Investigating and Mechanically Modelling the Material Properties of Biological Tissues Forming the Vertebral Column

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Introduction

At Technical University Ilmenau a research team funded by the state of Thuringa, is developing a **P**eristaltically **A**ctuated **De**vice for **M**inimal **I**nvasive **S**urgery (PADeMIS). The primary application of the device is the minimal invasive spine surgical treatment of herniated discs. Thus, the project is in co-operation with the department of spine surgery at Rhönklinikum Bad Berka.

The surgery will be performed in an open MR for monitoring, navigation and safety reasons. The device is travelling by peristaltic means like an earthworm, is entering the spinal canal at the os sacrum and is progressing cranially between the vertebral body and the dura mater spinalis. Due to the irregular sized pathway (diameter ranging from 4mm to 15 mm) and the radiated magnetic field the device is entirely going to be made of liquid rubber silicone, a material that is flexible, hyper elastic and permitted for medical use. The active part of PADeMIS is a hollow silicon cylinder. At regular intervals, fluid chambers are integrated in the shell of the silicon cylinder. Changing the pressure in theses chambers in an cyclical fashion the chambers deform periodically and produce a peristaltic wave on the outer surface. The device is dragging a hollow pipe linking it to the outside of the patient. Through the pipe, the surgeon is able to enter endoscopic tools reaching to the place of surgery.

The project PADeMIS is divided into five subprojects:

- Characteristics of the spinal canal
- Simulating the deformation of the silicon cylinder and strains of the silicon via FEM
- Locomotion and Control
- Manufacturing Technology
- Haptics

This paper is representing investigations of the spinal canal and portrays a principle of measuring mechanical parameters of biological tissue through Modal Analysis. Prospectively, this principle will be used for further tissue examination in the spinal canal. In the future, it may be utilized for diagnostic applications or haptic feedback.

The spinal canal

In the vertebral column the space between dura mater spinalis and vertebral body is called epidural space. PADeMIS is travelling along the dura inside the epidural space, which is filled with ligaments, fat tissue and a plexus venosus internus, which provide the drainage for the individual vertebrae. Therefore, the ability of movement in the epidural space is limited by size constraints and resistance. In order to compel these constrictions, the force required to set the device in motion is examined. At this research stage, experiments were carried out on just deceased pigs.

Haptic

In open surgery *fingering* is one essential tool of the surgeon for identification and manipulation of anatomical structures. In minimal invasive surgery for the purpose of diagnosis and orientation only endoscopes may provide limited information in terms of vision. The surgeon loses his tactile feedback and manipulative freedom that he gained by direct contact with the tissue in open surgery.

In order to compensate this ability the consistency of the tissue around the place of surgery or the position of the endoscopic tool must be identified.

Therefore, the intermediate aim of this subproject is the development of a method that acquires the mechanical properties and arrangement of biological tissue layers. The apparatus contacts the accessible top tissue layer and shall retrieve mechanical parameters of more layers underneath. I.e. cartilage can be identified underneath fat tissue and other tissue layers.

The method may be used for diagnosis during the surgical treatment, tactile feedback with an instrument stimulating the tactile senses in the surgeon’s finger tip and other applications.

The long term goal is the miniaturisation of the apparatus and integration into PADeMIS.

Measuring principle

Currently, a variety of techniques determining experimentally material properties of biological tissues are in practise or are arising. Most of these techniques involve some disadvantages: for example tension tests can only be applied in vivo or wave propagation measurements producing only global bulk properties.

In this work, a method applying Modal Analysis is observed. Modal analysis is a process, whereby the structure examined is described in terms of its natural dynamical characteristics (modal parameters), which are its natural frequencies, damping and mode shapes. A force that varies in a sinusoidal fashion and alternating frequency is applied to the tissue structure and recorded. Also, the response of the tissue structure is measured by an array of accelerometers. It can be observed, that the amplitude of the response changes depending on the rate of oscillation of the input force. The response amplifies when the input force oscillates at a frequency that approaches one of the natural frequencies of the tissue structure and is reaching its maximum at resonance frequency.

For analysis, the input and the response signals are transformed into the frequency domain by applying Fast Fourier Transformation and the frequency response function is computed.

Technically, the biological tissue may be modelled as a Multi Degree of Freedom System conveying as many natural frequencies as Degrees of Freedom and delivering the same number of modes. The technical model exists of masses, which are spread out in a three-dimensional grid and dynamically coupled by springs and dampers. When the modal parameters are obtained it should be possible to determine the values of the spring constants and damping values of each link. These results reveal the local mechanical properties such as elasticity and viscosity that altering throughout one tissue and amongst different types of tissue. Also, the boundary between two neighbouring tissues should be recognized.