Laboratory Directed Research and Development – Los Alamos National Laboratory

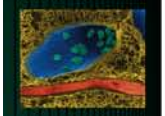
LDRD DAY

A Look Into the Future of Los Alamos

Magnetic Resonance Imaging to Understand the Brain and Protect our Borders

Petr Volegov, Principal Investigator

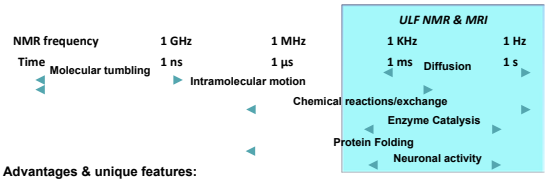
Innovation for Our Nation



What is Ultra-low Field MRI?

Conventional MRI uses relatively high magnetic fields to produce anatomical images. Typically, these field strengths are in the range of 1 – 3 Tesla and they are often produced using a large superconducting electromagnet.

On the other hand, *ultra-low field (ULF) MRI utilizes the same basic physical phenomena that drive high field (HF) MRI, but with magnetic fields that are one thousand to one million times smaller.*



How can ULF-MRI be used to enhance our national security?

ULF-MRI can be utilized to achieve:

- Lightweight, portable MRI instrumentation for the battlefield
- New methods for imaging neuronal activity in the brain, providing insight into the nature of cognition
- New techniques for screening threat substances such as liquid explosives

Advantages & unique features:

• Overlapping of the Larmor frequency with the characteristic frequencies with some of the most fundamentally interesting and unexplored areas of molecular dynamics and biological processes provides new insights in the dynamics involved.

• Imaging in the presence of metal (shrapnel, etc.).

•Flexibility in fields generation and manipulation.

MRI in the Field

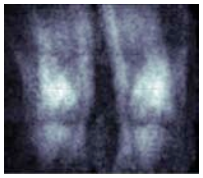
MRI is a powerful diagnostic tool for soft-tissue anatomy and injuries. HF-MRI is common in hospital settings but remains too expensive and bulky for deployed applications such as in the battlefield.

ULF-MRI instrumentation is ideal for fielded applications because it does not require a powerful magnet. This leads to systems that are:

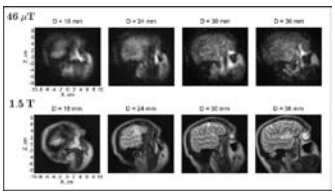
- Less expensive, smaller footprint, open design
- Operationally simpler and safer; will not cause movement of nearby metal objects, shrapnel in the patient, etc.

ULF-MRI instrumentation can be made portable while still allowing anatomical imaging. One of our machines designed for detection of liquid explosives in a security portal (shown to the left), has been disassembled, transported to a distant location, and subsequently reassembled and rendered fully functional within a few days.

This same instrument is capable of creating anatomical images.



We have moved towards whole-body imaging capabilities with our instrumentation. To the right is an image of human knees obtained with the ULF-MRI machine shown above.



Our group was also the first to demonstrate ULF-MRI imaging of a human brain (Zotev, V.S., et al., 2008).

These images (upper panels) were obtained in the same instrumentation that acquired magnetic signals associated with brain function, a feat not possible with conventional MRI.

Direct Neuronal Imaging for Insight into Cognition

The accurate, non-invasive mapping of neuronal activity in the brain may be used to "detect" the presence of certain thought processes, such as the ignition point of visual recognition, cognition, or deception.

We have proposed a *new neuroimaging approach* that is capable of directly imaging neural activity in the brain, providing both (Kraus, R. H., 2008)

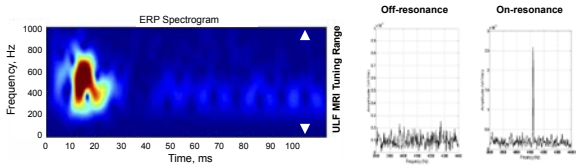
- accurate localization of activity
- rich temporal information of activity

This will give us a better understanding of the nature of cognition, which in turn could lead to increased understanding of how the brain works. Our approach utilizes the fact that the neural activity will create a small magnetic field, and this magnetic field will locally alter the MRI signal.

Development of this approach using ULF-MRI rather than HF-MRI poses several advantages:

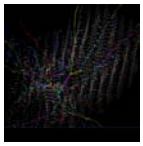
• High field MRI signals are dominated by effects from blood chemistry which drown out the neural signals. This, so called "BOLD", signal is not present at ULF.

• The frequency of the proton precession (which gives rise to the MRI signal) at ULF can overlap with the frequencies of neural activity, while the proton frequencies at HF are much too high. This can result in a resonance, enhancing the neural signal.



The average power spectral density for activated neurons (left panel), shown here for rat whisker barrels, overlaps with the proton precession frequency under ULF conditions. This poses the potential for enhancement of the MRI signal due to resonant absorption. Changing the ULF frequency (red line) we can potentially *scan the frequency* content of brain activity.

Building a realistic neuronal model to calculate MRI signal change.



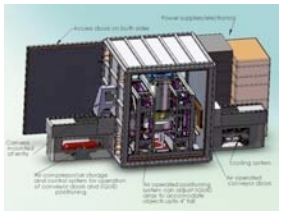
The currents induced during neuronal activity were used to calculate the magnetic field around a single neuron. These fields were used to predict the expected change in the MRI signal associated with neural activity.

Our theoretical estimations and phantom experiments show we are within an order of magnitude of the required sensitivity.

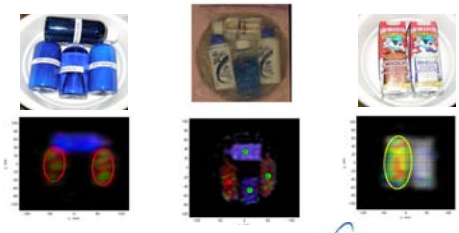
MagViz: Airport Screening of Threats

ULF-MRI can be used to remotely characterize liquids and identify possible threats.

Our group built a ULF-MRI instrument, MagViz (R&D 100 Award Winner), specifically designed to screen threat substances at airport screening portals. It was tested successfully at the Albuquerque Sunport in December 2008. MagViz discriminates threats from benign items using the same MR contrast mechanisms for brain imaging. This is presently one of the only non-invasive techniques that can determine chemical composition *in multiple unopened bottles, and through opaque and foil containers and without exposure to large magnetic fields.*



We tested numerous items from streams of commerce as well as known threat materials.



MagViz produces a 3D scan of the containers. Therefore, it can identify threats that are masked by other bottles or even hidden inside other bottles.

LA-UR 09-05085

Los Alamos NATIONAL LABORATORY EST. 1943

LDRD Innovation for our nation