A Compressed Sensing Technique for Multistatic Three-dimensional Millimeter-Wave Personnel Screening

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ALERT — AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

Northeastern

Abstract

The design of an active three dimensional (3D) millimeter wave imaging system for personnel security screening using compressed sensing is presented in this work. The system is able to produce a high-resolution 3D reconstruction of the whole human body surface and reveal concealed objects under clothing. Innovative multistatic millimeter wave radar designs and algorithms, which have been previously validated, are combined to improve the reconstruction results over previous approaches. Compressed Sensing techniques are used to drastically reduce the number of sensors, thus simplifying the system design and fabrication. Representative simulation results showing good performance of the proposed system are provided and supported by several sample measurements.

Introduction

This work presents Compressed Sensing (CS) based algorithmic improvements to a previous millimeter-wave (mm-wave) based portal system design [1], which generates three-dimensional (3D) high-resolution images of the whole human body. CS technique has been successfully applied in several SAR imaging problems [2], [3]. The algorithm, first introduced in [4], is a novel signal processing theory, which states that sparse signals can be recovered using far fewer samples or measurements than those required by the Nyquist sampling criterion. The proposed technique allows for good imaging using a very reduced number of receiving antennas.

Technical Approach

Millimeter Wave Radar system configuration

The incident beam is generated with an elliptical reflector antenna [5] capable of providing a narrow beam in elevation (z axis) and constant amplitude in azimuth. The scattered field is acquired in two 90°-arcs placed above and below the reflector antenna. A 2D SAR image is generated on the slice illuminated by the beam.

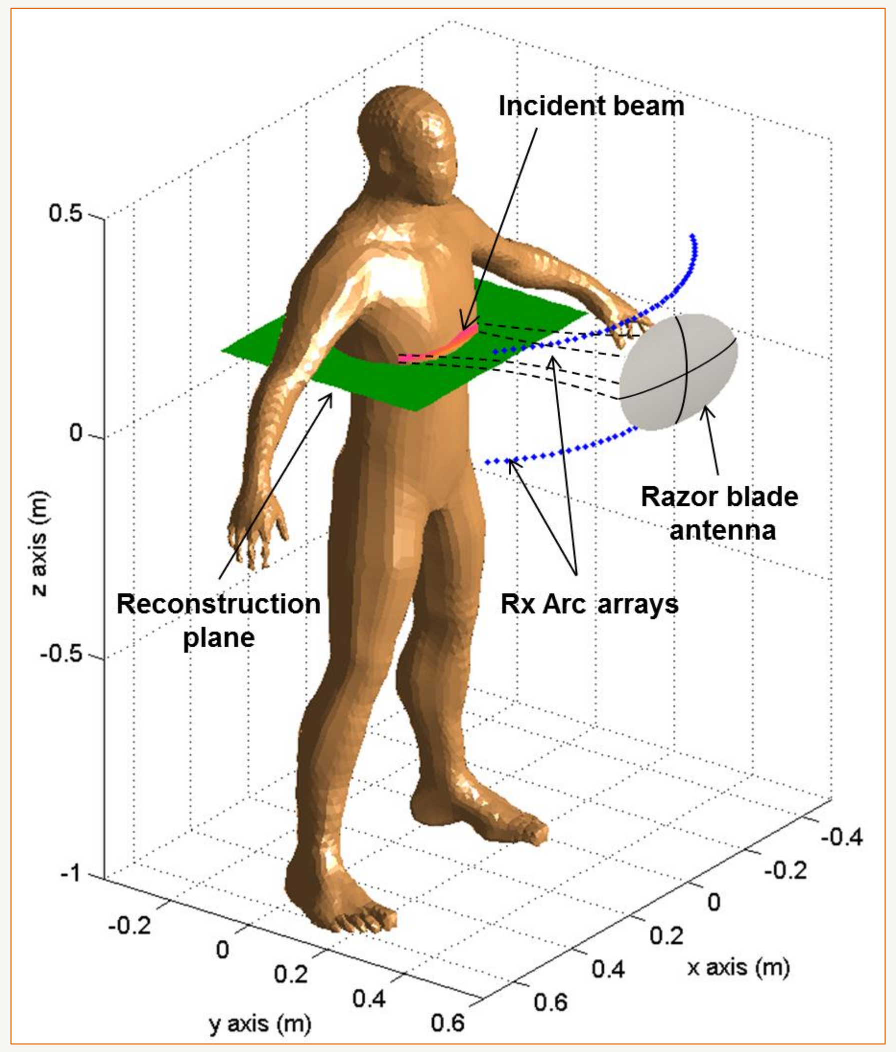

Fig. 1. Proposed mm-wave system setup scheme.

Compressed Sensing Algorithm

The mm-wave imaging problem can be mathematically written as solving a linear system of equation $y=Af$, where y is the vector containing the measured field at the receiving antennas, f represents the reflectivity vector on the imaging area and A is the sensing matrix. The CS formulation is given by:

$$\arg\min \|\alpha = \Psi f\|_1 \qquad s.t. \|y = Af\|_2 < \epsilon \qquad (1)$$

where Ψ is a functional used to find a sparse representation α of the mm-wave image, and is the ϵ error of the reconstruction. In this contribution, CS-SAR inversion is implemented by means of the Nesterov algorithm, provided as a Matlab toolbox [6].

CS Human Body 3D Profile Reconstruction

CS images are generated with just 25-30 % of the samples required by the Nyquist sampling criterion. As a test case, two metallic objects are placed on a human torso model, as shown in Fig. 2 The forward problem is simulated with Physical Optics (PO), assuming that skin is a good conductor. To create 3D images, 2D reconstructions are generated and then stacked to form a full body surface. Fig. 3 represents the 2D CS and SAR images when the Blade Beam antenna is illuminating the z = 0 m slice. The automatic profile extraction described in [1] is applied to the images to create a 3D mesh, as shown in Fig. 4.

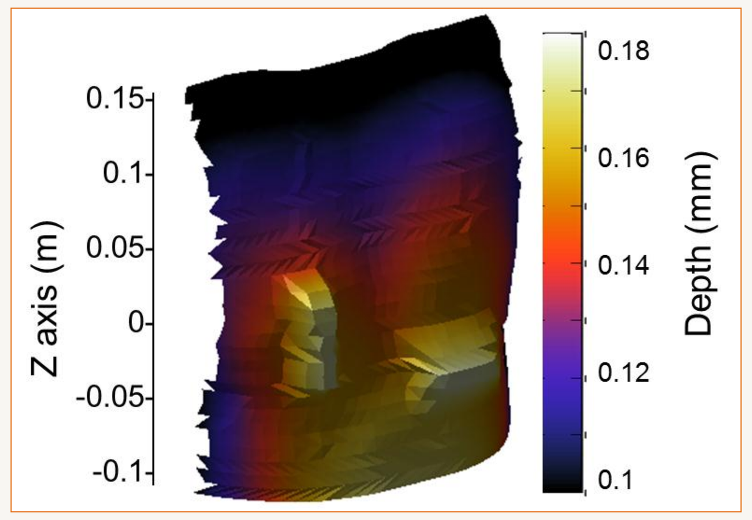

Fig. 2. Original human body torso with two objects mesh.

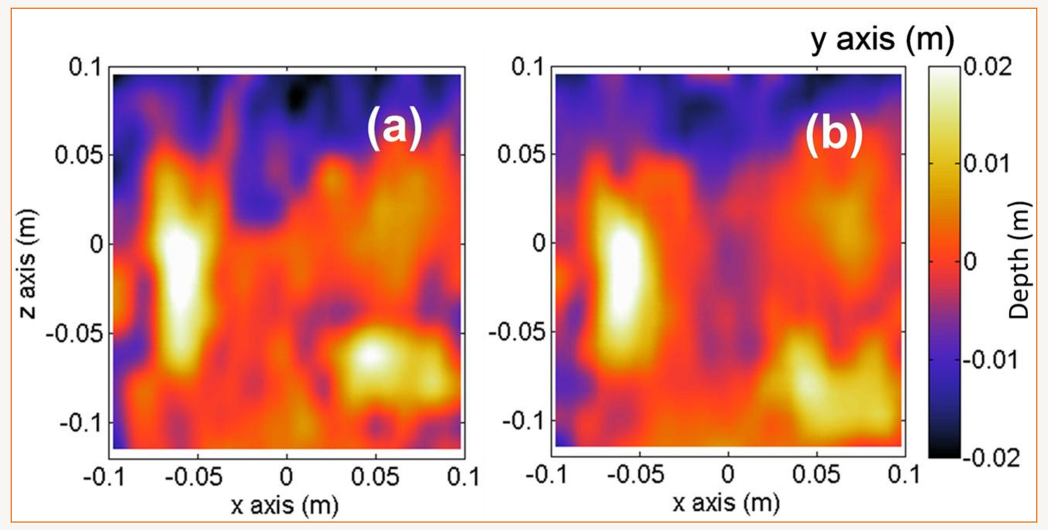

Fig. 4. Difference in range between the reconstructed 3D profile and a smoothed one. (a) SAR results using 150 receivers per arc. (b) CS results using 40 receivers per arc.

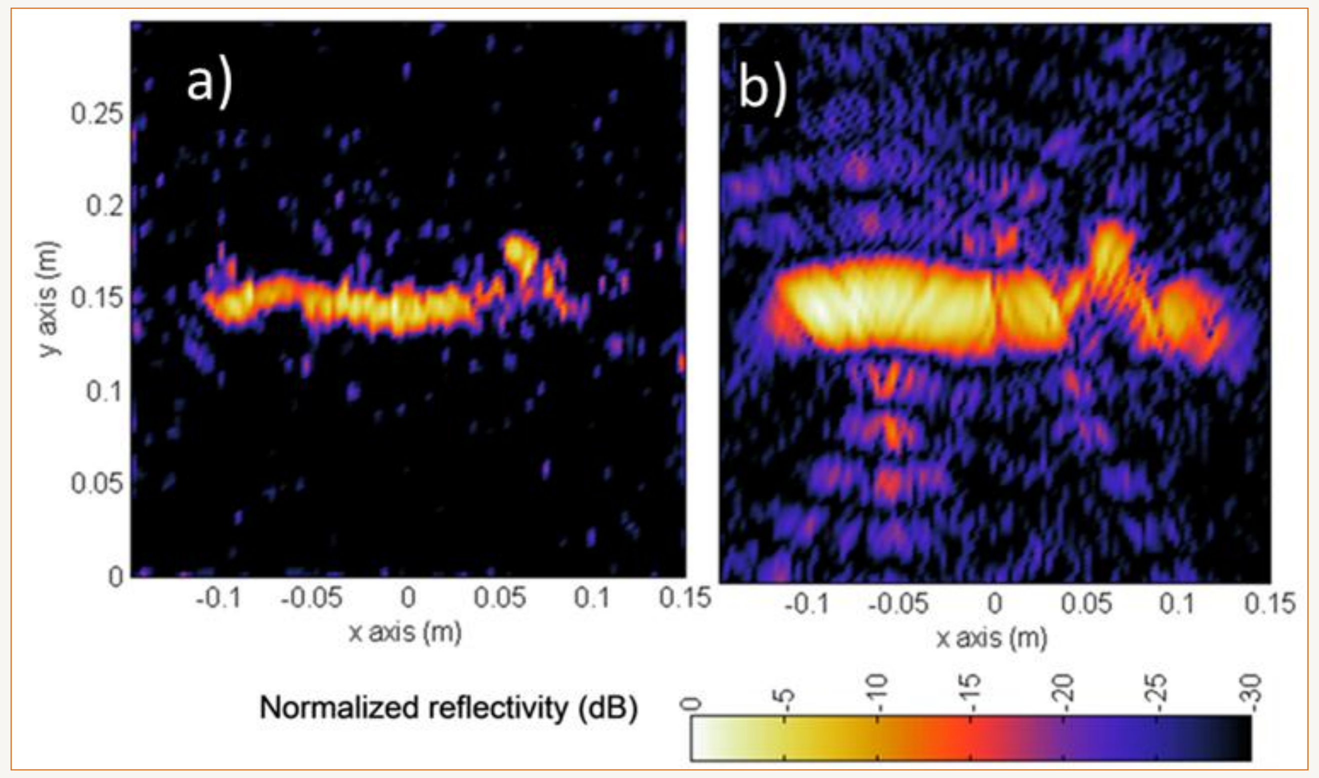

Fig. 3. CS and SAR images (normalized reflectivity, dB) recovered on the z = 0 m slice. (a) CS image using a random set of 40 receivers in each arc, (b) SAR image using two arcs of 150 receivers each.

Validation with measurements

In order to validate the simulation results, a set of experimental measurements were collected [7]. Fig. 5 shows the setup of the experiment and Fig. 6 shows the reconstructed images using SAR and CS.

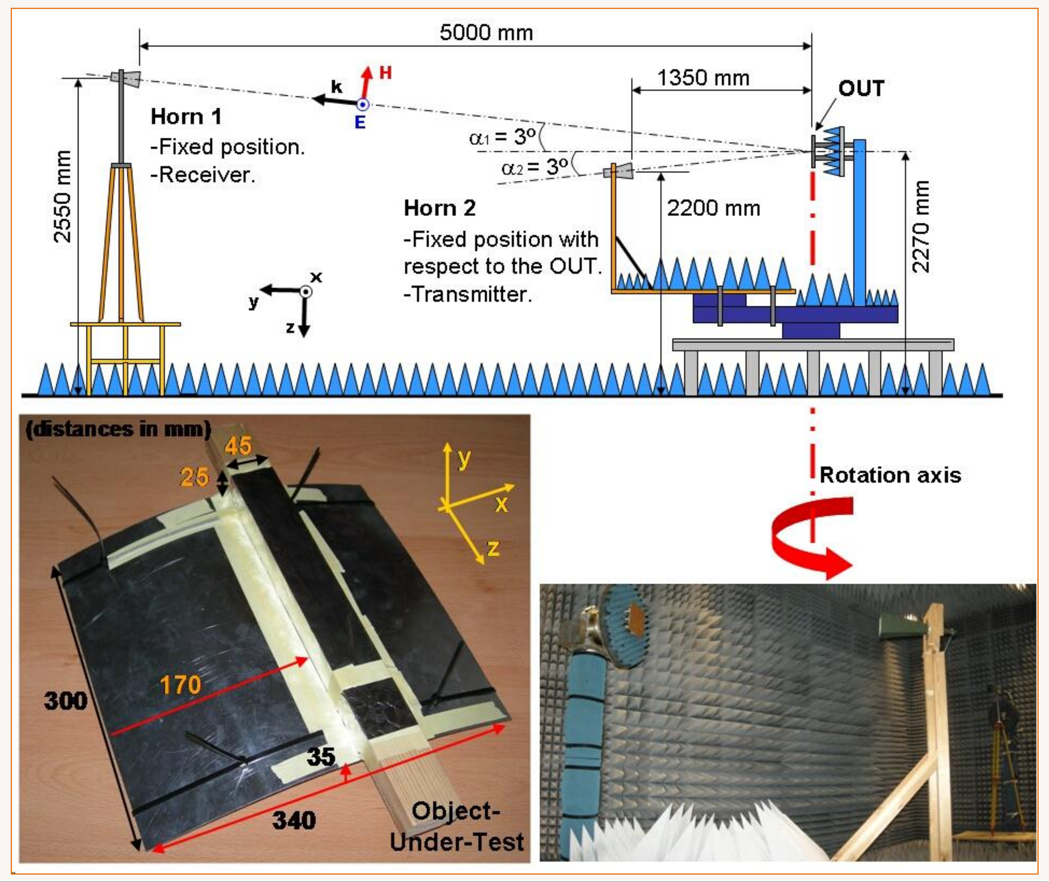

Fig. 5. Experimental measurement setup (top). Metallic curved object-under-test (OUT), which has *z* axis (height) invariant geometry (bottom left). Anechoic chamber (bottom right).

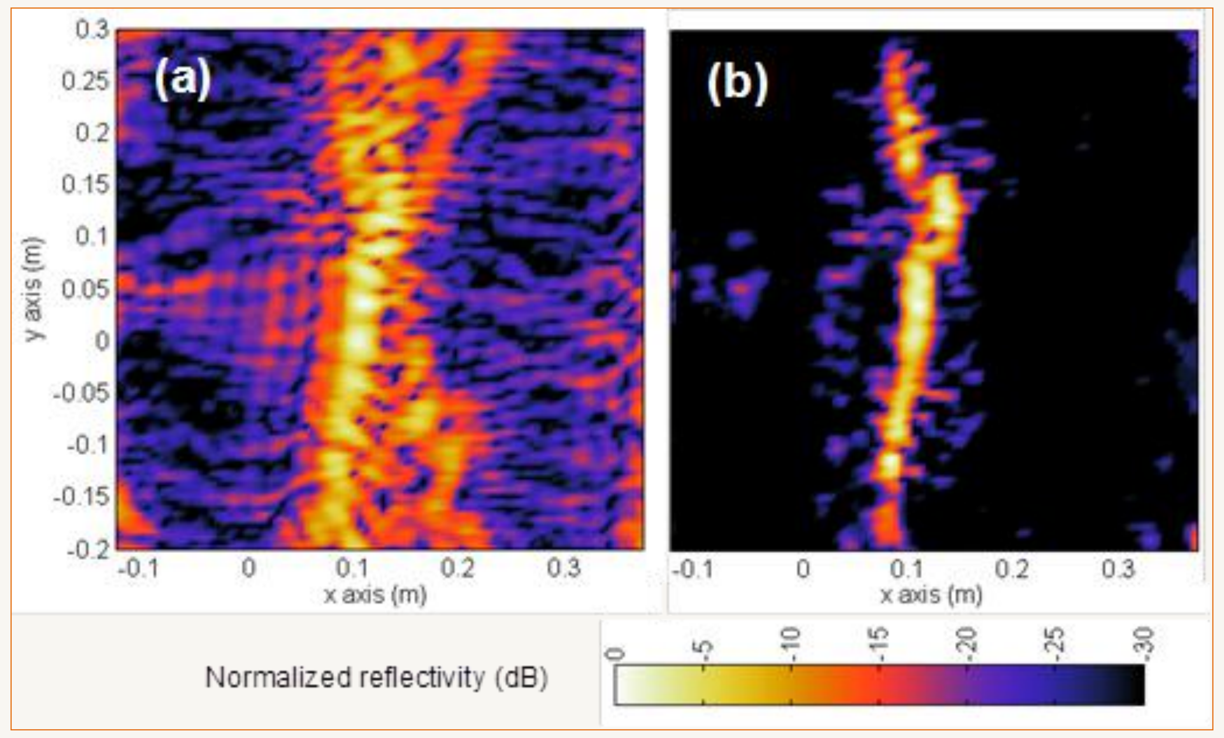

Fig.6. SAR (a) and CS (b) images from 30 randomly selected positions in a 90º-arc.

Opportunities for Transition to Customer

The Compressed Sensing based inversion is a key feature of the hybrid X-ray/MMW radar whole body imaging system being developed under ALERT funding. This system will be able to substantially improve the image quality of current X-ray or MMW systems. The use of a very reduced number of receiving elements allows for reducing the cost of the system and eases the transition of the proposed technology to the corresponding agencies.

Conclusions

Compressed Sensing (CS) techniques have been successfully introduced to reduce the number of receivers needed for a mm-wave portal-based concealed objects detection system.

The proposed hardware implementation is considerable more cost effective (from a 150 to 40-element arrays). Results show that CS allows an accurate 3D profile reconstruction using only 25% of the minimum number of receivers required for traditional SAR imaging processing.

References

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