Lung Indentation and in-situ Imaging

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Abstract
The object of this design project is to incorporate an optical coherence tomography (OCT) camera and a mechanical bio-indenter into a single system. As the OCT to be placed in series with the indenter weighs several hundred grams and the forces of interest to measure are of single grams, the main challenge in this design is determining a method to move the relatively heavy system with the small indentation force. After examining several ways to design a system capable of this, it was found that a magnetic suspension system, on which the indenter is horizontally loaded, would best accomplish the goals of the project. Theoretically the magnetic suspension system has no friction and is easily tunable. In this way, the OCT-indenter system could be moved with sufficiently low force. The final system will be a 7.20 in x 4.75 in x 2.0 in ABS plastic cart that is suspended from a 430 stainless steel plate. There are a total five electromagnets, each with their own corresponding distance sensor, and two permanent magnets on the cart. The distance sensors are paired with electromagnets in order to regulate the air gap between the cart and the steel plate. Three of the electromagnets will be placed on the top surface of the cart in order to counteract gravity and maintain a desired air gap. The remaining magnets will be placed on the sides where they will interact with additional stainless steel plates to maintain lateral stability.

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The Need for Project

In order to determine the mechanical properties of alveoli in lungs it is necessary to combine an OCT camera with a mechanical bio-indenter.

The lab sponsoring this project indents lungs in order to determine local mechanical properties of alveoli. When sufficient compressive or shear force is applied to the lung surface, the alveoli collapse. When the force is removed the alveoli can re-open or remain collapsed, depending on their interaction with the environment. The lab currently performs their experiments with two separate tests. In one, the lung is indented and visualized with an OCT camera to image alveoli during deformation. The second test gathers force and displacement data during lung indentation. These two tests cannot be directly correlated, as they are performed at different times currently. The goal for this project is to combine these two tests into a single system that allows the lab to simultaneously collect data.

The Design Project Objectives and Requirements

The main design objective is to move a relatively heavy system with a small indentation force.

Design Objectives

The goal of this project is to incorporate an OCT camera and a mechanical bio-indenter into a single system. As the OCT camera weighs 195 g and the forces of interest are in the range of 1-18 gram-force, the main design objective of this project is to move the relatively heavy system with the small indentation force.

Design Requirements

The final system design must be able to move the OCT camera and holder system, which weighs several hundred grams with 1-18 grams of force. The system will have a lateral resolution of 100 µm and a displacement resolution of 10 µm.

Design Concepts Considered

A number of low friction linear rails were considered and rejected as the force...
required to move them was outside of the desired range. materials is that the coefficient of friction (0.04 kinetic at the lowest) is too great for this project’s application, also removing solid Teflon from consideration.

Next, linear bearing rails where considered. These rails are off the shelf solutions from companies such as Thomson Linear Motion. The best rail offered had a coefficient of friction of 0.003. However, these rails had to be preloaded properly to work, generating 17 grams of friction force. This is unacceptable as it is a significantly higher than the indentation force.

The next system design that was considered was an air rail. Like air hockey table, these rails rely on air flow to lift a cart. There is no friction in these systems as there is no physical contact. After a prototype was developed it was determined that significant optimization would be required for any stability. The off the shelf version of this system, such as the one from Nelson Air Corp. costs upwards of $5,000, which is far above the budget for this project.

Recommended Design Concept

For our recommended design, we are suspending a cart which holds the OCT camera below a stainless steel plate. The cart uses a system of electromagnets and distance sensor to counteract the force of gravity, effectively floating without friction.

Design Description

This problem requires a frictionless linear rail system due to the relatively low forces applied at a low actuation speed. Several rail types were considered before moving forward with magnetic suspension. With magnetic suspension, a combination of permanent magnets and electromagnets allows the cart holding the OCT to hang below a steel surface. These electromagnets in conjunction with distance sensors can be regulated to suspend the cart a set distance from the stainless steel surface. Simply put, the electromagnets are counteracting
the force of gravity. Horizontal motion will also be controlled using permanent magnets and electromagnets on opposite sides of the cart interacting with vertical stainless steel walls.

The cart will travel through a u-channel consisting of 430 stainless steel attractive surfaces and a wooden support structure. Four 1/16” stainless steel sheets are stacked to form 0.25” thickness on the top and side surfaces for accurate electromagnet response. Supporting the steel sheets are 2x4s with adjustable feet for leveling the surface perpendicular to gravity.

The cart design has three electromagnets on the top surface located to create a plane parallel to the stainless steel surface. A distance sensor attached next to each electromagnet relays position to the Arduino board to regulate electromagnet strength. Each electromagnet has a 25 lb holding force at contact when fully powered by the Arduino. The Arduino code reads the output from the distance sensors signals the electromagnet to vary the strength of the electromagnetic field. In this way the three electromagnets on the top of the cart have the necessary strength to counteract gravity and suspend the cart at a desired distance from the stainless steel sheet.

On one side of the cart are two electromagnets controlling horizontal motion. These electromagnets are regulated in the same way as the three on the top of the cart with their own distance sensors. To deal with the lack of gravity in the horizontal direction are permanent magnets, which provides a force simulating gravity. The electromagnets will be regulated to counteract the permanent magnets and maintain lateral stability.

The cart is a 3D printed ABS part containing threaded
inserts for the attachment of the electromagnets and distance sensors. Sections were strategically removed from the cart for weight reduction. 3D printed ABS spacers are used to position the distance sensors 1mm below the top of the electromagnets. This puts the inductive distance sensors within their output range of 1 to 4 mm. Spacers are also used on the side of the cart for the same purpose. It was determined through testing that mu-metal shielding would not be necessary for the protection of the OCT camera.

The OCT camera will be held against the bottom of the cart using a bracket, so that the indenting lens of the camera extends past the front of the cart. The bracket is a three piece 3D printed part, the central piece of which is a flat surface that the OCT camera rests on with vertical posts to limit sliding along the width of the part. The sides of the bracket are adjustable vertically on the cart to clamp the OCT in place.

**Analytical Investigations**

The appropriate design envelope and material selection was accomplished using magnetic force calculations and free body diagrams, to offset the cart weight with a reasonable safety factor. Computational software was used to predict magnetic field strengths and flux penetration. Further analysis was performed using Arduino coding through logic controllers and PID to maintain reasonable reactivity to changes in cart separation from the stainless steel surface.

**Experimental Investigations**

Two key experimental investigations involved device survival and functionality. In the first, the group performed several tests with different amounts of protective mu-metal to determine the extent of magnetic fields on the electronic components of the OCT, and their effect. B-field strength was
measured via gauss meters, with different thicknesses of mu-metal. Effects on electronics were determined via test pieces provided by ThorLabs (OCT manufacturer), at their request. B-fields were determined to have a negligible effect on OCT operation.

**Key Advantages of Recommended Concept**

The key advantages of this concept are functionality (zero friction) and flexibility. Once design specs and solutions are determined for this indenter system, they can be scaled for different sizes and loads, making them useful for other contact equipment in tandem with imaging systems.

**Financial Issues**

The cost of the prototype of this system is expected to come in at under $1,750 with additional cost from prior scrapped designs. Developing a prototype for this project is reasonably inexpensive. It is expected that this project will come in under $1,750 in total expenditures. The main associated costs include the five electromagnets, 3 motor drivers, and the steel sheets necessary for attractions, with the largest cost attributed to the high precision Balluff distance sensor. Upon further analysis, the less expensive sensors were empirically proven to be inadequate, and therefore were scrapped costs.

**Recommended Improvements**

This system could potentially be modified to support the suspension of different weights. A possible future direction would be to allow for different distributions of weight on the cart, for which it was not explicitly designed.