The Millimeter-wave ISAR Imaging of Concealed Objects

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Abstract

The detection of concealed objects like weapon, explosives, and other dangerous items became very important problem for defending people against terrorist attacks. Recent time, many methods have been developed but number of methods are not efficient to effectively solve this problem. The main aim of the research in this work is devoted to the detection of concealed dangerous objects by increasing sensitivity and resolution in obtained images. In this paper, we propose to use inverse synthetic aperture radar (ISAR) technology for the detection of hidden items in the millimeter-wave length. The millimeter-wave ISAR imaging of concealed cubes and a gun are studied. The theoretical background employed for the reconstruction of measurement results is briefly described. The millimeter-wave ISAR measurement setup is presented. Then, measurements carried out for different scenarios are explained. Finally, the reconstructed results are shown for all conducted measurements.

1. Introduction

Millimeter-waves can penetrate many optically opaque materials such as wood, ceramics, plastics, clothing, concrete, soil, etc. Infrared and optic wave are not able to show this unique property which millimeter-waves bring. Thus, millimeter-wave region is frequently used in many applications such as security (the detection of a concealed weapon), non-destructive testing (the assessment of the deterioration of concrete structure) [1,2]. Another important property of millimeter-waves is that they allow the usage of wide frequency bands in such applications. Due to these advantages, high resolution radar images can be obtained in the range direction as well the resolution in the cross-range direction is inherently improved thanks to usage of short wave lengths.

For the above mentioned reasons, millimeter-wave ISAR imaging has currently been studied in the cooperation of International Laboratory for High Technologies (ILHT) in TUBITAK-Marmara Research Center (MRC) and the department of Electric-Electronic Engineering in Mersin University. The classical Fourier method for far field approach in ISAR imaging in polar coordinate [3] was selected and applied to the measured data of metallic and dielectric cubes and the real gun which were covered with different type of textiles. The results are illustrated in the comparison of reconstructed images. The main aim is the ISAR image reconstruction of *1 cm*^{3} metallic and dielectric cubes, and the gun, successfully.

The paper is organized as follows: In Section 2, the theoretical background of the classical Fourier method for the far field assumption in polar coordinate system is briefly given. In Section 3, the experimental setup is explained and the investigated objects and the coverage textile materials are presented with their electromagnetic parameters. The measurement process and the obtained results are also presented in this section. Conclusions are given in the final section.

2. Review of classical ISAR imaging

The range length is chosen so that the object under evaluation is in the far field of the phase center of antenna [4]. Length (R) is chosen so that the following condition is met

$$R = \frac{2D^2}{\lambda} \tag{1}$$

where R is the range length, D is the maximum cross-sectional dimension of object under test and λ is the free space wave length.

As shown in Figure 1-a, the radar is stationary while the object is rotated through the equally spaced angle variations with respect to the center of object coincided with the center of the measurement Cartesian coordinate system. The total received field assumed to have finite number of scatterers [5]. Therefore; one can write

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$$G(\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g_\theta(u,v) e^{-j2kv} du dv \tag{2}$$

where $g_\theta(u,v)$ is the reflectivity function of the object, $G(\theta)$ is the total instantaneous received fied for a particular aspect angle θ. The phase term e^{-j2kv} represents the propagation delay factor along the range axis. The relation between the fixed and the rotated coordinate can be derived as

$$v = y\cos\theta - x\sin\theta; \qquad k = \frac{2\pi}{\lambda}. \tag{3}$$

where k is wave-length. Substituting the relation (3) in (2) yields

$$G(\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y) e^{-j\frac{4\pi}{\lambda}(y\cos\theta - x\sin\theta)} dxdy. \tag{4}$$

By defining the new variables

$$k_x = -2\frac{\sin\theta}{\lambda}; \qquad k_y = -2\frac{\cos\theta}{\lambda} \tag{5}$$

Eq. (4) becomes

$$G(k_x,k_y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y) e^{-j2\pi(k_x x + k_y y)} dxdy \tag{6}$$

The equation derived above represents the two dimensional (2D) Fourier transform (FT) of $g(x,y)$. Thus, the reflectivity density function $g(x,y)$ can be recovered by applying an inverse Fourier transform (IFT) to $G(k_x,k_y)$. The two functions together form a FT pair as

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(k_x,k_y) e^{j2\pi(k_x x + k_y y)} dk_x dk_y \tag{7}$$

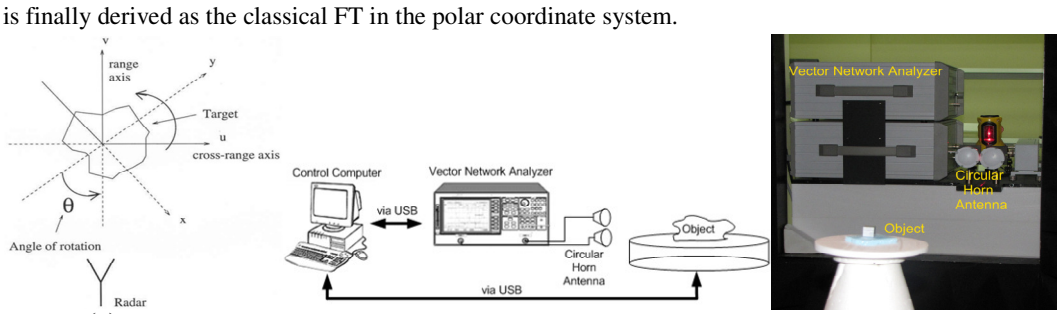
In order to write (7) in the form of the polar coordinate system, the transformation pairs can be defined as

$$k_x = f.\cos\theta; \qquad k_y = f.\sin\theta; \qquad df_x f_y = f.df.d\theta \tag{8}$$

and substituting the equation above in (7), we can obtain the 2D IFT in the polar coordinate system as

$$g(x,y) = \int_0^{2\pi}\int_0^{\infty} G(k,\theta) e^{j2\pi k(x\cos\theta + y\sin\theta)} k.dk.d\theta \tag{9}$$

Eq. (9) is finally derived as the classical FT in the polar coordinate system.



(a) (b) (c)

Figure 1. (a) 2D ISAR Geometry, (b) measurement setup, (c) position of the *1 cm*^{3} metal cube during the measurement

3. Experimental Setup and the Results

The measurement setup, used in the study of bistatic ISAR imaging at millimeter wave length range, consists of the measurement chamber operating from *1 GHz* to *100 GHz*, Elmika network analyzer (ELMIKA S4403), antennas (WR-10 circular horns), working in quasi-monostatic condition, and the turn table on which the target was placed as seen in Figure 1-b and c. In addition, it should be defined that the network analyzer and the turn table controls are fully automated with the control computer. The scattered electric field from the target on the turn table that was located at 1.3

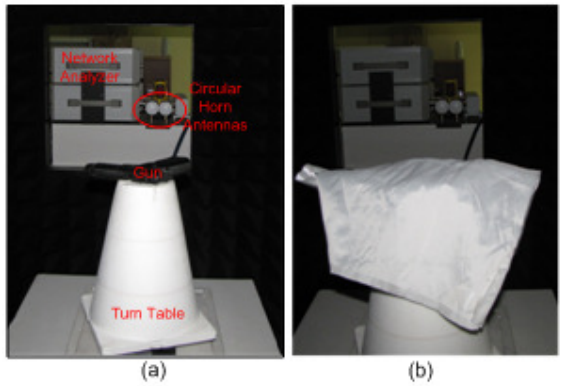


Figure 2. (a) The position of the gun during a measurement, (b) the gun covered with 2 Stratified Textile-2

meter away from the radar was measured for the selected frequency bandwidth at each angular position. In this study, measurements with listed parameters in Table 2 were performed for two different scenarios shown in Table 1. During these measurements, three different objects, *1 cm*^{3} Metal cube, *1 cm*^{3} Teflon cube, and the real gun were explored. As the study of the millimeter-wave imaging of concealed objects, two different textile materials, a %100 cotton textile (Textile-1) and %100 Polyester textile (Textile-2) were utilized during experiments. The permittivity of textile-1 and textile-2 are known as 1.6859 (F/m), 1.2451 (F/m), respectively.

Table 1. The Measurement Scenarios

Object	Scenarios	
	1	2
Teflon Cube	no Textile	no Textile
	Covered with 2 stratified Textile-1	Covered with 2 stratified Textile-2
Metal Cube	no Textile	no Textile
	Covered with 2 stratified Textile-1	Covered with 2 stratified Textile-2
Gun	no Textile	no Textile
	Covered with 2 stratified Textile-1	Covered with 2 stratified Textile-2

Table 2. Experimental Parameteres

	Start Frequency	Band Width	Total Angle	The Step Size of Angle
Textiles	80 (GHz)	20 (GHz)	360°	1°
Gun	80 (GHz)	10 (GHz)	360°	1°

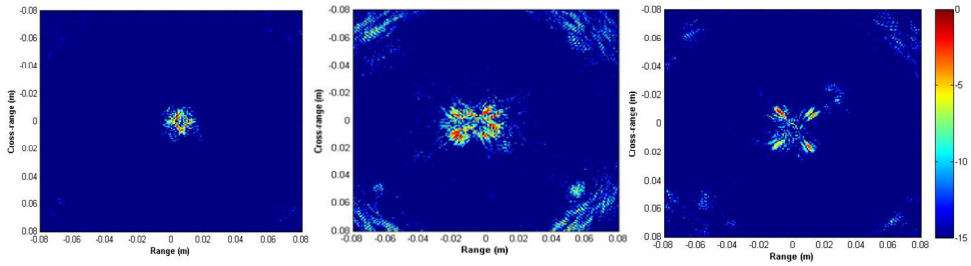
The millimeter-wave images of Teflon cubes for the first and second scenarios are shown in Figure 3. It is seen from the figure that although the locations of dielectric cube covered with two stratified textile are truly reconstructed, there is degradation in the images of Teflon which were covered with Textile-1 and Textile-2.

The images of metal cube for the first and second scenarios are given in Figure **4**. It can be seen from the figure that the positio two stratified textiles.

The reconstructed images of the real gun for both scenarios are illustrated in Figure 5. It is clear from the figure that the outline of the real gun can be reconstructed when the gun was covered with 2 stratified textiles. However, there is also deterioration on the outline of the real gun because of being covered with textiles. The deterioration is higher when the gun is covered with Textile-1 due to its high permittivity.

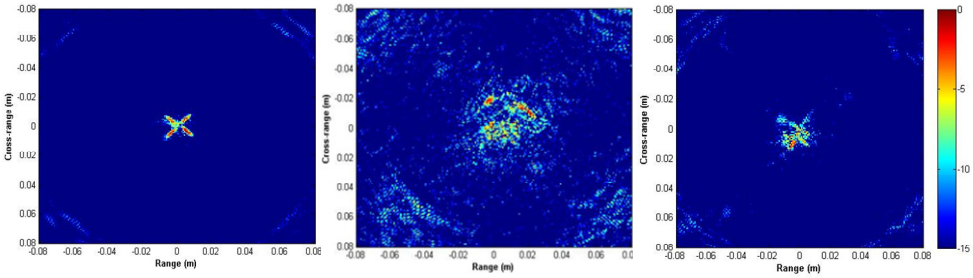
4. Conclusion

In this work, the millimeter-wave ISAR imaging of metal and dielectric concealed objects underneath textile materials were studied. The classical Fourier method based ISAR in polar coordinate system was applied to the real data that was measured in our anechoic chamber room. The resultant images of the metal cube are satisfactory for the accurate detection, placement together with its shape. The constructed images of the Teflon cube are also clearly determined at its true location while there is deterioration around its shape. The reconstructed image of the real gun is also successfully carried out with degradation around its shape. Further study will focus on the millimeter-wave imaging of similar concealed objects using different signal processing algorithms including Matched filtering [6].



(a) (b) (c)

Figure 3. ISAR images of Teflon cube (a) no textile, (b) 2 Stratified Textile-1, (c) 2 Stratified Textile-2.



(a) (b) (c)

Figure 4. ISAR images of Metal cube (a) no textile, (b) 2 Stratified Textile-1, (c) 2 Stratified Textile-2.

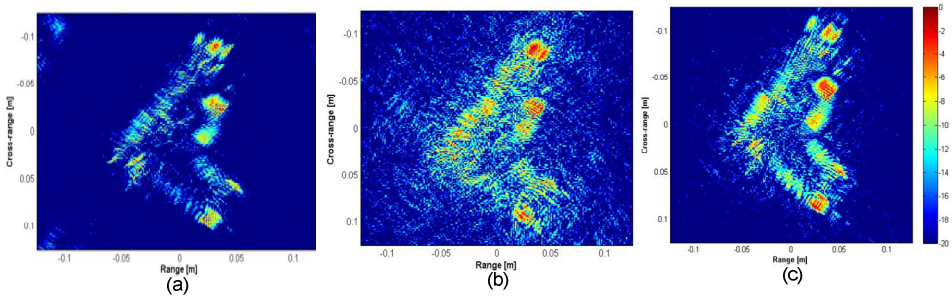


Figure 5. ISAR images of the real gun (a) no textile, (b) 2 Stratified Textile-1, (c) 2 Stratified Textile-2

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