201
4	Number of traces	1024
5	Horn Antenna Gain	20 dB
6	Antenna Beamwidth	49.68(H Plane), 59.36 (E Plane)

B. Signal Processing

After data collection, processing steps given in the flow chart as shown in Fig. 2 are applied to extract breathing frequency representing life sign. Micro-vibration activities are observed in every scanning data which can be used to differentiate them from the static targets. The biologic and static object have much difference in the same range, so we can extract the vital information and remove the static objects. As to human, the heartbeat frequency is around 1-2 Hz and the respiration/breathing frequency 0.2-0.5

Hz. The static object's frequency is around 0 Hz. Thus, if we find the frequency in 0.2 to 2 Hz, we can detect/extract the vital information.

Step 1. Read trace data in frequency domain:

Data collected by placing an antenna just above the chest of human being is considered. SFCW radar received the data in frequency domain, and stored in matrix form of dimension 201×1024. To read the first trace, column 1 of data matrix is pick up and so on for all 1024 traces.

Step 2. Frequency domain to Time domain:

. The first trace data is converted into time domain by using Inverse Fast Fourier Transform (IFFT) [22]. The signal due to single trace after IFFT is given by;

$$s(t) = \sum_{k=1}^{K} S(f_k) \exp(j2\pi f_k t) \qquad (1)$$

where t varies from 0 to *(K-1)/BW* with step interval of *1/BW*, *BW* is bandwidth of the system , *K* is maximum number of frequency points and $S(f_k)$ is the received reflected signal in frequency domain at k^{th} frequency.

Step 3. Time domain to spatial domain

The time domain signal is converted into spatial domain. The location of human being is determined by constructing a range profile in the spatial domain. Range profile is one dimensional information and given by expression as;

$$s(z) = \sum_{k=1}^{K} S(f_k) \exp(j2\pi f_k (2z/c)) \qquad 0 < z < z_{max} \qquad (2)$$

where c is velocity of light and z is down range distance which is given as

$$z = {(c \times t)}/{2} \qquad (3)$$

Maximum distance calculated using equation (4) gives the values as

$$z_{max} = {c(K-1)}/{2BW} \qquad (4)$$

But for analysis, maximum distance is taken as per the room dimension i.e., up to 5 m.

Step 4. Stacking all traces:

A single range profile will give information about presence of target only. It does not indicate amplitude variations due to breathing and respiration. For this radar must illuminate more number of traces. To see the amplitude variations all the range profiles are stacked one over other. Thus the steps from 1 to 3 are repeated to collect information from all 1024 traces.

Step 5. Clutter reduction using SVD

The major problem in life sign extraction is loss of substantial amount of energy of received signal due to reflections from wall. The reflections occur due to contrast between dielectric constant value of wall and air. Due to reflection, small amount of energy is passed through wall and reach to human being. The signal is reflected back by the chest of human being and reaches to receiving antenna after passing through wall again further reducing its signal strength. SVD divides the data into target and clutter subspaces. Data is represented by the matrix with dimensions $M \times N$; where M is set to value of index representing maximum range i.e ., 5 m and N is number of traces i.e., 1024 respectively.

The SVD can represent as:

$$X = USV^T \qquad (5)$$

where T denotes Hermitian transpose, U and V are $(M \times M)$ and $(N \times N)$ unitary matrices. S is rectangular matrix of same size of X with singular values σ_r on the main diagonal arranged in decreasing order i.e., $\sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_r \geq 0$.

The matrix X can be decomposed into subspaces as:

$$X = \sum_{i=1}^{N} \sigma_i u_i v_i^T \qquad (6)$$

$$X = M_1 + M_2 + \ldots + M_N \qquad (7)$$

where M_i are called as i^{th} *Eigen image* of X. Aim is to identify which *E*igen image represents target response. The *Eigen* image which represents human being response can be obtained from:

$$\bar{R} = M_2 = \sigma_2 \times u_2 \times v_2^T \qquad (8)$$

$\bar{R}$ represent the image having focused target response and reduced clutter. Second *Eigen* image represents information related to human being. For more details about the clutter reduction technique, the interested reader is referred to [13].

Step 6. Determination of location based on standard deviation (SD)

The purpose of processing should be to help the radar operator to clearly understand whether life sign of a person hiding behind wall is present or absent. The amplitude value in all the range profiles at different distances should be observed. If there is no amplitude variation then target is absent.

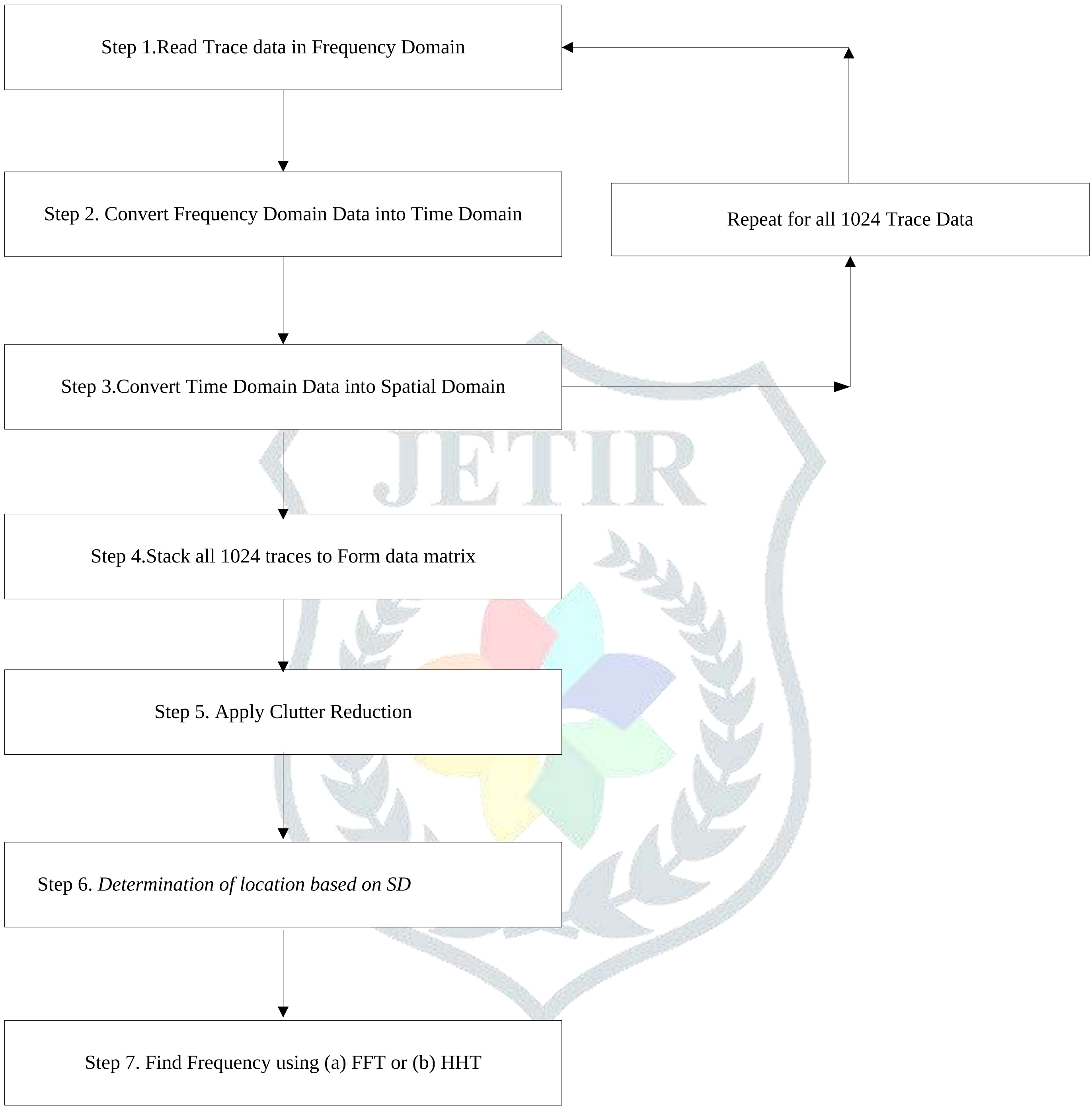


Fig.2 Flowchart for Signal processing steps

To verify that if amplitude variation is present then target is present, standard deviation (SD) is calculated at all the distances over all the range profiles using equation (9).

$$SD_n = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}(x_i - \mu)} \qquad (9)$$

where n is distances which varies upto 5 m with step size of 0.075 m and N is total number of traces.

The value of SD at human being location will be highest compared to static objects.

Step 7. Find Frequency using (a) FFT (b)HHT

(a)Fast Fourier Transform Method

The steps below shows the algorithm based on Fast Fourier transform (FFT) method for extraction of life sign from signal after clutter reduction technique is applied.

Step i: Search for peaks in range profile of each trace and then observe the peak variations in all the traces.

Step ii: Note the peak location at which we get variations i.e where SD is highest.

Step iii: Extract the signal amplitude from all traces for the peak location obtained in step ii.

Step iv: Convert the extracted signal in step (iii) (amplitude versus number of traces) into frequency domain by applying FFT.

In frequency spectrum if we get presence of frequencies in range of 0.2 to 2 Hz, we can say that a human being life sign is extracted. At the same time, the location of human being is also obtained.

(b) HHT Method

The HHT is a nonlinear and non-stationary signal analysis technique based on the combination of the two processes i.e., Empirical Mode Decomposition (EMD) and Hilbert spectral analysis (HSA) [23]-[25].

The EMD algorithm can be understood from the following steps :

a) Determine the local extrema (maxima, minima) of the signal and connect the maxima and minima with an interpolation function to create an upper and lower envelope respectively.

b) Calculate the local mean as half the difference between the upper and lower envelopes.

c) Subtract the local mean from the signal to form the residue.

d) Iterate step (a) to (c) on the residual until the signal becomes Intrinsic Mode Functions (IMF). This is repeated until the final residue is a monotonic function.

The signal of interest from the human target can be clearly displayed in the time–frequency domain. The spectrum is obtained by taking HHT to every IMF, which is known as Hilbert Spectrum Analysis. Most of the energy is confined in IMF which is having highest peak power.

III. RESULT

A. Processing for presence of target behind wall

Data is process according to flowchart described in Section II. Fig.3 show range profiles for all the 1024 traces obtained. The figure is plotted between distances versus magnitude. From the figure it is observed that first peak is due to weak isolation between transmitting and receiving antenna, second peak is due to wall reflection and third peak is due to reflection from human being. The encircled shaded portion represents presence of target. Since the distance between antenna and target is 1.05 m, fluctuation in reflections is observed at 1.05 m marked by data tip as shown in Fig. 3. We can observe from Fig. 3 that the amplitude of the clutter (i.e reflection due to antenna air interface, wall reflections, and multiple reflections is higher than reflection due to human being. By using clutter reduction technique the improvement in the target signal can be achieved which is described in next section.

B. Data after clutter Reduction

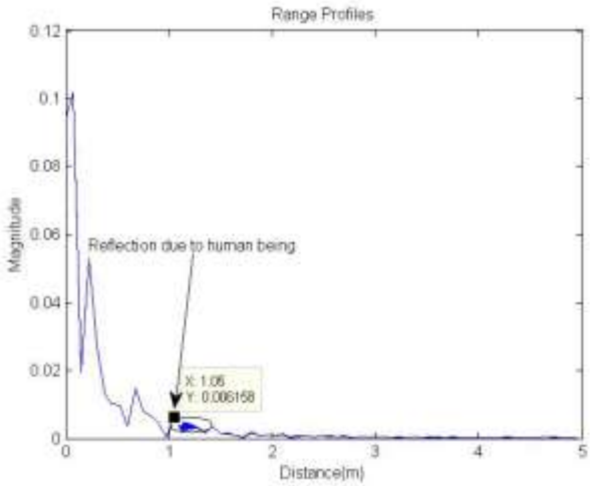
All the range profiles acquired are stacked one after another so that two dimensional images is obtained in which on x-axis, number of traces and on y-axis, down range distance is plotted. This set of traces is assembled together in a two dimensional data matrix and visualized as an image as shown in Fig. 4. The clutter reduction as described in Section II (B) is applied on image. In Fig. 5 , the changes in the amplitude at target location due to human subject movements can be easily observed i.e., from Fig. 5, at 1.05 m in range, there is amplitude variation as observed with dark and light shaded portion, which was not visible in Fig. 4.. From this image it can be visualize that target is enhanced with suppression of clutter. To measure the performance of clutter reduction technique, average target signal strength is calculated. The signal strength value before clutter reduction at target location is 0.0012 whereas after clutter reduction it is 0.3207. Thus it is observed that the value of target signal strength at target location after clutter reduction due to SVD is improved.

C. Location determination using standard deviation

To obtained the location of human being, SD is calculated at all locations using equation (9). It is observed that at human being location, SD value is high compared to static object locations due to amplitude variations. Amplitude variations occur due to respiration and heart beats. The location at which maximum value of SD is obtained is verified and same as with the location of human being set during experimental setup.

D. FFT based Results

For better understanding, the amplitude values for detected peaks *i.e.* peak due to antenna-air interface, due to wall surface and due to human target are observed from all 1024 traces. It is clearly observed that for the first two peaks i.e. peak due to antenna-air interface and peak due to wall surface, there is no variation in amplitude for all 1024 traces, while, there is significant amplitude variation at human target location. So in the next step, only amplitude variation portion is extracted with the help of SD value which is shown in Fig. 6.



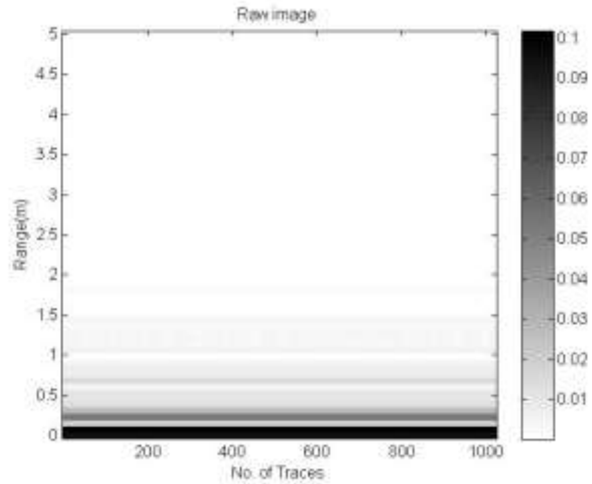
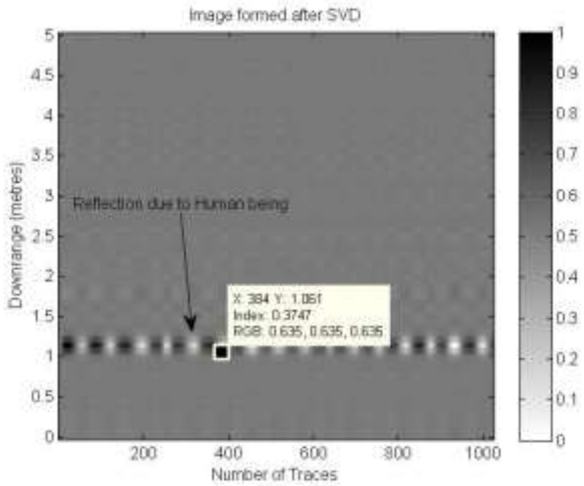


Fig.3 Range profiles for all 1024 traces in the presence of target. Fig. 4 Image before clutter reduction



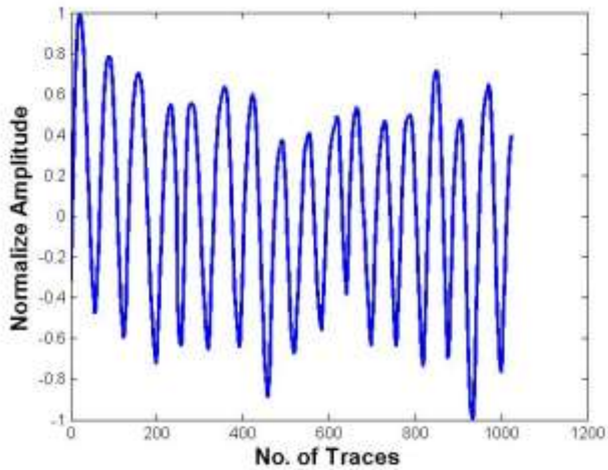


Fig.5 Image after clutter reduction Fig. 6. Amplitude variation at target location

After applying the FFT to the amplitude variations, the result is obtained and is shown in Fig. 7. In frequency spectrum, peak is detected at 0.3125 Hz which is nothing but the breathing frequency (0.2-0.5 Hz) for human. In this heartbeat frequency (1.2-1.7 Hz) was not detected because of small amplitude variation. The FFT result also includes other clutter frequencies present in signal.

E. HHT based Results

The extracted amplitude variation from peak locations for all the traces is obtained in the same way as explain in above. The amplitude variation at target location as shown in Fig. 6 is taken as input for EMD. Now, on this result, we had applied the Empirical Mode Decomposition (EMD) algorithm to decompose it into a finite set of IMF, until the residue become monotonic as described in algorithm above.

The signal is decomposed into five IMF components. The total energy is decomposed into different component. Here stoppage criteria used for EMD is squared difference (*SD*) [24]. The threshold value ε is set to 0.3 (typical value). If the squared difference (*SD*) is smaller than threshold, the shifting process will be stopped. Hilbert transfer of IMF gives us instantaneous frequency contained in IMF component. The time-frequency plot obtained after applying Hilbert transform on IMF 1 is shown in Fig. 8. In time-frequency plot, we got frequency nearly at 0.3998 Hz which is slightly different from result obtained using FFT method. It is also observed from result of HHT, that all the energy is concentrated around 0.3998 Hz which is not the case in FFT method. Hence compared to result obtained using FFT, the result obtained using HHT shows significant improvement in extraction of breathing frequency.

CONCLUSION

Experimental result demonstrates the effectiveness of clutter reduction technique. We conclude that after clutter reduction using SVD, the human life sign signal strength is increased. This paper demonstrates the extraction of human breathing using two different signal processing techniques i.e., FFT and HHT. The paper also described about how the location of human being is estimated using SD. The experimental results show that FFT and HHT methods have successfully extracted the breathing frequency of human i.e., 0.3125 Hz and 0.3998 Hz respectively. Compared to FFT, HHT produce less harmonic distortions. In future, need to work for complex environment or real life scenario. We have successfully extracted breathing frequency, but heartbeat signal is not detected. Advanced signal processing technique can be developed to improve the performance of extraction of heartbeat signal.

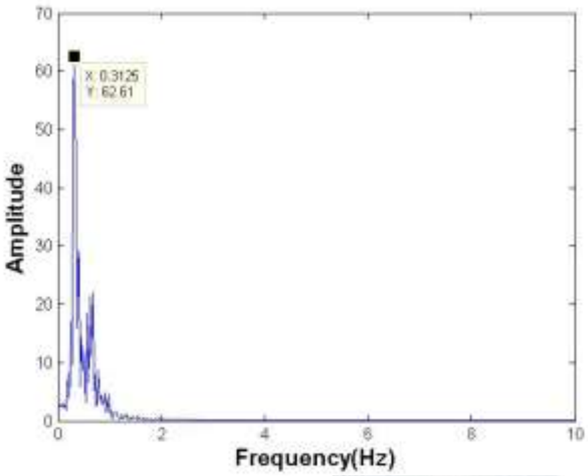


Fig. 7. Frequency spectrum after applying FFT

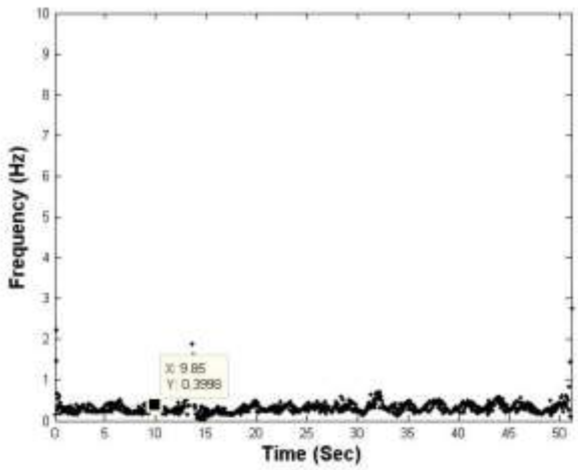


Fig. 8. Time-frequency plot after Hilbert transform

ACKNOWLEDGMENT

We would like to thank UGC, New Delhi, Govt. of India, for financial support under Major Research Project (MRP F.No. 43-306/2014 (SR) dated 05 Sep. 2015. Authors express their gratitude to head of department Prof. Dr. N P Jawarkar, Principal Dr. H B Nanvala and Management, for providing necessary facilities in the department for conducting experimentations.

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