Near field fast forward models and signal processing for whole body imaging

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Abstract

We investigate a method for implementing the Modified Equivalent Current Approximation [4] (MECA) method using CUDA for near-field imaging of the human body. In the proposed configuration, a narrow slice of the body is illuminated with a specially-designed reflector antenna transmitter and the scattered millimeter-wave fields are received with a circular arc antenna array.

The MECA forward model in CUDA C allows the analysis of dielectric and lossy geometries and reduces to the well-studied Physical Optics (PO) formulation in the case of PEC scatterers. We discuss implementation details and performance of the CUDA C code as opposed to the previous OpenMP version of the code [3]. We show through simulations that the port to CUDA C is effective at reducing the MECA algorithm computation time.

Relevance

The signal processing algorithms have demonstrated a substantial improvement in the quality of 3D images. The main reason for such an image quality improvement is the use of multiple bistatic channels, which is different from currently used monostatic systems. Multi-bistatic and multistatic radar eliminates troubling artifacts such as dihedral responses which appear to produce a "tail" between legs. These signal processing techniques can be easily used to fuse the information provided by complimentary X-ray sensors to improve the performance of the system in terms of threat detection and target identification.

Technical Approach

Millimeter Wave Radar system configuration.

The system configuration is presented in Fig. 1 and 2. A reflector antenna, which has a parabolic and elliptical profile in the horizontal and vertical plane, respectively, has been used.

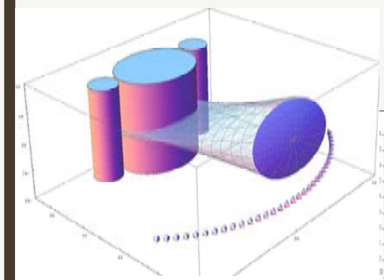


Fig. 1 System configuration based on a reflector antenna and an array of receivers.

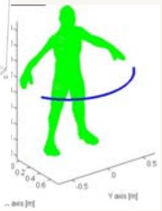


Fig. 2 General view of the person under test .

The basic configuration produces a rectangular beam when projected onto the person under test (see Fig. 1). This special type of illumination is ideal for 2D analysis, which is optimal for reducing the computational cost of the inversion algorithm. It is also optimal for use in a multiple bistatic configuration, where an array of receivers are located on a circular arc.

Step Frequency Modified Equivalent Current Approximation (MECA) Forward Model

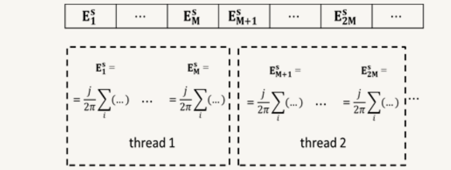
We have developed a forward model using the MECA method in CUDA C, which can calculate currents from dielectrics and lossy scatterers.

The simulations conducted are performed using an NVIDIA Tesla™ C2070 Computing Processor, which contains 448 stream processors and has a floating point point peak performance of 515 GFLOPs.

In MECA, the scattered electric field $\boldsymbol{E}_k^s$ at the observation point $\boldsymbol{r}_k$ is the sum of the contributions of all the facets *i* of a given mesh geometry as [1]:

$$\boldsymbol{E}_k^s = \frac{j}{2\lambda}\sum_i \frac{e^{-jk_1 r_{ik}}}{r_{ik}}\left[\boldsymbol{E}_{ik}^a - \eta_1 \boldsymbol{H}_{ik}^a \times \hat{\boldsymbol{r}}_{ik}\right], \quad (1)$$

where λ is the wavelength, k_1 is the first medium wavenumber, and $\boldsymbol{r}_{ik} = r_{ik}\hat{\boldsymbol{r}}_{ik}$ is the position vector from the *i*-th facet centroid to the observation point $\boldsymbol{r}_k$. A previously implemented OpenMP C version implements Eqn. (1) as shown in Fig. 3(a). For the CUDA implementation shown in Fig. 3(b), changes were made to account for the GPU architecture and exploit parallelism.



a) Each thread computes for a set of observation points (OpenMP C approach)

b) nT threads computer each facet in nr kernels, parallel reduction [5], and last kernel (nr threads) computes field (CUDA C approach)

Fig. 3. OpenMP & CUDA MECA implementations

For a square plate geometry with varying facets and a fixed number of observations, the CUDA C implementation is anywhere from 1.5 to 9.3 times faster than the OpenMP C implementation, as seen in Fig. 4 and 5.

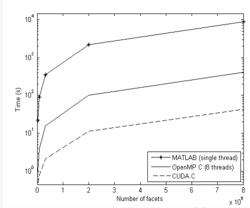


Fig. 4. Runtime vs. number of facets for near-field calculations.

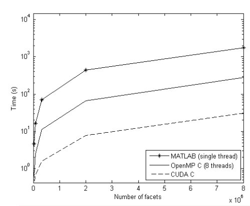


Fig. 5. Runtime vs number of facets for far-field calculations.

Fig. 6 shows the scattered fields on a half-cylinder placed around a human body that was illuminated by a plane wave. The fields were generated by the CUDA C MECA code.

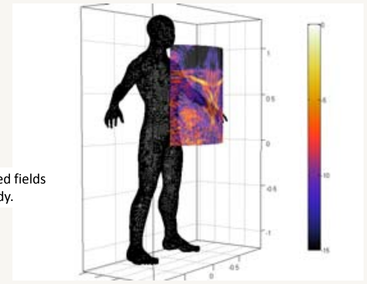


Fig. 6. Scattered fields off human body.

In addition to MECA, we have developed other signal processing methods. Table 1 shows the different classes of forward and inverse models being developed.

Table 1: Forward/Inverse models developed/under development

Forward models	FMCW		Step Frequency MECA		Step Frequency FMM	
	CPU	GPU	CPU	GPU	CPU	GPU

Inverse models	Inverse FMCW		Inverse FMM	
	CPU	GPU	CPU	GPU
Legend	Complete		In progress	Future work

Opportunities for Transition to Customer

The fast forward algorithms presented in this poster are an important component of the hybrid X-ray/MMW radar whole body imaging system which is being developed under ALERT funding. This system will be able to substantially improve the image quality of current X-ray or MMW systems, and the transition to TSA agents can be quickly implemented.

Accomplishments Through Current Year

During the current year we have prototyped a GPU version of the step frequency MECA forward model algorithm with the Jacket [2] GPU add-on toolbox for MATLAB.

To decrease computational time and resources, the Jacket MATLAB code was ported to CUDA C. In addition, a MATLAB version of the Fast Multipole Method (FMM) was developed and ported to C.

Future Work

We will continue working in improving the quality and speed of our forward models and inversion algorithms by means of:

1) Porting the FMM forward model to CUDA C, which will provide the same resolution compared to the MECA forward model in a faster time.
2) Development of a fast inversion algorithm in CUDA C based on the Fast Multipole Method.
3) Move towards real-time inversion algorithms.

References

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