Point Target Localization and Imaging with Plane Wave Using SAR

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ABSTRACT:
In this work a plane wave is used to localize a point target and in addition to speeding up the imaging scenario rather than moving the antenna to synthesize the long aperture as done in conventional SAR instead of moving the antenna to synthetize the long aperture a single plane wave transmitter and a linear passive antenna array for the receiver are used. Single plane wave transmitter in far field is considered as an abundance of narrow beam width along a line parallel to the target. Transmitter antenna illuminates the target in all positions directions that the radar used to move in SAR technique. The Linear array is put in a closer distance to the target and collects the back scattered field coherently in a several positions. This collection will be considered as a strip map SAR mode. The proposed technique is implicitly the same as SAR technique. The SAR standard imaging image processing, back projection algorithm is used to construct the image. Since the proposed technique transmits a plane wave for a single time and the linear array collects data in all positions simultaneously, the speed of this technique is considerably more than the conventional SAR

KEYWORDS: synthetic aperture radar, plane wave, imaging, linear array, localization, image processing, back projection algorithm

1. INTRODUCTION

Radar Pulses propagate with the speed of light. By measuring transmit and received times, the distance to the target, i.e., target range can be calculated. The pulse width determines the range resolution. Larger bandwidth means better resolution in this dimension. In an imaging radar, radar moves along a flight path and illuminates the coverage area. Antenna length determines the cross-range resolution. The longer length of the antenna causes a better resolution in the azimuth. In order to improve the resolution, synthetic aperture radar uses a technique called aperture that collects the returned signal required to construct the image. By moving a real aperture or antenna in certain parts of the path, synthetic aperture is created.

SAR is a general technique used to produce radar images with a better resolution. SAR has unique imaging capabilities such as producing image in all times of day and night without affecting by sun radiations; and widely used in imaging of Earth surface, sea level detection, landmine detection, moving target detection, soil moisture determination and through the wall imaging. Many studies have been done that show SAR application in different cases; for example, [2] introduce a finite-difference time domain simulator that his document provides accurately models the interaction of microwaves with realistic soils, specifically from spaceborne interferometric synthetic aperture radar (InSAR). Novel change detection technique based on stepped-frequency continuous-wave synthetic aperture radar interferometry to detect human beings in motion inside a building is presented in [3]. The proposed approach to moving-target indication consists of radar image formation, noncoherent energy change detection, and interferometric phase detection. An algorithm for imaging of targets behind walls is proposed in [4] to reduce the wall reflection and enhance the signal to-clutter ratio. The image formation is based on differential synthetic-aperture-radar image formation employing a continuous-wave radar system. In this approach, instead of using individual backscattered signals, the image is formed by employing the difference signals obtained by subtracting two successive signals along the track. Through-wall imaging/sensing using a synthetic aperture array technique is studied in [5] by employing ultrawideband antennas and for wide incidence angles. The propagation through building walls, such as brick and poured concrete in response to point sources near the walls, is simulated by using high-frequency methods. Reciprocity is used to find the responses of point targets behind walls, which are then used to simulate the synthetic aperture radar (SAR) imaging through the walls. [6] Presents a generalized three-dimensional (3-D) beamforming algorithm for the focused imaging of targets behind multilayered building walls. The far field layered medium Green's function is incorporated in the 3-D beamformer for the compensation of the wall effect. 3-D polarimetric imaging is exploited in TWRI for enhanced target identification and feature extraction as well as wall effect mitigation.

In synthetic aperture radar as the radar moves, sends a pulse to the target or ground in any position and the reflection received and stored coherently through the receiver. And the processing of these raw data cause the construction of the image. In fact the resolution factor in cross range is a processing of returned signal in several position. Data collecting is a time-consuming process because radar moves in a prescribed line and store back projected signals, also the volume of raw data is very high and a lot of memory is needed for processing, it takes even several days to process these raw data to create an image. To circumvent these problems a single plane wave transmitter is used instead of moving the antenna in multiple position in SAR, plane wave considered as several pencil beam antenna illuminate the target in several position; to construct an image backscattered field should be collect in several position, in order to use SAR processing a linear antenna array is located in a closer distance to the target to store back projected in multiple position, this strategy is implicitly as a SAR with a difference that in a plane wave imaging strategy all location transmit a pulse simultaneously and also linear array collect the scatter from the target all together. This cause the imaging processed faster and despite the SAR the required memory to store and process the raw data in plane wave imaging is less. In this paper the processing algorithm is the SAR standard imaging technique.

The remainder of this paper, in Section I SAR imaging techniques described. Then, in the second part plane wave imaging scenario was described. In the third part talks about the simulation results and will be conclude in Part IV.

2. SYNTHETIC APERTURE RADAR IMAGING

For free space synthetic aperture radar imaging, the image of the targets can be reconstructed by applying the matched filter or adjoint operation of the forward scattering operator to the measured scattered field at each image pixel [7].

$$I(r) = \int_{L_{\min}}^{L_{\max}} \int_{L_{\min}}^{k_{\max}} E_s(r_{rm}, r_{tm}, k_n) e^{j\omega_n \frac{R_{tm}+R_{rm}}{c}} dr_{rm} dk_n$$

(1)

where I(r) is the reconstructed image pixel at position r, $E_s(r_{rm}, r_{tm}, k_n)$ is the received scattered field at the m-th receiver location due to the illumination of the m-th transmitter, r_{rm}, r_{tm} and r are the position vectors of the transmitter, receiver and target, respectively, i.e.,

$$r_{tm} = \hat{x} x_{tm} + \hat{y} y_{tm}, \quad r_{rm} = \hat{x} x_{rm} + \hat{y} y_{rm},$$

$$r = \hat{x} x + \hat{y} y;$$

k_n is the freespace wave number of the n-th transmitting frequency, c is the speed of light in freespace, R_{tm} and R_{rm} are the distances from the m-th transmitter and receiver to the target, i.e., $R_{tm} = |r_{tm} - r|$, $R_{rm} = |r_{rm} - r|$.

Equations (1a) and (1b) are also referred to as the frequency domain standard backprojection (SBP) algorithm. The term $(R_{tm} + R_{rm})/c$ in (1a) and (1b) is essentially the wave propagation time from the transmitter to target then from the target to the receiver. Equation (1a) backprojects the measured signal to the position when it is excited and the coherent summation of the backprojected signal forms the image. Equation (1a) can also be written in the equivalent form in (1b).

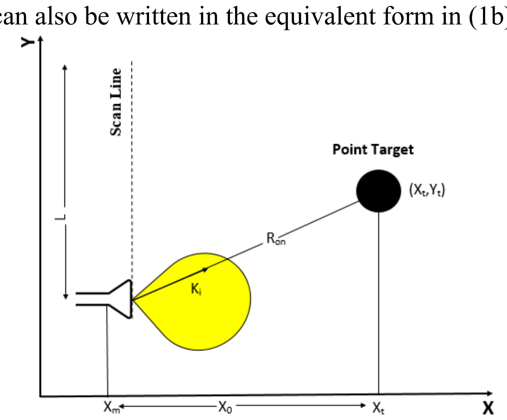


Fig.1. Target imaging/detection by using a moving transceiver antenna.

From electromagnetic perspective, the physical meaning of the beam former in (1b) is straightforward: the integral kernel is essentially the scattered field dividing by the free-space Green's functions G (r, r_{tm}, k_n) and G (r_{rm}, r, k_n) which relate the wave propagation process from the transmitter to the target and the target to the receiver, where

$$G(r_{rm}, r, k_n) = \frac{e^{-jk_n R_{rm}}}{4pR_{rm}}, \quad G(r, r_{tm}, k_n) = \frac{e^{-jk_n R_{tm}}}{4pR_{tm}}$$

(2)

For monostatic case $R_{tm}=R_{rm}=R_{0n}$. The division of the Green's function is a compensation of the wave propagation process [8]. Fig. 1 shows a simple scenario of target detection using a SAR system.

3. PLANE WAVE

Backscattered signal from the target is necessary for imaging, to collect the scattered field form a target to be localized and imaged, a single plane wave transceiver is used to propagate in multiple position, the plane wave is considered as a several pencil beam antenna in a line as a linear array that propagate all together and illuminate the target from different position as a SAR, to collect the backscattered in multiple position a linear array antenna is placed closer to the target, fig. 2 shows the detail of this technique, the receiver is linear array antenna in a y direction with interelement spacing of yd, to collect the back projected signal in a different distance. The big difference between plane wave technique and SAR is the beam width of transmitter, SAR antenna has a wide beam width and cause the number of sampled from the target to be increased and finally has a better resolution but a lower speed, although the plane wave has not good resolution, the imaging process is fast and the required memory to store the raw data and process is less.

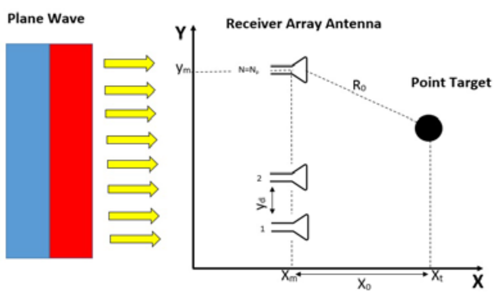


Fig.2. Target imaging/detection by using a plane wave transceiver and linear array receiver

3.1. Localization of point target with a plane wave

Fig.2. shows the geometry of a plane wave technique, since the distance of the array to the target, R_0, is different for each receiver, the amplitude of the receiver is different for each element, the position of point target is evaluated with this fact that the closer antenna to the target receives the stronger reflected signal. In this scenario the array are parallel to the target and the biggest received amplitude is for an antenna that located the opposite side of the target exactly due to the shortest distance, consequently by knowing the location of each element of the receiver array, the element with biggest amplitude shows the location of point target in cross-range (parallel to the target $y_t = y_m$), to calculate the target distance in x, range, the conventional technique is used, with the time delay between transmitter and receiver and speed of wave propagation in free space, c_0 range is evaluated as:

$$X = C_0 * (t_0 + t_1) / 2 \quad (3)$$

Where t_0 is transmitted pulse time, and t_1 is a time of received signal.it worth to notice that this technique just localize the point target and can be applied in through the wall imaging for alarming the presence of a target.

3.2. Imaging with plane wave

To construct an image as can be seen from fig.2 Np number of receiver antennas along a line parallel to the target to collect the target returned signal in various locations. This technique is implicitly as a SAR imaging and the SAR standard image processing can be used in the proposed technique, the transmitter and receiver are along line parallel to the target like a strip-map SAR. Back projection algorithm is also used to construct an image for plane wave imaging. received signal for each element array is substitute in $E_s(r_m, k_n)$ in (4) which R_m is distance from the target to m-th receiver, although receiver and transmitter are not collocated can be assumed as a monostatic due to the characteristic of plane wave that phase and amplitude in a plane are equal and using of (4) is absolutely true.

4. SIMULATION RESULTS

Some numerical results for different target-receiver distance are presented in this section to show the effectiveness of the proposed plane wave imaging technique. In order to show the validity and efficiency of the technique, however, we first present some localization results for different target-receiver distance scenarios and then present some imaging results for different target-receiver distance scenarios compare with existing SAR imaging algorithm. The scattered field was generated using a two-dimensional (2D) Finite difference Time Domain (FDTD) with MATLAB software where the transmitter is modeled as a modulated Gaussian pulse with center frequency of 2 GHz point source, fig.3 shows the source in time domain. In all simulation receivers are located at x_m = 15 cm parallel to the target.

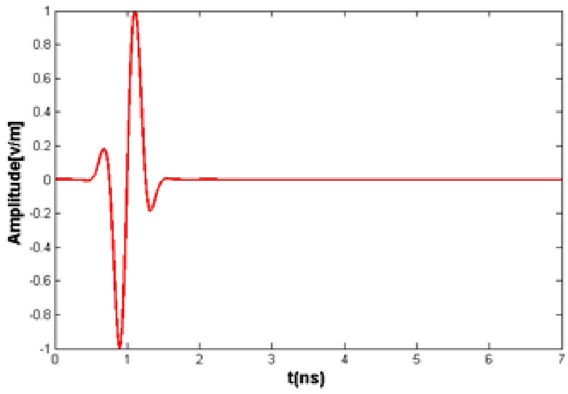
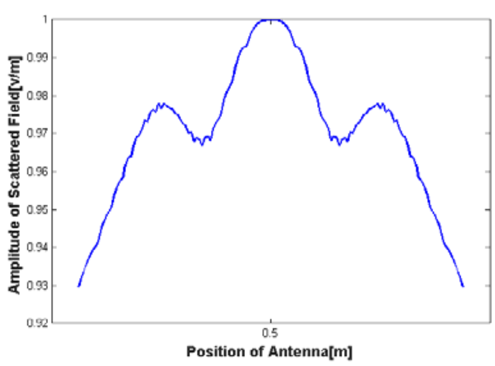


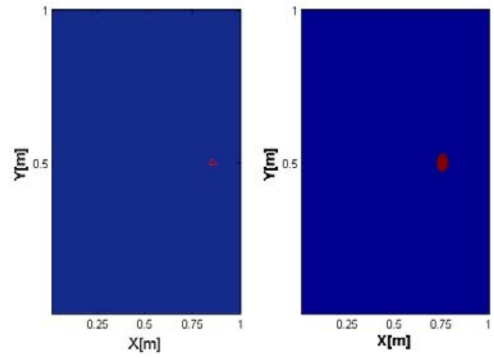
Fig.3. Modulated Gaussian source in time domain

4.1. localization of point target

To demonstrate the effectiveness of the proposed plane wave technique and validate its accuracy in localizing a point target, we first investigate localizing of a target in several position. For first example, as Fig. 4 (c) shows, target is placed at (x_t ,$y_{t,}$) =(75,50) cm and the horizontal target – receiver distance is X_0=60 cm. Number of receiver is N_p=75 parallel to the target with element spacing y_d=0.5cm in y direction. As figure 4. (a) Shows maximum received signal is belong to array which is located in front of target in place of y_m=50.08cm that is the position of a point target along the y axis. The time duration between sending and receiving the back scattered signal is t=4.44ns and with the speed of wave in free space the location of target in x axis is calculated as x_t=74.2cm, fig.4.(b) shows the evaluated position of a point target in x-y plane.



(a)



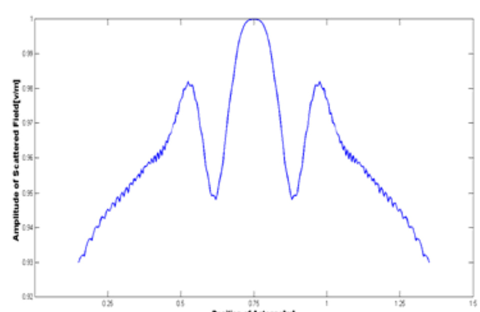
(b) **(c)**

Fig.4. (a) Amplitude of received scattered filed. (b) Center of point target evaluated by plane wave technique. (c) Position of point target.

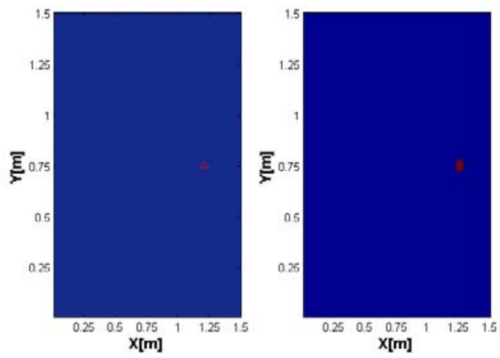
In the Second example the position of a point target is (x_t ,$y_{t,}$) =(125,75) with X_0=110 cm distance to the target and , with N_p=125 antenna array receiver element spacing y_d=0.5cm, fig.5 (c) shows the position of point target to be localized, as fig.5.(a) shows the element with maximum signal at y_m=75.8cm has a maximum received signals. Fig.5.(b) shows the calculated center for point target in x-y plane.

4.2. Imaging of point target

To demonstrate the effectiveness of the plane wave imaging of a point target for different stand of distance to the receiver, some numerical results are presented in this section and compared with the image obtained by a SAR imaging technique. In all simulation frequency of operation is from 1 to 3 GHz, and the step frequency is 12.5 MHz and the transceiver are placed at x_m=15cm parallel to the target. In the first numerical example the point target assumed to be at (x_t ,$y_{t,}$) =(75,50) as shown in Figure 6 (right), The measurement configuration for



(a)



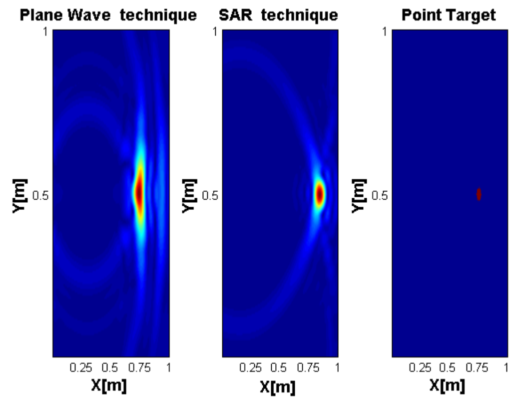
(b) (c)

Fig.5. (a) Amplitude of received scattered filed. (b) Center of point target evaluated by plane wave technique. (c) Position of point target.

the plane wave is as follows; the N_p=40 receiver antenna array measures the scattered field at a horizontal standoff distance 60 cm along a line parallel to the target with an interelement spacing of y_d=1 cm in y direction .

The synthetic aperture length is 75 cm with a step of 2 cm. For the TM-polarized incidence field, the target is imaged, and the result is shown in Fig.6. Computation times to generate these images, on a four-core P4 2.66G CPU, 32G memory computer, were 300 and 1980 s for the proposed plane wave imaging in this paper and the SAR imaging technique, respectively. Plane wave imaging is done a considerably faster than SAR imaging that shows the effectiveness of proposed imaging technique.The parameters for tow imaging scenario are given in Table 1.

Second example shows the same imaging scenario with the N_p=40 array placed at a standoff distance of 110 cm from the Point target for plane wave imaging, and the antenna is moved in steps along a line with steps of 2 cm over the length of L = 120 cm. The obtained image is shown in fig.7 and table.2 represents the parameters of two imaging technique. Fig. 8, again shows the point target at the correct locations which obtained with the N_p=50 elements array at a horizontal standoff distance of 160 cm to the target. Other parameters for plane wave and SAR imaging technique are given in table.3

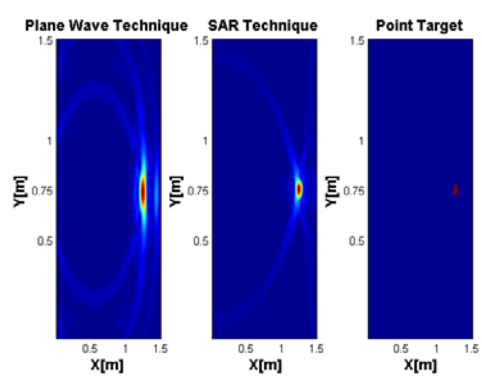


(a) (b) (c)

Fig.6. 2-D imaging of a point targets. (a) Plane wave image. (b) Standard SAR image (c) target position, (x_t,y_t)=(75 cm,50 cm)

Table 1. SAR and Plane wave imaging parameters.

	Plane Wave Imaging	SAR Imaging
Length of L	40 cm	75 cm
Inter Element spacing	0.5 cm	1 cm
Target-receiver horizontal distance	60 cm	60 cm
Imaging process time	300 s	1980 s



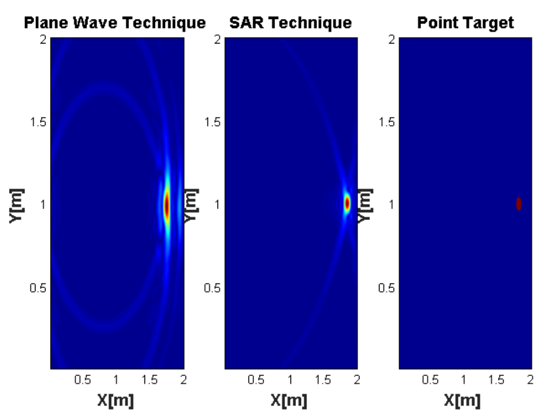
(a) (b) (c)

Fig.7. 2-D imaging of a point targets. (a) Plane

wave image. (b) Standard SAR image (c) target position, (x_t,y_t)=(125 cm,75 cm)

Table 2. SAR and Plane wave imaging parameters.

	Plane Wave Imaging	SAR Imaging
Length of L	40 cm	120 cm
Inter Element spacing	1 cm	2 cm
Target-receiver horizontal distance	110 cm	110 cm
Imaging process time	431 s	37080 s



(a) (b) (c)

Fig.8. 2-D imaging of a point targets. (a) Plane wave image. (b) Standard SAR image (c) target position, (x_t,y_t)=(175 cm,100 cm)

Table 3. SAR and Plane wave imaging parameters.

	Plane Wave Imaging	SAR Imaging
Length of L	50 cm	175 cm
Inter Element spacing	1 cm	4 cm
Target-receiver horizontal distance	160 cm	160 cm
Imaging process time	612 s	65880 s

5. CONCLUSION

Point target has been localize with a plane wave. To improve speed of imaging technique with synthetic aperture radar instead of moving the antenna in a line, single plane wave transceiver was used. Plane wave was considered as several antenna with a narrow beam with in a multiple position along a line parallel to the target illuminates the object to be imaged. To receive signals from a target in different distance a linear antenna array parallel to the target collect the reflected signal in several position as a strip-map mode SAR. Simulation results show the good performance of proposed technique. The speed of Plane wave imaging in considerably faster than SAR imaging.

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