Research Proposal (white paper)

Title: **Magnetic Induction Tomography with Cold Atoms**

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Magnetic Induction Tomography (MIT) is a non-invasive technique, used for more than 20 years, to monitor the passive electromagnetic properties (conductivity, permittivity and permeability) of materials. It appears also under other names such as Electromagnetic Tomography or Mutual Induction Imaging and is complementary to other techniques such as Electrical Impedance Tomography and Electrical Capacitance Tomography which, on the contrary, make use of electrodes on the material to be examined.

MIT working principle is simple: an oscillating magnetic field is irradiated on the object and the perturbing magnetic field generated by the object (mainly eddy currents) is detected as a function of the relative position of object and detector. A map of the conductivity and/or permittivity and permeability can be obtained by recording the amplitude and phase of the induced magnetic field [1]. The choice of the oscillating field frequency from a few Hz to MHz allows tuning the penetration depth and the spatial resolution.

Applications of MIT span from process and quality control in industry [2] to in-vivo biomedical monitoring [3] but also to security and defence [4]. This is possible because electromagnetic radiation in this frequency range can penetrate different shielding, even metal ones, without giving rise to health problems like other types of ionizing radiation. In summary, MIT is complementary to other imaging techniques for detecting concealed or distant and inaccessible objects, mainly thanks to non-invasive, non-toxic features and its sensitivity.

Recently, an interesting advance in MIT technology came from the use of the so-called Optical Atomic Magnetometers (OAMs), based on detection of Larmor spin precession of optically pumped atoms, as magnetic field detectors. OAMs can show comparable or higher sensitivity than “standard” magnetic field sensors, i.e. coils, giant magnetoresistance magnetometers (GMRs) and super-conducting quantum interference devices (SQUIDs). They are typically realized with alkali-metal vapours at room temperature in interaction with proper laser beams and magnetic fields. Examples of detecting conductive objects screened by a metal plates with sub-mm spatial resolution are provided in Refs [5-6].

We propose to further improve the performances of OAM-based magnetic tomography by using laser cooled and trapped atoms as magnetic sensors [7]. The exquisite control over all internal and external degrees of freedom given by laser manipulation of atoms at temperatures near the absolute zero will result in an expected improved sensitivity, improved spatial resolution and reduced background noise with respect to atomic sensors at room temperature. Finally, the use of a more sophisticated setup leading to a quantum degenerate state of matter, a Bose-Einstein condensate, as magnetic sensor [8], should produce further improvements in sensitivity at the expenses of a reduction in the measurement repetition rate. Moreover, the implementation of multiple optical traps or an optical lattice can mimic the use of multiple sensors and further improve the spatial resolution of the tomography.

In conclusion, we propose to build a cold-atom magnetometer to be used for Magnetic Induction Tomography in view of application in detection of distant, concealed conductive objects.

[1] H. Griffiths, *Magnetic Induction Tomography*, Meas. Sci. Technol. **12**, 1126 (2001).

[2] Ma, L., Hunt, A and Soleimani, M. (2014) *Experimental evaluation of conductive flow imaging using magnetic induction tomography*. International Journal of Multiphase Flow **72**, 198-209 (2015).

[3] M. Zolgharni, H. Griffiths, and P. D. Ledger, *Frequency-difference MIT imaging of cerebral haemorrhage with a hemispherical coil array: numerical modelling*, Physiol. Meas. **31**, S111 (2010).

[4] B. J. Darrer, J. C. Watson, P. Bartlett, and F. Renzoni, *Magnetic Imaging: a New Tool for UK National Nuclear Security*, Sci. Rep. **5**, 7944 (2015).

[5] C. Deans, L. Marmugi, S. Hussain, and F. Renzoni, *Electromagnetic induction imaging with a radio-frequency atomic magnetometer* Applied Physics Letters **108**, 103503 (2016).

[6] A. Wickenbrock, N. Leefer, J. W. Blanchard, D. Budker, *Eddy current imaging with an atomic radio-frequency magnetometer*, arXiv:1603.05067v1 [physics.ins-det] 16 Mar 2016.

[7] N. Behbood, F. Martin Ciurana, G. Colangelo, M. Napolitano, M. W. Mitchell, and R. J. Sewell, *Real-time vector field tracking with a cold-atom magnetometer*, Appl. Phys. Lett. **102**, 173504 (2013).

[8] M. Vengalattore, J. M. Higbie, S. R. Leslie, J. Guzman, L. E. Sadler, and D. M. Stamper-Kurn, *High-Resolution Magnetometry with a Spinor Bose-Einstein Condensate*, Phys. Rev. Lett. **98**, 200801 (2007).