Magnetic Induction Tomography with Atomic Magnetometers

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Imaging – is there a need for more systems?

Widely used in medicine and in security applications (cargo scanning etc)

No imaging system is universal – limitations in performances or in use

Xray: **unsafe** (foetus)
**illegal** (cargo scanning in France)

Sometime the “right” imaging systems does not exist (e.g. how to image current loops in the heart)?
Principles of Magnetic Induction Tomography (MIT)
The secondary field has the same frequency of the driver, but different phase. From the phase lag and amplitude, one can reconstruct $\sigma$, $\mu_r$, $\varepsilon_r$

$$\Delta B/B \approx Q \omega \mu_0 [\omega \varepsilon_0 (\varepsilon_r - 1) - i \sigma] + R (\mu_r - 1)$$
Maxwell Equations

Object properties (conductivity map)

Forward problem (easy)

Maxwell Equations \rightarrow \text{Measured voltage/phase}

Inverse problem (hard…)

- Provides a 3D image (map of } \sigma) \text{ given the measurements}
- In general undetermined

\textbf{ad hoc solutions}

Planar geometry
Back projection
The 16/32 channel Graz MIT system

16/32-channel system for low-resolution imaging of brain oedema
In-vivo image of the human head
The UCL 400-channels planar MIT system

Planar geometry

No solution of the inverse problem required
Imaging through metallic enclosures

MIT for Cargo screening

The use of dual frequencies allows imagining through metallic screens

New challenges for MIT: diagnosis of atrial fibrillation

It affects 3-5% of the population over 70
Main complication: increase risk of stroke

ATRIAL FIBRILLATION
Impulses have chaotic, random pathways in atria

Baseline irregular, ventricular response irregular
Atrial fibrillation: causes and treatment

Causes

Atrial fibrillation occurs when abnormal electrical impulses suddenly start firing in the atria. These impulses override the heart's natural pacemaker, which can no longer control the rhythm of the heart. This causes you to have a highly irregular pulse rate.

The cause is not fully understood…

Treatment

medication to prevent a stroke
medication to control the heart rate or rhythm
… controlled electric shock to restore normal rhythm
cather ablation, to prevent atrial fibrillation from occurring
having a pacemaker fitted…
AF mechanisms, rotors identification, and ablation

**Rotors:** rotational activity around a centre

**Hypothesis:** rotors activate rapidly enough to cause disorganized AF

**Rotors** are the target of RF ablation
Rotors identification via multielectrode cardiac mapping

64 pole catheter for cardiac mapping

Map of activation times
The proposed approach

Cardiac mapping using MIT

identification of zones of anomalous conductivity

Requirements:

- extreme sensitivity
- resolution
Why atomic magnetometers?

- Potential for miniaturization
- Extreme sensitivity
- Room temperature operation
- Resolution
The NIST system for Magnetoencephalography

Distance between sensor center and skull: < 4 mm

- Sensor Head
- Vapor Cell

- Laser and Control System
- Optical Fiber Links
- Sensor Head

- Optical Fiber
- Lens
- Prism
- Vapor Cell
- Light Direction

- Optical Fibers and Heater Connections
- Lens
- Prism
- Modulation Coil

- Magnetic Field (pT)
  - Frequency (Hz)
  - Time (s)

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Precession of a spin in a magnetic field at the Larmor frequency

\[ \omega = \gamma B \]

Preparation of the spin (optical pumping)

Detection of the Larmor precession (via an optical probe)
De-polarizing collision with the walls of the glass cell
Solution: coating

Short interaction time with the laser field
Solution: buffer gas

Alternative/complementary approach: re-polarize the atoms by optical pumping
Optical pumping pulse synchronized with the Larmor precession
Working point

Feedback off

Feedback on

Self-oscillation frequency (kHz)

Larmor frequency (kHz)
MIT with Atomic Magnetometers
Next generation of MIT systems
Where are we now?

Luca Marmugi, Sarah Hussain Jenelle Rajroop (NPL/UCL)

L. Marmugi and FR, submitted.
Conclusions

- Principles of Magnetic Induction Tomography
- “Magnetic images” are conductivity maps
- Atomic magnetometers are the ideal sensor
- Applications in medicine