MR Endoscope with Software-Controlled Tuning, Device Tracking and Video

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Introduction

We developed a combined optical and MR-capable endoscope with spatial tracking capability. This novel device provides the ability to view spatially registered optical and MR images of the tissue under examination in real time, as well as to obtain spatially registered MR scans of the surrounding anatomy, yielding a more sensitive and accurate diagnosis. The combined optical and MR capability enables conventional visual detection of potentially cancerous lesions in body cavities such as the respiratory, GI and reproductive tracts, but adds the ability to “see” into the lesion or beyond the cavity wall to determine if invasion of surrounding tissue has occurred. The tracking capability enables the MRI scanner’s field of view to follow the tip of the endoscope in real time, or mark its instantaneous position on the MR and optical images. The device includes a collapsible RF coil, means to tune it to the scanner operating frequency under constantly changing conditions of positioning, bodily motion and dimensional adjustment, an intralumenal RF preamplifier, means to electronically detune the coil during transmit pulses, an electronic interface to the scanner and to a remote computer for managing the tuning, a light source, a miniature video camera, and a tip steering mechanism (Figures 1 and 2). In this report we examine the MR performance of the endoscope and characteristics of the coil tuning algorithm.

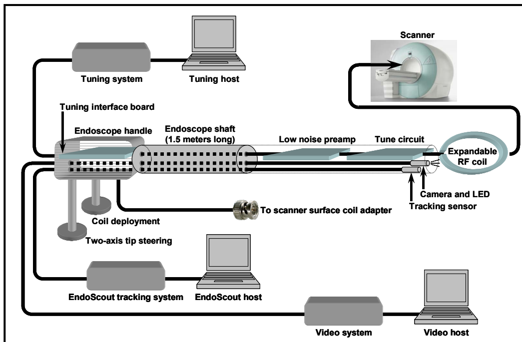

Figure 1. Block diagram of the endoscope system.

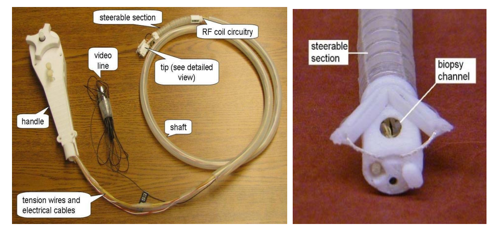

Figure 2. Endoscope photos.

Materials and Methods

Tuning and preamplifier circuits were fabricated on circuit boards 4 mm wide to fit within the 12 mm outside diameter of the endoscope, leaving room for video, LED and tensioning cables, and passages for water and air. Coil tuning and matching is accomplished with a pair of NTE-618 high capacitance varactor diodes biased by voltages from a USB-connected Data Translation DT9806 data acquisition system. The preamp used an Avago MGA-62563 low noise pHEMT GaAs MMIC. An interface circuit in the endoscope handle connects to the surface coil adapter of the Siemens Avanto 1.5 T scanner. The interface routes PIN diode pulse emitted by the scanner around the preamp to a Microsemi UM9401B PIN diode on the tuning board, and routes the preamp output into the scanner surface coil adapter. Manual tuning of the endoscope coil is accomplished by adjusting the varactor bias voltages with sliders in a GUI developed in Microsoft C# Express. To provide the capability for continuously optimized automated tuning as the RF coil is repositioned, resized or affected by physiological motion, we employed the Nelder-Mead simplex algorithm to find and continuously maintain optimum tune and match conditions, using reflected RF power (lab bench) or transmit pulse pickup (scanner) as the cost function. The standard simplex algorithm assumes that functions being optimized are stationary. However the optimum tune and match capacitances vary at unpredictable times as external factors randomly impact the coil, requiring the algorithm to continually seek new optima. The algorithm was therefore augmented by imposing a lower bound on simplex size to prevent tight convergence, preserving the ability to find a new optimum in a reasonable number of steps. A simplex size upper bound was imposed to prevent wild jumps that could take the system to the boundaries of the tuning space, possibly becoming trapped in false optima.

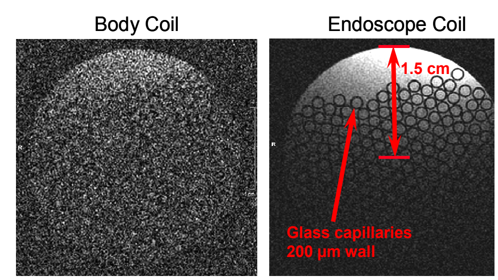

Figure 3. Comparison of body and endoscope coil+preamp reception.

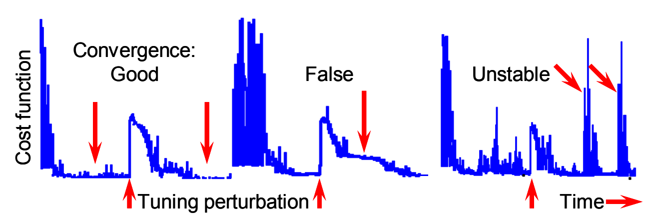

Figure 4. Possible convergence regimes during simplex automated tuning by reflected power.

Results and Discussion

The endoscope coil exhibited a near-field SNR 47x the body coil, achieving 130 μm spatial resolution with usable image quality up to 1.5 cm from the coil in a 3-minute GE scan (Figure 3). In Monte Carlo trials of tuning convergence from given initial conditions or recovery from a tuning perturbation, a narrow range of simplex upper and lower bounds led to good convergence of the tuning algorithm, avoiding either false convergence or gross instability (Figure 4).

Conclusions

Although significant work remains to achieve full functioning of all system components, the feasibility of a deployable coil MR endoscope with automated remote tuning was established.