Rendering Invisibility

Final Report for CS39440 Major Project

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12th April 2015

Version 1.0 (Draft)

This report is submitted as partial fulfilment of a BSc degree in  
Computer Graphics, Vision and Games inc. Industrial Placement (G451)

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**Declaration of originality**

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* I have read the sections on unfair practice in the Students’ Examinations Handbook and the relevant sections of the current Student Handbook of the Department of Computer Science.
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Signature ……………………………………………. (Katherine Rose Farmer)

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**Consent to share this work**

In signing below, I hereby agree to this dissertation being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Signature ……………………………………………. (Katherine Rose Farmer)

Date …………………………………………………

# Acknowledgements

I am grateful to Bernie Tiddeman for being my supervisor and helping me progress through this project. The amount of mathematical and graphical problems that I had seemed insurmountable at first but Bernie was always there to give me a hand.

I’d like to thank Oliver Roe for being a steadfast rock at my side when the stress of this project was getting too much. I am almost certain I would not have made as much progress if I didn’t have such brilliant emotional support and rubber-ducking coming from him! I’d also like to thank many of the other fourth years for being supportive when I was stressed and for being there to bounce ideas off when I was stuck. Also to my parents for putting up with all the technical jargon I was throwing their way when they asked how this project was going!

I’d also like to thank Aberystwyth University for the last 4 years and the chance to complete this course and all the work that has been done to support my continuing progress through this course. This project is the culmination of all that I’ve learned here and I can only hope it reflects the high quality of teaching I have received here.

# Abstract

Invisibility being a realistic possibility, without the use of optical illusions, is a recent discovery and is in large part due to the progress made in the field of transformation optics and metamaterials. With this recent progress, the idea of virtually simulating the theory presented is an interesting one. Hence why this project was undertaken. A virtual simulation can model any potential pitfalls that could occur while science cannot currently create a structure that would render an object invisible to the naked eye using the theories presented.

The main aim of this project was to produce a virtual model that was based on the theory presented and then to adjust any of the parameters involved to see what effects could be achieved. A side aim of the project was also to test the various geometrical shapes the cloak could take and how this would affect model. The project aimed to prove that the theory could be presented in a virtual simulation and that by adjusting certain parameters, certain effects could be achieved.

The model was produced using WebGL in combination with Three.js. The model has been created in a spherical, cylindrical and conical shape, all with a solid and shell structure included. The effects that were achieved were perfect invisibility, a chromatic effect and showing the cloak from a single viewpoint, looking into how the cloak might appear if you were able to view the cloak from one point all the way through. The project has proven that it is possible to render an invisibility cloak using the theory presented and to produce various effects based on the theory. My results are somewhat compromised by the language used and Three.js as the results are inconclusive based on the rendering being controlled by the language in a way that has produced some results that appear to be correct according to the theory but when tested separately produces incorrect results. In conclusion, further work would be needed to create a completely accurate model, mostly into determining how far the language is affecting the model and how that can be counteracted.

Contents

[Acknowledgements 3](#_Toc417830726)

[Abstract 4](#_Toc417830727)

[Background, Analysis & Process 6](#_Toc417830728)

[Introduction 6](#_Toc417830729)

[Reason for Project Choice 6](#_Toc417830730)

[Background 6](#_Toc417830731)

[Analysis 6](#_Toc417830732)

[Research Method 6](#_Toc417830733)

[Design 7](#_Toc417830734)

[Implementation 8](#_Toc417830735)

[Testing and Results 8](#_Toc417830736)

[Unit Testing 8](#_Toc417830737)

[System Testing 8](#_Toc417830738)

[Experiments 8](#_Toc417830739)

[Results 8](#_Toc417830740)

[Conclusions 8](#_Toc417830741)

[Overall Conclusion 8](#_Toc417830742)

[Issues Encountered 8](#_Toc417830743)

[Critical Evaluation 9](#_Toc417830744)

[Research 9](#_Toc417830745)

[Design 9](#_Toc417830746)

[Implementation 9](#_Toc417830747)

[Testing 9](#_Toc417830748)

[Overall Evaluation 9](#_Toc417830749)

[Appendices 11](#_Toc417830750)

[A. Third-Party Code and Libraries 11](#_Toc417830751)

[B. Code Samples 12](#_Toc417830752)

[Annotated Bibliography 13](#_Toc417830753)

# Background, Analysis & Process

## Introduction

Invisibility cloaks are starting to enter more and more into the realm of possibility. There are already many projects that both theorise and display practical solutions to the problem of how to create true invisibility such as the ‘Rochester Cloak’ [1] that using a series of lens of differing focal length to bend light around an object. Currently this is limited by the angles that it can viewed from and some edge problems that ruin the invisibility by hinting at the object cloaked or distorting the background behind the object.

What this project aimed to tackle was the idea of a 3-D rigid structure that would cloak an object within it. The difference was this project aimed to render such a structure in the virtual space and thereby obtain results about how well current theories into metamaterials, transformation optics and their relation to invisibility can be displayed in a virtual space and what this can inform us about those theories. One of the reasons for working in a virtual space when it comes to these theories is that currently they cannot create structures big enough to cloak in all directions and still work on the visible light spectrum in a reasonable amount of time. This is due to the structure needing to be less than a few hundred nanometres for each metamaterial ‘atom’ in the structure [2]

The direction the project ended up taking was to create multiple geometrical models of the invisibility cloak using the WebGL refraction model and manipulating it to use transformation optics, the mathematical equations behind metamaterials being used to create invisibility cloaks, and then to manipulate those equations to create effects that would be comparable to an invisibility cloak if it were created in reality.

## Reason for Project Choice

The author’s reasons for this project choice are threefold. One is that the subject of invisibility is universally fascinating and being able to delve more deeply into this project and the subject matter behind was a brilliant opportunity to expand and gather more knowledge in a field they had little knowledge of.

The second reason was that the author’s course and skills were more directed towards graphical projects, with previous experience in Javascript, WebGL and HTML5 being most useful for this project. This would provide a good example of their graphical skills as well as an example of their web and research skills. The ability to delve more deeply into extra libraries such as Three.js and to use WebGL for a more complicated challenge was also a draw to accepting and completing this project.

The third reason was that their industrial placement had provided little chance to use their graphical skills in a professional environment or a project of a large size. This meant that will their skills were more directed towards this area, these skills were unused and their other software engineering skills were enhanced. By using this opportunity to enhance their graphical skills while maintaining their other software engineering skills, they will show a wider range of abilities to future employers.

## Background

What was your background preparation for the project? What similar systems or research techniques did you assess? What was your motivation and interest in this project?

## Analysis

Taking into account the problem and what you learned from the background work, what was your analysis of the problem? How did your analysis help to decompose the problem into the main tasks that you would undertake? Were there alternative approaches? Why did you choose one approach compared to the alternatives?

There should be a clear statement of the research questions, which you will evaluate at the end of the work.

In most cases, the agreed objectives or requirements will be the result of a compromise between what would ideally have been produced and what was felt to be possible in the time available. A discussion of the process of arriving at the final list is usually appropriate.

## Research Method

You need to describe briefly the life cycle model or research method that you used. You do not need to write about all of the different process models that you are aware of. Focus on the process model or research method that you have used. It is possible that you needed to adapt an existing method to suit your project; clearly identify what you used and how you adapted it for your needs.

# Design

This section should discuss the overall hypothesis being tested and justify the approach selected in the context of the research area. Describe the experiment design that has been selected and how measurements and comparisons of results are to be made.

You should concentrate on the more important aspects of the method. Present an overview before going into detail. As well as describing the methods adopted, discuss other approaches that were considered. You might also discuss areas that you had to revise after some investigation.

You should also identify any support tools that you used. You should discuss your choice of implementation tools or simulation tools. For any code that you have written, you can talk about languages and related tools. For any simulation and analysis tools, identify the tools and how they are used on the project.

If your project includes some engineering (hardware, software, firmware, or a mixture) to support the experiments, include details in your report about your design and implementation. You should discuss with your supervisor whether it is better to include a different top-level section to describe any engineering work.

# Implementation

# Testing and Results

## Unit Testing

## System Testing

## Experiments

## Results

# Conclusions

## Overall Conclusion

## Issues Encountered

This section should discuss issues you encountered as you tried to implement your experiments. What were the results of running the experiments? What conclusions can you draw from these results?

During the work, you might have found that elements of your experiments were unnecessary or overly complex; perhaps third party libraries were available that simplified some of the functions that you intended to implement. If things were easier in some areas, then how did you adapt your project to take account of your findings?

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

If you had multiple experiments to run, it may be sensible to discuss each experiment in separate sections.

# Critical Evaluation

## Research

## Design

## Implementation

## Testing

## Overall Evaluation

Examiners expect to find in your dissertation a section addressing such questions as:

* Were the requirements correctly identified?
* Were the design decisions correct?
* Could a more suitable set of tools have been chosen?
* How well did the software meet the needs of those who were expecting to use it?
* How well were any other project aims achieved?
* If you were starting again, what would you do differently?

Such material is regarded as an important part of the dissertation; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honours degree.

There will be good things and room for improvement with any project. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

Review the discussion on the Evaluation section from the lectures. A recording is available on Blackboard.

# Appendices

* 1. Third-Party Code and Libraries

If you have made use of any third party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. The key requirement is that we understand what is your original work and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

As an example, you might include a definition such as:

**Apache POI library** – The project has been used to read and write Microsoft Excel files (XLS) as part of the interaction with the client’s existing system for processing data. Version 3.10-FINAL was used. The library is open source and it is available from the Apache Software Foundation **Error! Reference source not found.**. The library is released using the Apache License **Error! Reference source not found.**. This library was used without modification.

* 1. Code Samples

This is an example appendix. Include as many appendices as you need. The appendices do not count towards the overall word count for the report.

# Annotated Bibliography

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