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Suicide Bomber Detection Using Millimeter-Wave Radar

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Abstract

Amidst the manifold threats currently afflicting public welfare, that of body-worn explosives is significant if not altogether paramount. Commonly referred to as "suicide bombers," the bearers of body-worn, improvised explosive devices (IEDs) enter crowded public areas in order to detonate the IED, inflicting lethal damage to themselves and surrounding individuals. Constructed of non-standard parts and veiled under layers of clothing, these body-worn IEDs go frequently undetected.

The aim of this research is to examine the feasibility of using millimeter-wave (MMW) radar to detect body-worn IEDs at distances up to 50 meters. In order to achieve a beamwidth capable of illuminating a single human at 50 meters, which in this case would be approximately 0.01 radians, while still maintaining a practical aperture size, we require a wavelength on the millimeter scale. The radar made available for testing, provided by Raytheon, operates at 77GHz. At a wavelength of 3.89mm, this radar provides, at a testing distance of 10.1 meters, an adequate simulation of a human-torso-sized beamwidth at 50 meters. This research also examines the role of the Gregorian Dual Confocal Reflector antenna in achieving smaller beamwidths from apertures of limited size.

Problem Description

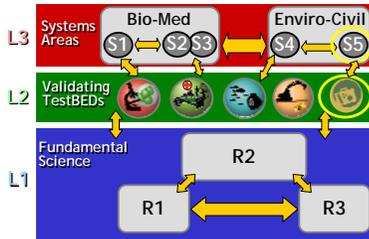
- Explosive devices, most often consisting of cylindrical, metal objects filled with explosives, require detection by radar.
- Testing protocols must be developed to model realistic conditions.
- Unique scattering patterns may be obtained using a cross-polarized signal, but existing radar can only facilitate one polarization at a time.
- Existing radar aperture does not result in desired beam width.



Objective

Determine a reliable and detectable characteristic of non-standardized body-worn IED assemblies. Implement experimental test protocols to verify detectability of objects with high conductivity for a variety of geometries.

Three-Level Diagram



Testing Equipment

In order to achieve a beamwidth capable of illuminating a single human torso at large distances while still maintaining a feasibly-sized aperture, one requires a small wavelength. This can be seen mathematically in the equations for half-power beamwidths for a rectangular aperture of area $a \times b$ where b is the dimension parallel to the electric field vector [1].

$$\theta_{3dB} = \frac{50.6}{b/\lambda} \quad \theta_{3dB} = \frac{68.8}{a/\lambda}$$

For this research, a radar has been provided by outside sources. This radar was originally developed for automotive intelligent cruise control technology [2]. This radar proved an attractive fit for suicide bomber detection research in that it operated at 77GHz and thus provided a beamwidth in the millimeter wave region, the region in which we can expect to work if we hope to achieve long-range radar detection. It should be noted that although in this presentation and other documentation we refer to our operating frequency of 77GHz as existing in the millimeter wave region, according to IEEE standards of 1984, we are technically operating at the lower end of the W band [3].

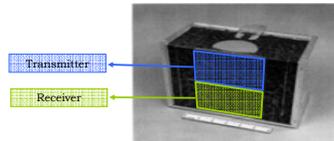


Figure 1 – 77GHz Testing Radar

As you can see in Figure 1, where the electric field is polarized so that the field vector is parallel to the shorter dimension of the transmitter aperture, the radar has the capability of producing electric field that is polarized vertically, parallel to the length of the human body, and also field that is polarized horizontally, perpendicular to the length of a human body.

The testing location provided is an anechoic chamber of size sufficient to perform experiments that illuminate the width of one human torso and the height from approximately knee to slightly above the head. We were also provided with a canvas vest with multiple pockets for carrying primarily cylindrical metal pipes through other metal objects could also be inserted.

Testing Methods

Inasmuch as the goal of this testing is to determine the feasibility of detecting body-worn IEDs on humans using high-frequency electromagnetic waves, the goal may also be considered one of finding different geometries of metal worn by a human, since we expect differing scattered fields only when our variable is one of high conductivity. We also expect human flesh to exhibit highly conductive characteristics at our frequency since human flesh has been shown in earlier paper to exhibit the constitutive properties of "dielectric constant 27 and conductivity 30 S/m at 25 GHz [4].

In view of this, the approach to testing has been to vary the amount of metal worn by human subjects in the supplied vest and to compare these with the returns from human bodies without body-worn IED simulates, i.e. cylindrical metal pipes.

Radar Software Operation

The provided radar came complete with data-processing software capable of providing magnitude of electric field return from different distances. This is achieved by taking the Fast Fourier Transform of each scattered voltage signal or chirp. The transmitted chirp consists of a Gaussian pulse whose frequency is linearly ramped over a range of approximately 300MHz to just below 77GHz. When this is done, one effectively has both magnitude and range for radar input. A sample of the data received is shown in Figure 2.

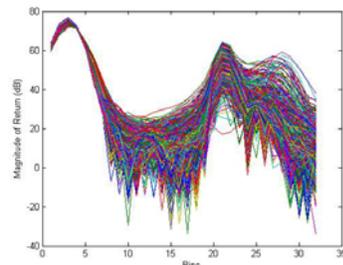


Figure 2 – Sample of Data Returned from a Human Subject Target

In order to process the data shown in Figure 2 into a usable result, one must normalize and average it. It must be normalized because intermodal actuation causes the entire data set to shift amplitude periodically. It must be averaged because of the obvious variation shown. A diagram of the further data processing is shown below.

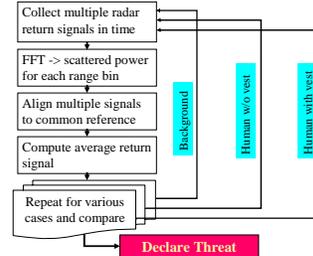


Figure 3 – Post FFT Data Processing

It should be noted that in Figure 2, each bin effectively reflects a progressive distance. It is known through addition of objects in the chamber that the target location occurs at the 20th bin. The distance from radar to target is known to be 10.1m; thus, range can be determined simply. Upon implementation of the data processing outlined in Figure 3, a return similar to Figure 4 is obtained.

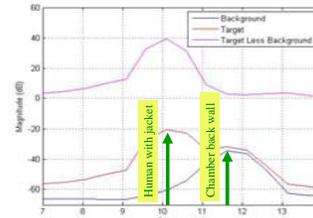


Figure 4 – Processed Return Data

While many tests have been performed with a variety of objects – including pipes and metal plates not on humans – the focus of the testing has been on collecting data for a variety of human subjects wearing everyday clothes, the empty vest, and the vest filled with increasing level of pipes. The most practical amount of pipes that the vest can hold without slipping of the subject is nine, so the majority of "vest with pipes" experiments have been performed with nine pipes. A summary of results follows for both polarizations of the radar where the recorded average returns are sorted and compared in decibels and where each color represents a different human subject.

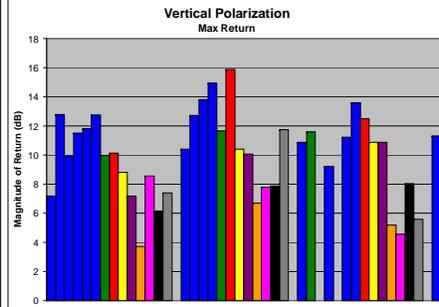


Figure 5 – Compiled Results For Human Subjects at Vertical Polarization

Horizontal Polarization

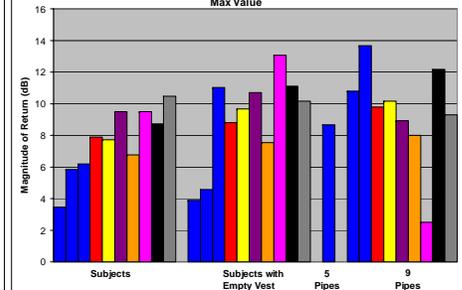


Figure 6 – Compiled Results For Human Subjects at Horizontal Polarization

As you can see in Figures 5 and 6, the results vary dramatically between cases and while some cases can provide desirable results independent of other cases, it becomes difficult to set threshold levels for the general population that give any acceptable false alarm rate.

Continuing Work

Data is in the process of being collected and there are twenty more human subject cases that have already been collected though not yet processed and included with the data shown in Figures 5 and 6. Other detectable characteristics of the data are also being considered. First, it has been considered that the reflection from cylindrical pipes may lend itself to more angular uniformity than that of a human body without them. It is the same principal as a metal plate of finite thickness versus that of a metal cylinder; where the reflected field off a plate will vary dramatically when it is facing the radar and when it is facing at any other angle, the return from a large metal cylinder would be the same regardless of angle. Additionally, the effect of the target on the return from the background is also being considered. Essentially, it has been hypothesized that the change in the scattered field from ranges beyond the target could correlate to the objects worn by a human subject.

Long Term Antenna Design

Determining a reliable detectable is the immediate concern. Still, should this application prove feasible at these closer distances, an antenna must be developed to accommodate ranges up to and including 50 m, which is the ultimate goal. One proposed design is that of the Gregorian Confocal Dual Reflector (GCDR) which is illustrated in Figure 7.

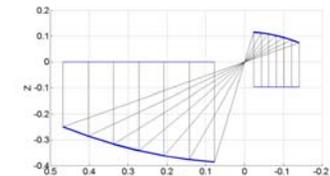


Figure 7 – Gregorian Confocal Dual Reflector

The principal of the GCDR system is that a smaller aperture, by means of a sub-reflector, shown in the upper-rightmost portion of Figure 7, and a main reflector, shown in the lower-leftmost portion of Figure 7, a smaller aperture may be magnified in direct proportion to the ratio of the focal length of the main reflector to the focal length of the sub-reflector. The sub-reflector may be optimized in order to achieve constant path length, and thus phase. However, previous research by Jose Martinez has shown the gains made by sub-reflector shaping and optimization are negligible and thus standard parabolic reflectors may be utilized.

References

[1] Balanis, Constantine A., *Antenna Theory: Analysis and Design*, 3rd Ed., John Wiley & Sons Inc., Hoboken, NJ, 2005.
 [2] Russell, M. E., Crain, A., Curran, A., Campbell, R. A. and Drubin, C. A., IEEE Transactions on Microwave Theory and Techniques, vol. 45, n. 12, pp. 2444-2453, 1997.
 [3] Skolnik, Merrill L., *Introduction to Radar Systems* 3rd Ed., McGraw-Hill Companies, Inc., New York, NY, 2001.
 [4] Angell, Amanda & C. Rappaport, *Computational Modeling Analysis of Radar Scattering by Metallic Body-Worn Explosive Devices Covered with Wrinkled Clothing*, p. 2.