URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Behind the Wall Heartbeat Detection using SVD and MTI Filtering

Vineet Singh(1), Aman Kumar(2), Somak Bhattacharyya* (3), and Pradip K. Jain(4)
1-4 Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi-221005, India
4 Department of Electronics & Communication Engineering, National Institute of Technology Patna-800005, India

Abstract

Heartbeat frequency of a living being is a key characteristic as it lies within a certain range. The heart beat frequency of a human subject behind the wall has been identified by applying singular value decomposition (SVD) based clutter reduction technique along with moving target indicator (MTI) filtering. The application of SVD improves the signal to clutter noise ratio (SCNR) of a signal coming from a human subject and make it possible for life feature detectable by MTI for through the wall detection. The final detection of human subject by tracking its heartbeat frequency from its distance measured referred to the antenna position is provided in a range doppler (RD) plane.

1. Introduction

Heartbeat monitoring is essential in many application areas like medical sector, sport-fitness observation, defense sector, rescue operations, etc. [1,2]. The frequencies of respiration and heartbeat are the essential characteristics of any living animal. Although the human subject is in the rest condition, still there is some micro motion present owing its physiological phenomenon in which heartbeat and breathing are main components because these two causes significant displacement in human torso [2]. The heartbeat frequency of a human being lies between 0.8 to 2.5 Hz, and that of for respiration is 0.2 to 0.5 Hz [3]. Since these frequencies lie in a certain range of frequencies, they can be treated as the characteristic signature of human-being presence.

The sensing of life characteristics behind a wall poses challenge due to incorporation of large amount of clutter on the received signal. An effort to enhance through the wall life sign signal has been carried out previously where the clutter reduction technique has been tested by implementation of singular value decomposition (SVD) for living static target [4,5]. Moving target indicator (MTI) based approach can be considered as an efficient method to discriminate between living and non-living beings which allows lower frequencies associated to human physiological properties by filtering out the static frequencies (f=0) [3,6]. The combination of SVD with MTI can be used to develop a system for life characteristics with higher sensitivity.

In this article experimental study on through the wall human heartbeat detection using ultra-wideband continuous wave radar has been carried out. In this regard, stepped frequency continuous wave (SFCW) radar system has been developed in the laboratory using vector network analyzer (VNA) and a pair of identical horn antennas. The post processing of the collected data has been performed in two major stages. The first stage deals with the improvement of received signal which possess the life sign information by improving the signal to clutter noise ratio and the later stage is dedicated for detection of life characteristics in the range doppler (RD) plane.

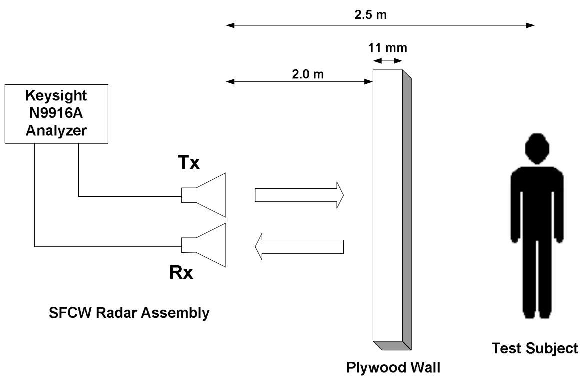


Figure 1. Experimental setup schematic placed within the anechoic chamber along with human subject.

Table 1 Experiment specification

Sr. No.	Parameter	Value/specification
1.	Antenna Type	C-band Horn
2.	Source	Keysight FieldFox (N9916A)
3.	Freq. range	4-6 GHz.
4.	Range Resolution	7.5 cm.
5.	Transmitted power	-15 dBm
6.	Max. Unambiguous range	15 m.
7.	No. of points	201
8.	No. of sweeps	400

2. Experimental Setup and Data Collection

The ultra-wideband bi-static radar based on the stepped frequency continuous wave (SFCW) system was assembled with the help of Vector Network Analyzer of Keysight (N9916A) along with a pair of identical horn antennas of C-band, RF coaxial cables, and connectors as shown in Figure 1. A human subject standing behind a plywood wall has been exposed to the bi-static radar system in rest condition during the data collection. The thickness of the wall was 1.1 cm and its distance from the antennas was considered as 2.0 m while the distance of the human being from the antennas has been taken as 2.5 m. The entire setup along with human subject is placed in an anechoic chamber so that the effects of other external environments could be minimized. MATLAB script has been used to interface the VNA and it was programmed to sweep from 4 GHz to 6 GHz following 201 linear frequency step increments. The details of other parameters of VNA and antenna systems are listed in Table 1. The frequency domain data was collected for 400 sweeps for the antenna to subject distance of 2.5 m.

3. Processing Methodology

A composite model of heartbeat and breathing can be expressed as a bi-harmonic function as shown in (1) where, $\tau > 0$, r_0 is the average distance, A_H and A_B are amplitudes, ω_H and ω_B are frequencies while ϕ_H and ϕ_B are initial phases of heartbeat and breathing respectively [1].

$$r(\tau) = r_0 + A_H \sin(\omega_H \tau + \phi_H) + A_B \sin(\omega_B \tau + \phi_B) \qquad (1)$$

If the human subject is stationary then three frequencies can be expected in the overall system viz, a zeroth order frequency corresponding to stationary surrounding objects and two doppler frequencies associated with heartbeat and respiration.

The collected frequency domain A-scan data has been converted to spatial domain range profiles and stacked to form a matrix of dimension $M \times N$. The SVD has been applied on mean difference image for relative enhancement of signals associated with human subject and it has been retrieved in first subspace of SVD and thus acquiring the dimension of $M \times N$ matrix. Each column of the aforementioned $M \times N$ matrix undergoes MTI filtering followed by Fourier transform processing successively which yields the RD plane from where the life characteristics frequency can be easily obtained at certain distance. The following subsections deals with the fundamental concepts used in the post signal processing steps.

3.1 SFCW Radar Range Profile Generation

The SFCW radar determines the target distance by generating the range profile in the spatial domain. The stored data collected for the processing is in the frequency domain and is transformed into the time domain and scaled into spatial domain [7]. If z is downrange distance of the target, calculated as $z = ct / 2$, where t is the round trip travel time of signal and c is the speed of light in air, then the spatial domain expression can be given by equation (2) where $s(f_k)$ is received signal in frequency domain f_k is frequency at k^{th} frequency point, K is the maximum number of frequency points.

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

The maximum unambiguous range and the range resolution expressions are given in (3) and (4) respectively, where f_k is frequency step size

$$z_{max} = c / 2\Delta f \qquad (3)$$

$$\Delta z = c / 2k\Delta f \qquad (4)$$

3.2 Singular Value Decomposition (SVD)

SVD is widely used in the field of image processing and signal processing. In this work SVD based decomposition technique has been used to separate clutter and signal subspaces in order to increase the signal to clutter ratio [4,7]. Let a data stacked image is represented by $M \times N$ matrix (where $t = 1, 2........M$ and $p = 1, 2.......N$). Here t denotes the spatial index and p is scan the scan number. The mean difference image x can be decomposed as shown in (5).

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

Here U and V are left hand side and right hand side unitary matrices respectively and their columns are known as singular vectors. The matrix S contains singular values or weights (σ) as its diagonal elements satisfying the property of $(\sigma_1 \geq \sigma_2 \geq ..... \geq \sigma_r)$. The mean image can be decomposed in different subspaces as following

$$X = M_1 + M_2 + ... + M_N \qquad (6)$$

Our aim is to identify the subspace containing the target response. In our case we are getting target response in M_2 corresponding to σ_2 and is given as

$$I_{target} = I_2 = \sigma_2 \times u_2 \times v_2 \qquad (7)$$

3.3 Moving Target Indicator (MTI)

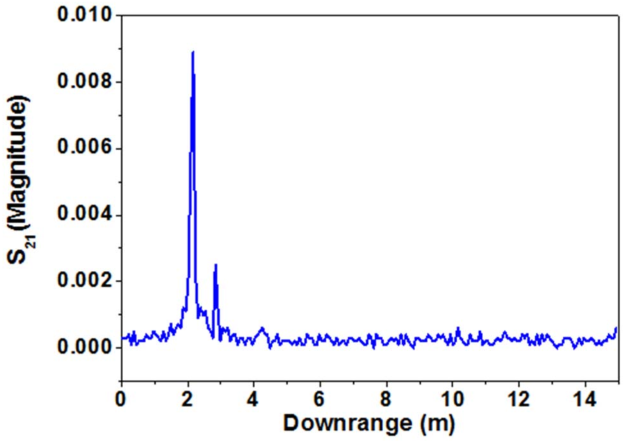
In the output response spectrum, clutter with high energy is centered about the DC (f=0) and pulse repetition frequency. The purpose of an MTI filter is to suppress target-like returns produced by clutter and allow returns from moving targets to pass through under little or no degradation [6]. The transfer function for the MTI can be expressed in (8), where K is the gain factor, which controls the gain response. By increasing the value of K, the MTI filter response can be flattened. The filter with flatter response has more bandwidth with least gain variation in its pass-band.

$$H(z)=\frac{1-z^{-1}}{1-Kz^{-1}} \tag{8}$$

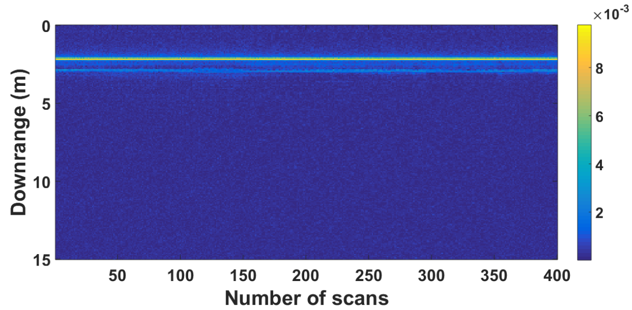
4. Results and Discussion

All the frequency domain collected data has been translated to spatial domain and the range profile has been obtained as given in Figure 2(a). Two major peaks have been observed in the single range profile as shown in Fig. 2(a), where the first peak appearing nearer to the antenna position is associated with wall reflection with relatively higher amplitude while the other one corresponds to the human subject reflection and small in magnitude. The electromagnetic wave radiated towards the human subject has to travel twice through the wall material and it results lowering of the magnitude of subject associated reflection. In the range profile of a single scan, the obtained ranges of wall and human subject are found to be 2.17 m and 2.85 m respectively which are greater compared to the respective actual positions. Since the wall position detection is suffering from the antenna impedance mismatch delay while the human subject position is suffering from antenna impedance mismatch as well as the speed reduction of the propagating electromagnetic wave within the wall, the calculated ranges differ from the actual one. All the 400 A-scans have been staked together as shown in Figure 2 (b). Here, the range information is contained along *y*-axis while number of scans are represented on *x*-axis while the intensity in the image is represented by the color bar. The highest intensity in this image is appearing with a yellow line which is constant for all the scans and at a distance of 2.17 m and it indicates the wall location. Another line whose intensity is varying in number of scan direction and at constant distance of 2.85 m in down range direction is representing the human subject position. The intensity variation occurs due to motion of human chest which modulates the reflected wave phase and magnitude.

The clutter reduced range profile using SVD method eliminates the wall reflection completely from the range profile and enhances the human subject reflection significantly as illustrated in Figure 3(a). The detailed effect on each A-scans is represented by Figure 3(b) where the wall reflections and background noise is absent while the subject associated reflections are preserved which consists of life characteristics information. The signal to wall clutter ratio for the given scan in Figure 2(a) was 35% and after SVD application this improves to 489% for Figure 3(a).

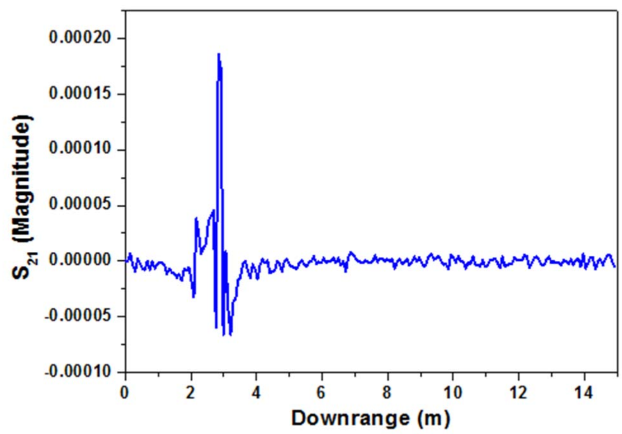


(a)

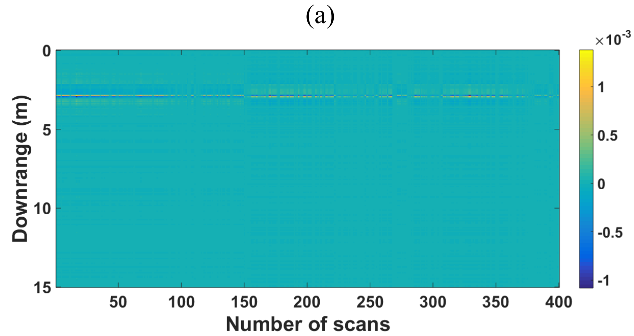


(b)

Figure 2: (a) A single range profile and (b) all A-scans stacked data image before clutter reduction



(a)



(b)

Figure 3: (a) A single range profile and (b) all A-scans stacked data image after clutter reduction using SVD.

To obtain the present frequency information in the clutter reduced data the MTI processing has been applied which eliminates the clutter coming from the static environment around the experimental setup as well as the static part of the human being in rest condition like head limbs etc., and allows only the signals reflected from moving parts. The Fourier analysis retrieves the present frequency components in each rangebin and the obtained RD plane is shown in Figure 4. It is observed from Figure 4 that highest intensity point is present at 2.85 m away from the bi-static radar with heartbeat frequency of 1.42 Hz and thereby indicating the presence of life signature characteristics at the same distance from the antenna system.

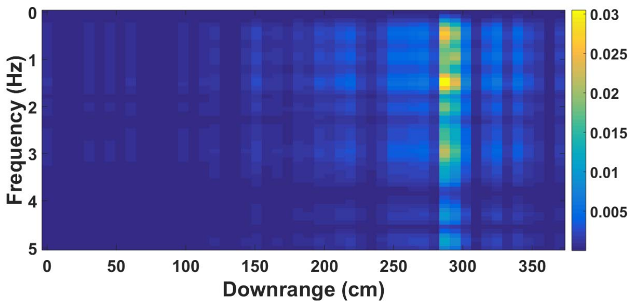


Figure 4: Range Doppler plane after SVD and MTI processing

5. Conclusion

Through the wall life signature detection has been identified by applying SVD based clutter reduction and MTI filtering. The application of SVD improves the SNCR and hence make it possible for life feature detectable by MTI for through the wall detection. The final detection of human subject by tracking its heartbeat frequency from the antenna is detected in Range Doppler plane.

6. Acknowledgements

VS would like to acknowledge my Mr. Akhilendra Pratap Singh, Research Scholar Department of Electronics Engineering, IIT (BHU) Varanasi for his support in experimental discussions. SB acknowledges the research grant from Science & Engineering Research Board, India.

7. References

1. Y. Zhou, L. Kong, G. Cui and J. Yang, "Remote Sensing of Human Body by Stepped-Frequency Continuous-Wave," *2009 3rd International Conference on Bioinformatics and Biomedical Engineering*, Beijing, July 2009, pp. 1-4, doi:10.1109/ICBBE.2009.5163301.

2. M. Jelen and E. M. Biebl. "Multi-frequency sensor for remote measurement of breath and heartbeat." *Advances in Radio Science,* **4**, B-3, September 2006, pp. 79-83, doi: 10.5194/ars-4-79-2006.

3. S. Shirodkar, P. Barua, D. Anuradha and R. Kuloor, "Heart-beat detection and ranging through a wall using ultra wide band radar," *2011 International Conference on Communications and Signal Processing*, Calicut, March 2011, pp. 579-583, doi: 10.1109/ICCSP.2011.5739391.

4. A. N. Gaikwad and K. S. Dongre, "Improvement in detection of human life sign signal hidden behind the wall using clutter reduction technique," *2016 International Conference on Emerging Trends in Communication Technologies (ETCT)*, Dehradun, November 2016, pp. 1-5, doi: 10.1109/ETCT.2016.7882972.

5. S. A. Rane, A. Gaurav, S. Sarkar, J. C. Clement and H. K. Sardana, "Clutter suppression techniques to detect behind the wall static human using UWB radar," *2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)*, Bangalore, 2016, pp. 1325-1329, doi: 10.1109/RTEICT.2016.7808046.

6. B. R. Mahafza and A. Elsherbeni, *MATLAB simulations for radar systems design*. 2003, Chapman and Hall/CRC.

7. A. N. Gaikwad, D. Singh and M. J. Nigam, "Application of clutter reduction techniques for detection of metallic and low dielectric target behind the brick wall by stepped frequency continuous wave radar in ultra-wideband range," *IET Radar, Sonar & Navigation*, **5**, 4, pp. 416-425, April 2011, doi: 10.1049/iet-rsn.2010.0059.