Tracking of object movements for artefact suppression in Magnetic Induction Tomography (MIT)

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Abstract

One main difficulty in MIT is that movements of the object to be imaged can cause signal changes which are in the same order of magnitude or even higher than the wanted signals from the interior of the body. As patient fixation is unwanted and not always possible the best way to correct for movement artefacts is tracking of changes of the surface boundary. As additional sensors are, in general, undesirable we suggest retrieving the tracking information directly from the MIT signals. The basic idea is to place on the surface of the body a set of strategically placed active markers which consist of small loops of a very thin wire which can be opened and shorted via a tiny switch. When the loop is open it does not allow eddy currents to flow and therefore it is invisible in the reconstructed image. When the switch is closed, strong eddy currents flow and the signal essentially yields information on the marker positions. Our switches are remotely controlled MOSFETs mounted in a zone of low sensitivity of the coils so that they do not cause additional eddy currents. Image reconstruction then once provides the body information and the marker positions separately.

1 Introduction

Magnetic induction tomography (MIT) is an imaging modality which aims at the contact-less mapping of the complex electrical conductivity inside an object, e. g. a human body [1]. This is achieved by placing the object inside an array of transmit coils (TXC) which, by applying an AC magnetic field, cause eddy currents to flow. The resulting secondary magnetic field depends on the conductivity distribution inside of the coil array. The conductivity distribution is reconstructed from the voltages induced by the total magnetic field in an array of receiver coils (RXC). In medical MIT changes of the induced voltages by conductivity changes inside the object are by many orders of magnitude lower than the voltage induced by the primary field and hence there are many difficulties to be overcome both in hardware design as

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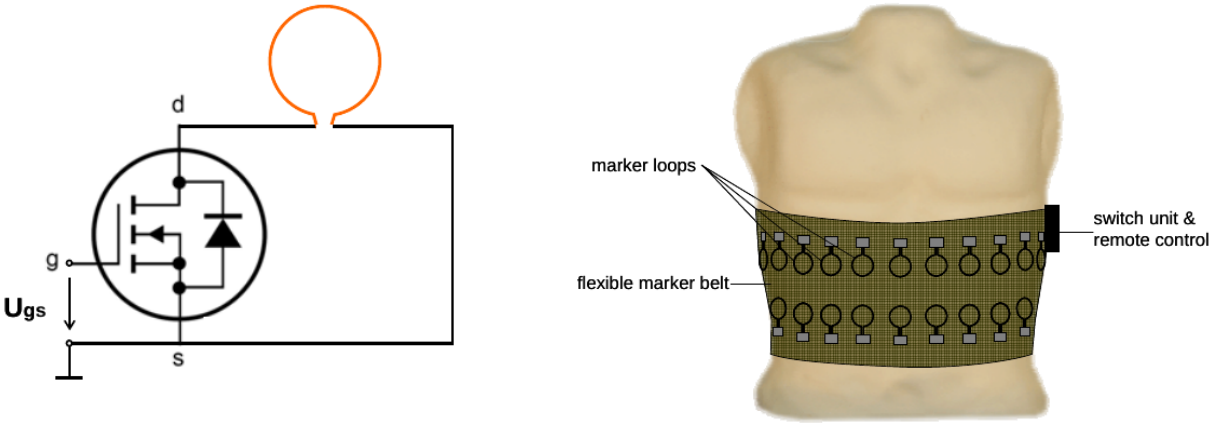
well as in image reconstruction.

One main difficulty is that the space inside of the coil array consists of a conducting and a non- conducting subdomain corresponding to the test object and the surrounding air, respectively. A particular problem is the boundary between the object and the surrounding air, because the eddy currents are confined to flow within the object and the voltages induced in the RXC depend strongly on the currents close to this boundary. In practice one is usually interested only in a small perturbation inside a background object (human head or thorax), while actually the total signal is essentially produced by the eddy currents close to the surface of the background object. A conducting perturbation with a diameter of 10% of that of a thorax and a conductivity of twice that of the background typically yields a signal which is 3 orders of magnitude less than that of the thorax itself. This in turn means that a small displacement of the background object or a small change of its boundary shape can induce a much larger voltage change than a diagnostically significant perturbation and image reconstruction becomes extremely difficult. Thus absolute MIT is very difficult but also time-differential ('dynamic') imaging may fail if the object movement is so fast that there is a significant shift between two states [2]. The artefact can, however, be filtered out if the movements of the outer object boundary are known [2]. Consequently the boundary should be tracked as exactly as possible, which could be achieved e. g. with a camera system or with an array of distance sensors. However, additional sensors are, in general, undesirable. Thus it would be a great advantage to get the tracking information from the MIT sensors (the coils). We suggest to place on the surface of the body a set of markers which produce a signal strong enough to reconstruct their positions and hence approximate changes of the object surface. The signal, however, must not perturb the object signal which is being used for the image reconstruction.

2 Methods

2.1 Experimental setup

In order to clearly separate the signals from markers and object we implemented as marker a small loop (radius 1 cm) of a very thin wire (diameter 0.05mm) which can be opened and shorted via a tiny CMOS-switch as schematically drawn in fig. 1. When the loop is open it does not allow eddy currents to flow and is invisible in the reconstructed image. When the switch is closed, strong eddy currents flow and the marker position can be reconstructed. Fig. 2 shows a possible arrangement in form of an elastic belt for tracking a thorax surface. In our experimental setup we mounted 16 markers on the surface of a plastic cylinder with a diameter of 200 mm. The positions were chosen such that the markers were in front of the gradiometers employed in the Graz MIT Mk2-system [3]. The distance from the gradiometers was 1 cm and the



(a) Active marker consistingof a wire loop and a CMOS switchfor shorting the loop.

(b) Schematic of an active marker system in form of an elastic belt with several loop/switch units which are controlled remotely from the data acquisition control unit.

Figure 1

exact position was in the zone of maximum sensitivity of the coils, respectively. The on/off operation of the 16 markers was realized by means of 16 N-channel MOSFETs (BSN20, Philips). Due to their small plastic SMD-package and placement 10 cm apart from the marker coils outside the sensitive region of the transceivers they do not contribute to the formation of eddy currents. The measurement frequency was 500 kHz.

Every frame was acquired twice, once with the switch closed and once with the switch opened. Then we carried out an experiment in order to investigate the visibility of the markers in their on and off- state, respectively, as well as the SNR of the marker signal. In total 45 frames were acquired whereas the first 15 were not used as measurement signals but served for phase calibration according to [4].

2.2 Simulated reconstruction of marker positions

The electromotive force in a coil in the presence of a magnetic G field B can be expressed as,

$$E = -j\omega \int_S \vec{B} d\vec{S},$$

where dS represents the surface element bounded by the coil contour pointing outward to that surface and ω is the angular frequency. According to the reciprocity theorem, the electromotive force in the receiver coil due to an active marker can be expressed as follows,

$$\nu = \eta e_T e_R$$

where e_T and e_R represents the electromotive force in the marker coil created

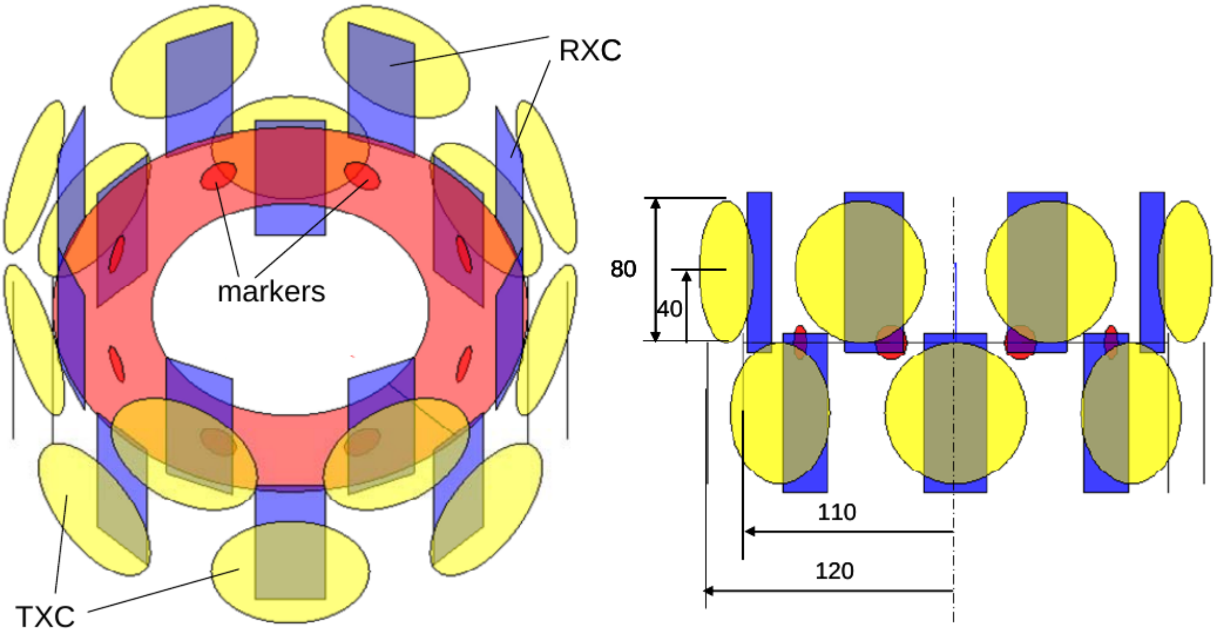


Figure 2: Geometry of the simulation model. All measures in mm.

by the transmitter and receiver coils, respectively and v is the measured voltage in the receiver coil due to the marker signal. η is the admittance of the marker coil. Let N_T and N_R denote the number of transmitter and receiver coils respectively and NM represents the finite number of possible marker configurations. Thus, by computing v for NM different marker placements, it is possible to express a $(N_T \times N_R$) by N_M sensitivity matrix S. Referring to ζ as the unknown marker placement, the corresponding marker reconstruction can be established by using the iterations as follows,

$$\zeta_{n+1} = \zeta_n + (S_n^T S_n + \lambda R^T R)^{-1} S_N^T (\nu_n - \nu_{\text{meas}})$$

where $S^T S$ is an approximation of the Hessian and R and λ are the regularization matrix and regularization parameter, respectively. ν_n is the forward solution in step n and ν_{meas} is the measured voltage.

For the simulations the geometry of the Graz MIT Mk2-system was approximated as shown in fig. 2. In contrast to the experiment, however, only 8 markers were positioned 1 cm in front of the gradiometer ring in the median plane. In order to get realistic results noise was added to the forward simulated voltages corresponding to an SNR of 100 dB of the marker signal. As shown in the section 'results' this is a realistically attainable value. As signal we defined the voltage difference between marker switched on and marker switched off while noise was the standard deviation of the voltage when the marker was switched off.

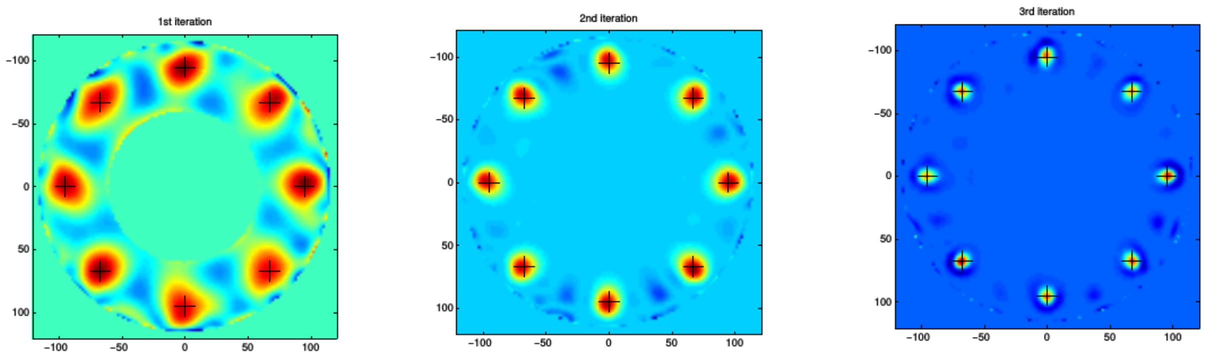


Figure 3: GReconstructed position of the markers after one, two and three iterations. The crosses mark the true positions

3 Results

3.1 Experimental results

The marker signal was clearly visible in both the real and imaginary part of the signals when switched on. The imaginary part was higher than the real one because the on-resistance of the MOSFET (max 15 Ω) dominated the loop impedance and made it more resistive than reactive. The SNR was about 91 dB when the switch was closed and below 0 dB when the switch was open.

3.2 Reconstruction results

The markers could be clearly reconstructed as shown in fig. 3. With the assumed SNR of 100 dB the localization error (deviation between true position and maximum of the reconstructed blob) was less than 1 mm.

4 Discussion

The achieved simulated images show that a reasonably accurate reconstruction of the markers can be achieved when assuming an SNR which is close to that which was determined experimentally. Thus it appears feasible to track object boundaries by only using the MIT signal. However, further investigations must reveal the most appropriate marker designs and measurement frequencies so as to achieve optimum results. Furthermore alternative switches, e. g. PIN-diodes should be considered in order to further lower the on-resistance and the ease of marker control.

5 Acknowledgements

This work was supported by the SFB project F32-N18 (Austrian Science Fund).

6 References

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