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NON-INVASIVE CONCEALED WEAPON DETECTION AND IDENTIFICATION USING V BAND MILLIMETER WAVE IMAGING RADAR SYSTEM

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ABSTRACT

This paper presents a millimeter wave imaging radar system operating at 60 GHz for non invasive and non- destructive concealed weapon detection and identification. In order to mimic, the concealed weapon target, an aluminum toy gun covered with cloth has been used. Different signal processing techniques were applied in order to fully detect and identify the concealed weapon target. Techniques like; discrete convolution, mean and standard deviation based thresholding and canny edge detection were applied and their applicability was tested towards successful hidden target identification. The correct target location and shape identifi- cation validates the MMW radar's capability towards stand- off concealed object detection and identification. Further, the proposed technique can be used with other different kinds of weapon targets for applications requiring personal screening and security check.

Index Terms: Millimeter Wave, Imaging, Radar, Non-Invasive, Thresholding, Template Convolution, Edge Detection.

I. INTRODUCTION

The millimeter wave (MMW) region of the electro- magnetic spectrum fills the gap between microwaves and infrared frequency. The field of MMW science and tech- nology has changed significantly within the last few years, which can be attributed to several new advances in the MMW technology such as; filters, signal sources, ampli- fiers, antennas, etc.[1]. This encourages new interest in applying this waveband for high resolution imaging[2]. There are several merits of MMW wave spectrum, like; higher transmission rate, capability of spread spectrum, less crosstalk interference due to larger bandwidth, reduced hardware size and easy penetration to dielectric materials with enough resolution[3]. This is mainly useful in security applications where MMW imaging can be used as a system of detecting concealed weapon. MMW imaging system is similar to the conventional radar system except transmitted frequency.

There are different imaging techniques available that can be used for detection and identification of concealed ob- jects, viz.; active MMW, passive MMW, terahertz (THz) and X-ray[4]. Each of these methods exploit properties that provide unique information in the resultant images. X- ray systems can provide high-resolution but it is not good for health[5]. THz systems are sensitive to temperature. In the passive MMW imaging mode, signal is not emitted by transmitter, but the receiver receives MMW radiation from the local environment. Passive imaging works on the concept that objects above absolute zero emits some form of MMW radiation[6]. However, active MMW sys- tems provide higher-resolution and three-dimensional (3- D) imaging that provides the shape of concealed targets for better identification. Active MMW imaging can be fully coherent, which permits the system to obtain three- dimensional (3-D) imaging. These systems can also rapidly obtain the data at high signal to noise ratios. Finally, be- cause of the coherent collection of scattered data, different image enhancement techniques can be used to perform high- resolution imaging without using lenses or reflectors for focusing. All focusing is performed mathematically using computer image reconstruction techniques [7] [8].

In this paper, we have used indigenously designed 60 GHz active MMW imaging radar for concealed target detection and identification for security applications. For the con- cealed weapon, we have used aluminum toy gun placed at stand-off distance. The remaining paper is organized as follows: section II describes MMW radar setup, section III discusses different signal processing techniques used for target detection and identification. Results are discussed in section IV and section V gives the conclusion.

II. MILLIMETER WAVE RADAR SETUP DESIGN

A. Experiment Set Up

The geometrical arrangement for millimeter wave imag- ing radar system is shown in the fig. 1[9]. The stepped frequency continuous wave (SFCW) radar is indigenously assembled using Agilent vector network analyzer PNA- N5247A. The typical radar system parameters are given in Table 1. A pyramidal horn antenna in a mono-static mode was used for transmitting and receiving the SFCW signal having bandwidth 2GHz. In SFCW mode, impulse waveform is synthesized from series of continuous wave signals in the complete frequency range. That is, MMW signal is sent out periodically with the help of SFCW radar and a receiver receives the reflection of that signal from the target. Owing to transmission of continuous signals, mean transmitted power increases, thus compared to pulse more distance can be covered which is desirable. The timing of the return signal gives spatial information about target. Target under test is mounted on the 2D scanning wooden frame in front of the fixed horn antenna. This arrangement allows target to move smoothly in horizontal as well vertical directions, thus, the target is scanned fully by the fixed, narrow beamwidth antenna. The scanning position is denoted by (x,y), where x denotes lateral(or cross range) point (ranging from 1 to X) and y denotes vertical (or height) point, (ranging from 1 to Y). Spacing between two consecutive scan positions is kept 0.02m in both vertical and horizontal directions. In our experiment, we have taken 30 cross range locations and 18 vertical locations for scanning from a distance of 0.5 meter.

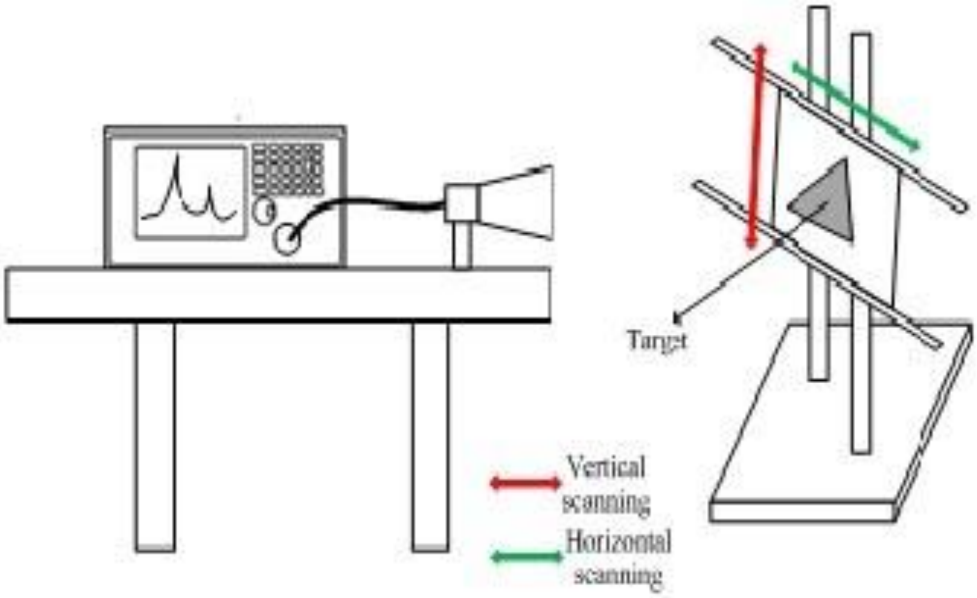


Fig.1. Experimental setup for millimetre wave active imaging radar with target mounted on a 2D scanning frame

Table I Specification for SFCW Based Active Millimeter Wave Imaging Radar

S. No	SFCW imaging radar parameter	Typical Values
1	Operating frequency	60 GHz
2	Bandwidth	2GHz (59-
3	No. of frequency points	201
4	Transmitted Power	10dBm
5	Range resolution	7.5cm
6	Cross range resolution	0.417,cm
7	Beamwidth (E, H Plane)	9.1, 10.4
8	Gain	25dBi
9	Swath	56.88,cm2

B. Target arrangement for concealed weapon detection

Next, we prepared the target arrangement for concealed weapon detection from a stand-off distance. For this, we have put a large wooden sheet on the 2D scanner and on the top of which, we have placed a thick polystyrene sheet (thickness = 2.6 cm). On this overall arrangement, we have put our test target. The advantage of using the polystyrene sheet is to suppress any undesired reflection from the target surrounding and provide a better visibility and contrast to the concealed target. For the test target, we have used a aluminum foil wrapped toy gun, covered it with cotton cloth for the concealed weapon detection application.

Fig.2. Target arrangement used for millimeter wave stand-off concealed weapon detection and identification (a) Toy gun, (b) concealed toy gun covered with cloth piece.

III. METHODOLOGY: SIGNAL PROCESSING TECHNIQUES

The reflected signal from the concealed target is col- lected as the one port complex reflection coefficient (S11) and further undergoes different signal processing steps in order to retrieve useful information for concealed target identification. The detailed steps are shown in the flowchart in fig. 2 and are described in the following subsections

A. Signal Pre-processing

The received signal is in frequency domain form, and thus, converted to time domain using inverse fast Fourier transform (IFFT). This time domain signal is further con- verted to spatial domain or range profile to extract infor- mation related to target location in down range. Received signal reflected from the target at a distance z from radar in complex scattering coefficient s(z) is defined as;

$$S(Z) = \sum_{n=0}^{N-1} S(f_n) e^{j2\pi f_n (2z/c)} \qquad (1)$$

Where, $f_n = f_0 + n\,\Delta f$, n = 0,1,2,.......... N-1. The un- ambiguous range of the radar is given by $c/2\Delta f$. Here, Δf is the frequency step size of the SFCW radar. Also, some delay added by the antenna system to the received signal, which could mislead us about the correct target distance. Hence, a delay calibration is performed by placing a large metal sheet at the flare of the horn and the corresponding distance is subtracted in the range profile plot to retrieve exact target location and is given as[9],

$$S(Z) = \sum_{n=0}^{N-1} S(f_n) e^{j2\pi f_n (2Z/c - 2Z_{ref}/c)} \quad (2)$$

Where, t_{ref}, z_{ref} represents time delay and distance due to metal sheet at antenna flare.

B. Image Enhancement techniques

The 2D C scan image of the concealed target is formed at the down range location, where, the reflection intensity is maximum. However, the extracted C scan image is of very poor resolution due to the noise added from the oblique and multipath reflections, reflection from target surroundings, etc. So, different image enhancement tech- niques were applied in order to improve the image quality.

1) Template Convolution: Target image enhancement can be achieved using linear filtering operation through discrete (template) convolution. Discrete convolution is a neighborhood operation where a filter kernel or mask is sequentially convolved with each of the image pixel. Mask is generally odd in size so as to position it correctly and symmetrically over any pixel. However, choice of particular mask shape and size determines the quality and intelligibility of the resultant image. Here, we have used the 3x3 gaussian filter kernel because of its optimal performance as compared to other averaging filters[10].

2) Image segmentation: Once the image quality isimproved, thresholding operation is performed so as to segment the target from the background. Since, statisti- cal parameters of any image carry vital information in determining image spatial characteristics, we have used image statistics based thresholding technique. Mean and standard deviation based global thresholding technique has been used here. The value of threshold is determined as;

Threshold (T)=mean(μ)+n X standard deviation(σ)

Where, n is the scaling factor.

3) Edge detection: Next, in order to determine the actual shape of the target, its features need to be extracted. For this, the technique used is called the edge detection. Edge detection basically determines the boundary of the target depending upon the intensity contrast between the target and the background. Out of different available edge detection techniques viz., Sobel, Canny, Prewitt, Roberts, we have used canny based edge detector because of its better performance in terms of improved signal to noise ratio and adaptive local gradient measurement[11].

IV. RESULTS AND DISCUSSION

The 2D C scan image of the concealed test weapon is shown in fig. , plotted at the target downrange lo- cation and obtained after signal pre-processing. In order to improve the visibility and quality of the image, next gaussian convolution is applied using a 3 x 3 filter kernel. Considerable enhancement in the image is observed as shown in fig.

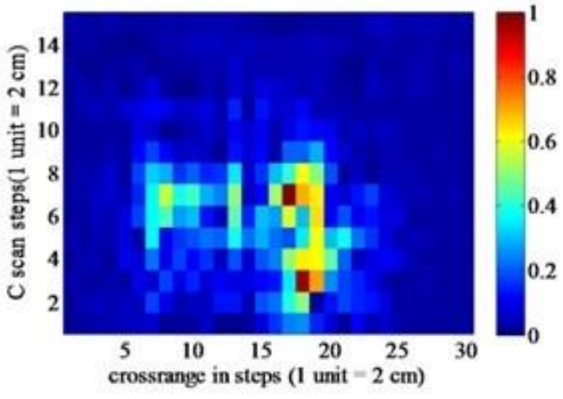


Fig.3

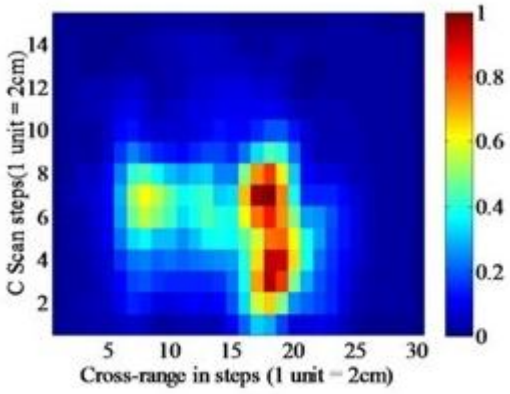


Fig.4

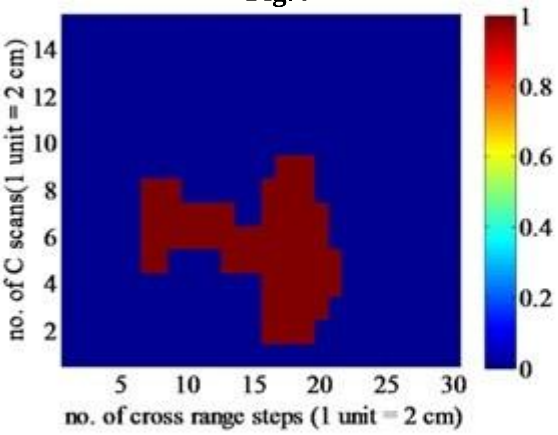
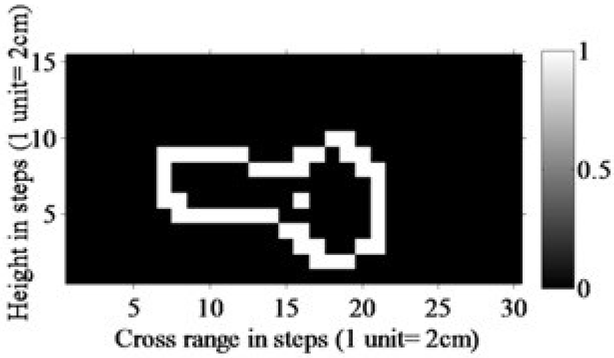


Fig.5

Further, the concealed target image is segmented from the background using mean and standard deviation based thresholding as shown in the fig. . Finally, in order to identify the concealed weapon beneath the cloth its boundary features were retrieved using canny based edge detector as shown in fig. . Clearly, as visible from the figure, the target can be easily recognizable as a hand gun concealed beneath the clothing. This approves the capability of the millimeter wave radar system to detect and identify any concealed metallic object from a stand-off distance. Further, this approach can be applied and tested for other different target types and materials.



VI. CONCLUSION

We have demonstrated the experimental results for target detection and identification using the V band millimeter wave imaging radar system for concealed weapon de- tection. The undercover metallic weapon (toy gun) was detected from a stand-off distance of 0.5 meter. Further, actual shape of the gun was successfully recognized us- ing different image processing techniques, viz., discrete convolution, thresholding and edge detection. As a future work, we plan to detect and identify different others types of weapon targets of different dielectric materials.

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