MAT-MI acoustic source reconstruction using ultrasound B-Scan imaging

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Abstract. We present in this study an ultrasound B-scan based imaging approach for magnetoacoustic tomography with magnetic induction (MAT-MI) to reconstruct electrical conductivity distribution. In MAT-MI acoustic waves are generated in the sample by placing it in a static and a time-varying magnetic field. The acoustic waves from these sources propagate in all directions. In the present approach these acoustic signals are collected with a focused ultrasound transducer which confines the collected signal to that from sources along a line. The focused transducer also gives signal gain in the focus region improving the MAT-MI signal quality. The time-resolved acoustic signals are back projected to form a one-dimensional (1D) image of the source distribution along the line. The complete cross-section of the object is obtained by acquiring 1D images along multiple directions in the cross-sectional plane. A simulation model of the image reconstruction method is developed with ultrasound simulations using the Field II program. The present reconstruction results suggest that acoustic source imaging in MAT-MI can be achieved using the much practical ultrasound B scan imaging technique. The developed method is applied to MAT-MI in experiments. This method should allow combining MAT-MI with clinical ultrasound imaging methods and broadening the potential applicability of the technique.

1. Introduction
Electrical impedance imaging of biological tissue has been of considerable interest in recent years. Several approaches like electrical impedance tomography (EIT) [1],[2] magnetic resonance electrical impedance tomography (MREIT) [3],[4], magnetic induction tomography (MIT) [5],[6] magnetoacoustic tomography [7],[8] and hall effect imaging (HEI)[9],[10] have been explored to image tissue impedance distribution. Magnetoacoustic tomography with magnetic induction (MAT-MI) [11]-[14] is a recently proposed approach to image electrical impedance distribution. In MAT-MI ultrasound is generated in the object to be imaged by placing it in a dynamic and a static magnetic field. Eddy currents are induced in the object due to the dynamic field. The static field leads to generation of acoustic vibrations from Lorentz force on the induced currents. The acoustic vibrations are at the same frequency as the dynamic magnetic field which is chosen to be in the ultrasound frequency range. This allows us to reconstruct the acoustic source distribution in the object using possible ultrasound imaging approaches. The conductivity distribution of the object can then be reconstructed from the obtained acoustic source map [12], [13].

In the current study, a focused transducer is used to reconstruct the MAT-MI ultrasound source distribution. With a specific focusing gain map, the focus transducer receives signal mainly from sources in a relatively narrow beam region along its acoustic axis. These sources are time resolved in
the collected signal due to time of flight difference to the transducer. The signal obtained is backprojected to reconstruct acoustic sources in the beam region. However, the signal received from a smoothly distributed acoustic source is the strongest when the transducer axis is perpendicular to the source distribution [15],[16]. Therefore to obtain a complete image of the MAT-MI sources, we need to set the transducer to face the various edges of the source distribution. This is achieved by shifting and rotating the transducer to scan along various lines through the object. The reconstructed images from individual scans are added up to form the final image.

2. Theory

2.1. MAT-MI

In MAT-MI static and dynamic magnetic fields induce ultrasound in the object. The induced Eddy currents \( (J) \) in the object depends on both the magnetic stimulation and conductivity distribution [13]. The eddy currents in the presence of a static magnetic field \( (B_0) \) are subject to Lorentz force \( (J \times B_0) \). The generated acoustic waves are governed by the following equation [8]:

\[
 \nabla^2 p - \frac{1}{c_s^2} \frac{\partial^2 p}{\partial t^2} = \nabla \cdot (J \times B_0)
\]  

(1)

where \( p \) is the pressure and \( C_s \) is the acoustic speed in the medium. Using Green’s function the solution to equation (1) can be written as (2) [8], [12]

\[
p(r, t) = -\frac{1}{4\pi} \int_V \frac{dV'}{R} \left[ J(r') \times B_0(r') \right] \delta(t - R/c_s/R)
\]  

(2)

where \( R=|r-r'| \),  and \( V \) is the volume containing the acoustic source.

2.2. Image reconstruction with B-Scan

The ultrasound reconstruction with the focussed transducer involves backprojecting the signal along the focus of the transducer. This gives a 1D image of the object also known as B-scan. The complete image is obtained by scanning multiple 1D lines of the object. This is done by performing sector scans at a number of locations around the object to get a complete image [15]. The effect of transducer’s directivity is corrected for during backprojection [17].

3. Computer Simulation

Ultrasonic imaging simulations were performed with Field II software. The software allows defining transducers of various geometries. The spatial impulse response of the transducer is calculated in the software by breaking the transducer surface into smaller rectangles. The program also allows simulating the transducer’s electromechanical impulse response. In the current simulations this is set to the measured electromechanical impulse response of the transducer obtained with a wide band hydrophone acting as a point receiver.

The MAT-MI acoustic source for simulation was assumed to be from conductivity boundaries in the object. This is consistent with previous MAT-MI simulations and experiment studies [13], [14]. In the current simulation these sources have been assumed to be of equal strength. An object space of 20mm by 20mm was used in the present simulation study. The simulated source distribution is shown in figure 1 (a). A 500 KHz, 4 cm diameter transducer is simulated. The received signal is computed according to equation (2). The image reconstruction is done by backprojection [16], [17]. Sector scans at 11 locations over 180 degree view angle [15] around the object were used in the current setup for reconstruction. The image reconstruction results are shown in figure 1 (b). The resolution of the reconstruction is about 3-4 mm at 500kHz transducer frequency [18].
4. Discussion
We have applied to MAT-MI a commonly used ultrasound reconstruction method, i.e. B-scan imaging. This allows using the mature scanning techniques in ultrasonography to reconstruct MAT-MI acoustic sources [19]. The reconstructed images in computer simulation show a good agreement with the simulated target source profiles. Similar results are also obtained in our MAT-MI experiments using a B-scan mode MAT-MI system. In this system, sector scan is achieved by mechanically rotating a focus transducer. In a practical setting, this could also be done by beam forming and beam steering using a transducer array with better efficiency and accuracy. In addition the discrete number of scanning locations needed for reconstruction allows using MA- MI when a limited number of acoustic windows are available to collect ultrasound signal. Thus a method like this promises to broaden the applicability of MAT-MI for human imaging.

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