FRANKFURT UNIVERSITY OF APPLIED SCIENCES

MASTER THESIS

Finite Difference Time Domain Method Implementation in C++

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A thesis submitted in fulfillment of the requirements for the degree of Master of Science

in

High Integrity Systems

Faculty 2: Computer Science and Engineering

December 21, 2020

Declaration of Authorship

I, Xhoni ROBO, declare that this thesis titled, "Finite Difference Time Domain Method Implementation in C++" and the work presented in it are my own. I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Abstract

Faculty 2: Computer Science and Engineering

Master of Science

Finite Difference Time Domain Method Implementation in C++

by Xhoni ROBO

This thesis is the final documentation for a project in the Master of Science degree of High Integrity Systems supervised by Prof. Dr. Peter Thoma and Prof. Dr. Egbert Falkenberg. In this thesis, the author will explain the basics of electromagnetic simulation and demonstrate a simple application that will produce both electric and magnetic field data, which can then be visualized through the help of third party applications such as Paraview[3].

This thesis is heavily focused on theoretical aspect of such an application, and as such the code will be simplistic and not use any advanced external libraries not included by default in the basic C++ package. The application will not have a User Interface (UI), therefore the only way to customize the initial values of the code variables would be through an Integrated Development Environment (IDE) that can handle C++, such as Eclipse [1]. The benefit of not relying on any external open source libraries is the ability for this code to be used by any machine regardless of operating system and easy integration into applications that need such simulations.

Alongside this document, the project also included the code files found in the GitHub repository[4]. As the base LaTeX template of this thesis was found online[5], these files are also included, with the license allowing viewing and modification so long as it is for a non-commercial use. After the official deadline of January 5th 2021, this project will be considered complete and no further changes will be made.

Keywords: *Finite, Time, Domain, Difference, C++, High, Integrity, Systems, 1D, 2D, 3D*

Acknowledgements

First and foremost I would like to thank my academic supervisor, Prof. Dr. Peter Thoma. It is only due to his patience, perseverance, and willingness to spend his time aiding me, that I was able to complete this project. Even before that, I would like to thank him for his course of Simulation Methods in the High Integrity Systems M.Sc. degree, that convinced me that such a subject would make an interesting thesis for me.

I would also like to the Prof. Dr. Falkenberg, not only for his assistance throughout my higher academic studies, but also because I would not be able to officially start working on this thesis without his acceptance.

Thank you to my friends, who although far away have helped me keep my spirits high during a rather dark year not just for me, but for the world as a whole. It would have been difficult to push through to the end of this degree otherwise, if not impossible.

And lastly, my deepest thanks to my parents, who taught me discipline, and also acceptance. They did their best to set me up for a rich academic life, by straining themselves physically, mentally, and economically just so that I could have the best possibilities available to me. It will take an eternity to repay them back for their sacrifices, but hopefully this is, at the very least, a step in the right direction.

Sincerely,
Xhoni Robo

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List of Abbreviations

FDTD	**F**inite **D**ifference **T**ime **D**omain (Method)
WSF	**W**hat (it) **S**tands **F**or

Physical Constants

Speed of Light $\quad c_0 = 2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$ (exact)

List of Symbols

Symbol	Name	Unit of Measurement
a	distance	m
P	power	W ($\mathrm{J\,s^{-1}}$)
ω	angular frequency	rad

1 Introduction

As humanity strives to better understand the world and universe around it, the physical limitations of our species become more and more apparent. While we have made considerable progress in our struggles to move forward, such as being able to record the movement of a light particle on camera despite it being the fastest moving object we know of so far[6], or being able to capture an image of a black hole[2], such achievements would not have been possible if our scientists did not have realistic expectations of how they should approach these challenges, or the expected results.

In order to achieve what they have, scientists needed to first understand the phenomena they were studying: the light having the particular properties of both particle and wave and the ability of black holes to distort space around them. All of this would not have been possible without simulations.

1.1 Electromagnetic Simulations

1.1.1 Maxwell Equations

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1.1.2 Solving the Wave Equation

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1.2 Finite Difference Time Domain Method

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1.3 FDTD Implementation

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1.3.1 Project Plan, Requirements, and Tools Used

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2 FDTD - 1 Dimensional Scenario

2.1 Main Section 1

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3 FDTD - 2 Dimensional Scenario

3.1 Main Section 1

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4 FDTD - 3 Dimensional Scenario

4.1 Main Section 1

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5 Conclusion

5.1 Main Section 1

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A Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:

`\hypersetup{urlcolor=red}`, or

`\hypersetup{citecolor=green}`, or

`\hypersetup{allcolor=blue}`.

If you want to completely hide the links, you can use:

`\hypersetup{allcolors=.}`, or even better:

`\hypersetup{hidelinks}`.

If you want to have obvious links in the PDF but not the printed text, use:

`\hypersetup{colorlinks=false}`.

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