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MASTER THESIS

NONLINEAR MATERIAL PARAMETER IDENTIFICATION OF SOFT MATERIALS BASED ON AN INVERSE FINITE ELEMENT METHOD APPROACH

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Declaration of Authorship

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Aachen, 1st of January 3000

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1 Introduction

Precise knowledge about the biomechanical characterization of soft tissues has gained attention in medical research, e.g. medical image analysis and visualization. For many years, the obtained medical diagnosis have come from assumptions of experts or accumulated experience. This information although proven to be useful, has its limitations when computed-assisted systems like, medical diagnosis, therapy ,and training, rely on more quantificable data. (kauer 2002) To gather this data, it is important to gained access to the tissues and perform in-vivo testing experiments, where in cases of organs it is nearly impossible to achieve, because this would involve a very invasive procedure. Also in case of extraction some of the properties may change as in case of biomaterials. Their biomechanical properties also depends from other variables e.g., changes in blood presure. Furthermore, another encountered issue is the lack of samples, not only due to the lack of a tissue sample, but also because the time-dependent material properties. This will cause a change a in the material properties and analogically, an inaccurate result.

In the situation where the soft material's data can be gather in a constant, fast and realiable process, the data enables the system to predict the behaviour of soft tissues and give pre-operative calculations. Therefore, the material models represent a vital part for the computational models, as their help to increase the accuracy of the simulation and ist applications in other systems.

In soft materials analyses a non-linear situation is mostly encountered, for which a finite element method becomes a common approach. The application of the finite element method facilitates to analyze complex structures with complex material behaviour and aids in solving continuum mechanical problems. Nevertheless, in order to simulate a material with complexity requires complex algorithms with high computational costs. One of the goals of this study to identify the key parameters and their influence in a material model to approximate such a complex material and applied a simplified material model for medical research applications.

With the application of the experiment testing ,and the finite element method is possible to identify some key parameters through an inverse finite element method approach. With this method a framework can be established and the results of computaional model can be matched to the experimental data, and be validated with other experiments.

1.1 State of the art

1.1.1 Experimental techniques for soft materials

Uniaxial testing

This method allows the validation of several computational models as it provides with searched parameters done with other experimental procedure

Aspiration experiment

Tissue aspiration experiments introduces an aspiration tube which is put against the soft tissue, generating a vacuum. With the help of a mirror placed next to aspiration hole, the reflection of the side-view of the tissue can be captured with a video camera. This camera captures the images of the iluminated surface of the material and the aspiration pressure is captured through a sensor. Through this process the captured profile of the tissue is obtained and this can be used to characterize the deformation and analyze the viscoelastic properties of the soft tissue. (kauer 2002)

Indentation

Indentation have being gaining popularity in the last decades and it is now one of the most spread experiments for material parameter identification.

As some materials do not allow the use of uniaxial or biaxial tensile testing, the use of identation testing is essential for this case.

-identation in materials - Identation in soft materials (organs) - Why is identation relevant in organs -what advantages and disadvantges does identation provides - why is relevant for this project

1.1.2 Material Modeling of Soft Tissues

1.1.3 Inverse Finite Element Method for Parameter Identification

An inverse finite element (FE) approach requires usually a certain experimental model, which generates certain information e. g. load-displacement curve, and through a verified computational model match the given data curve to obtain further information of the material's behavior e. g., stress-strain curve.

Specially for nonlinear cases (husain2004), where the complexity of the problems increases, and the interest is focused to generate an action which results in a certain output response, is where an inverse finite element approach can be helpful to discover a certain variable going from an ouput data. Through an iterative process it is possible to describe the material's behavior and validate the output data it through other established testing e. g., uniaxial testing.

Though this approach does not always give a hundred percent match in all obtain points or zones, it allows the researcher to understand the influences of certain parameters for the materials. This is specially useful for complex materials as biomaterials.

Biomaterials, as mentioned previously, depends on multiple external factors, e.g., blood pressure, affected diseases and the their material properties is constantly changing. This issue does not allow the researcher to develop a proper material model which is usable for multiple use-cases.

Therefore, the importance of the inverse element method as relevant key for estimating constantly changing parameters in soft materials.

For biomechanical models, where the models require knowledge from local properties (chai 2013), as the biomaterial is not isotropic; it is possible to identify a parameter e.g. Young's Modulus from a 3D model. The model can be matched to multiple experiments and multiple samples in different areas, which allows a better representation of the material for further analysis.

The inverse FE approach can used by optimizing the searched parameter by matching the simulated data to a section of a experimental curve and extending this process through some iterations. Nevertheless, it is important to clarify that this method also requires making assumptions to some values. Furthermore, it is relevant to document these assumptions for the further analysis. With the combination of assumptions, experimental data, and a optimized and matched simulation curve, it is possible to solve the complexity of biomechanical models.

In next sections some of the experimental models and the material models for bio and soft materials are going to be explained to get a further understanding in how is possible to get a realiable computational model for further reasearch

Synthetic soft materials

Synthetics materials are commonly used to validate an inverse parameter identification process. Usually these synthetic, soft materials provide similar mechanical behaviour to it's biomaterials counterparts. This characterization allows to validate a proposed inverse finite element approach process before its applicatoin with a biomaterial, where the measurements to gather the experimental data are some in-vivo, and more challenging to recreate.

For example, Silgel, a very soft gel-like material (M. Kauer, 2002) was used for the experimental validation of the inverse method proposed to characterized the tissue of of a human uteri. In this work, the tensile behaviour of the material was predicted through the parameters obtained in the aspiration method.

Biomaterials

1.1.4 Standard Verification and Validation for computational solid mechanics (ASME)

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2 Inverse Finite Element Method for Material Parameter Identification

2.1 Experimental model

The chosen experimental technique was indentation. In Fig.. the ellipsoidal specimen with the a first radius r_1 of 30 mm and a second radius r_2 of 60 mm is positioned in a rest status(?) on a fixed platform that suits the ellipsoidal geometry of the specimen. A metal pin with a rounded head with a radius r_3 3 mm is attached by the holding grips followed by a force load cell. The measured force data showed a very small number, so the first 50 N load cell displayed a lot of noise in the measured data. Therefore, the load cell was change to 10N to reduce this interference. The 10 N load cell displayed the initial contact between the indenter and the specimen in a finer way. In order to get the measurement of the load and unloading process of the indentation a displacement sensor was attached to the tensile machine

2.2 Material model framework assumptions

2.3 Computational model

The quasi static nature of the indentation experiment allows the use of a static structural analysis.

Their a two main factors which increases the complexity of the validation of the simulation and those are, the contact nonlinearity, and the element distortion due to indentation experiment. These issues make the computational time expensive, as it requires to manual solutions for the meshing in the area of importance, and small time steps.

A force-displacement curve, shown in Fig... is generated from the first assumption, for this case

For both cases

2.4 Material model

In an ideal and first scenario, this material can be assumed as linear, isotropic, elastic and nearly imcompressible. For this case, there are two main variables, the Young's Modulus E, and the Poisson's ratio ν.

A Frequently Asked Questions

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

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