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Radar Imaging of Concealed Targets

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Abstract— **Visualization of concealed/buried targets is of high interest to military, paramilitary and law enforcement organizations. But in reality human vision cannot penetrate solid walls and earth. See-Through Wall Radar or Through-Wall Radar can be used for detecting the activities of persons behind walls and Ground Penetrating Radar (GPR) can detect buried anti-personal mines and other objects. In this paper the implementation of some of the Radar Imaging Algorithms like Backprojection, Kirchhoff's Migration and Stolts (f-k) Migration is described. The imaging is done in both 2-D and 3-D. MATLAB® 7.1 has been used for the development.**

Keywords— **Radar imaging, GPR, Through-Wall Imaging Radar, Kirchhoff's Migration, Stolts Migration, Back Projection Backpropagation, MATLAB.**

I. INTRODUCTION

Man was interested in knowing of unknown from the very beginning of the human history. Our human eyes help to investigate our environment by reflection of light. However, wavelengths of visible light allow transparent view through only very small kinds of materials. On the other hand, Ultra Wideband (UWB) electromagnetic waves with frequencies of few gigahertz are able to penetrate through almost all types of materials around us. With some sophisticated methods and a piece of luck we are able to investigate what is behind opaque walls. Rescue and security of the people is one of the most promising fields for such applications.

The capability of seeing concealed / buried targets is of high interest to many organizations including military and law enforcement. The reality however, is that human vision cannot penetrate solid walls and earth. In our case, we are interested in radar systems that can detect the activities of persons behind walls (See-through Wall Radar) and buried anti-personal mines (Ground Penetrating Radar).

The main requirement for detecting a person behind walls using radar is that the radar signals can propagate through the walls. The safety of victims, hostages, or security forces placed at risk often depends on the ability to assess situations quickly and accurately. Many dangerous situations also require that assessment be done discreetly so as not to alert criminals or the enemy to the intentions of security force personnel. This information must then be presented to the operator in a clear and simple way.

Through-the-Wall Radar Imaging (TWRI) system is capable of monitoring the location of people in a room, by looking through the walls, floor, and/or ceiling of the room have been developed by a number of organizations. It allows police, fire and rescue personnel, first responders, and defense forces to detect, identify, classify, and track the whereabouts of humans and moving objects. Electromagnetic waves are considered the most effective at achieving this objective, yet advances in this multi-faceted and multi-disciplinary technology require taking phenomenological issues into consideration and must be based on a solid understanding of the intricacies of EM wave interactions with interior and exterior objects and structures [1].

Ground Penetrating Radar (GPR) is considered as being one of the most promising technologies for close detection and identification of buried Anti Personnel (AP) Landmines, due to its ability of detecting non-metallic objects in the sub-surface [2].

Another area of interest is to detect concealed targets like drugs inside body cavities on humans, and this can range from the less dramatic knife and gun carriers to the hardened terrorist [1].

In all the above applications, radar imaging plays a key role in the detection and is required to spot the potential risks. Radar / Microwave Imaging include both Signal and Data Processing.

Imaging radar works very like a flash camera in that it provides its own light to illuminate an area on the ground and take a snapshot picture, but at radio wavelengths. A flash camera sends out a pulse of light (the flash) and records on film the light that is reflected back at it through the camera lens. Instead of a camera lens and film, a radar uses an antenna and digital computer tapes to record its images. In a radar image, one can see only the light that was reflected back towards the radar antenna.

II. THE EXPERIMENTAL SETUP

An experimental set-up was made for collecting data for Through Wall Radar Imaging. This set-up consists of an EATON Advanced Electronics' Impulse Generator (60 KHz - 1GHz) and a Teletronix DPO 71604 Digital Phosphor Oscilloscope with 16 GHz/50 GS/s.

For this measurement bi-static pair of horn antenna is used with antenna separation of 14 cm. To generate a 2-D scanning array of antennas the antenna platform was manually moved along the cross range (X) and height (Z) directions. A cross range resolution of 30 cm and a height resolution of 15 cm were considered in the experiment. Initial height from ground was 110cm, later it was moved to 125 cm and 140 cm. A scan array size of 8 × 3 was considered for the measurement (8 points along cross range and 3 points along height directions). Distance of the Transmitter (Tx) / Receiver (Rx) pair from wall is 27.5 cm. A wooden wall of thickness 8 cm was considered.

Fig. 1: Bi Static pair of Horn Antenna placed on one side of wall

Fig. 2: Three objects placed on other side of wall

For GPR imaging, public domain data generated by Royal Military Academy, Brussels was used. The laboratory set-up shown in Figure 1 was used for this measurement. The C-Scan data was obtained by moving the antennas in the X & Y directions. Two Ultra Wideband (UWB) Horn antennas were used as the transmitting and receiving antennas.

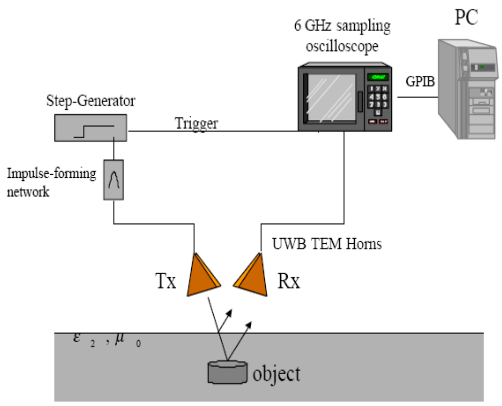


Fig. 3:Experimental Set-up for GPR data collection

III. Imaging Techniques

The most popular and effective techniques used in Radar imaging are the Backprojection and Backpropagation (Migration)Techniques[3]. Backprojection technique has its origin in Synthetic Aperture Radar (SAR) and Backpropagation techniques like Kirchhoff Migration & Stolts (*f-k*) Migration [4] have their roots in Seismology. Stripmap SAR and Spotlight SAR are other techniques used in Radar Imaging.

In this work, I have used the Backprojection (for through-wall radar imaging) and Kirchhoff & *f-k* migration techniques for GPR imaging. The details of these algorithms are outlined in this section.

(a) Backprojection Algorithm:

The data from each received signal consist of a set of electric field values as function of the time travelled by the radar signals. The signal received at a given time can be from all pixel locations where the total flight time is equal to this specific time bin. The total flight time is the time to travel from the transmitting antenna to the pixel and then back to a receiver. Fig 4 shows example of pixel location where the reflected signal can come from for a set of collocated transmitting and receiving antenna elements. The back projection techniques consists of recording the amplitude of each time bin on a spatial grid based on the total flight time, after that, all the recorded amplitudes from each channel are added together on the spatial grid. At the target locations the signal amplitude will add up coherently and should build up quickly [5]. The back projection algorithm has been implemented as follows:

1. Divide the whole region into small surface areas or pixels.
2. For each pixel, calculate the total flight time from transmitter to pixel and pixel to a receiver.
3. Record the corresponding received time bin amplitude for each pixel.
4. Repeat step 2 and step 3 for all receivers.
5. Sum the recorded amplitudes on the spatial grid.

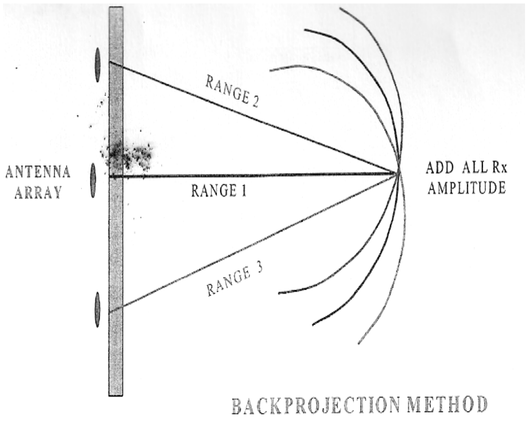


Fig. 4: Backprojection Method

The Backprojection algorithm is as shown below:

Step 1: Divide the whole region into small surface areas or pixels.

Step 2: For each pixel, calculate the total flight time from transmitter to pixel and pixel to a receiver.

Step 3: Record the corresponding received time bin amplitude for each pixel.

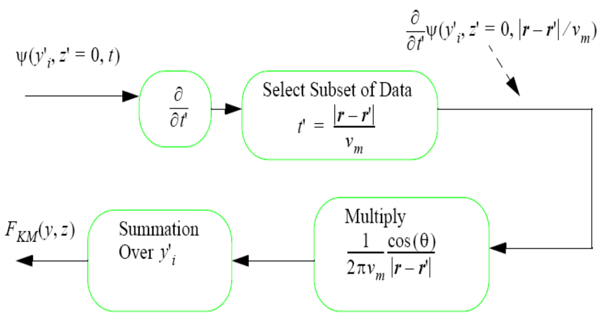
Step 4: Repeat step 2 and step 3 for all receivers.

Step 5: Sum the recorded amplitudes on the spatial grid.

(b) Kirchhoff migration algorithm:

Kirchhoff Migration (KM), which is also known as reverse-time wave equation migration or wave field extrapolation, is based on an integral solution of the scalar wave equation [5]:

$$\nabla^2\psi(\mathbf{r}, t) - \frac{1}{v_m^2}\frac{\partial^2}{\partial t^2}\psi(\mathbf{r}, t) = 0 .$$



The Kirchhoff Migration algorithm is as shown below:

Step 1: Exploding source model.

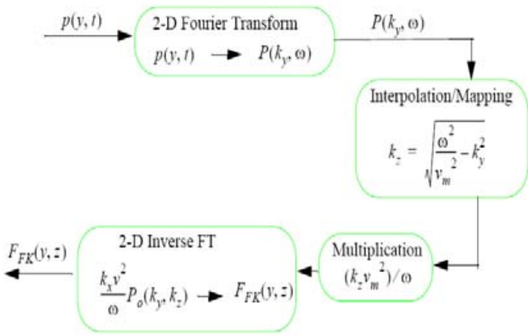
Step 2: Solving the scalar wave equation for Kirchhoff integral, using the Green's Function.

Step 3: Finding the derivative of the data. The total path length in the air and in the ground for each A-scan is calculated. Oblique factor and spreading factor is calculated for each A-scan.

Step 4: Summation of each A-scan shifting each sample by its corresponding time delay, to obtain summation of each A-scan.

(c) Stolts/F-k Migration Algorithm:

Frequency-Wavenumber (F-K), or Stolt Migration, was first developed by R.H. Stolt in 1979. It is also based on the exploding source model and the scalar wave equation. The final result closely resembles the final form of the Stripmap SAR algorithm. Also important is that F-K migration is theoretically identical to Kirchhoff Migration [5].



The Stolts/F-k Migration algorithm is as shown below:

Step 1: Load input file.

Step 2: Take FFT along *x*-axis.

Step 3: Mapping to *z*-axis.

Step 4: Interpolation in k_x domain.

Step 5: Multiplication with k_z factor.

Step 6: Perform 2D Inverse FFT (IFFT) of data obtained.

IV. RESULTS

Some of the results obtained are described below:

(a) See-Through Wall Radar:

In the first experiment, a Conical Antenna and an Asymptotic Conical Dipole (ACD) Sensor were used as the target. They were placed at a distance of 3.7 m from the Transmit/Receive System. No wall was present in between. The experiment was conducted inside an all-welded metallic enclosure, whose back wall was at approximately 6 m from the Transmit/Receive System. The image (at resolution 128 × 128) obtained after applying the 2D Backprojection algorithm is given in figure 5 (image size 5 m × 8 m).

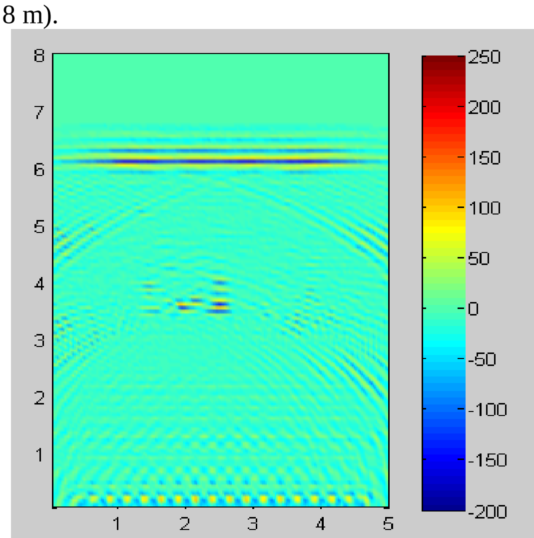


Fig. 5:Back-projected Image of Two Objects

In the second experiment, a horn antenna, a conical antenna and a metallic cylinder were used as the target. A wooden wall of thickness 8cm was present between objects and the antenna. Objects were placed at a distance of 6 cm from the wall and distance of Transmit/Receive System from wall is 27.5 cm. The image (at resolution 64 × 64) obtained after applying the 2D Back projection algorithm is given in figure 6. The image presented here has been truncated to exclude the wall.

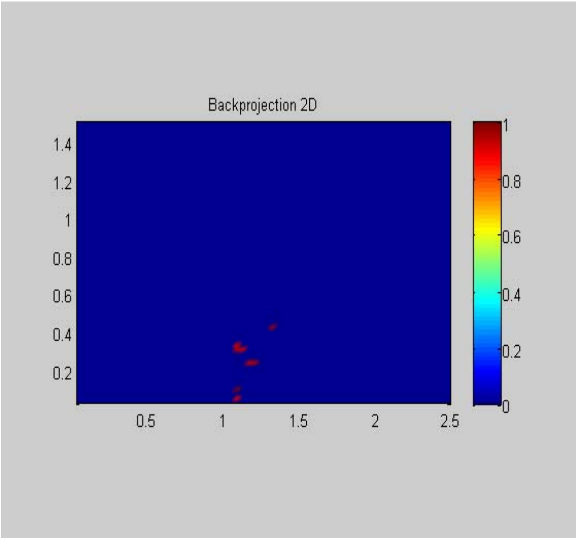


Fig. 6: Back-projected Image of Three Objects

(b) Ground Penetraing Radar

Data from Royal Military Academy, Brussels, for a buried mine was imaged using Kirchhoff migration. The migrated image in 2D is in figure 7.

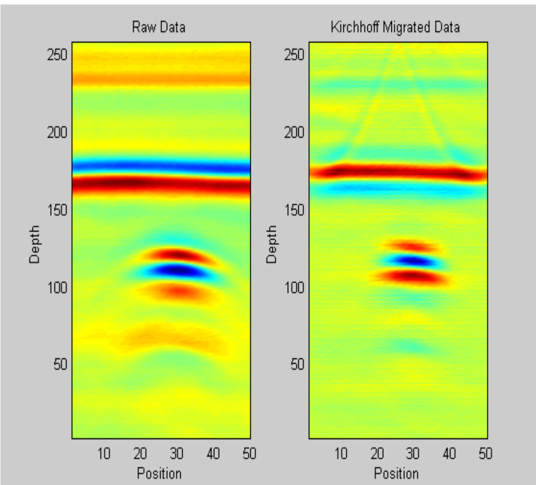


Fig. 7: Kirchhoff Migrated Image of a Buried Mine (2D view)

The migrated data after applying 3D Kirchhoff Migration is in figure 8.

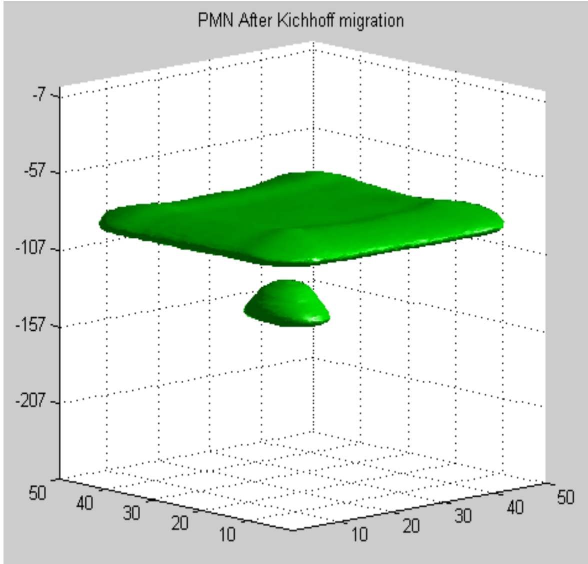


Fig. 8: Kirchhoff Migrated Image of a Buried Mine

The same buried mine was imaged using 2D Stolts (*f-k*) migration. The migrated image is in figure 9.

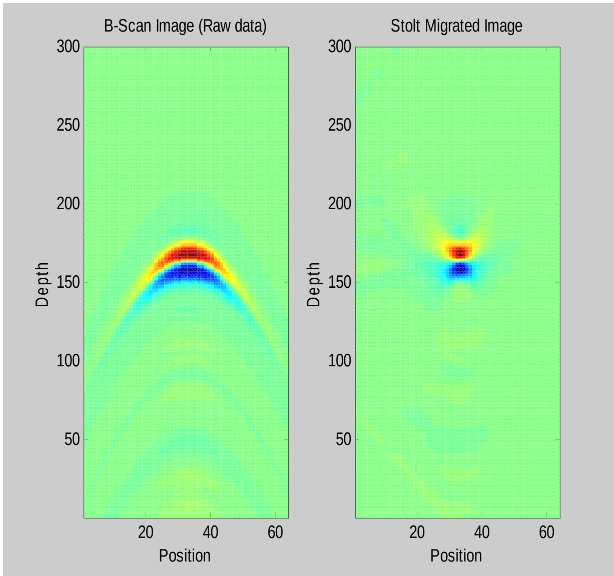


Fig. 9: Stolt Migrated Image of a Buried Mine

(c) Performance Analysis

All the algorithms were implemented in MATLAB 7.1. Backprojection takes 5.149 s for 2D at resolution 128 × 128.

Kirchhoff and Stolt Migration performances are given in table below. From this table it is evident that Kirchhoff Migration is superior in terms of Computation Time, but *f-k* Migration provides a more focused image.

TABLE I
FCOMPARISION TABLE FOR KIRCHOFF AND STOLT MIGRATION

Algorithm	**Execution**	**Comput-ation Time (Sec)**	**Average Computa-tion Time (Sec)**
Kirchhoff	Run 1	0.053603	0.050657
	Run 2	0.050829	
	Run 3	0.050013	
	Run 4	0.046931	
	Run 5	0.051909	
Stolts	Run 1	0.310727	0.2765148
	Run 2	0.255928	
	Run 3	0.280266	
	Run 4	0.270216	
	Run 5	0.265437	

V. CONCLUSION

Radar imaging of a See-Through Wall Radar and a Ground Penetrating Radar was done by using well-established Radar Imaging techniques like Backprojection & Backpropagation (Migration). A comparison of the performance of these algorithms is also presented. No performance optimization techniques were used in the implementation. The data collection was done using standard horn antennas. Better quality results can be obtained by using Impulse Radiating Antennas (IRA) and a more detailed study is required for comparing the computational performance of the above algorithms.

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