Simulating Cardinal Movements of Human Labour Using Finite Elements

Zelimkhan Gerikhanov

Supervisor: Dr. Joost Noppen

School of Computing Sciences

University of East Anglia

Upgrade Report

January 2015

Contents

List of Figures

List of Tables

Statement of Originality

Chapter 1

Introduction

1.1 Background

Computer based simulations find numerous applications in medicine. Such applications include training of medical personell, diagnosing patients based on digital data and scientific research to gain better understanding of physiological phenomena. Bio-mechanical simuations are one of the most challenging uses of computer based simulation in medicine. The underlying principles are very complex and thus require sophisticated theoretical formulations and considerable software development efforts.

One of the areas where bio-mechanical simulations are very important is obstetrics related medical simulations.

The main focus of this project is creating a realistic real-time computer based simuation of human childbirth. Simulations of this kind require modeling biomechanical interactions of high complexity. As mentioned, this implyies highly sophisticated. This report will therefore attempt to cover the important aspects of human childbirth.

1.2 Human labour

1.2.1 Cardinal movements

1.2.2 Problematic labour

1.2.3 Childbirth simulators

There are a number of mechanical childbirth simulators that exist already. Such simualtors are designed to allow tranee obstetricians and midwifes to interact with a maniquin of a birthing woman. The maniquin is normally made of plastic and/or metal. The section

The motivation behind using a computer based simulation in childbirth modeling is dictated by a number of reasons. While having certain advantages the mechanical childbirth simulators often lack very important features. Primarily, mechanical maniquin will typically be very poorly customizable. Such simulator is typically used for training juniour personnel and in many of training cases the

simulation scenario is required to be changed based on the type of the case that is being practiced. Using mechanical simulator means that only a specific scenario is available for training with only slight variations. Additional maniquins of a different type will have to be acquired to perform training for alternative scenarios. Contrary to this, computer based simulations allow unrestricted customizability. It is also worth mentioning, that there exsits a hybrid type of simulators, that combine a computer based underlying bio-mechanical model with an external mechanical maniquin to provide the interface between the trainee and the simulator. Such, simualtors combine the advantages of both types of simulators, but also carry the drawbacks of at least one of them.

Computer simulations provide a good tool for representing real world phenomena, but they are only capable of representing the simulated objects to a certain degree of approximation. Better approximations are predominantly much more expensive in terms of computational power. With the increased processing power of modern computers, it is possible to perform simuations with a higher degree of fidelity. However, even the most performant machines can struggle with certain types of high-cost simulations. In such cases, we have to utilize the underlying hardware to the highest degree possible. This can be achieved by a number optimization techniques. One of the most effective techniques is using parallel processing in order to speed up the computation.

1.3 Reverse vs Forward engineered approaches

There is a number mong the existing mechanical and computer based simulators of human childbirth. It is crucially important to contrast the approach chosen for this research project from the existing reverse-engineered simulations.

1.4 Finite element method in surgical simulations

Finite element method (FEM) is

It is desired to achieve the highest fidelity of the simulaitons with as little latency as possible. To this end, performance optimizations and GPU utilization for Finite Element Analysis is one of the main focuses of this thesis. Several

available application programming interfaces (API's) will be overviewed as the candidate tools for implementation. It is then shown how the chosen API is used to achieve highly efficient implementation of FEA for soft-tissue simulation.

Another important aspect of creating a computer based simulation of childbirth is acquiring realistic 3D models of the underlying physiological structures. Namely, the fetal body and maternal lower body geometries are required. The possible ways of constructing the required meshes will be covered in this thesis. The approach is not yet decided on.

1.5 Report overview

The organization of the remainder of this report is presented here.

In chapter 2 a literature review is conducted presenting the body of already existing relevant research. The review is split based on relevance to a particular aspect of this research project.

Chapter 3 describes the work that has already been undertaken as of the date of this report.

Three publications have been successfully made in the duration of this PhD course, each of which covered an important topic related to the area of interest of this research. All three papers will be covered in this report. The papers are include in the **??**.

There is a considerable amount of work still left to complete. The 4 chapter focuses on describing the required steps aimed at achieving the objectives of this research project. An approximate work plan is also presented in this chapter featuring a Gannt chart.

Finally chapter 5 presents a proposed thesis structure for the final write-up.

Chapter 2

Literature Review

2.1 Introduction to Literature Review

The literature review in this report contains an overview of the key literature related to work conducted so far in the Traceability Forensics Project. Specifically this is a brief overview of traceability and requirements traceability (section **??**), reverse engineering of source code (section **??**) and mining of source code repository data (section **??**). Clustering techniques potentially offer the ability to determine semantic relationships and links between software components as an aid to comprehension and so is covered in section **??**. Some of these sections are limited in scope for brevity (traceability) or because the topic is a relatively newly investigated part of the project (clustering and to a lesser extent repository mining).

Literature was primarily found through searches of related keywords in Google scholar and DBLP, along with forwards and backwards citation analysis in addition to targeting specific conference proceedings. It is foreseen that the literature review for the PhD thesis will be significantly more detailed within the sections included in this report as well as containing a number of additional topics.

Chapter 3

Methodology

3.1 Overview

This chapter covers the work that has been completed to date. The description of the undertaken tasks will be included along the justification for the particular choise of the approach.

It will start by describing the initial developments on creating a forwards-engineered childbirth simulation. Further steps on improving the software system.

3.2 Forwards-engineered Childbirth Simulation

3.3 Simulation System Engineering

3.4 Finite Element Method based childbrith simulation

3.5 Parallel FEA Simulations Using GPU

Chapter 4

Future Work

This chapter outlines future work to be performed as part of the project, split into different areas of focus.

4.1 Experiments

The main target of this research is establishing all seven cardinal movements of human labour in a simulated environment without imposed trajectories. Purely physics based simulation is to be used to accomplish this, as opposed to the hybrid method described in the previous section.

Unfortunately we do not possess any quantitative data on the trajectory of fetal descent that can be used to meaningfully compare with the observed trajectory during our simulation.

4.1.1 Bony structures with a basic pelvic floor model

A scenario where the fetal skull is descending through the maternal pelvis with a simple pelvic floor model attached. This scenario is a potential starting point for simulation experiments. This experiment will be directed at validating the simulation system. The work presented in **?** !!! represents a very simillar scenario, although more simplified. We beleive that having a realistic skull model will improve fidelity of the observed experimental values.

4.2 Volumetric mesh generation

Mesh generation is designated as one of the higher priorty tasks to accomplish. Having acquired or generated high quality tetrahedral or hexahedral meshes is a crucial requirement in being able to perform the research experiments.

4.3 Improved contact model

Mesh generation is designated as one of the higher priorty tasks to accomplish. Having acquired or generated high quality tetrahedral or hexahedral meshes is a crucial requirement in being able to perform the research experiments.

Chapter 5

Proposed Thesis Structure

1. Introduction
2. Literature Review
   (a) Introduction
   (b) Reverse-engineered Simulators
   (c) Physics Based Simulators
   (d) Finite Element Analysis
   (e) Mechanical Contact Modeling
3. Methodology
   (a) Forward-engineered simulation of childbirth
   (b) Finite Element Method based simulation of childbirth
      i. Theoretical principles
      ii. Explicit Dynamic approaches
      iii. Total Lagrangian Dynamic Explicit FEM
   (c) Parallel implementation of FEM on GPU
      i. General Purpose Graphics Processing Units
   (d) Mechanical contact
4. Experiments and Results
   (a) Validation
      i. Comparison with other FEM packages
         A. Abaqus CAE
         B. NiftySim
   (b) Experiments
      i.
5. Conclusion

Bibliography

Chapter 6

Appendices

6.1 BirthView application screenshots