Capsules Navigated and Heated by MRI for Localized Drug Delivery

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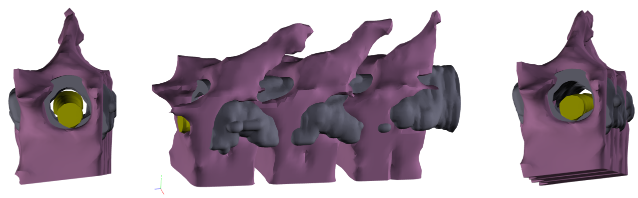

Fig. 1. Processed MRI scan of the spine of a healthy 31-year-old male. Shown are three vertebrae (pink), connective tissue (grey), and the spinal cord (yellow). The gap around the spinal cord is filled with CSF.

***Abstract*— This paper presents a controllable drug delivery vehicle powered, imaged, and controlled by a a medical Magnetic Resonance Imaging (MRI) scanner. An MR scanner can power, image, and control small capsules containing ferrous material. A tuned coil antenna can be used to heat the capsule. This paper presents designs for imaging, control ,and optimizing heating. Experiments on capsule control and localized heating demonstrate the viability of this technique.**

I. Introduction

Robots can be powered, imaged, and controlled using Magnetic Resonance Imaging (MRI) scanners [**?**], [**?**], [**?**].

Goal is to use these capsules to deliver drugs at targeted locations. Current clinical MR scanners have low gradient strength, which dictates that capsules should be deployed in liquid-filled body regions with little to no flow. The cerebrospinal fluid (CSF) in the spinal canal and brain ventricles is a reasonable target.

[[here are some clinical needs and procedures done in csf space]]

[[csf space is convoluted, but the spinal canal is wide enough that a 2mm capsule can be navigated through]]

[[Current techniques that rely on surgery or on endoscopes are risky – it would be better to use a wireless/tetherless capsule]]

II. Related Work

A. Clinical Forces

B. Capsule Navigation

moving capsules [**?**]

controlling multiple capsules with MRI [**?**]

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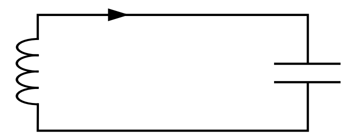

Fig. 2. A series LC circuit.

III. Theory

A. Heating model

B. Gradient coils unable to heat

C. Coil design

A series LC circuit, with inductance L and capacitance C is characterized by its resonant frequency f_0:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

The *Q-factor* is the ratio of peak energy stored in the circuit over average energy dissipated in it per radian at renounce. A high Q circuit is underdamped and resonants well.

$$Q = \frac{1}{2\pi f_0 RC} = \frac{2\pi f L}{R} \tag{2}$$

The unit less damping factor ζ is given by

$$Q = \frac{1}{2\pi f_0 RC} = \frac{2\pi f L}{R} \tag{3}$$

A wide range of capacitors can be purchased inexpensively and come in surface-mount configurations (1.6 mm×0.8 mm Jameco 603 ASSORTMENT).

Inductors can be formed by coiling coated copper wire. An approximate formula for inductance for a long cylindrical air-core coil is

$$L \approx \frac{1}{\ell}\mu_0 K N^2 A \tag{4}$$

for L in henries, μ_0 the permeability of free space ($4\pi \times 10^{-7}$ H/m), ℓ the length of coil (m), K a coefficient which approaches 1 if coil is much longer than diameter [**?**], [**?**], [**?**], [**?**], [**?**], N the number of turns, and A the cross sectional area of the coil (m^2). An approximate formula for inductance for a short cylindrical air-core coil is

$$L \approx \frac{25400 r^2 N^2}{9r + 10\ell} \tag{5}$$

for L in henries, r the outer radius of the coil (m), ℓ the length of the coil (m), and N the number of turns [**?**], [**?**].

IV. Design

V. Experiment