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A GPU Ray Tracer for Modeling Electromagnetic Scattering from the Human Body

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ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

Abstract

A GPU accelerated ray tracing algorithm is presented for near-field imaging in millimeter wave personnel screening systems. Ray tracing is a well-known method for approximating high frequency electromagnetic behavior. Ray tracing theory is applied here to model the scattering behavior of the human body in the near-field. Since all rays can be computed independently, the method is well suited for implementation on graphics processing units (GPUs), offering great speedups in both 2D and 3D when compared to conventional methods. Realistic simulations were performed using a triangular mesh representation of the human body. The CUDA-based NVIDIA OptiX ray tracing engine was used to compute ray-triangle intersections and a novel ray aggregation scheme was used to compute the scattered field. This technique allows multiple frequencies to be calculated at no additional cost. Numerical results are compared with Method of Moments solutions.

Real World Application

Person-borne weapons and explosives present a major threat to security in airports and other highly populated or highly secure areas. With the rise of nonmetal threats, including improvised explosives, liquids, plastics, and ceramic weapons, metal detectors are no longer sufficient security measures. Millimeter-wave imaging systems provide an alternative, using non-ionizing electromagnetic radiation to detect any object underneath an individual's clothing.

A new design has been developed to improve on the limitations of current systems. Computational algorithms that are both fast and accurate are required in both the design phase and implementation of improved scanners. These algorithms are needed to understand the interactions of radiation with realistic human body types, weapons, and explosives, to efficiently explore complex hardware sensor designs., and to enable real-time image reconstruction.

Goal

The overall goal of this research effort is to create a next generation whole-body millimeter-wave imaging system to improve on the detection capabilities of current systems. These improvements will be made by developing novel hardware designs and novel algorithms.

The goal of the work presented in this study is to develop a real-time algorithm for simulation and imaging.

Technical Approach

Millimeter Wave Radar Configuration

The design of the proposed system is shown in Fig.1. An elliptical reflector antenna is used to produce an incident beam 1 cm thick in elevation (z). Two arrays of receivers are used to capture the scattered signal from the body. This configuration moves along the z-axis to illuminate the entire body [1].

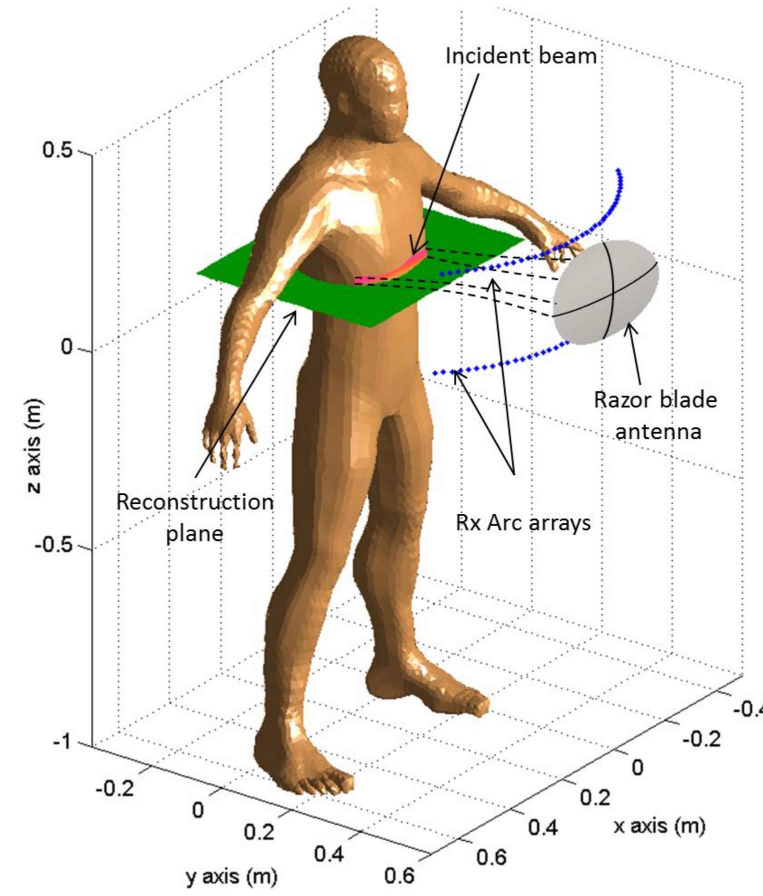

Fig 1. Proposed hardware setup.

Ray Tracing Algorithm

A transmitting point source is located in the far-field of the mesh's triangular facets. Rays are traced to the scattering body and secondary rays are computed by applying Snell's law and an interpolation algorithm to find normals within a triangle (Fig. 2). Secondary rays are traced until they reach an array of receivers.

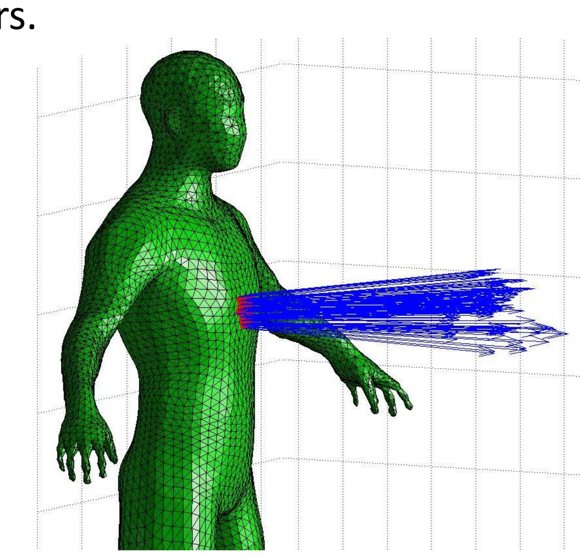

Fig 2. Tessellated human body model and reflected rays emanating from chest.

A ray aggregation technique is used at the receiving array to calculate the scattered field from individual ray pathlengths. The receiving array is discretized into segments (surface patches in 3D) the size of a half wavelength. Any rays that terminate within a given segment are added in a complex sense.

GPU Implementation

The simulations conducted in this study were performed using an NVIDIA GTX 680 graphics card, with 1536 CUDA cores running at 1.006 GHz. Each ray is computed on an independent thread. Fig.3 illustrates the CUDA threading model, or the relationship between host, device, and threads.

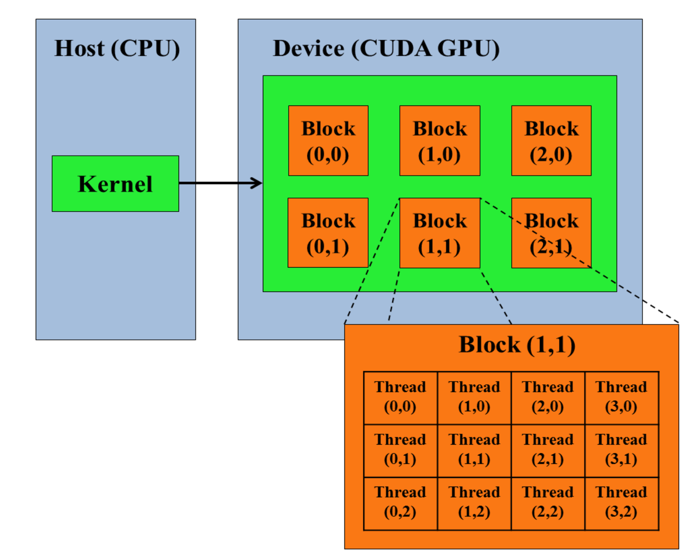

Fig 3. CUDA threading model.

The algorithm was implemented using CUDA 4.2 and NVIDIA OptiX Engine 2.6. The OptiX Engine is a general framework for building ray-tracing based applications. It provides the developer with flexible options for ray generation, acceleration structures, and intersection programs. The flowchart for the algorithm developed in this study is shown in Fig. 4.

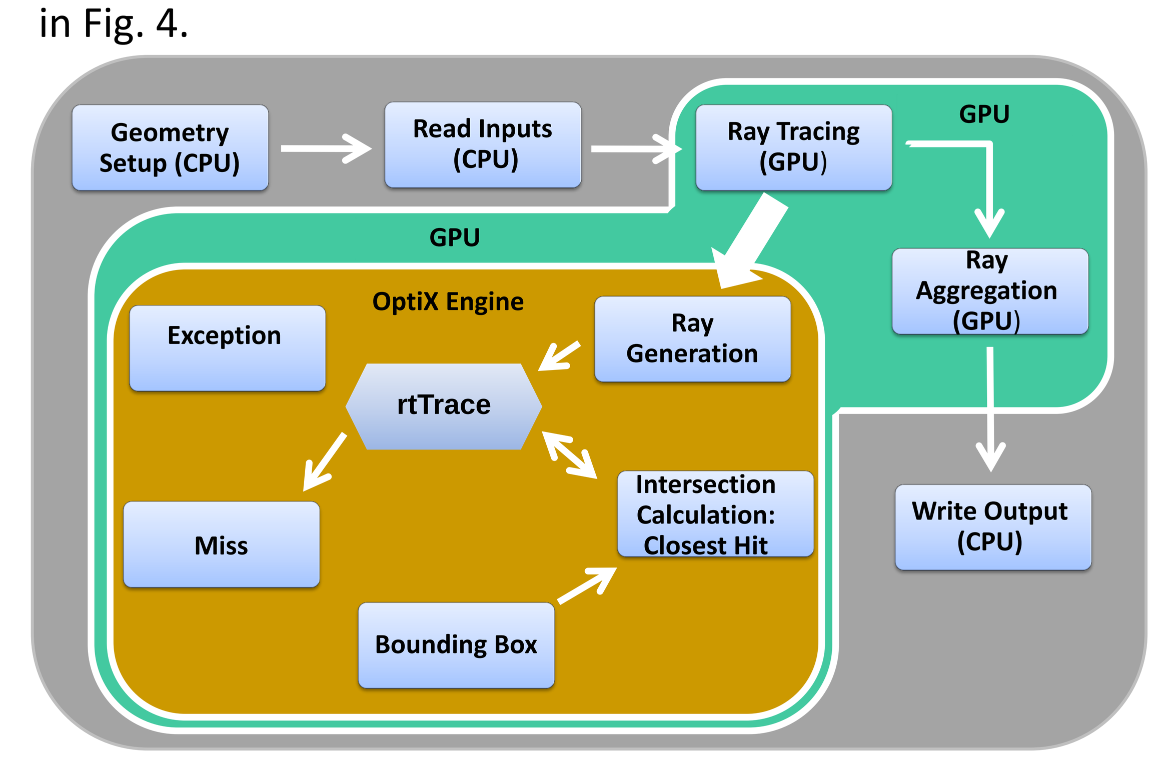

Fig 4. Algorithm flowchart.

Advantages over Conventional Methods

Conventional methods such as the Method of Moments or Finite Difference Frequency Domain (FDFD) offer exact solutions to scattering problems, but are slow (minutes or hours) in 3D. Ray tracing speed depends on the number of triangles, which can be discretized as large as a wavelength. Ray tracing, unlike conventional methods, can also compute multiple frequencies at no additional cost, offering scattered field solutions on the order of seconds.

Results

Ray tracing is used as a forward method to calculate the scattered fields on a 90˚ receiver arc from 2D slices on the z-axis of the body (Fig 5 a,b,c). A SAR algorithm is used to generate reconstructions of the original slice. Combining these slices provides a 3D reconstruction of the human body. The results generated using ray tracing are compared to results generated with the Method of Moments. A frequency band of 7GHz was chosen for the simulations.

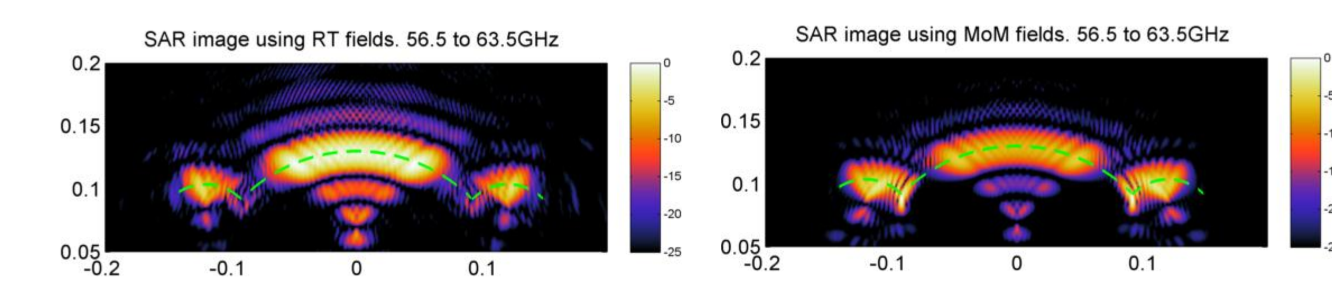

Figure 5a. SAR images for an "ideal" torso shape using ray tracing (RT) and Method of Moments (MoM).

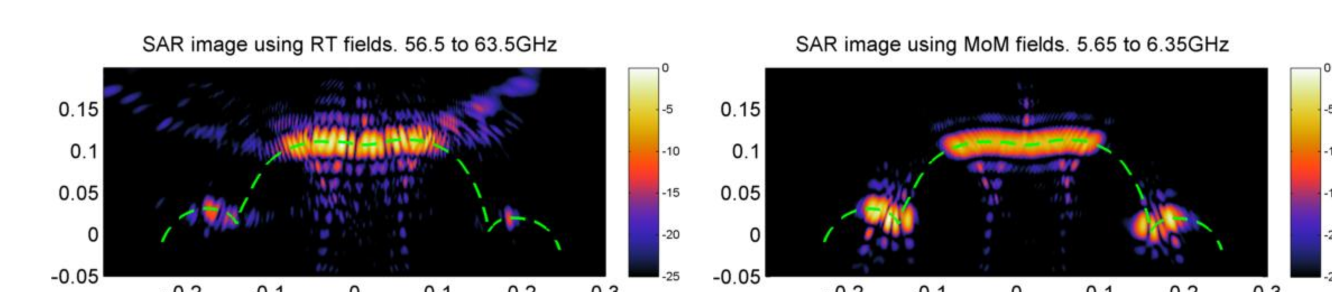

Figure 5b. SAR images for a realistic torso, arms.

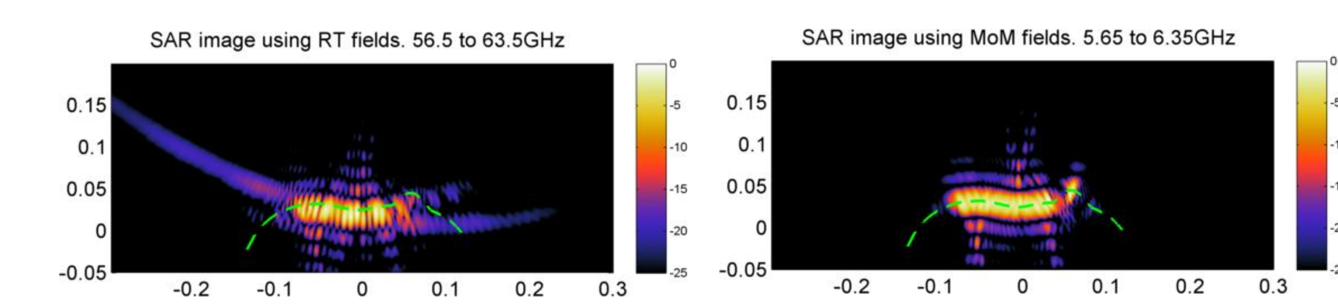

Figure 5c. SAR images for a section of the torso with an object.

Conclusions and Future Work

The ray tracing algorithm in this study is capable of providing scattered field solutions comparable to the Method of Moments, with the advantage that solutions can be computed in seconds. Future work includes additional speed optimizations, implementing 3D ray aggregation, studying the accuracy of ray tracing when introducing small scatterers that mimic concealed objects, and developing an imaging algorithm based on ray tracing.

References

1. K. Williams, C. Rappaport, A. Morgenthaler, J. Martinez, R. Obermeier, F. Quivira, "Computational Modeling of Close-In Millimeter Wave Radar for the Detection of Concealed Threats," presented at the Gordon Research Conference, Italy, June 2011.
2. K. Williams, C. Zhongliang, L. Tirado, B. Gonzales-Valdes, J.A. Martinez Lorenzo, C.M. Rappaport, "Ray Tracing for Whole Body Imaging: Simulation and Inversion," 2012 IEEE Conf. on Antennas and Propagation, Chicago, Ill, July 2012.

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