A Portable Low-Field System for Localized NMR Measurements

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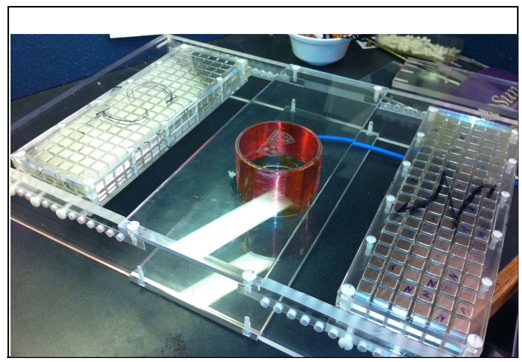
Overview Many medical applications that would benefit from NMR measurements are not performed due to the size, cost, and availability of MRI scanners. A portable MR device can fill this gap. This requires a suitable magnet, compact electronics, sensitive detectors, and elimination of the rf shielded room. We describe such a system and two medical applications for such a device, – "Lung Density Monitor" (LDM) and "Ventilation Stethoscope" (VS). The magnet utilizes a monohedral permanent magnet design of modest dimensions and field strength. Through active noise cancellation and a multi-channel desktop spectrometer (MR Solutions) we expect to circumvent the need for a bulky RF shielding enclosure. The surface of the magnet is placed on the posterior portion of the chest allowing the homogeneous field region to be located inside the lung. The signal thus obtained provides regional information about lung density, when detecting 1H (LDM) or ventilation, when detecting hyperpolarized gas (VS).

Motivation. Acute Lung Injury (ALI), which includes acute respiratory distress syndrome (ARDS), is a relatively common clinical condition characterized by sudden respiratory failure and a 38.5% mortality [2]. ARDS/ALI is characterized by flooding of the alveoli with fluid, protein, and cellular debris. By applying positive pressure, mechanical ventilation is used to open flooded or collapsed regions of the lung to reduce mortality associated with this condition. Too much pressure, however, can result in barotrauma or damage to the delicate septal tissue. At present, ventilators are adjusted with little quantitative information, often relying on the best arterial blood gas parameter, which could cause more harm than good. Thus, the ability to assess regional lung density would allow a clinician to find minimal ventilator pressure to safely maintain lung patency but without causing barotrauma. A portable device with such capabilities would also allow monitoring pneumonia in the ICU.



Methods The permanent magnet dipoles are composed of 480 NdFeB magnets, each with $B_r \sim 1.3T$. The magnet assembly is around 70x50x10 cm (Fig 1). The magnets generate a region 75mm above the surface, where B_y (in plane with the coil radius) forms a saddle-point while $B_x = B_z = 0$. At the center of the ROI the field reaches ~86G±0.26G. The parameters of the field were simulated prior to the assembly and later measured using a robotic field-mapping system developed in-house. A 12 cm diameter coil positioned between the dipoles serves as the transmit-pick-up coil at f_0=369 kHz. We used a solenoid design for the surface coil with 54 turns of Litz wire, in order to improve SNR. Additional pulses before and after the main 90º excitation pulse as well as the inverting 180º pulses help mitigate the effects of ringdown on the pulse shape (3). The ringdown effects can saturate the preamplifier thereby adding dead-time, and necessitate longer delays before the acquisition. Similar to the idea in NMR-tomography [4], where field gradients provide spatial labeling, the desired spatial localization of the measurement is achieved due to the fact that the specific value of the B_0 field to which the receiver is tuned is spatially limited to the region around the saddle point above the coil. The boundaries of the region can then be varied by limiting the bandwidth accordingly. The central value of the field implies frequencies of 368 and 102.5 kHz for ^{1}H and ^{129}Xe nuclei respectively.

In addition, we have developed a noise-cancelling algorithm, which will obviate the use of RF shielding, thus rendering our device truly portable. The algorithm considers random, and spurious components of the noise acquired by an independent coil. It then formulaically transforms the noise signal before subtracting it from the contaminated NMR signal, thus greatly improving SNR. It also takes advantage of the fact that the elimination of the noise can happen offline, thus relaxing computational speed requirements, unlike the case for audio applications where noise has to be cancelled in real-time.

Results and Discussion We have built a prototype based on a monohedral permanent magnet array aimed at measuring vital lung parameters, such as ventilation and parenchymal density. The device is capable of acquiring a signal stemming from nuclear polarization at a location removed from its surface by ~10 centimeters, such as that situated inside the lung, within a region of interest defined by an imposed frequency bandwidth and field uniformity. The low magnetic field regime in principle implies reduced signal intensity for proton samples. On the other hand this device benefits from sampling a larger "voxel" as opposed to MR imaging, since it combines signals from a region of interest of about 1 cubic inch. In addition we are currently working on implementing hyperpolarized Xe NMR on such a device. Here, we will benefit from the independence of the Xe magnetization on the magnetic field's strength.

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