SDFSDFSDF

Bern University of Applied Sciences

UNIVERSITÄT BERN

Faculty of Medicine
Biomedical Engineering

Master of Science Thesis

3D Liver Reconstruction from Tracked Ultrasound

by

Luca Sahli

of Wohlen b. Bern, Switzerland

Supervisors
MSc Iwan Paolucci and Prof. Dr.-Ing. Stefan Weber

Institutions
ARTORG Center for Biomedical Engineering Research, University of Bern

Examiners
Prof. Dr.-Ing. Stefan Weber and MSc Iwan Paolucci

Bern, October 2018

Abstract

The abstract should provide a concise (300-400 word) summary of the motivation, methodology, main results and conclusions. For example:

Osteoporosis is a disease in which the density and quality of bone are reduced. As the bones become more porous and fragile, the risk of fracture is greatly increased. The loss of bone occurs progressively, often there are no symptoms until the first fracture occurs. Nowadays as many women are dying from osteoporosis as from breast cancer. Moreover it has been estimated that yearly costs arising from osteoporotic fractures alone in Europe worth 30 billion Euros.

Percutaneous vertebroplasty is the injection of bone cement into the vertebral body in order to relieve pain and stabilize fractured and/or osteoporotic vertebrae with immediate improvement of the symptoms. Treatment risks and complications include those related to needle placement, infection, bleeding and cement extravazation. The cement can leak into extraosseous tissues, including the epidural or paravertebral venous system eventually ending in pulmonary embolism and death.

The aim of this project was to develop a computational model to simulate the flow of two immiscible fluids through porous trabecular bone in order to predict the three-dimensional spreading patterns developing from the cement injection and minimize the risk of cement extravazation while maximizing the mechanical effect. The computational model estimates region specific porosity and anisotropic permeability from Hounsfield unit values obtained from patient-specific clinical computer tomography data sets. The creeping flow through the porous matrix is governed by a modified version of Darcy's Law, an empirical relation of the pressure gradient to the flow velocity with consideration of the complex rheological properties of bone cement.

To simulate the immiscible two phase fluid flow, i.e. the displacement of a biofluid by a biomaterial, a fluid interface tracking algorithm with mixed boundary representation has been developed. The nonlinear partial differential equation arising from the problem was numerically implemented into the open-source Finite Element framework *libMesh*. The algorithm design allows the incorporation of the developed methods into a larger simulation of vertebral bone augmentation for pre-surgical planning.

First simulation trials showed close agreement with the findings from relevant literature. The computational model demonstrated efficiency and numerical stability. The future model development may incorporate the morphology of the region specific trabecular bone structure improving the models' accuracy or the prediction of the orientation and alignment of fiber-reinforced bone cements in order to increase fracture-resistance.

Acknowledgements

Here you may include acknowledgements.

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche kenntlich gemacht. Mir ist bekannt, dass andernfalls der Senat gemäss dem Gesetz über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, October 31^{th} 2018

Luca Sahli

Contents

Chapter 1

Introduction

In this chapter hallo test

Generate Result (click "Generate" to refresh) Copy to clipboard

RCI 01 (R)	Yes	No, 2.2	3	7.3	4.6	18.5	3	11.1	9.8	25.6	6	7.8
RCI 02 (R)	Yes	No, 4.2	4	9.7	3.5	8.1	11	9.2	10.4	12.5	5, 8	10.2
RCI 03 (L)	Yes	No, 5.2	>4	7.6	4.7	6.1	13.2	8	11.5	21.7	5	9.3
RCI 04 (R)	Yes	No, 5.6	>4	8.7	3.2	13.8	4.7	2.4 (3.5)	11	24.1	5, 8	8.8
RCI 05 (R)	Yes	No, 2.7	>4	5.3	9.7	16.8	6.5	14.2	8	16.6	5, 6	11
RCI 06 (L)	Yes	No, 4.9	>4	7.2	4	11.7	8	7.4	11.1	16.5	5	9.6
RCI 07 (R)	Yes	No, 3.6	3 (-)	9.3	2.9	11.1	8	7.2	11	16.7	5, 8	8.6
RCI 08 (R)	Yes	No, 4.1	>4	6.2	6.8	12.5	9.6	10	8.4	13.6	5	8.3
09 (R)	Yes	No, 3.8	3 (-)	8.3	3.3	10.7	8.8	9.1	11.7	18.8	5, 8	8.8
TB15 F3 (L)	Yes	No, 3	>4	10.3	3.6	14.4	4.5	6	9.2	11.5	5,6,8,9	8.5
TB15 F5 (R)	Yes	No, 4.8	>4	9.6	4.8	12.9	7	7.6	9.4	18.3	5	8.7
TB15 F6 (R)	Yes	No, 4.3	>4	8.4	2.9	19	2.3	11.3	9.7	27.5	6	9.1
TB15 F13 (R)	Yes	No, 4.4	>4	4.7	8.7	10.1	12.5	7.6	3	4.8	5	8.5
TB15 F14 (L)	Yes	No, 3.2	>4	8.8	3.6	6.9	12.1	7	12.2	18.9	5, 8	7
TB15 F16 (R)	Yes	No, 3.1	>4	5.7	7.2	10	11.8	8.8	6.4	8.6	5	8.4
TB15 F17 (R)	Yes	No, 4.3	>4	7.7	4.4	7.9	11.5	8.6	11	15.5	5	8.8
TB15 T1 (L)	Yes	No, 4.2	4	6.8	7.5	14.7	7	11	8.3	6.7	5	8.8
TB15 T4 (R)	Yes	No, 5.1	>4	7.7	4.2	3.8	16.1	6	6.3	22.6	4, 5	9.5
TB15 T7 (R)	Yes	No, 4	>4	13.8	0*	0*	19.5	0*	17.8	35.6	In Tripod*	7.9
TB15 T8 (L)	Yes	No. 3,2	3	11	1.4	9	34.2	15.2	15.1	18	8	8.8

1.1 Motivation

1.2 The Liver

1.2.1 Liver Anatomy

1.2.2 Liver Cancer

1.3 Liver Resections

1.4 Objectives

Chapter 2

State of the art

2.1 Intraoperative ultrasound

Ultrasound imaging works by the *pulse-echo* principle. A short ultrasound-pulse is emitted from a transducer. Then the soundwaves get transmitted and reflected differently by different tissues. The reflected soundwaves travel back into the transducer and get converted into an electrical signal. After post-processing these signals become ultrasound images. Basically the ultrasound measures the mechanical properties of the tissue. The tissues have different acoustic impedance, which is the product of tissue density and ultrasound speed in travelling through the tissue. The resolution of the ultrasound images depends on the frequency of the ultrasound waves. High frequencies lead to high resolutions but low depth into the tissue because the absorption of the sound energy increases with frequency too. Therefore the useability to see deep structures is limited [10].

2.2 Navigation for liver resections

Navigation in liver surgeries is mostly done by registering the patient to a pre-operative 3D computer tomography (CT) scan of the liver during the surgery. All surgical instruments have trackable markers attached to them. A tracking camera sees these markers and can differentiate the different instruments from their attached markers. The achieved navigation accuracy was $4.5mm \pm 3.6mm$ averaged over nine surgeries [9]. Current research tries to compensate for deformations of the liver after the CT scan to the actual shape [7] [8].

2.2.1 Registration methods

Different registration methods exist. Discrete landmarks, surface scans and volumetric sonography scans are just a few of the approaches that can be used to achieve precise alignment of the preoperative image data with the surgical site [5].

2.2.2 Tracking modalities

To track (define the position and orientation in real time) surgical instruments and patient's anatomy during naviagated surgery a tracking system is needed. Tracking can be done by different technologies. The most used tracking modalities are optical or electromagnetic tracking.

Optical tracking

Optical tracking is the most used tracking modality in naviagated liver surgeries. Passive markers (spherical, retro-reflective that reflect infrared light) or active markers (infrared-emitting markers that are activated by an electrical signal) [11] are attached to the objects that need to be tracked. A tracking camera is then emitting infrared light by illuminators on the position sensor (only for passive markers). The position sensor determines the position and orientation of the tracked instruments based on the information it receives from those markers. [1]

Electromagnetic tracking

2.3 Surface reconstruction

2.4 Others

Chapter 3

Problem Statement

Chapter 4

Concept

4.1 System

4.2 Functionalities

4.2.1 Surface Reconstruction

4.2.2 Tumor Segmentation

(Automatic 3D)

4.2.3 Resection Planning

4.3 Workflow

4.3.1 Resection planning for non-anatomical ...

Chapter 5

Implementation

This chapter

5.1 Surface Reconstruction

5.1.1 Surface contact detection

5.1.2 Outlier removal

5.1.3 Reconstruction Parameters

grid search

5.2 Tumor Segmentation

graph cuts initialization method

5.3 Resection Planning

5.3.1 Cone fitting around tumor

5.4 Visualization for navigation

5.4.1 Ultrasound overlay

5.4.2 3D model

5.5 UI Concept

Chapter 6

Experiments

6.1 Surface Accuracy on a technical phantom

work presented in this section was presented at CURAC, Luca

6.1.1 Methodology

6.1.2 Results

6.1.3 Discussion

6.2 Surface reconstruction on retrospective data

6.2.1 Methodology

Retrospective data from Banz et. al

6.2.2 Results

6.2.3 Discussion

6.3 Usability Test

3 surgeons questionnaire surface accuracy (using surface registration)

6.3.1 Methodology

6.3.2 Results

6.3.3 Discussion

Chapter 7

Discussion and Conclusions

7.1 Discussion

Interpret your results in the context of past and current studies and literature on the same topic. Attempt to explain inconsistencies or contrasting opinion. Highlight the novelty of your work. Objectively discuss the limitations.

7.2 Conclusions

Formulate clear conclusions which are supported by your research results.

Chapter 8

Outlook

Provide a vision of possible future work to continue and extend your thesis research.

Bibliography

[1] Polaris Spectra and Vicra.

[2] D. Adalsteinsson and J. A. Sethian. A fast level set method for propagating interfaces. Journal of Computational Physics, 118(2):269–277, May 1995.

[3] R. Akhtar, S. Eichhorn, and P. Mummery. Microstructure-based finite element modelling and characterisation of bovine trabecular bone. Journal of Bionic Engineering, 3(1):3–9, Mar. 2006.

[4] E. Aulisa, S. Manservisi, R. Scardovelli, and S. Zaleski. Interface reconstruction with least-squares fit and split advection in three-dimensional cartesian geometry. Journal of Computational Physics, 225(2):2301–2319, Aug. 2007.

[5] V. M. Banz, P. C. Müller, P. Tinguely, D. Inderbitzin, D. Ribes, M. Peterhans, D. Candinas, and S. Weber. Intraoperative image-guided navigation system: development and applicability in 65 patients undergoing liver surgery. Langenbeck's archives of surgery, 401(4):495–502, 2016.

[6] G. Baroud. High-viscosity cement significantly enhances uniformity of cement filling in vertebroplasty: An experimental model and study on cement leakage., 2006.

[7] L. W. Clements, J. A. Collins, J. A. Weis, A. L. Simpson, T. P. Kingham, W. R. Jarnagin, and M. I. Miga. Deformation correction for image guided liver surgery: An intraoperative fidelity assessment. Surgery, 162(3):537–547, 2017.

[8] L. W. Clements, J. A. Collins, Y. Wu, A. L. Simpson, W. R. Jarnagin, and M. I. Miga. Validation of model-based deformation correction in image-guided liver surgery via tracked intraoperative ultrasound: preliminary method and results. In Medical Imaging 2015: Image-Guided Procedures, Robotic Interventions, and Modeling, volume 9415, page 94150T. International Society for Optics and Photonics, 2015.

[9] M. Peterhans, A. vom Berg, B. Dagon, D. Inderbitzin, C. Baur, D. Candinas, and S. Weber. A navigation system for open liver surgery: design, workflow and first clinical applications. The International Journal of Medical Robotics and Computer Assisted Surgery, 7(1):7–16, 2011.

[10] G. Torzilli. Ultrasound guided liver surgery. Springer, 2014.

[11] A. D. Wiles, D. G. Thompson, and D. D. Frantz. Accuracy assessment and interpretation for optical tracking systems. In Medical Imaging 2004: Visualization, Image-Guided Procedures, and Display, volume 5367, pages 421–433. International Society for Optics and Photonics, 2004.

etc.

Appendices

Appendix A

Vector and Tensor Mathematics

A.1 Introduction

...

A.2 Variable Types

...

Appendix B

Another Appendix

B.1 Section 1

...

B.2 Section 2

...