THREE DIMENSIONAL IMAGING

FOR THROUGH-THE-WALL HUMAN SENSING

P. Kishore Kumar[1], T. Kishore Kumar[2]

[1,2]Department of Electronics & Communication Engineering,
National Institute of Technology, Warangal, Andhra Pradesh, 506004, India

***Abstract* — Through the wall sensing is seeing a rapid growth with the present day technology. Particularly Ultra Wideband (UWB) technology paves the way for this. Three dimensional imaging of humans behind the walls, foliage or any other rubble gives information which can help to save lives. This paper simulates a human like structure with the environment of being behind wall and extracts the three dimensional imaging of the human structure. Electromagnetic signals were transmitted and based on the received echoes after processing a 3D Imaging is obtained. Signal processing aspects before imaging and the method used for obtaining the tree dimensional imaging is also discussed.**

***Index Terms* — Human Sensing, Impulse based signals, Ultra-Wideband, Through-the-wall, Synthetic Aperture, Three dimensional imaging.**

I. INTRODUCTION

Human detection behind walls, buildings, foliage, rubble e.t.c., is very much needed to save lives particularly in urban warfare environment. Many imaging and non-imaging techniques were used to achieve the task but succeeded partially. The advent of Ultra Wide Band (UWB) technology makes many challenging things possible like the high data rate transmission, secure communication, high resolution achievement in radars and many more. All these are because of very high bandwidth i.e., ultra wide bandwidth which is in the range of 3.1GHz to 10 GHz as defined by FCC. For through-the-wall imaging applications the frequency range is extended from 1.9 GHz to 10 GHz. This is because low frequency content has high penetration capabilities with less amount of attenuation. Because of the ultra large bandwidth, UWB technology shows a sophisticated way for Through-the-wall radar imaging with very high resolution which is of greater importance in urban warfare environment where the human entry is not possible [1], [2].

Much content of the literature [3], [4], [5] related to through-the wall-radar-imaging is focused only up to the B-scan images where the range and azimuth direction distances of targets are indicated. But in actual real time scenario this information is of limited usage and the soldiers may not get enough information about the target and hence cannot decide about the target whether to consider it or not. Much importance will be given if the target seems to be human being. In such situations it will be important to get the shape, size & orientation information of the target hidden behind the wall. An attempt of three dimensional imaging is done in [6].

This paper is organized as follows: Section II describes the simulated measurement scenario used for three dimensional imaging; Section III gives a note on raw radar data processing. A brief account on back projection algorithm and its extension for three dimensional imaging along with the algorithm description is given in Section IV. Section V summarizes all the simulation results and finally conclusions are given in Section VI.

II. MEASUREMENT SCENARIO

A simplified sketch of the measurement layout is shown in fig 1. The radar system was horizontally scanned parallel to the front wall. The dimensions of the room are 10m×10m×10m which indicates the length, width and height of the room. Since the intention of the paper is to retrieve the three dimensional image of the target hidden behind the wall, for simplicity we assume that the wall attenuation is very less (approximately zero) and the delay is also zero. This assumption may not valid on the field. The assumption may show the shift in the object position.

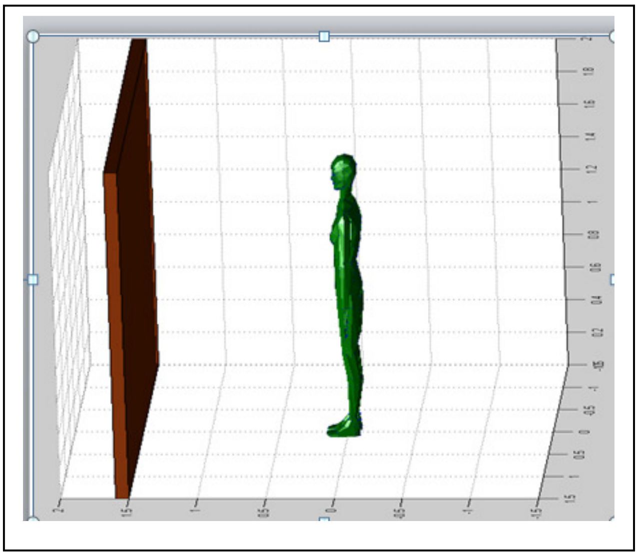

Figure 1: Orthographic View of the scenario

[2,]Associate Professor
[2]kishorefr@gmail.com, [1]pulikishorekumar@gmail.com

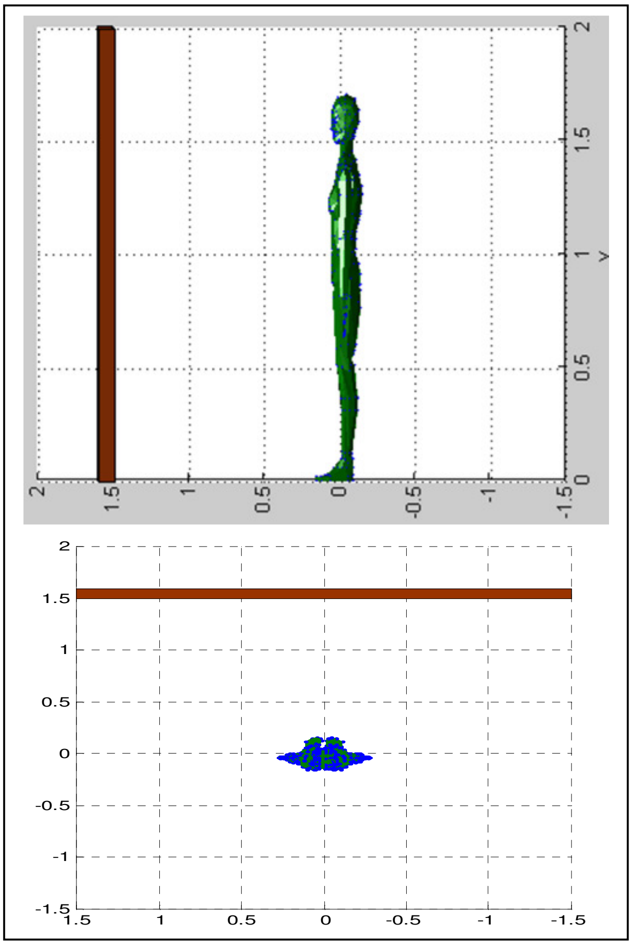

Figure 2: Side View and Top View of the scenario

The human behind the wall is considered to be as a target and is at 1.5m behind the wall. It is crafted by assuming that there exists a patch at a particular coordinate. By defining different coordinates whose contribution with the basic building block gives a structure like human. It took 996 basic building blocks to represent the entire human. The coordinates that we define here are later used for three dimensional reconstruction of an image. These coordinates are generally called scattering centers. In real time application identifying the scattering center is a difficult task and demands for different methods for accurate estimation.

Ultra-Wideband (UWB) signals have the better penetration properties and has the capability of obtaining high resolution images, we use an impulse signals particularly Gaussian derivative is used. The resolution is proportional to the bandwidth of the signal[3, 4] and is given by

$$\Delta R = \frac{c\tau}{2} = \frac{c}{2B} \qquad (1)$$

Where ΔR : Range Resolution

τ : Pulse Width

B : Bandwidth and $c = 3\times10^8$ m/sec is the velocity of light in free space.

The reason of selecting Gaussian doublet or the second derivative of the Gaussian pulse for transmitting is that it has only one peak which can be easily noticed in the time domain and also has the longest lobe in the frequency domain, creating the large bandwidth of the signal. Another pulse would not fit these requirements since it would not have both the large single pulse in the time domain and cover a large spectrum in the frequency domain [2].

Since the signal transmitted by the antenna is the derivative of the input signal, to make use of Gaussian doublet Gaussian first derivative is given as input signal to the antenna. The expressions for Gaussian pulse and its derivatives (up to second order derivative) are given by

$$\left.\begin{aligned} f(t) &= A\exp(-\frac{t^2}{2\tau^2}) \\ f'(t) &= -\frac{At}{\tau^2}\exp(-\frac{t^2}{2\tau^2}) \\ f''(t) &= -\frac{A}{\tau^2}(1-\frac{t^2}{\tau^2})\exp(-\frac{t^2}{2\tau^2}) \end{aligned}\right\} \qquad (2)$$

The signal that was used here has the pulse width of 0.5 nsec and the with centre frequency of 1.83 GHz and 3.3 GHz bandwidth. The plot of the Gaussian derivative and its spectrum is shown in figure 3.

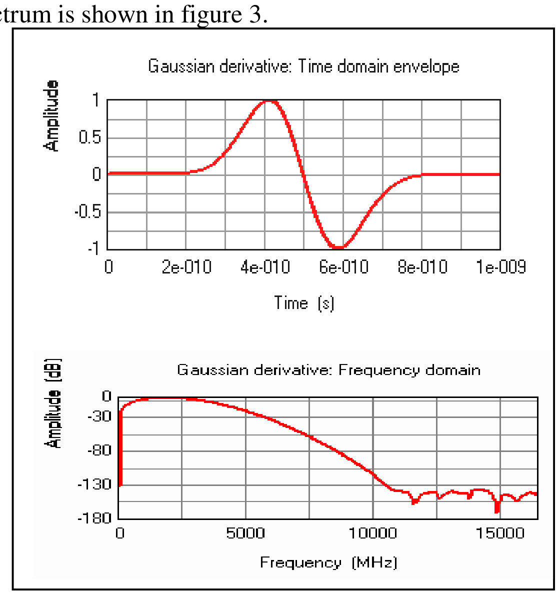

Figure 3: (a) Gaussian Derivative (b) Its frequency Spectrum

III. ANTENNA CROSSTALK REMOVAL, RANGE GATING AND TIME VARYING GAIN

Crosstalk is the part of the signal that travels directly between the transmitting and receiving antennas. It is the first and often the largest peak in the A-scan signal which affects the mean value of the signal. This signal constantly presents in all the measurements and contains no information of the scanned scene. Sometimes this largest peak signal may cross the maximum current rating of the receiver circuit over which the performance may be degraded [7]. Hence it is very important to remove the crosstalk. The crosstalk can be obtained by measuring with radar in the free space, or with absorbers around (anechoic chamber).

$$A_{pcr}(n) = A_p(n) - c_p(n) \qquad (3)$$

Where $A_p(n)$ and $c_p(n)$ are the A-scan signal and crosstalk at p^{th} position of an antenna respectively and $A_{pcr}(n)$ represents the A-scan signal at p^{th} position with crosstalk removed.

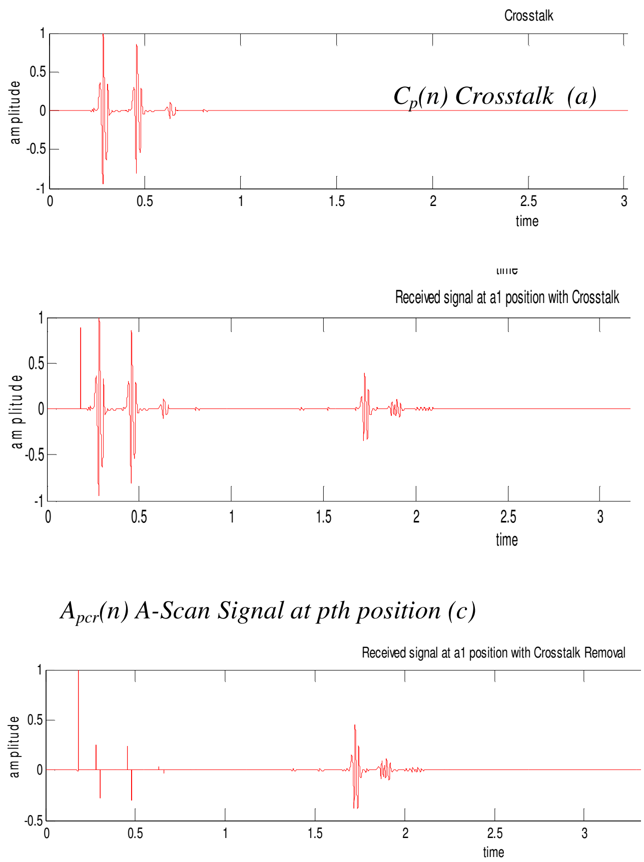

Fig 4: (a) Crosstalk Measurement, (b) Received A-scan signal (c) A-scan signal after removing the crosstalk

Range Gating is the basic preprocessing technique that decides to fix the maximum range of the scanned area [8], [9]. The receiver is made to switch on up to the delay that was fixed by the maximum range. After that delay the signal is assumed to be of even farther distance and hence ignored. The delay that was obtained for 500cm range is 46.6×10-9 sec. Since the velocity inside the wall is get reduced by a factor of $\sqrt{\mu_r \varepsilon_r}$ the delay was increased to 55×10-9 sec which occurs at the index of 110000th sample. Figure 5(a) & 5(b) gives the received echo after range gating.

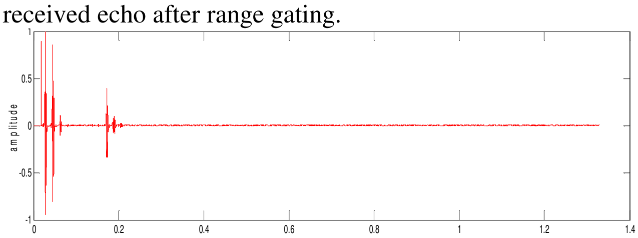

Figure 5: (a) A-scan signal without Range gating

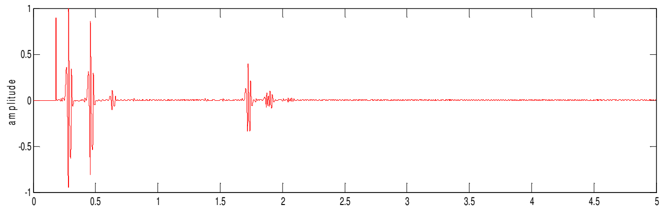

Figure 5: (b) A-scan signal without Range gating

Time varying gain is the concept that was introduced in sonar system where the signal gets attenuated as it gets delayed to reach the receiving antenna. This has a great advantage of increasing the dynamic range and even to detect the targets which gives small strength echoes. The detection of the target with and without time varying gain is clearly demonstrated in the results. Generally speaking as the signal gets delayed to reach the receiver antenna the strength of the signal also reduces. Keeping this in view the gain of the received signal also is made increased based on the delay. In [10] it was given the gain is proportional to the square of the elapsed time measured.

In this paper a constant gain of factor 100 is used. This constant gain is applied to the received signal after the delay of 6nano seconds. The signal before the delay represents the strong clutter from the wall. Figure 6(a) & (b) shows the A-scan signal without and with constant gain factor

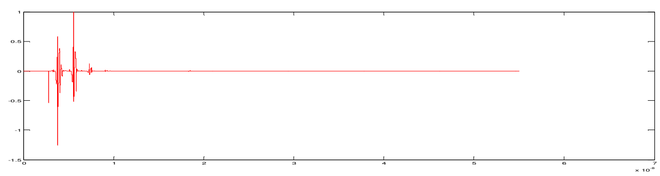

Figure 6: (a) A-scan signal without constant gain factor

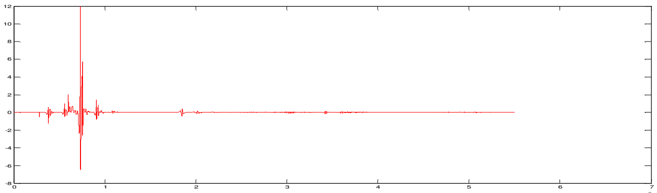

Figure 6: (b) A-scan signal with constant gain factor

IV. Modified Back Projection Algorithm

This algorithm retrieves the image of the scanned area by making use of the A-scan signals at different receiver positions. Since the image is of 3D and is represented by an L×M×N matrix, the aim is obtain the corresponding numerical values to fill the matrix, such that the formed image should represent the scanned scene. Each numerical value in the L×M×N matrix represents a voxel (VOLume piXEL) value of an image. In our simulation to represent the entire room volume we took L=M=N=50 which gives about 1,25,000 voxels.

The numerical value at any voxel position should be the contribution of the A-scan signals at all receiver positions. Since the range is fixed to 700 cm and the number of voxels in the range direction is M (M represents cross range, L represents the range and N represents the height), the range bins are selected such that the maximum range should not cross the prescribed value.

The A-scan signal received at each receiver position assuming P targets in the region is represented as [11], [12]

$$A_{ij}(t) = \sum_{k=1}^{P} a_{ijk}\, s(t - t_{ijk}) \qquad (4)$$

Where $A_{ij}(t)$ is the A-scan signal at $(i,j)^{th}$ receiver position, a_{ijk} is the reflection coefficient of the k^{th} tatget and t_{ijk} is the delay of the signal from the transmitter at (i,j) position to k^{th} tatget position and to the receiver at (i,j) position and is given by

$$t_{ijk} = \frac{2R_{ijk}}{c} \qquad (5)$$

Where R_{ijk} is the distance from the transmitter at (i,j) position to the k^{th} target position.

A weight factor also should be there in eq (4) representing the attenuation of the signal. Similarly a term should be added in eq (5) representing the reduction of velocity inside the wall. Since the intention is to obtain the image, these terms are given little importance in this paper.

The three dimensional point spread response (3DPSR) which represents the spreading of signal energy in three dimensional space of a given A-scan signal is given by

$$f_p(x_i, y_j, z_k) = A_p(t - \tau(x_i, y_j, z_k)) \qquad (6)$$

Where $i = 0,1,2,3.....L,$ $j=0,1,2,3......M$

$k = 0,1,2,3.....N$ and $\tau(x_i, y_j, z_k)$ is the focusing delay[9] in the image space.

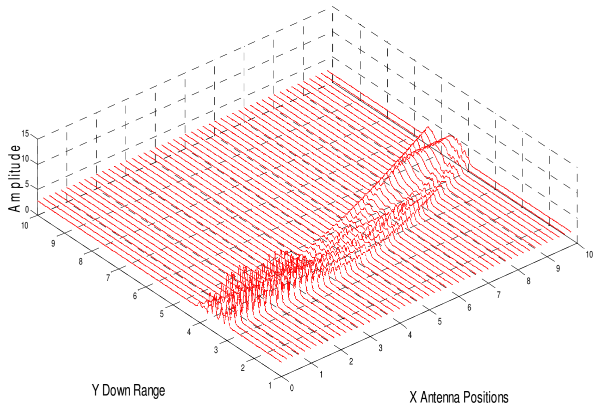

Figure 7: Received signals at Z=2.8 m

But the final image should have the contribution of all A-scan signals and hence all the three dimensional PSR's should be added. The expression is given by

$$B(x_i, y_j, z_k) = \sum_{p=1}^{L} f_p(x_i, y_j, z_k) \qquad (7)$$

V. Results

Computer simulations implementing the impulse signals for through the wall imaging is done. The back projection algorithm is used to retrieve the three dimensional image of the human and the results obtained are shown in figures (8) & (9). Data collected from the receivers at different receiver positions are used in MATLAB to implement the algorithm.

Since the total number of voxels in the simulation is 1,25,000 it is time consuming process to represent all the voxels. Instead the author tries to represent only those voxels that corresponds to the target leaving other voxels for not representing. For that case the intensity value of all voxels are first normalized to unity and then, since our parameter is the voxel value of 0.75 value that is pertaining to the target. This eliminates 99% of the major clutter in the three dimensional image.

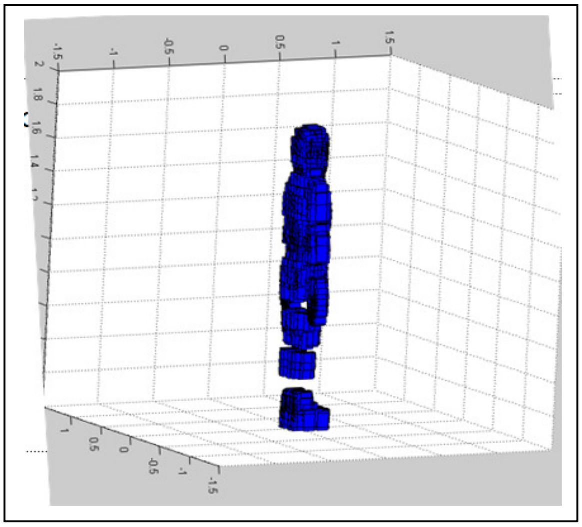

Figure 8: Modified Back Projected 3D image Orthographic view

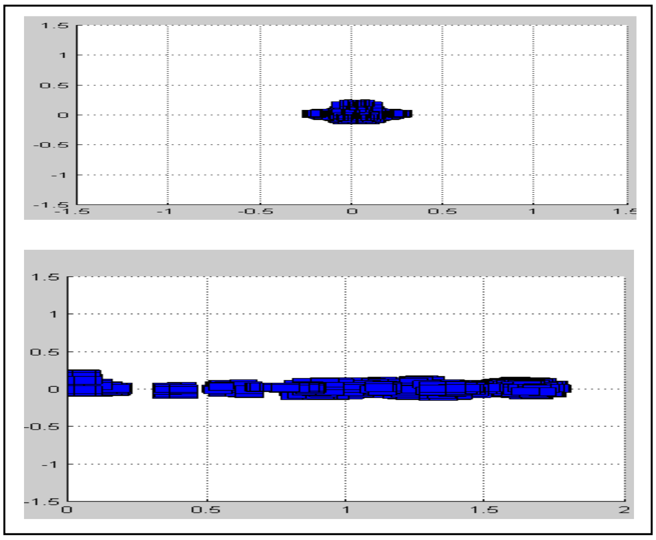

Figure 9: Modified Back Projected 3D image side view & Top View

The Results clearly demonstrates that the three dimensional structure of human is almost similar to the original simulated one.

VI. CONCLUSIONS

We have presented an approach of making use of impulse based signals for three dimensional through the wall radar imaging. Back projection algorithm is analyzed and used in retrieving the three dimensional image of the scanned region. The difficulty that we face in real time is to obtain the scattering center.

From the results it is observed that the three dimensional structure of the human is obtained which enhances the target information helps to save human lives.

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