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Investigation of Radar Propagation in Buildings: A 10 Billion Element Cartesian-Mesh FETD Simulation

Mark L. Stowell, Benjamin J. Fasenfest, Daniel A. White

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Investigation of radar propagation in buildings: A 10 billion element Cartesian-mesh FETD simulation.

Mark L. Stowell, Benjamin J. Fasenfest, and Daniel A. White*
Lawrence Livermore National Laboratory, P.O. Box 808, Livermore CA, 94551. white37@llnl.gov

Abstract

In this paper large scale full-wave simulations are performed to investigate radar wave propagation inside buildings. In principle, a radar system combined with sophisticated numerical methods for inverse problems can be used to determine the internal structure of a building. The composition of the walls (cinder block, re-bar) may effect the propagation of the radar waves in a complicated manner. In order to provide a benchmark solution of radar propagation in buildings, including the effects of typical cinder block and re-bar, we performed large scale full wave simulations using a Finite Element Time Domain (FETD) method. This particular FETD implementation is tuned for the special case of an orthogonal Cartesian mesh and hence resembles FDTD in accuracy and efficiency. The method was implemented on a general-purpose massively parallel computer. In this paper we briefly describe the radar propagation problem, the FETD implementation, and we present results of simulations that used over 10 billion elements.

1 Introduction

The problem of interest is to simulate radar pulses directed at buildings, with the goal of better understanding the complex scattering mechanisms, and to provide benchmark data for evaluating imaging algorithms. In this paper we focus on a particular generic building, and investigate different wall materials, plain solid concrete walls versus walls with re-bar and cinder block voids. The building that we modeled is a two story structure with doors, windows, hallways, several rooms, and a stair well. The size of the building was 22.6m$\times$10m$\times$6.75m. Electromagnetic fields are generated by an idealized point source at an arbitrary point outside of the structure, above the ground. Two different assumptions about the building materials were considered; generic homogeneous concrete walls and cinder block and re-bar construction. The cinder block used consisted of rectangular bricks with two holes per cinder block. For simplicity, the re-bar was modeled as PEC with a square cross-section with an edge length of 2.2 cm. The original CAD files of the building were provided by Johns Hopkins University Applied Physics Laboratory (APL). The hypothetical radar has a center frequency of around 700 MHz.

The interaction of the radar pulse with the building is simulated by solving the full-wave Maxwell's equations using a Finite Element Time Domain (FETD) method. The version of FETD used here solves the coupled first-order Maxwell's equations with $H(Curl)$ basis functions for the electric field and $H(Div)$ basis functions for the magnetic flux density. For efficiency, a tensor product Cartesian mesh is used to describe the building. When using first order basis functions along with the trapezoidal rule for element integration, our FETD is completely explicit when applied to a Cartesian mesh [1]. In fact, our FETD has the same computational complexity and second-order accuracy as Finite Difference Time Domain (FDTD) [2]. In our software, the explicit FETD algorithm is a special case of a more

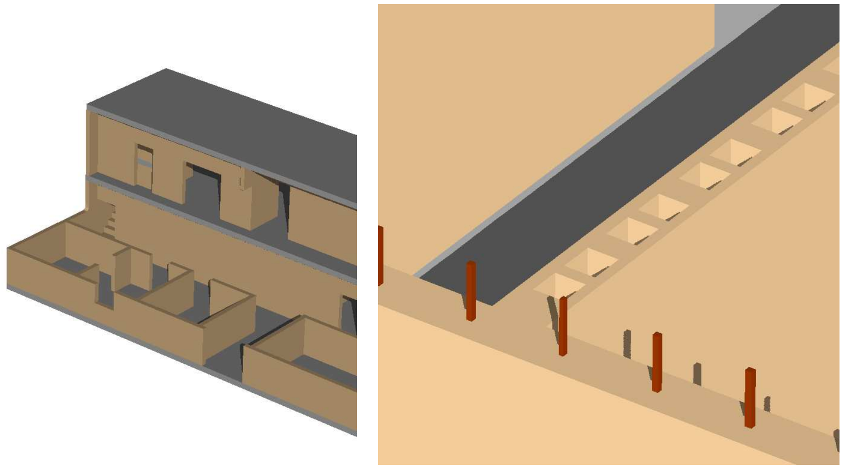

Figure 1: (Left) The simulated building with some exterior walls cutaway to show interior rooms. (Right) A cutaway of the walls showing the cinderblock voids and re-bar in detail.

general code framework that supports unstructured meshes, higher-order basis functions, and a variety of time integration methods [3].

The re-bar and the cinder block voids are defined by the computational mesh, with a mesh resolution varying from 0.75 cm to 1.425 cm. The resulting mesh consisted of 10,114,695,855 elements, which is quite large and requires a massively parallel computer. While there are more complex methods that could be used, it is interesting to see how far the Cartesian-mesh FETD method can be pushed, and this simple "brute-force" FETD approach can be used to verify more advanced numerical methods and approximate physical model, such as ray-tracing. Due to the need for extensive computing power, most of our simulations for this project have been conducted on the ZEUS Linux cluster at Lawrence Livermore National Laboratory. This computer consists of 288 nodes each with 8 AMD Opteron processors running at 2.4 GHz, with a total memory limit of 4,608 GB.

2 Simulation Results

The mesh was truncated on five sides with a first order absorbing boundary condition. No buffer space at all was used beneath the building but rather just a perfect electrical conductor boundary condition which approximates, roughly, the expected ground bounce. With these buffer zones the overall mesh dimensions were 40m$\times$40m$\times$15m.

The simulation used 6 CPUs per node on 256 nodes for a total of 1536 processors. The allocated memory was 1.82515 TB (7.3 GB per node) and the total memory usage was 2.10858 TB (8.4 GB per node) which gives an average memory overhead of 1.1 GB per node.

The simulations were run roughly long enough for the pulse to travel the distance from the transmitters to the far corner of the building and back again. The average wall clock times were 11.21 hrs and 18.95 hrs, respectively for the narrow side and broadside transmit, respectively.

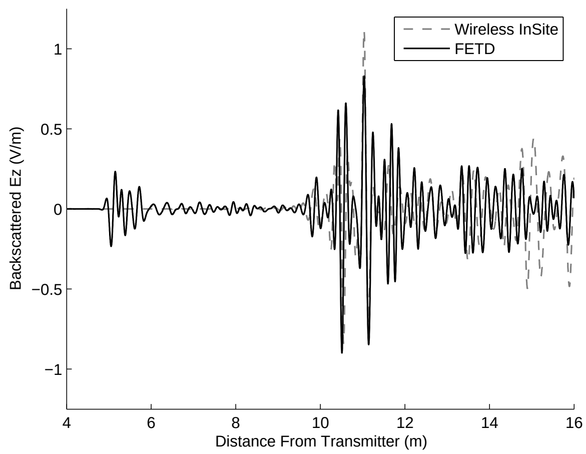

Figure 2: A comparison of the backscattered z-component of the electric field for the broad side pulse between the Wireless InSite ray-trace code and the FETD results.

The backscattered electric field was compared for the Wireless InSite ray-trace code [4] and the FETD results in Figure 2. The major features are similar, although there is some discrepancy. It is expected that better agreement could be seen if diffraction off wall edges was enabled in the ray-trace code.

Some insight into the the differences between the homogeneous wall case and the re-bar reinforced cinder block wall case can be obtained by looking at a 2D snapshot of the fields within the building both with and without re-bar, seen in Figure 3.

3 Conclusions

The interaction of radar pulses with buildings was simulated using a FETD algorithm implemented on a general purpose massively parallel computer. The purpose of these simulations was twofold, the first goal was to push the FETD algorithm to its limits on the available computer system. We were able to simulate a highly detailed building model consisting of over 10 billion mesh elements. The second goal was to investigate different wall materials, in particular a comparison between solid concrete walls and re-bar reinforced cinder block walls. As expected, there were interesting differences between the results. These brute-force full-wave simulation results can be used to benchmark alternative approximate models, and a brief comparison with a commercial ray-tracing program was performed.

4 Acknowledgements

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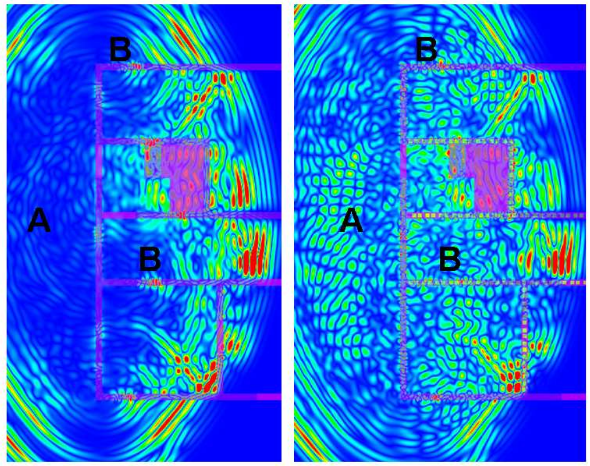

Figure 3: Side by Side comparison of solid wall (left) vs. cinder block wall with re-bar (right). Regions “A”, the backscattered field, as well as “B” within the walls, show different behavior for the two cases.

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