MICROSCOPIC NMR IMAGING

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ABSTRACT

A commercial 60MHz nuclear magnetic resonance spectrometer has been modified to perform non-invasive, high resolution, two dimensional proton density imaging on samples smaller than 10mm.

Orthogonal magnetic field gradients are applied during the experiment to impart a spatial tag to the nuclear spins. The resultant nuclear signal detected by the spectrometer corresponds to a sampling of Fourier space. The exact trajectory in this space depends on the magnitude and timing of the applied gradients. The technique used in this work samples k space in a radial fashion and is termed filtered back projection. Image reconstruction is implemented on a 16 bit personal computer using a two dimensional fast Fourier transform algorithm.

Due to the small volume elements employed the available signal to noise ratio limits the resolution attainable. It is therefore important that the S/N be maximized within the system. To this end careful attention has been paid to the transfer of the nuclear signal from sample to spectrometer. Signal averaging is also used to improve the S/N although this does result in long imaging times (typically 30 to 60 minutes). At present a resolution of about 30µm is achievable for a slice thickness of 1.5mm and a S/N of 40. At the time of initial publication in June 1986, this corresponded to a voxel resolution an order of magnitude better than that obtained by other workers in this field.

The orthogonal field gradients used are capable of generating gradients of up to $2Tm^{-1}$. This provides the possibility of measuring self diffusion coefficients in an intact sample, using the pulsed field gradient spin echo technique - something which would be difficult to achieve with a large scale imaging system. This thesis reports the first measurements of localised self-diffusion coefficients using a combination of the PFGSE technique and NMR imaging.

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A	Cross sectional area of rf coil.	41
$\mathbf{B_0}$	Main magnetic field, directed along the z axis.	3
$\mathbf{B_1}$	Magnetic field due to applied rf.	6
C	Spatial resolution contrast ratio.	54
dV	Volume element.	16
$\mathbf{F}$	Fourier transform operator.	19
F	Noise factor of spectrometer.	41
F(n)	Filter function.	49
f_r	Frequency corresponding to the edge or a cylinder of radius r.	63
$\mathbf{G}$	Magnetic gradient vector.	16
$\hbar$	Planck's constant/2π.	3
$\mathbf{I}$	Angular momentum vector.	3
I	Spin quantum number.	3
I	Coil current.	40
Im[ ]	Imaginary part of complex term in brackets.	49
j	$(-1)^{1/2}$	16
$\mathbf{k}$	Reciprocal space position vector.	16
k_B	Boltzmann's constant.	38
L	Length of conductor used in rf coil.	42
L	Inductance of rf coil.	41
ℓ	Length of rf coil.	38
$\mathbf{M}$	Magnetization vector.	6
m	Representation of r in the computer.	45
m	Spin magnetic quantum number.	6
m_r	Number of data points representing the radius of a cylinder.	47
n	Representation of k in the computer.	45
n_b	Number of points characterising the decay of the filter function.	50
N	Number of data points in fid.	33
N_{acc}	Number of time domain accumulations.	33
N_h	Number of hydrogen nuclei per unit volume.	6
N_k	Noise level in k space.	49
N_p	Number of projection used In FBP.	37
N_r	Noise level in image space.	49
N_t	Number of turns on coil.	38
$\mathbf{P}$	Principle part.	67

$P_{\pm}$	Probability that the nuclear spin will be aligned (-) with or opposed (+) to B_0.	38
p	Wire circumference.	42
p_2	$= T_2\Delta f$.	54
Q	Quality factor of rf coil.	41
Re[ ]	Real part of complex term in brackets.	25
R	Rf coil radius	38
r	Image space position vector.	16
r_c	Rf coil resistance.	41
r	Rf coil wire radius.	38
S(FBP)	Smoothing function used in FBP.	71
S(FZ)	Smoothing function used in FZ.	52
S_k	Spatial frequency domain data.	45
S_r	Image domain data.	45
T	Total sampling time.	45
T_1	Spin-lattice relaxation time.	10
T_2	Spin-spin relaxation time.	10
T_2^*	Transverse relaxation time.	12
T_c	Coil temperature in Kelvin.	41
T_r	Experiment repetition time.	76
T_s	Sample temperature in Kelvin.	38
V_c	Volume of coil.	42
V_s	Volume of sample.	38
V_c	Carrier level.	99
V_m	Modulation level.	99
γ	Gyromagnetic ratio.	3
Δf	Frequency domain bandwidth of spectrometer.	41
Δy	Slice thickness.	46
Δz	Spatial resolution in the final image.	38
$\Delta\omega$	Offset from resonance.	146
δ	Skin depth.	42
θ	Tip angle.	9
$\boldsymbol{\mu}$	Magnetic moment vector.	3
μ_0	Permeability of free space.	40
μ_r	Relative permeability.	42
ξ	Induced EMF amplitude.	10
ρ	Proton density function.	16
ρ	Coil wire resistivity.	42

σ	Coil proximity factor.	42
$\boldsymbol{\tau}$	Torque.	3
τ	Short time interval.	12
τ_c	Molecular correlation time.	10
φ	Projection angle.	35
Ψ	Filtered profile.	36
ω_0	Larmor precession frequency due to B_0.	5
ω_1	Larmor precession frequency due to B_1.	8