



# Millimeter wave standoff radar detection system with motion compensation and 3D imaging capabilities



Galia Ghazi, Jose A. Martinez and Carey M. Rappaport, Fernando Quivira  
Northeastern University, Boston, MA 02115, ghazi.g@husky.neu.edu

## Abstract

In this poster we present our latest results in the area of standoff detection of potential suicide bombers using millimeter wave radar. We have collected experimental data using a mm-wave radar, with a multiple bistatic configuration. The data has been processed, by using a Synthetic Aperture Radar (SAR) technique, in order to create two dimensional images on the target region. Then, a feature algorithm based on entropy level has been applied to the SAR image in order distinguish between threat and no threat cases. This SAR has a moving rail over a linear aperture of 1.85m and has Frequency Modulated Continuous Wave (FMCW) signal. In this work we have implemented a new motion compensation algorithm in order to improve the SAR images generated from the measured data with different threat objects. Also presented are simulation results for a possible extended version of mm-wave standoff radar configuration which would have the potential for 3D imaging capabilities. For this purpose, the system consists of a two-dimensional aperture array of receivers, which ultimately improves the detection performance of potential hazards.

## Relevance

Standoff detection of explosives is important because it is very valuable to detect the threat at a safe blast distance. The mm-waves radar is the ideal modality for standoff detection because it can work at distances from 20 to 50 meters. In addition mm-waves can penetrate clothing, and have high resolving capability reacting to the dielectric contrast of interest (explosives). The rail-SAR is an inexpensive stepping stone to the mm-wave radar which can be expanded to the next generation of 3D fixed aperture radar.

## Radar Configuration

We use the SAR image processing of the measurements from a FMCW radar. The Radar has the following parameters: center frequency=94.2GHz, bandwidth=4GHz and pulse burst duration=83.36μs. The radar system has both monostatic and bistatic receiving antennas Fig.1(a). The configuration of the measurement consists of a person, who is the target and a corner cube in the target region Fig.1(b).

## Motion compensation algorithm

The unknown relative movement of the target produces distortions in the final images. To compensate for these errors, three steps are used in the correction algorithm:

- 1 Correction of the slight phase fluctuation occurring during the measurement in successive pulses.
- 2 Optimize the measurement parameters using the bistatic data. Parameters are the corner cube position and the monostatic receiver position in Fig. 1(b).
- 3 Compensate for the random phase error in the bistatic measured data with the phase of the measured data from monostatic antenna.

With the knowledge of the position of the bistatic receiver  $x(t)$ , the nonlinear optimization is performed, using the equation for the measured distance from the corner cube, given in equation (1). The optimized parameters in this equation are the position of the transmitting antenna ( $x_1$ ) and the position of the corner cube ( $x_0, y_0$ ).

$$\text{distance} = \sqrt{(x_0 - x_1)^2 + y_0^2} + \sqrt{(x_0 - x(t))^2 + y_0^2} \quad (1)$$

## Results

Photographs of test cases are shown in Fig.2. For distinguishing between threat and innocent targets the entropy criterion is utilized. Entropy is a statistical measure of randomness in the images and is as defined in equation (2). The parameter 'p' in this equation contains the histogram counts of the 2-dimensional images that are the result of SAR processing.

$$\text{entropy} = -\sum p \cdot \log(p) \quad (2)$$

- In threat cases, the entropy is higher because of the wider distribution of the hot spots. Introducing a threshold on the entropy of the images enables threat detection. The images for a male target without and with different threats are shown in Fig.3, with calculated entropy indicated.
- In Fig.3, the first image (a) is no threat, and images (b), (c), and (d) correspond to the objects depicted in Fig.2 (a), (b), and (c).
- The entropy for the innocent case is 4.14, while for the threat cases it is (5.59, 5.21, 5.48) which shows that the entropy method gives acceptable foreign object distinguishing results.

## Technical Approach

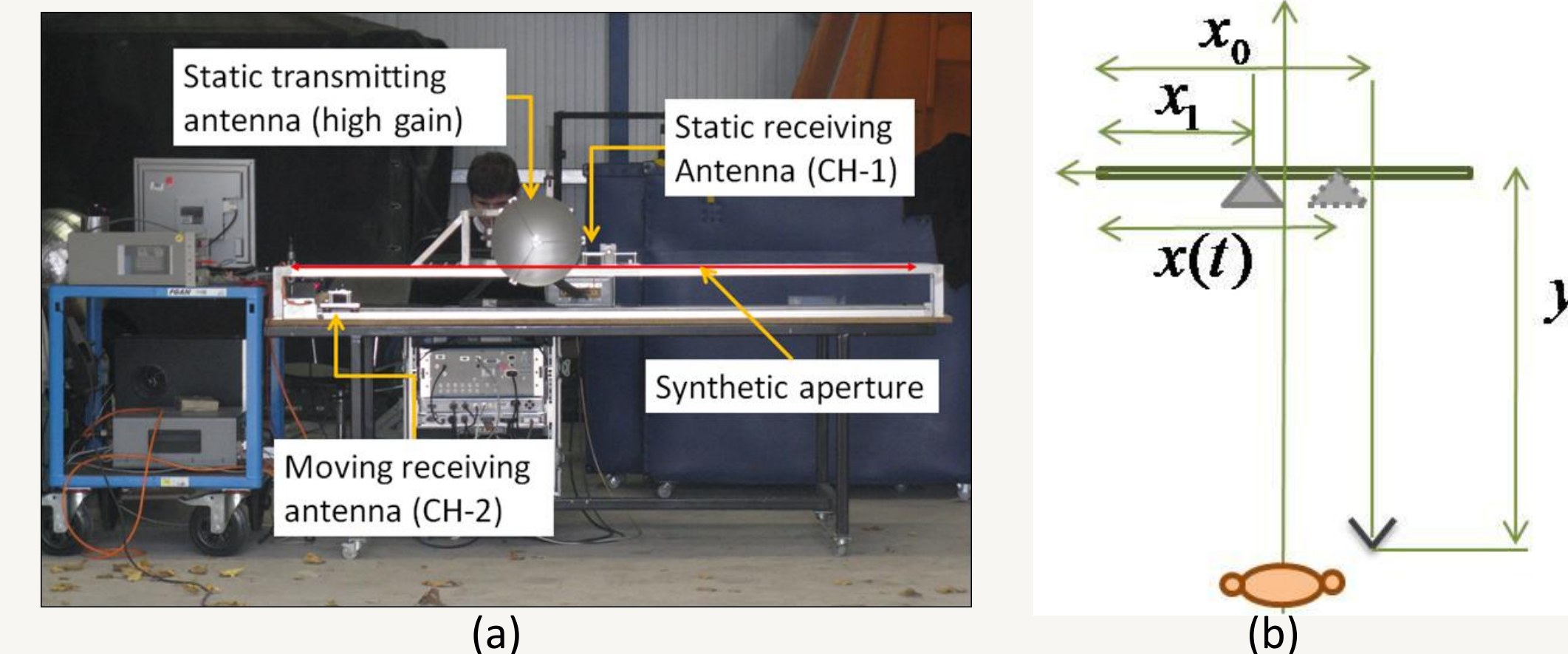


Figure 1: (a) picture of the real radar (b) measurement configuration.



Figure 2: image of the target with different threats (a) a silicon metallic object on the chest (b) metallic pipes on the chest (c) silicon pipes on the chest.

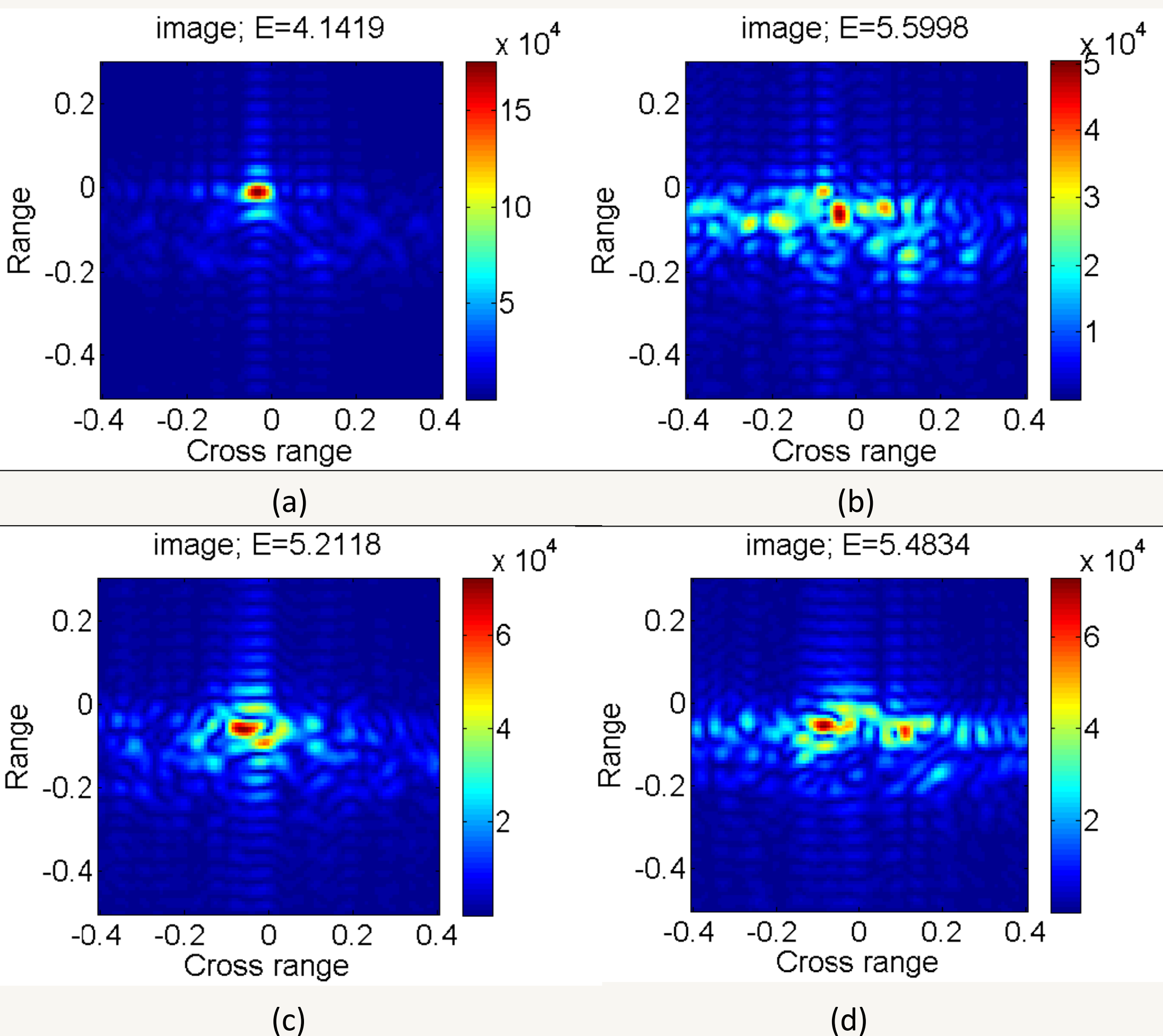


Figure 3: image of the target (a) without threat (b) with a silicon metallic object on the chest (c) with metallic pipes on the chest. (d) with a silicon pipes on the chest.

## 3D imaging simulation

The SAR processing is also used to simulate the 3D images of the targets using a planar array of static antennas. Fig. 4(a) presents the geometry with rectangular antenna array located at R=20m. The transmitter is a single element in the center of the receiving array, which consists of 26 line receivers uniformly distributed along a 0.7m z-aperture. Each line of receiver has 46 receivers uniformly distributed along a 1.85m x-aperture.

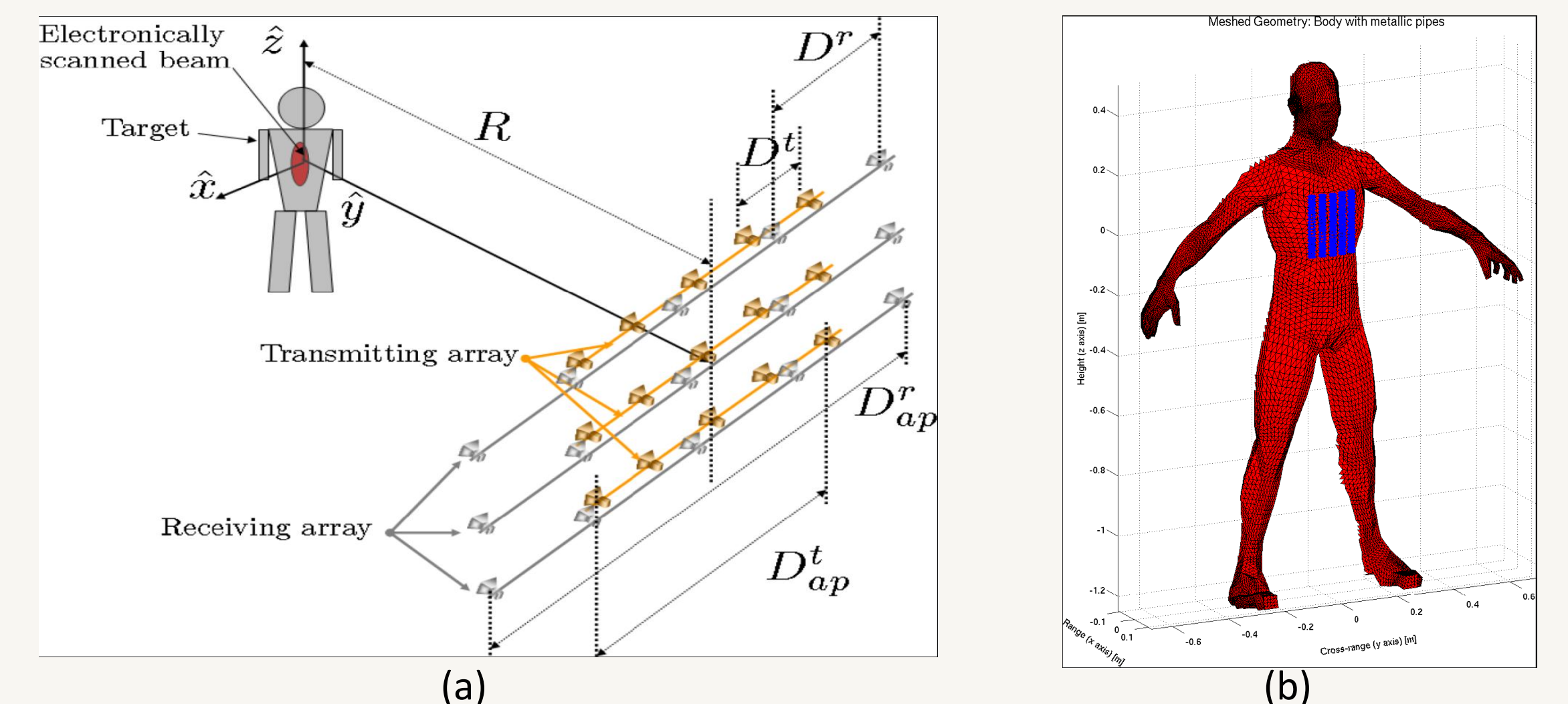


Figure 4: (a) Antenna array and target configuration. (b) Target geometry

The study tested the image reconstruction algorithm for 2 geometries: male body with and without metallic cylindrical pipes on the chest (Fig. 4(b)). The metallic pipes have a radius  $r = 0.01\text{m}$  and a height  $h = 0.2\text{m}$ .

- The simulation treated the centroid of every triangular patch in the body mesh model as an individual point source. The intensity of each individual point source was proportional to the area of the corresponding triangular patch.
- Figs. 5(a) and 5(b) show the reconstructed reflectivity of the body without metallic pipes and with metallic pipes on the chest. The difference between these two scenarios is displayed in Fig. 5(c).

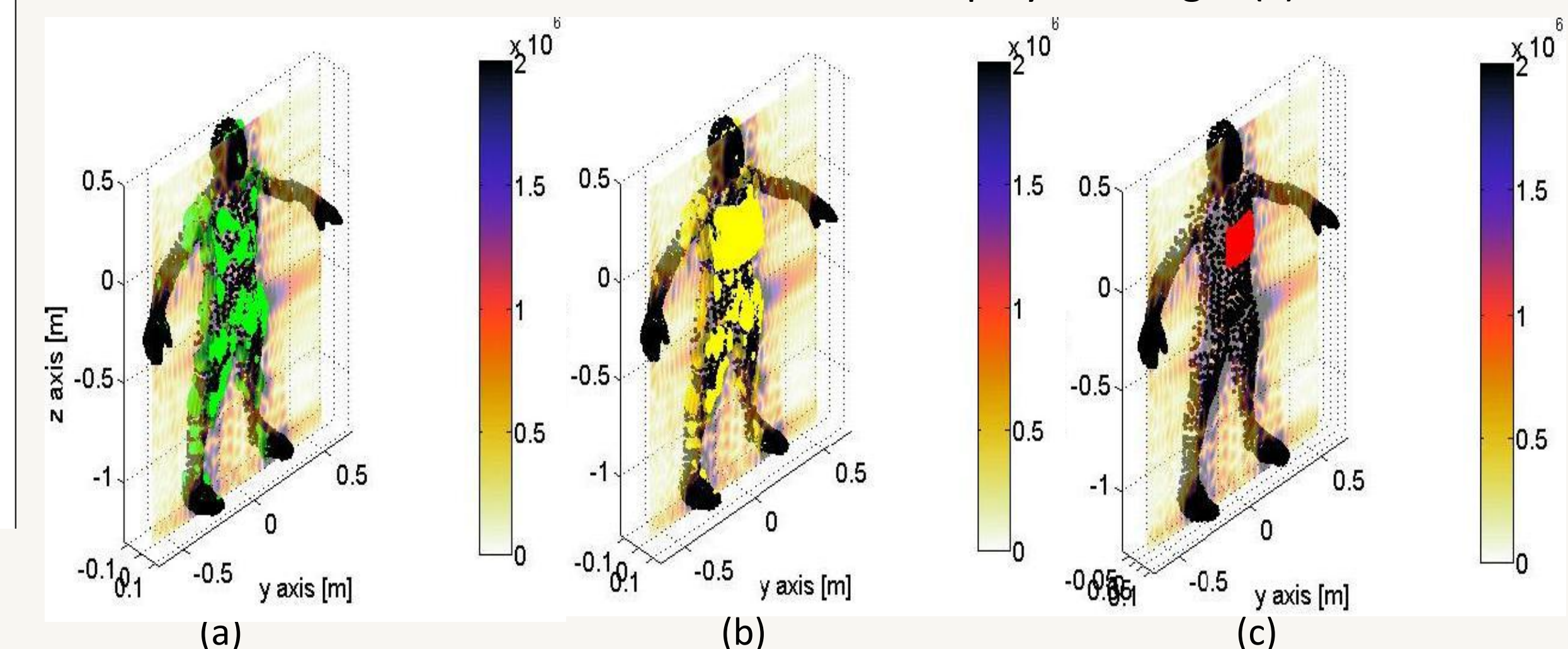


Figure 5: Image reconstruction: Reflectivity and isocontours of body (a) without metallic pipes, (b) with 5 cylindrical metallic pipes, and (c) with 5 cylindrical metallic pipes with higher threshold.

## Opportunities for Transition to Customer

Our standoff detection system has demonstrated the feasibility of using multiple bistatic data for generating images at standoff distances. This prototype must be upgraded before it is transitioned into the market. The most important upgrade is based on using a 2D aperture for creating three dimensional images. Once this upgrade is successfully implemented, the system can be easily delivered to any federal agencies like: DHS or DOD, as well as international partners which are aligned with the U.S. position in the war against terrorism.

## Accomplishments Through Current Year

The system shown in the figures and the measured data analysis are the accomplishments of this year. In addition, the 3D imaging simulation, forming the theoretical basis for extension of the physical aperture represents a modification that will improve the threat detection capabilities.

## Future Work

Our future work in this area will be focused on improving the inversion algorithms for the 3D system, and on accelerating our fast forward model using a multipole method in order to improve the quality of the synthetic data we use for the inversion algorithms.

## Publications Acknowledging DHS Support

1. Fernandes, J., Obermeier, R., Martinez-Lorenzo, J.A., and Rappaport, C., "FMCW SAR imaging of body worn explosives from FDFD modeled scattered field data," *Progress in Electromagnetics Research Symposium*, Cambridge, MA, July 2010, pp. 350.
2. Fernandes, J., Obermeier, R., Martinez-Lorenzo, J. A., and Rappaport, C., "Simulation results for standoff detection of suicide bombers at millimeter-wave frequencies using a full wave numerical analysis," *Homeland Security Summit*, Washington, DC, March, 2010.
3. Martinez-Lorenzo, J. A. and Rappaport, C., "SAR imaging of suicide bombers wearing concealed dielectric structures," *IEEE International Conference on Homeland Security Technology*, Waltham MA, Nov 2010.
4. Fernandes, J., Martinez-Lorenzo, J. A., Hagelen, M. and Rappaport, C. "A comparison of experimental and simulated millimeter wave imaging system for standoff detection of person-borne improvised explosive devices," *IEEE International Conference on Homeland Security Technology*, Waltham MA, Nov 2010.

## Other References

1. Curlander J. C., McDonough R. N., *Synthetic Aperture Radar: Systems and Signal Processing*, John Wiley Sons, Inc., USA, 1991.
2. Carrara W. G., Goodman R. S., Majewski R. M., *Spotlight Synthetic Aperture Radar: Signal Processing Algorithms*, Artech House, Inc., USA, 1995.