Excite by light: A novel MR-safe method of catheter tip tracking

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Introduction

Tracking of catheters and other devices within the human body during an MRI-guided intervention can be achieved with active or passive techniques. Passive methods are time-consuming, suffer from insufficient contrast and signal ambiguities. The very effective active techniques, however, often use long electrically conducting elements that can lead to potentially dangerous resonant RF heating. To avoid this hazards, optical connections have been proposed, e.g. to detune an inductively coupled tracking coil [1]. Another approach utilizes a fully optical localization technique by sensing the gradient fields with the Faraday effect [2].
In this work we combine an MR-safe optical technology with local RF excitation. Therefore, RF-modulated light is converted into an RF current in a small transmit coil at the catheter tip, and the generated MR signal is read out with conventional MR imaging coils.

Materials and Methods

A prototype optical transmit system was built (Fig. 1) that consisted of a small pick-up coil at the proximal end of a RF-modulated light source, a plastic fibre for RF signal transmission, and a distal optically driven transmit coil (catheter tip). At the proximal end the transmit RF signal of the MR system (here: the body coil) was received with a pick-up coil and converted into modulated red light using a laser diode (5 mW, λ = 640 nm). A distal pick-up coil rather than a direct RF coupling through the system's coil plugs was chosen because the MR system did not allow the setup of a local transmit coil with existing commercial receive coils. To optimize suppression of the surrounding MR signal due to unwanted RF excitation with the body coil, a very high gain at the distal amplifier was used. The modulated light was guided via a plastic optical fibre (length: 1.2 m, Ø = 1 mm) to a photodiode (Infineon SFH203P) at the distal end. The diode converted the light back into an RF current which was then used to drive a small resonant circuit tuned to the ^{1}H resonance frequency of the MR system. To provide an MR signal, the interior of the RF coil was filled with a small liquid reservoir.
This optical transmit system was tested at a clinical 1.5 T whole body MR system (Magnetom Symphony, Siemens, Erlangen, Germany) using a single element of the standard spine array coil for signal reception. Images of the reservoir were acquired with a non-selective 3D-FLASH pulse sequence (TR = 9.6 ms, TE = 4.2 ms, BW =180 Hz/px, resolution 0.5x0.5x1.5 mm^3, matrix 512x160, slice thickness =1.5 mm, 16 slices, acquisition time =25 s). To calibrate the system and to assess possible non-linearity effects in the photodiode, two series of images were acquired with different transmit flip angles: in one experiment, the transmit voltage of the body coil was varied between 1 V and 100 V at constant duration (100 µs) of the rectangular transmit pulse, and in a second series the duration of the pulse was varied between 20 µs and 1600 µs at a constant transmit voltage of 6 V.

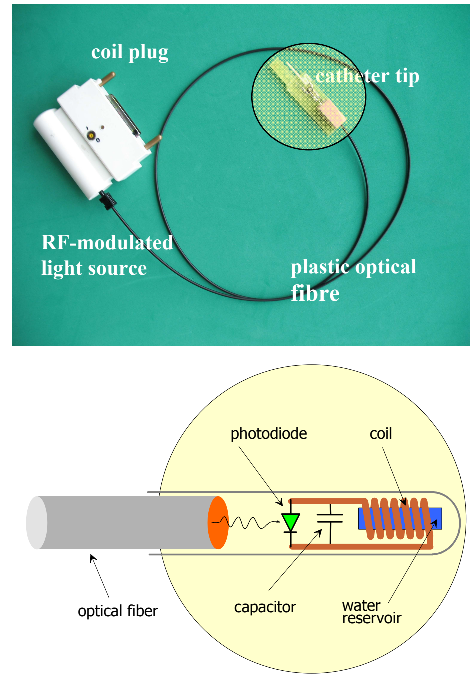

Fig.1: Modulated light is converted into RF current which generates local B_1 field at the tip of a catheter

Results and Discussion

The signal at the catheter tip closely follows the FLASH signal curve for both constant voltage and constant pulse duration (Fig. 2). This result indicates that signal non-linearities, which are expected at high body coil voltages, are minor in the given parameter range. Comparison of the signal at the catheter tip with the signal from a nearby phantom bottle shows the very low flip angle applied during RF excitation with the body coil, so that the catheter tip can be effectively visualized against a dark signal background.
With the current setup the generated MR signal is received with distal RF coils also used for MR imaging. To optimize the SNR at the catheter tip, the signal at the tracking coil should be detected with the tracking coil itself, which will be implemented in future refinements of the setup. Nevertheless, even these preliminary results show that optically driven RF excitation is a possible technology to built RF-safe MR catheters.

References

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[2] Bock M, Umathum R, et al. Phys Med Biol 2006, 51(4):999-1009.

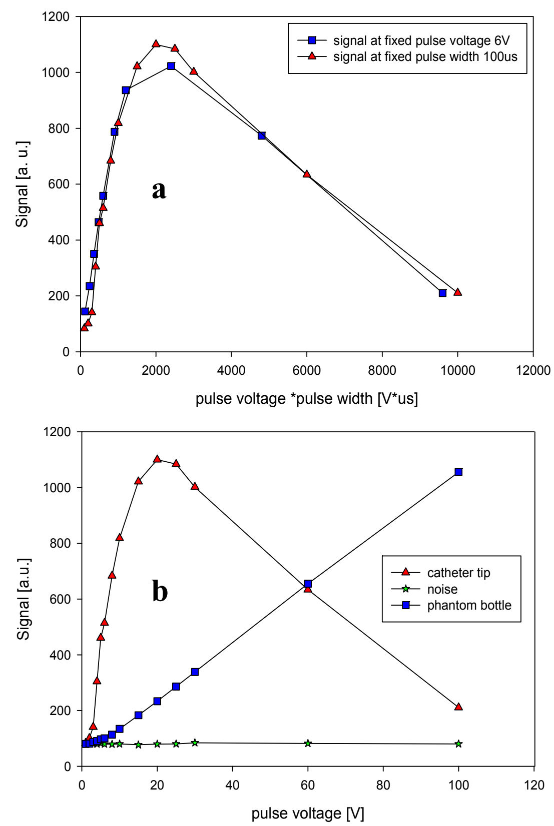

Fig.2a): Signal at the catheter tip as function of the pulse voltage times the pulse width (effective flip angle) for both fixed pulse voltage (blue) and fixed pulse width (red).
Fig.2b): Comparison of the reservoir signal with the signal from a neighbouring phantom bottle to demonstrate the effective signal suppression.