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Three-Dimensional Radar Imaging

G. Nagaraja¹, Dr. SVS Prasad²

¹Research Scholar in Department of Electronics and Communications Engineering, Shri Venkateshwara University, Gajraula, Amroha, Uttar Pradesh, India

²Professor, ECE Department, Narayana Engineering & Technical Campus, India

Abstract: This paper deals with the concept of three dimensional imaging in through the wall application. It is very clear that 2D imaging gives limited information of the target object which paves the way for the next step of this thesis called three-dimensional imaging. Knowing the range and cross range information of an object is not sufficed to take the right decision at the time of emergency. Portraying the shape of the object is a real challenging task for Through-the-Wall Imaging and is going to be addressed.

Keyword: MB- OFDM, 3D PSR, M-Sequence System, 2D Imaging

1. Introduction

Concept of three dimensional imaging in through the wall application. As 2D imaging gives limited information of the target object which paved the way for three-dimensional imaging. Knowing the range and cross range information of an object is not sufficed to take the right decision at the time of emergency. Portraying the shape of the object is a real challenging task for Through-the-Wall Imaging and is going to be addressed.

2. Three Dimensional Measurement Scenario

For three dimensional imaging the dimension of the room is taken as $10m \times 10m \times 10m$ which indicates the length, width and height of the room. Since the intention of this section is to retrieve the three dimensional image of the target hidden behind the wall, it is assumed that the wall attenuation is very less (approximately zero) and the delay is also zero. The orthographic view of the measurement scene is shown in Figure1. The top view and side view are shown in Figures 2 and 3 respectively.

A wooden stool, the common object that is usually found in any room is considered as the target of interest. The target object is crafted by assuming that there exists a cube at a particular coordinate of 20cm length. Different coordinates are defined whose contribution [5] with the basic building block "cube" gives a structure like stool which is an object inside the room with height of 320cm and width of 120cm. It took 96 basic building blocks [6] to represent the entire stool. The coordinates used to define the target object "stool" is given in Table 1.

For each coordinate defined, there exists a basic building block with this coordinate as one vertex. Since the length is fixed to 20 cm remaining seven coordinates can easily be anticipated. For example for the coordinate (5, 4, 0) the remaining vertices are given by the set {(5, 4, 0.2), (5, 4.2, 0), (5, 4.2, 0.2), (5.2, 4, 0), (5.2, 4, 0.2), (5.2, 4.2, 0), (5.2, 4.2, 0.2)}. Similar pattern is repeated for each coordinate to form the entire structure of the target.



Figure 1: Orthographic View of the Measurement Scene for 3D Imaging



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Unlike the two-dimensional imaging here the echoes are collected by moving the antenna both horizontally and vertically. The coordinates for the antenna platform positions are given in Table 2.

Totally 2500 platform positions are considered with 50 for each linear motion. The order of antenna positions is given by 50×50 . Each linear motion of antenna gives the information of that particular layer. Combining the information from all such layers [1] can help to portray the shape of the target. In this case Back Projection Algorithm is extended, whose details are given in the following sections.

 Table 1: Basic Building Block Coordinates to form the

 Target Object

Turget Object				
Target Object	X (cm)	Y (cm)	Z (cm)	
Stool Leg - 1	5	4	0:0.2:2.85	
Stool Leg - 2	4	4	0:0.2:2.8	
Stool Leg - 3	4	5	0:0.2:2.8	
Stool Leg - 4	5	5	0:0.2:2.8	
Stool Surface	4	4: 0.2 : 5	3	
~	4.2	4: 0.2 : 5	3	
~	4.4	4: 0.2 : 5	3	
~	4.6	4: 0.2 : 5	3	
~	4.8	4: 0.2 : 5	3	
-	5.0	4:0.2:5	3	

 Table 2: Coordinates of Antenna Platform Positions for 3D

 Imaging

Platform Positions	X (m)	Y (m)	Z (m)
1-50	0:0.2:9.8	0	0
51-100	0:0.2:9.8	0	0.2
101-150	0:0.2:9.8	0	0.4
151-200	0:0.2:9.8	0	0.6
:	:	:	:
:	:	:	:
:	:	:	:
:	:	:	:
2401-2450	0:0.2:9.8	0	9.6
2451-2500	0:0.2:9.8	0	9.8

3. Proposed Three Dimensional Imaging Algorithm

Lending the concept from the back projection algorithm given in section 4 a novel algorithm is proposed for three dimensional imaging that enhances the target information. Necessary equations, algorithm steps and its implementation for three dimensional imaging [2] in this section are developed. The 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 $L \times M \times N$ matrix, the aim is to obtain the corresponding numerical values to fill the matrix, such that the formed image represents the scanned scene. Each numerical value in the $L \times M \times N$ matrix represents a voxel (Volume piXEL) value of an image.

In the process of correlating the collected data at each platform position as a function of round-trip [3] delay three different coordinate systems are defined similar to that in 2D imaging . An object space, data space and 3Dimage space for three dimensional imaging is picturized in Figure 4.



Figure 4: Three Dimensional Imaging (a) Object Space (b) Data Space (c) 3DImage Space

Volume 3 Issue 11, November 2014 www.ijsr.net The received echoes at different receiver positions are used to map object space to data space. Data space is the function of platform position (cross range, height) and time, *dat* (x, z,t). Multiple curved surfaces are formed in the data space, an example with specified transceiver position is shown in Figure 4 (b). Each curve in the data space represents three dimensional PSR. The 3D image is represented by 3D matrix [4] of order L×M×N. This matrix is filled with numerical values based on the echoes. A-scan signal received at each receiver position assuming N targets in the scanned region is given by

$$A_{ij}(t) = \sum_{k=1}^{N} \alpha_{ijk} s(t - t_{ijk}) [1]$$

Where

 $A_{ij}(c)$: Received A-Scan signal at (i, j) platform position, i = 0, 1, 2.....P;

j = 0, 1, 2, 3....Q

 a_{ijk} : Reflection coefficient of k^{th} target when transceiver is at (t, j)

 t_{ijk} : Delay of the signal from (i,j) transceiver position to k^{th} target position and back to (i,j) transceiver position.

The expression for the delay is given by

$$t_{ijk} = \frac{2R_{ijk}}{c} [2]$$

3D PSR represents the spreading of signal energy in three dimensional spaces. For a given A-scan signal the PSR is given by

 $f_p(x_t, y_t, z_k) = A_p(t - \tau(x_t, y_t, z_k)) [3]$

Where fp(xi, yj, zk) represents the volume map as a function of voxel coordinate (*xi*, *yj*, *zk*).*i* = 0, 1, 2, 3.....*L*; *j* = 0, 1, 2, 3.....*M*; *k* = 0, 1, 2, 3.....*N*; _ (*xi*, *yj*, *zk*) is the focusing delay. The 3D PSR at transceiver position is indicated in Figure 5. It is observed that there exist multiple curves with different ranges indicating multiple target points.



Figure 5: Three Dimensional Point Spread Response

By collecting 3D PSR's at all transceiver locations, the 3D image is obtained from the equation. Where p varies from 1 to P, indicates the platform position defined for both vertical and horizontal motion.

$$B(x_{t}, y_{j}, z_{k}) = \sum_{p=1}^{p} f_{p}(x_{t}, y_{j}, z_{k})$$
[4]

4. Results and Conclusions

The proposed three-dimensional imaging algorithm is used to retrieve the shape of the target behind wall. The data collected from the receivers at different receiver positions is used to implement the algorithm. The volume matrix used to represent the 3D scene behind the wall consists of 1, 25,000 voxels with L = M = N = 50, where L, M, N represents the number [7] of voxels in x, y and z direction respectively. Since the total number of voxels is more in number it is time consuming process to represent all the voxels. Hence representation of those voxels that correspond to the target leaving other voxels is only considered. To identify the voxels pertaining to target, the intensity values of all voxels are first normalized to unity and then a threshold of 0.75 is considered to eliminate all other voxels which are not related to target from representation in the volume map. This eliminates major part of the clutter in the three-dimensional image.



Figure 6: Orthographic view of the target after proposed 3D imaging





Figure 8: Side-view of the target after proposed 3D imaging

Volume 3 Issue 11, November 2014 www.ijsr.net Figure-6, Figure-7 and Figure-8 show the orthographic view, top-view and side-view of the target respectively after processing with proposed three-dimensional imaging algorithm. The results clearly depict the 3D shape of the target object similar to that of the original target shape, and 53% of the voxels in the final 3D image belong to the original object defined in Figures 1, 2 and 3.



Figure 9: Orthographic view of the target after 3D imaging using M-sequence



Figure 10: Top-view of the target after 3D imaging using M-sequence



igure 11: Side view of the target after 3D imaging using M-sequence

Three-dimensional imaging using M-sequence with 9 shift registers and 511 chips is done and the results are shown in Figures 9, 10 and 11. Out of 100 voxels of the actual target only 7 are recovered in the final 3D image. This indicates that the accuracy of the final 3D image gets worse compared to the impulse based signals. But as explained in section

4.1.2, the hardware implementation of the system is easy compared to the impulse based systems.

Using MB-OFDM with 128 carriers and total bandwidth of 500MHz the results obtained for three dimensional imaging are shown in Figures 12, 13 and 14. The results depicted clearly gives the 3D shape of the object and the number of voxels that of the original target are found to be of 12 %. Even though this is less than that of impulse based systems, the advantage of selecting proper sub band is an additional advantage of MB – OFDM systems. It can be clearly observed that the relative performance of MB – OFDM system is hopefully good compared to that of the M – Sequence systems.

Even though three different signals gave different results based on its inherent behavior, it is based on the type of application and the environment, the stimulus signal is selected. Finally it is concluded that impulse based signals gives magnificent performance for through-the-wall imaging.



Figure 12: Orthographic view of after 3D imaging using MB-OFDM approach



Figure 13: Top-View of the target after 3D simulation using MB – OFDM



Figure 14: Side View of target after 3D imaging using MB - OFDM

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