**Accelerating Electromagnetic Simulations: GPU Implementation of FDTD Algorithm**

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ABSTRACT

Radar propagation models play a crucial role in various applications, yet their computational demands often result in prolonged simulation times. This project explores the potential of leveraging Graphics Processing Units (GPUs) to enhance the performance of radar propagation simulations. By implementing the Finite-Difference Time-Domain (FDTD) algorithm on GPUs, we aim to accelerate electromagnetic simulations, thereby reducing computation times. This research investigates the performance and accuracy trade-offs inherent in different propagation models, evaluates their suitability for GPU implementation, and quantifies the performance benefits derived from GPU acceleration.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics • **Networks** → Network reliability

1 INTRODUCTION

In recent years, Graphics Processing Units (GPUs) have emerged as powerful accelerators for a diverse range of computationally intensive applications, owing to their exceptional raw computational power, cost-effectiveness, and energy efficiency. Leveraging GPUs for general-purpose programming has revolutionized fields such as bioinformatics, computational physics, engineering simulations, image processing, and more. One particularly demanding application that stands to benefit from GPU acceleration is the simulation of electromagnetic (EM) fields using the Finite-Difference Time-Domain (FDTD) method. The FDTD method, a widely employed numerical scheme for EM field simulation, necessitates substantial computational resources and fast memory access to accurately model real-world scenarios. In this context, this study delves into the collaboration of Central Processing Units (CPUs) and GPUs to develop a parallel algorithm for the FDTD method. Specifically, the OpenMP API is utilized for GPU implementation, aiming to harness the parallel processing capabilities of both CPU and GPU architectures to accelerate EM field simulations while optimizing performance per dollar and performance per watt metrics.

The motivation for investigating the collaboration of CPUs and GPUs for parallelizing the Finite-Difference Time-Domain (FDTD) method lies in the pressing need to address the computational demands of electromagnetic (EM) field simulations. These simulations are integral to numerous critical applications, including radar systems, wireless communication networks, medical imaging, and more. However, the complexity of real-world EM scenarios often necessitates vast computational resources and imposes significant computational overheads. By harnessing the parallel processing capabilities of GPUs alongside the multi-core capabilities of CPUs through the OpenMP API, this research seeks to unlock the potential for accelerated EM field simulations while optimizing cost-effectiveness and energy efficiency. This endeavor aligns with the broader objective of advancing computational techniques to meet the growing demands of EM modeling in various domains, ultimately driving innovation and facilitating the development of more efficient and scalable simulation methodologies.

2 LITERATURE REVIEW

2.1  Collaborating CPU and GPU for the electromagnetic simulations with the FDTD algorithm

This literature paper discusses the collaborative utilization of CPUs and GPUs for electromagnetic simulations using the Finite-Difference Time-Domain (FDTD) algorithm with Uniaxial Perfectly Matched Layer (UPML) boundary conditions. The scope of this project is to optimize the implementation of the FDTD algorithm, coupled with uniaxial perfectly matched layer (UPML) boundary conditions, on GPU clusters. This optimization entails exploring various strategies to enhance execution efficiency, including leveraging GPU texture memory, pinned host memory, and optimizing data transfer between CPU and GPU. Additionally, the research delves into load balancing techniques to ensure an equitable distribution of computational workload between CPUs and GPUs, thus maximizing efficiency in collaborative computing mode. Furthermore, the study emphasizes the importance of numerical accuracy by implementing UPML boundary conditions and validating simulation results against analytical solutions. Performance evaluations are conducted to assess scalability, efficiency, and computational throughput, ultimately aiming to advance the field of electromagnetic simulation by achieving high performance and accuracy through collaborative CPU-GPU computing.

2.2 GPU Accelerated Finite-Element Computation for Electromagnetic Analysis

This literature paper presents a detailed overview of the FDTD assembly process on GPU architectures using CUDA. The scope of this project is to highlight the challenges faced in traditional CPU-based assembly and propose innovative parallelization methods tailored for GPU acceleration. These methods aim to optimize memory usage and minimize computational challenges, ultimately enabling efficient FDTD analysis on GPU platforms. The technical approach involves formulating the FDTD analysis for electromagnetic problems, introducing GPU software and hardware architectures, and proposing novel parallelization strategies. Specifically, this literature paper explores parallelization schemes such as atomic assembly, assembly-by-edge, and multi-GPU approaches to optimize computational tasks on GPUs. Implementation efforts encompass assembly and solution phases of FDTD on GPUs, including iterative solvers and sparse matrix operations. The project also evaluates the performance of different sparse matrix storage formats and provides examples demonstrating GPU speedups in solving electromagnetic problems. This literature paper proposes the following three parallelization methods to overcome these bottlenecks.

1. parallelizing the computation of elemental matrices on a single GPU with atomic assembly.
2. assembly-by-edge parallelization on a single GPU to eliminate atomic operations.
3. distributing the assembly phase across multiple GPUs.

The challenges

2.3 GPU-Accelerated FDTD Modeling of Radio-Frequency Field–Tissue Interactions in High-Field MRI

The scope of the project revolves around the development and implementation of a GPU-accelerated Finite-Difference Time-Domain (FDTD) method tailored for electromagnetic (EM) analysis, with a specific focus on its application in MRI coil design. This entails adapting the FDTD algorithm to exploit the parallel computing capabilities of GPUs, thereby significantly enhancing computational efficiency. The project delves into intricate details such as hardware specifications, CUDA programming for GPU utilization, and practical considerations for efficient computation. By leveraging GPU technology, the project aims to enable more accurate and detailed modeling of RF coil interactions, particularly in high-field MRI environments. A practical demonstration of this approach involves simulating the performance of a transceive volume-array coil for small animal imaging at 9.4 Tesla, showcasing the improved efficiency and effectiveness compared to traditional methods. Ultimately, the project contributes to advancing MRI technology by facilitating the development of more sophisticated coil designs through enhanced computational capabilities.

3 PROJECT PLAN

3.1 Timeline

The project timeline (attached in Appendix, Figure 1.1)includes data collection for theinitial setup an**d** familiarization with the OpenMP API for GPU implementation, followed by adaptation of the FDTD algorithm to leverage both CPU and GPU resources. Subsequent phases involve optimization techniquesand performance evaluation(week 7 - 12), with expected completion within a six-month timeframe.

4 CONCLUSIONS

REFERENCES



Appendix

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| A project schedule with multiple colored rectangular boxes  Description automatically generated with medium confidence |
| Figure 1: Project timeline |