SMART RETRACTOR FOR USE IN IMAGE GUIDED NEUROSURGERY

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INTRODUCTION

During brain surgery, a key challenge is ensuring removal of only the tumor tissue while the healthy tissue remains intact. Over the past decade, improvements in the areas of surgical visualization and surgical navigation have been made. Additionally, the development of intra-operative magnetic resonance image-guided surgery has improved the situation for tumor resections; however it has also highlighted the problem of brain shift, or brain shape deformations, that occurs during surgery [1]. An intra-operative non-rigid registration algorithm to predict the location and deformation of the brain during neurosurgery has been developed [2]. Application of this algorithm to pre-operative images that can not be acquired intra-operatively should enable accurate surgical guidance with these images. A brain retractor has been adapted so that it can measure the force it applies to the brain. With this information, we will attempt to validate and optimize the biomechanical model.

BIOMECHANICAL MODEL

The biomechanical model [2] employs a surface matching technique to calculate the deformation field within the brain, thereby estimating the location of the tumor over the course of the surgery as the brain changes shape. The main causes of deformation include shifts in the direction of gravity, the loss of cerebral spinal fluid, resection and retraction of brain tumor tissue by the surgeon, and swelling or shrinking caused by various anesthetic agents and drugs administered intra-operatively [3]. Prediction of these deformations and integration with a neuronavigation system, should allow the pre-operative images to accurately guide the surgery. The surfaces of the pre-operative images and most recent intra-operative images are sequentially matched. The algorithm for the biomechanical model assumes a linear elastic, isotropic material, and uses values based on in-vivo experiments of swine brain tissue [4]. The intraoperative three-dimensional volumetric images of the whole brain are acquired as required by the neurosurgeon, often up to five times during the surgery.

BRAIN RETRACTOR

In order to validate the biomechanical model, a ‘smart’ retractor has been developed. A brain retractor is typically used as an extra set of hands for the neurosurgeon during surgery. It is clamped to the table using a Bookwalter™ arm which initially allows the surgeon to set the retractor in any location and then can be tightened in place.

Integration of Sensors

Four force sensors have been laid out along the retractor about 8mm apart, center to center, such that a distributed load across the surface can be measured. These sensors, called Flexiforce® sensors (Tekscan, Boston, Ma), are constructed of two layers of substrate, such as a polyester film. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. The active sensing area is defined by the silver circle on top of the pressure-sensitive ink. The sensor is 9.54mm in diameter, 0.13mm thick, 20 cm in length and 12.7mm in width. Figure 1 shows that the retractor is a flat semi-rigid metal that can be bent at any location based on the desired depth required to hold the tissue in place. It is vital that the sensors are fairly flat as they must not introduce inadvertent pressure points on the brain.

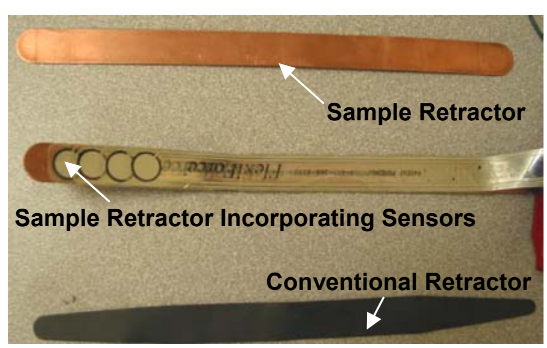

Figure 1. Brain Retractors

Design of Electronics and Instrumentation

One functional requirement of the design is that the instrument and circuit must be operable in the magnetic field created by the MRI scanner and the materials used must be MRI-compatible and RF shielded so as not to degrade the image quality by introducing geometrical artifact and noise or artifact into the system. The circuit was built on a breadboard and enclosed in a box. From the box, connectors routed cabling to 1) the retractor, 2) the power supply and 3) the data acquisition system (DAQ). The retractor and circuit were placed inside the MR room, and cables were run through the door out to the DAQ system and power supplies. Low pass filters in the cables prevented electromagnetic interference. A schematic for the system is shown below in Figure 2.

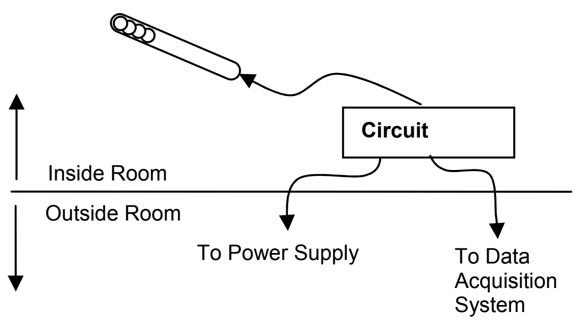

Figure 2. Schematic for Retractor/Instrument System

The sensors act as simple variable resistors which operate at 20MΩ at no load and 5kΩ at full load. The advertised force of the sensors range from 0-1lbs (0-0.45kg), which is sufficient for the small forces we are measuring. The circuit is a simple inverting amplifier circuit that takes the output of the sensor signals and amplifies them to a gain of roughly 10. This output signal is then routed to a National Instruments™ Data Acquisition Card running LabView™ software.

Characterization of the Sensors

The force sensors on the retractor were calibrated using known loads. A series of tests to understand the how the sensor reacts to various loading was performed. It was found that the sensor reading is independent of position of contact within the sensor area, however, when the size of the load was greater than the size of the sensor measurement accuracy decreased. This is due to the fact that some amount of surface roughness is necessary to activate the sensor. The problem was ameliorated by placing a soft landing pad behind each sensor to raise it slightly out of plane (approximately 2mm), which enabled the sensors to contact the specimen. The calibration of the sensors was found to be .18 kg/V.

EXPERIMENTAL APPARATUS

The design verification tests were performed on a gelatin phantom. The phantom was used to simulate the soft tissue properties of the brain. The experiments performed involved measuring the force at sequential displacements within the MRI scanner while capturing an image at each displacement. The phantom used for this experiment had an array of 3mm glass beads imbedded in a grid-like fashion so that they can be seen in the MR images.

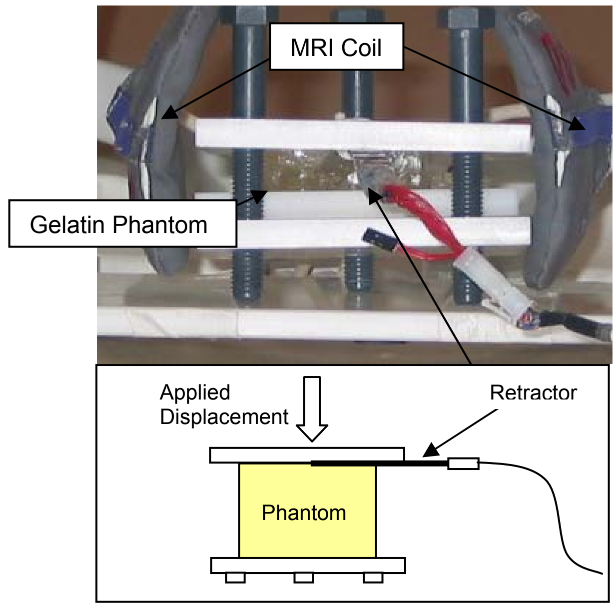

Figure 3. Retractor measuring force applied to gelatin phantom in MRI scanner

RESULTS

The initial testing of the retractor against the phantom showed that for a single displacement of 20mm, the largest force measured by a single sensor was 0.10 kg. This was done using a slightly raised sensor, as it was discovered that the results were much more repeatable and reliable when raising the sensor. The images acquired during this displacement step are shown in Figure 4.

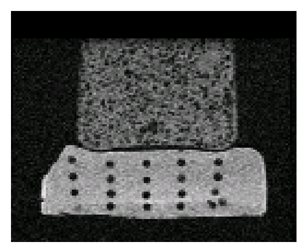

Figure 4. MR Images of deformed gelatin phantom

CONCLUSION

Initial testing has found that the design of a retractor incorporating force sensors is feasible. The retractor will be used in animal models for image-guided neurosurgery as a validation tool for an intraoperative biomechanical model to predict brain shift. Future work includes correlating the forces measured with those calculated by the biomechanical model. Additionally, further characterization of the sensors to understand the effects of surface contour on force measurements will be investigated.

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