1. NMR/MRI Experiment Teaching Solution: NMR/MRI Integrated Experimentation Platform

1.1 Introduction

The EDUMR system consists of a compact 0.5T NMR/MRI system combined with virtual data acquisition and image reconstruction teaching software (EDUVMR 2.0). This combination provides a convenient teaching platform which makes the realistic teaching of NMR principles and techniques much more achievable.

EDUMR20 MRI system is Niumag's original product, first used as an integral part of other products. After nearly 10 years of enhancements, its design and functionality are comprehensive and mature. EDUMR20 can be used by physics lecturers to demonstrate NMR experiments and imaging professionals to teach courses, so that multiple students gain experience in using MR technology without needing to operate expensive instruments.

Through a tailor made range of 32 experiments and related materials, students gradually learn to master NMR/MRI technology through observation of a range of diverse sequences, different magnetic resonance signals, K spatial distribution for different settings, imaging parameters organization, and the impact of different levels of image contrast. What is more, the accessible software and hardware architecture allow the functionality of the instrument to be extended and enhance the students' capability. Combining teaching and research greatly enhances the professional capacity of the university for research while at the same time providing the community the same quality of training as magnetic resonance imaging professionals.

The core of the NMR/MRI Integrated Experimentation Platform is a virtual platform combined with a magnetic resonance imaging test device. EDUVMR 2.0 is a virtual system and run independently to simulate the entire process of NMR/MRI. On the one hand, it allows many students to learn simultaneously without needing to invest in expensive hardware or needing several supervisors to train multiple users. Moreover, it greatly shortens the time in imaging with two modes selectable: normal mode and accelerated one. The latter one facilitates a faster imaging therefore improves teaching efficiency. On the other hand, EDUVMR 2.0 is able to demonstrate NMR sequences in a practical way. For instance, the performance of EPI, a complicated sequence, needs a demanding hardware which is beyond the basic configuration in the lab. However, EPI could easily programmed and purposely integrated in the virtual system which enables students to operate EPI-based experiments.Furthermore, with the parameter driven interface users can select imaging sequences, the original level and imaging technology, carry out the relevant data collection process and perform K space filling of reconstructed images.

With the assistance of EDUVMR 2.0, students become familiar with the relevant aspects of NMR and MRI analysis and system operation. If necessary, they can practice themselves on the EDUMR hardware (EDUMR20) to sharpen their skills and explore what NMR/MRI can further bring them.

1.2 Education NMR & MRI System (EDUMR20)

1.2.1 Introduction of EDUMR20

EDUMR20 is a compact desktop magnetic resonance imaging test instrument designed for magnetic resonance imaging technology teaching experiments. It can be used to teach NMR principles, demonstrate the magnetic resonance imaging process and conduct many other NMR/MRI experimental courses under the professional engineering disciplines (such as Modern Physics, Applied Physics, Radio Physics, Electronics and Information Engineering) and medical imaging related professions (Fig. 1. 1).

Operation Condition

1. 220 VAC, 50 HZ;
2. 22 – 28 0C;
3. Relative humidity 30 %- 70 %.

Fig. 1. 1 EDUMR20

Two main characteristics of this device：Openness and Authenticity

Openness: both the hardware and software are very accessible.

1. Accessible Hardware: In classroom presentations you can not only simulate continuous wave NMR experiments, but also disassemble and reassemble the hardware. With an oscilloscope, multi-meter, and other auxiliary tools, you can exercise the abilities of students, and enhance students' knowledge about the hardware configuration of the instrument.

2. Data accessibility: Accessing the open K-space raw data, enables image reconstruction to be carried out in simulation experiments for signal processing and data processing direction. This can provide a lot of real and effective data for students as well as lecturers, and thus use a variety of algorithms to expand research and investigate other aspects of the processed image.

Authenticity: The EDUMR medical magnetic resonance imaging apparatus uses the same modules as other working instruments which provides a real-life experience of the principle of magnetic resonance principles, instruments, and applications.

1.2.2 Description of the overall system structure

The five major sub-components of the instrument include the console with spectrometer (green), a radio frequency system (blue) and gradient unit (yellow), magnet cabinets (pink), and power supply (with thermostats). Structure of the device is shown below (Fig. 1. 2).

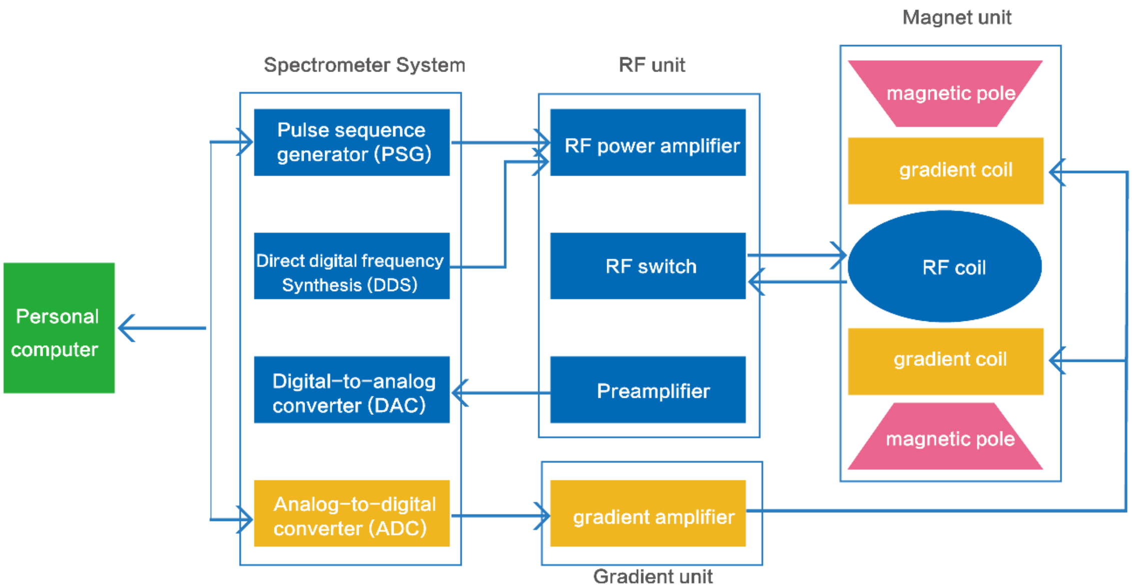


Fig. 1. 2

The console receives the operator's instruction and generates control signals to pass through the sequencer software to coordinate the work of the various components of the spectrometer system. The console also carries out tasks of data processing, storage, image reconstruction and display. The RF system mainly receives the transmitted RF signal and sampling pulse sequence, and the gradient system generates the magnetic field gradient. The magnet primarily provides a uniform, stable main magnetic field, and the temperature control system assists in maintaining a stable magnetic field. A block diagram of the magnetic resonance imaging hardware system is depicted below (Fig. 1. 3):

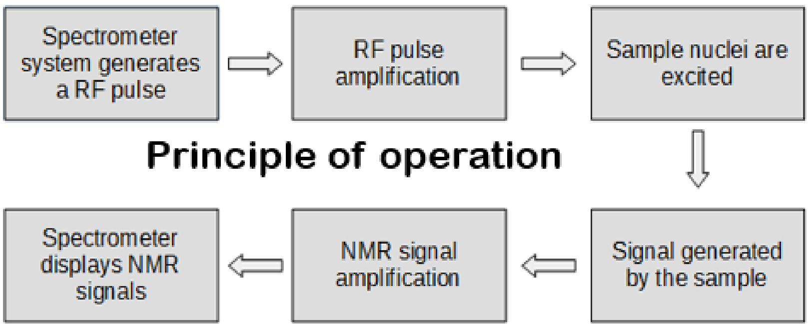


Fig. 1. 3

1.2.3 Low-field MRI teaching experimental program

An annotated version of the integrated software interface of EDUMR20 is displayed below (Fig. 1. 4).

1. 2. 3. 1 Imaging Experiments

- ✓ Understanding of various imaging sequences (SE, IR, and GRE sequences), imaging procedures and principles (Fig. 1. 5);
- ✓ Multi-dimensional imagings: understanding selected layer thickness concepts;
- ✓ Different weighted imagings: understanding how the relaxation time of different tissues or samples affect weighted grey scale image (Fig. 1.6,7,8,9 and 10);
- ✓ Analysis of how sampling parameters affect the image size and shape, observation of truncation artefacts, their causes and solutions.

Sequences:

No.	EDUMR20
1	FID
2	CPMG
3	IR
4	SE
5	MSE
6	GRE
7	3D-SE

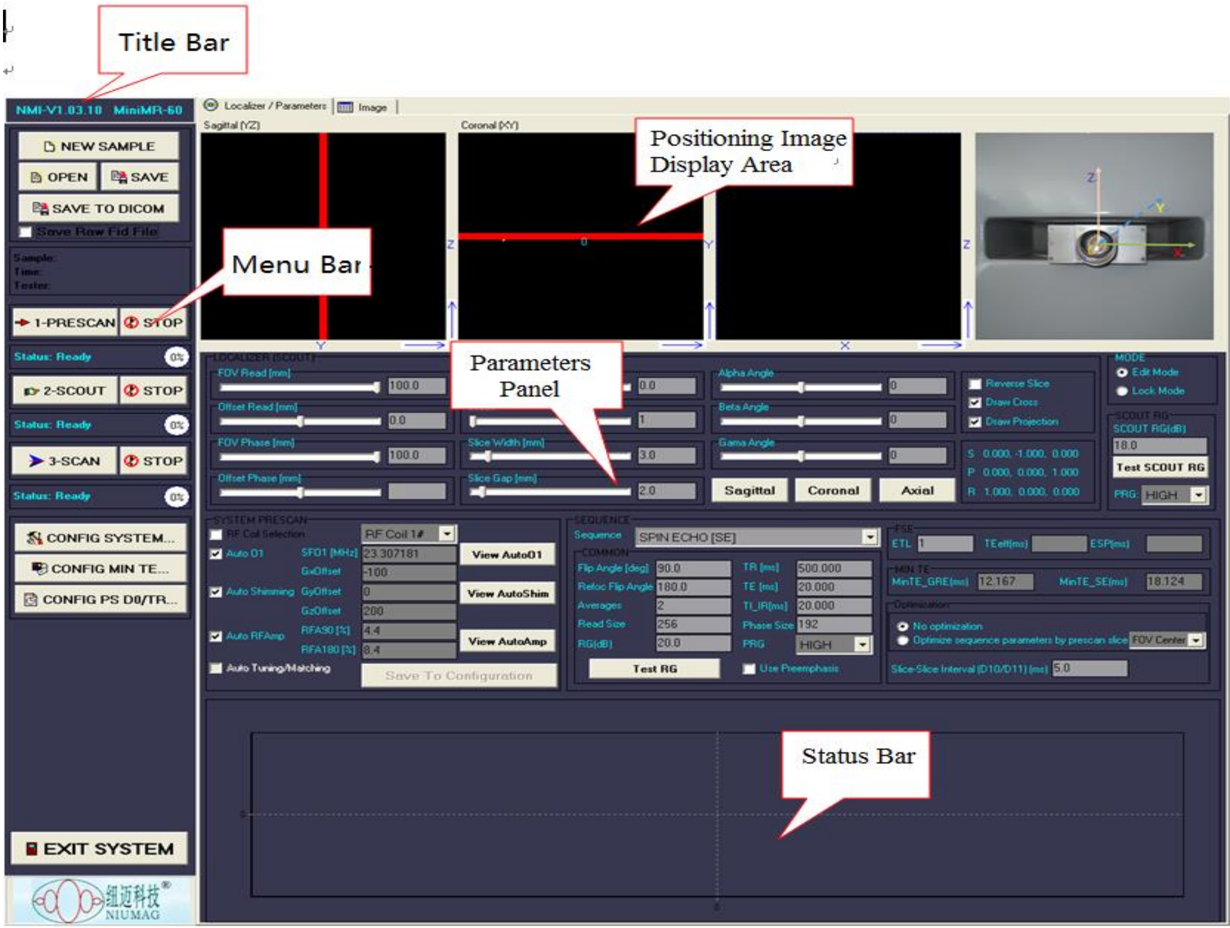

Title Bar
Positioning Image Display Area
Menu Bar
Parameters Panel
Status Bar
NMI-V1.03.18 MiniMR-60
NEW SAMPLE
OPEN
SAVE
SAVE TO DICOM
1-PRESCAN
STOP
2-SCOUT
3-SCAN
CONFIG SYSTEM...
CONFIG MIN TE...
CONFIG PS D0/TR...
EXIT SYSTEM
Sagittal
Coronal
Axial
SPIN ECHO [SE]
Test RG
Test SCOUT RG
View Auto01
View AutoShim
View AutoAmp
Save To Configuration

Fig. 1. 4

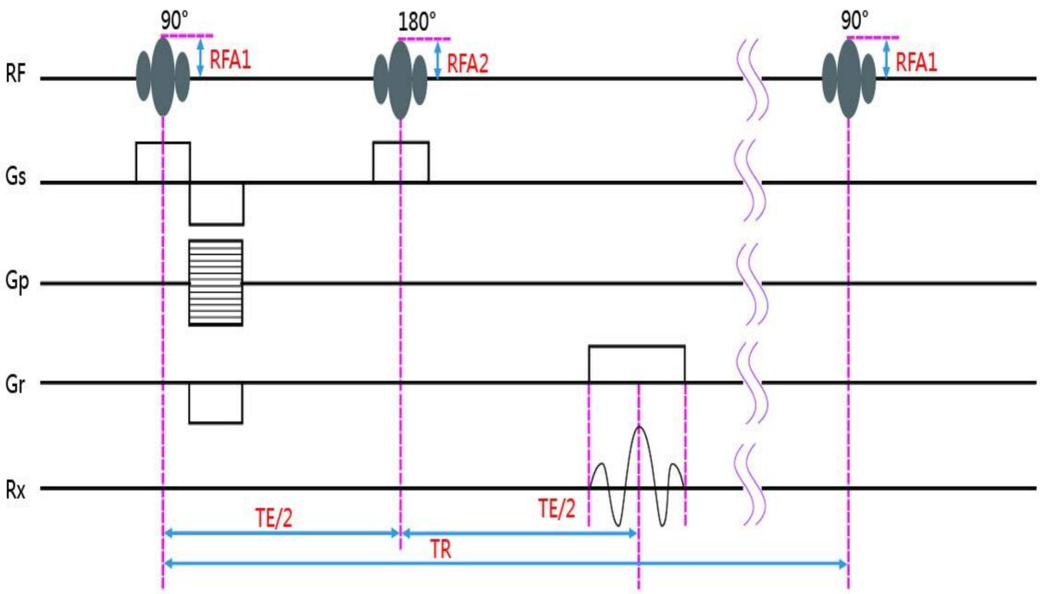

RF
Gs
Gp
Gr
Rx
90°
180°
90°
RFA1
RFA2
RFA1
TE/2
TE/2
TR

Fig. 1. 5

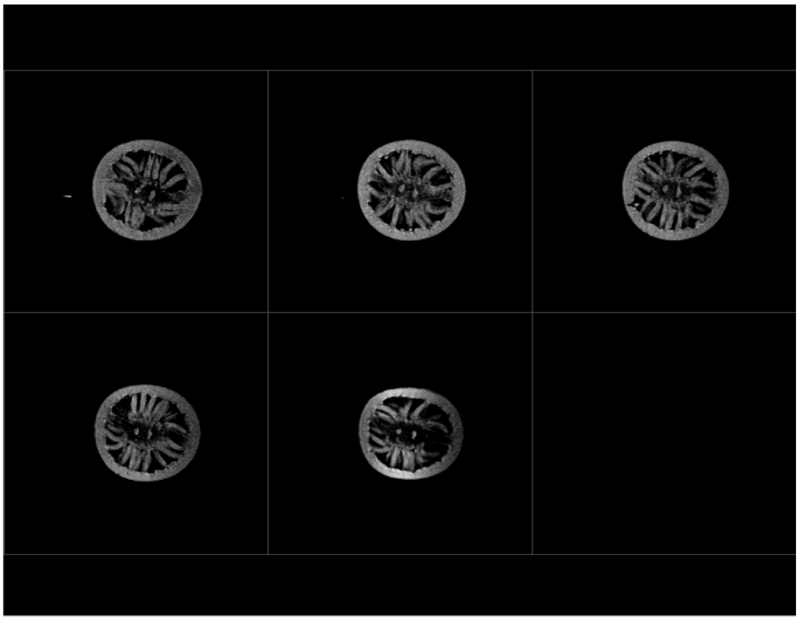
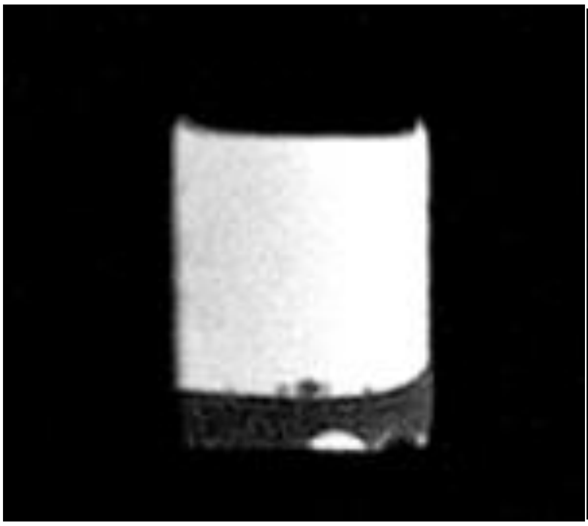


Fig. 1.6 SE images of multi-slice pepper



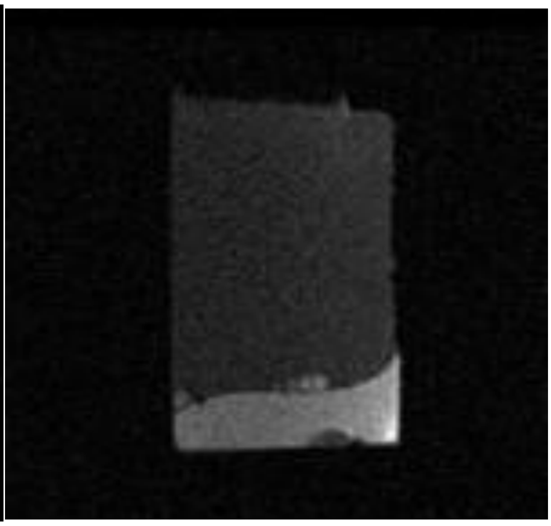


Fig.1. 7 T1-weighted image　　Fig. 1. 8 T2-weighted image

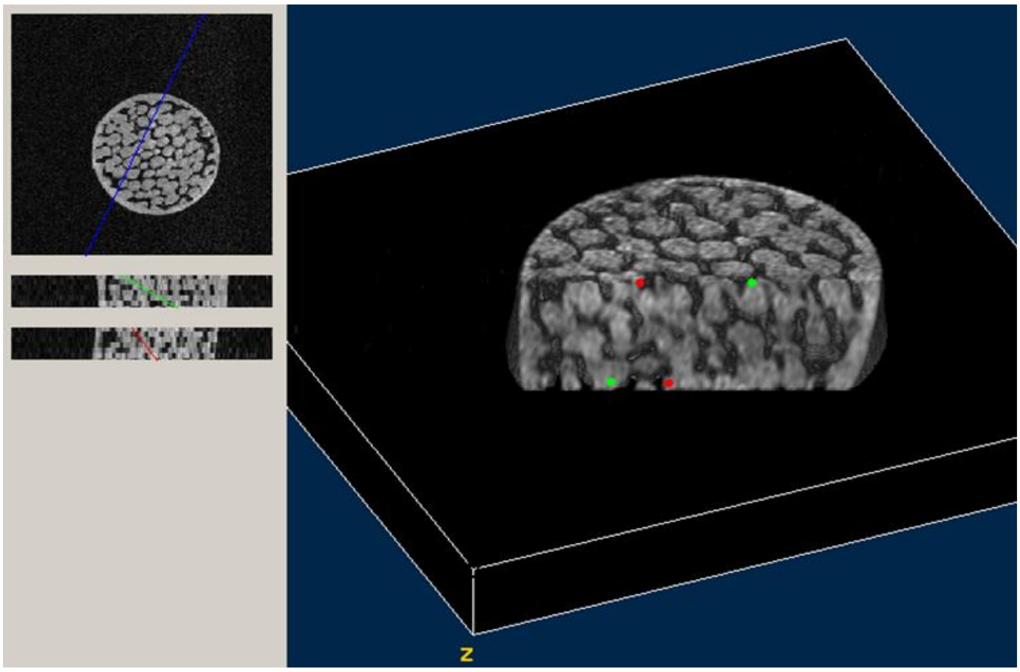


Fig. 1.9 3D MRI of sample 1

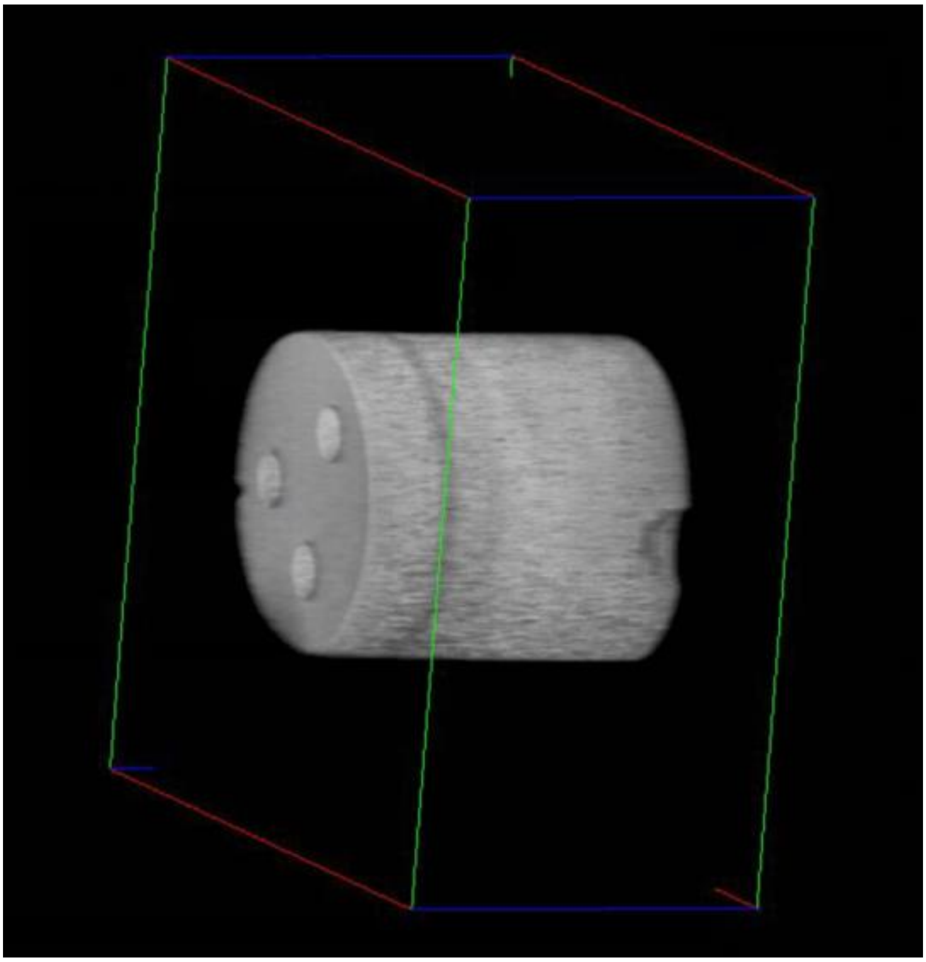


Fig. 1.10 3D MRI of sample 1

1. 2. 3. 2 Principles taught through the experiments

- ✓ Understand the importance of uniformity of the magnetic field, factors affecting homogeneity, and how to shim (Fig. 1. 11);
- ✓ Grasp the characteristics of the Free Induction Decay (FID), FID signal processing sequence, and understand the basic principles of nuclear magnetic resonance (Fig. 1. 12);
- ✓ Know the role and structure of a magnetic resonance spectrometer, at the same time grasp the impact of sequence and acquisition parameters on callback signals

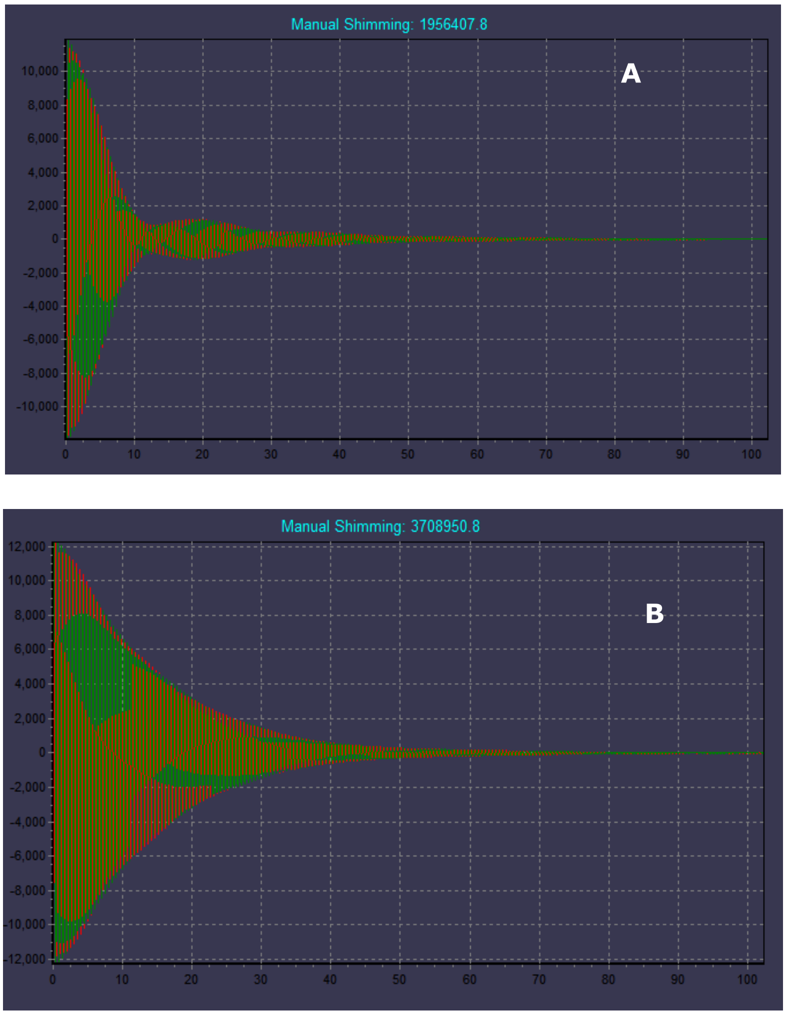


Fig. 1. 11 Before and after manual shimming (A and B)

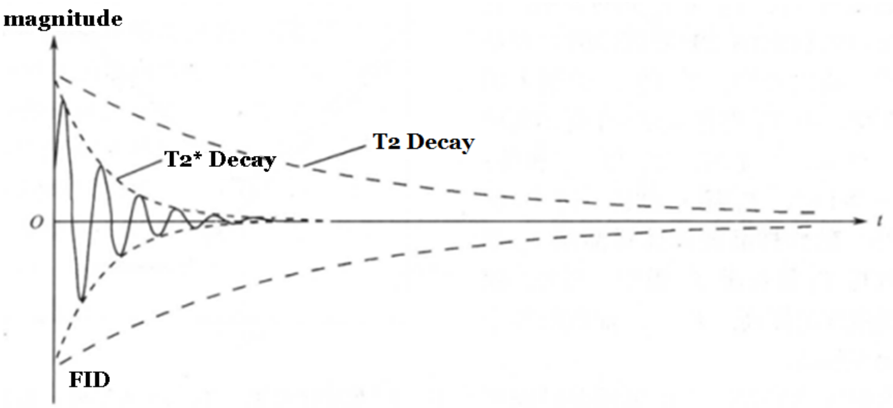


Fig. 1. 12Relaxation produced by the T2 characteristics of tissue and the T2* effects associated with magnetic field inhomogeneity

1. 2. 3. 3 Test Hardware architecture

- ✓ Master the principles of how the nuclear magnetic resonance signal is received and understand how to tune and match the receiving coil.
- ✓ Understand MRI systems emit radio frequency signals from the power amplifier, and method for receiving pulse sequences.
- ✓ Understand the principles and analog NMR signal data processing (Fig. 1. 13).
- ✓ Through NMR experiments understand the role and structure of magnetic resonance spectrometer core control system components, then understand how the various spectrometer systems generate control signals (Fig. 1. 14).

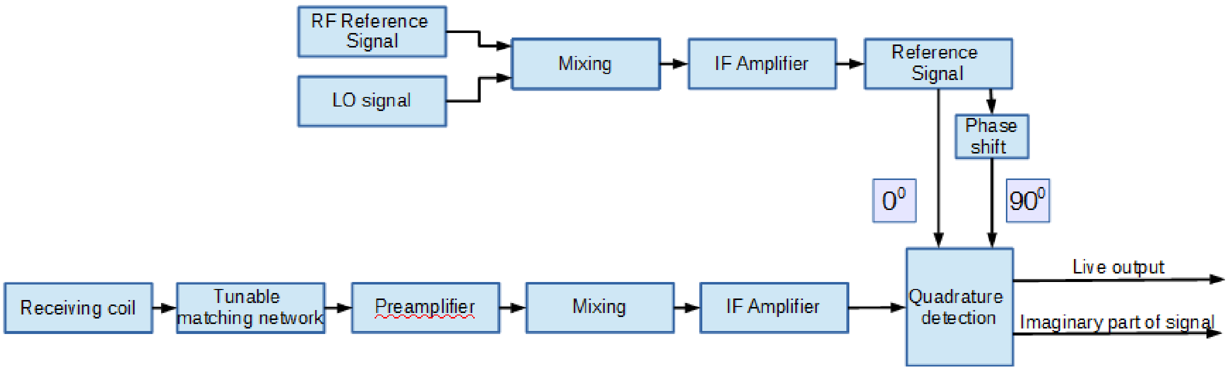


Fig. 1. 13Processing the magnetic resonance signals (analog portion)

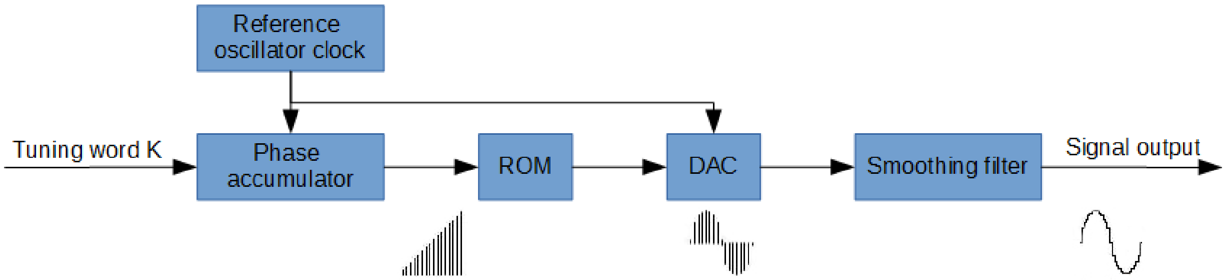


Fig. 1. 14 Block diagram of the digital synthesizer

1. 2. 3. 4 Application of development experiment

- ✓ After familiarization with the basic principles of nuclear magnetic resonance and imaging, MRI-related simulations could be created with Matlab software, such as magnetic resonance imaging, simulation of 2 D-FFT / 3D-FFT image reconstruction algorithm and assessment on magnetic resonance image quality;
- ✓ Apply low-field nuclear magnetic resonance to polymer materials, food and agriculture, oil and energy, life sciences and other fields. Use NMR analysis and the imaging teaching platform for related basic research and various applications.

1. 2. 4 Summary of the experiments performable with EDUMR20

A wide range of experiments are available, more than 30 experiments covering various aspects of MRI and NMR operation listed below (not all). Niumag will also collaborate with users who want to develop additional experiments.

EDUMR NMR/MRI theory and the equipment structure

NMR/MRI basic theory (Physics)

- ✓ Fundamental principles of NMR/MRI
- ✓ Nuclear magnetic resonance phenomenon
- ✓ Relaxation and NMR signal
- ✓ Spatial location of NMR signal
- ✓ Image re-construction of MRI
- ✓ Pulse sequences of NMR

EDUMR MRI system (Electronic information engineering)

- ✓ Magnetic unit
- ✓ Radio frequency unit
- ✓ Gradient unit
- ✓ Spectrometer
- ✓ Magnetic shielding and radio frequency shielding

EDUMR NMR/MRI advanced experiment items

NMR/MRI theoretic experiments

- ✓ Electronic shimming
- ✓ Measuring the Larmor Frequency by 90° FID Sequence
- ✓ FID signal in rotating coordinate system
- ✓ Hard RF determined by Hard Pulse-echo Sequence
- ✓ Soft RF determined by Soft Pulse-echo Sequence
- ✓ Soft Pulse-echo Sequence
- ✓ T1 determination by inversion recovery method (IR) and saturation recovery method
- ✓ T2 determination by CPMG

MR Imaging technicalexperiments

- ✓ Spin echo imaging (Fig. 1. 15)
- ✓ Multi-slice spin echo imaging
- ✓ T1, T2 weighted imaging (Fig. 1. 16 and Fig. 1. 17)
- ✓ IR imaging
- ✓ 2D imaging
- ✓ 3D imaging
- ✓ FOV, space location, slice gap, slice thickness, slice angle

some experiment results as follows picture:

Fig. 1. 15 Two echos of Spin Echo sequence results

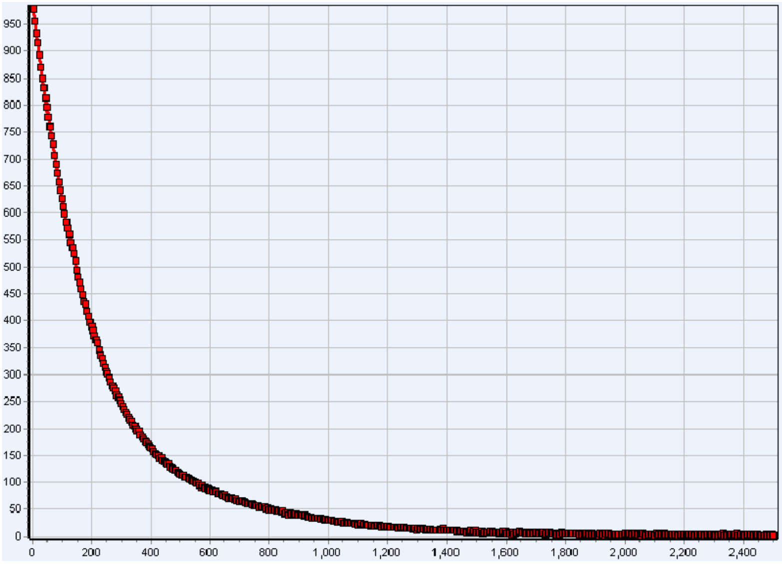


Fig. 1. 16 T2 measurement by CPMG sequence

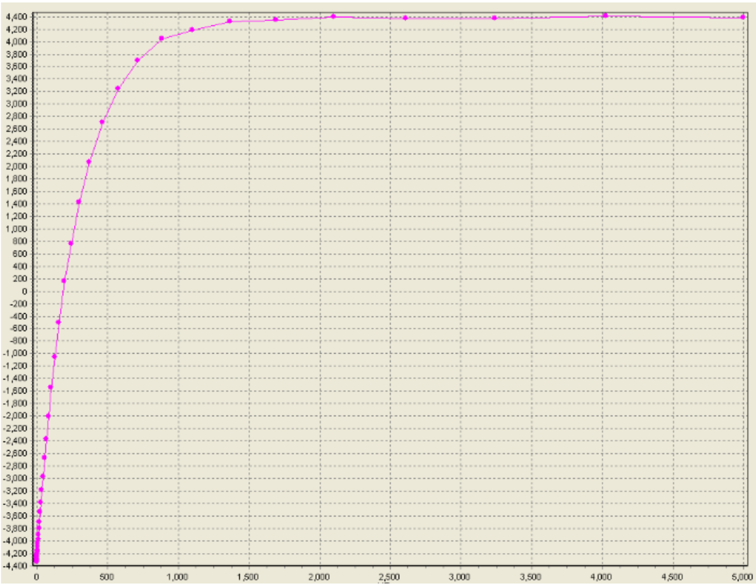


Fig. 1. 17 T1 measurement by IR sequence

1.3.5 Advantages of EDUVMR 2.0

Using the EDUVMR software platform has many advantages including:

- ✓ Perform virtual sequence selection, parameter adjustment, data acquisition, K space filling and image reconstruction function.
- ✓ The influence of magnetic field inhomogeneity and electronic noise can be simulated.
- ✓ Maximize the number of students trained with minimal investment in hardware.
- ✓ Perform fat suppression imaging.
- ✓ Perform water suppression imaging.
- ✓ Perform Half-Fourier scanning &Imaging technique.
- ✓ Overcome the problem of long time of acquisition through inadequate instrumentation.
- ✓ More than four pulse sequences (SE sequences, FSE sequence, IR sequence, GRE sequence)

can be used for virtual imaging data collection.
- ✓ Observe how the scan parameters affect the image.
- ✓ Minimize the impact of gradient eddy current and analog acquisition in severe T2-weighted images.
- ✓ Options in data acquisition (normal speed and very-fast speed).

1.4 NMR/MRI Integrated Experimentation Platform

For effective, efficient, and economic teaching Niumag recommends an integrated system that use 5 virtual systems combined with one actual experimental device.

This 5+1 configuration has the following advantages
- ✓ Quickly create a comprehensive NMR/MRI experiment teaching platform
- ✓ Meet the teaching demands while minimizing device costs
- ✓ Every student can get actual operation experience, without needing to become familiar with a different software interface.
- ✓ Expand teaching and experiment capacity by adding more virtual systems or specialized Niumag hardware systems later.

2. Appendices

2.1 Customer list of Educational NMR/MRI Platform

No.	Customers for educaton purpose
1	Tianjing Agricultural University
2	University of Science and Technology of China
3	University of Shanghai for Science and Technology
4	West China School of Medicine
5	Xi'an Jiaotong University
6	Xiangnan University
7	Xinjiang Medical University
8	Southern Medical University
9	Shanghai Medical Instrumentation College;
10	Qiqihar medical college

11	Capital Medical University
12	Guangzhou Medical College
13	Taishan Medical College
14	Tianjin Medical College
15	Tianjin Medical University
16	Shandong Wanjie Medical College
17	North Sichuan Medical College
18	Bengbu Medical College
19	College of Biological Science and Engineering, Fuzhou University
20	College of Life Science Sichuan University
21	College of Physics and Information Engineering, Fuzhou University
22	Department of Physics in Tsinghua University
23	East China Normal University
24	Fudan Physics Teaching Lab
25	Fudan University
26	Fujian University of Traditional Chinese Medicine
27	Guangdong Ocean University
28	Guizhou University
29	Harbin Engineering University
30	Harbin Institute of Technology
31	HelongjiangBayi Agricultural University
32	Institute of Chemistry Chinese Academy of Sciences
33	Institute of Process Engineering, Chinese Academy of Sciences
34	Jiangxi University of Traditional Chinese Medicine
35	Jilin Business and Technology College
36	Nanyang Technological University, Singapore
37	Ningxia University
38	North University of China
39	Ocean University of China
40	School of Electrical Engineering, Chongqing University
41	Shandong Normal University
42	Shanghai Jiao Tong University
43	Shanghai Normal University
44	SHANGHAI SHENKAI PETROLEUM & CHEMICAL EQUIPMENT CO.,LTD
45	South China Normal University
46	South University of Science and Technology of China
47	Southeast University
48	Suzhou Institute of Nano-Tech and Nano-Bionics(SINANO)
49	Department of Chemistry Fudan University
50	Beijing Institute of Technology
51	BEIJING POLYTECHNIC
52	BOHAI University
53	Nanyang Technological University, Singapore

54	MIT - Massachusetts Institute of Technology, USA

2.2 Publications

2.2. 1Material and Energy

1. 1H-NMR Relaxation and State Evolvement of Evaporable Water in Cement Paste
2 .Effect of Superplasticizer on Transverse Relaxation Time Curve of Cement Paste
3. Application of Composite Insulator Aging Test using Low Field NMR technology
4. Visualization experimental investigations of supercritical CO2 inject into porous media with the fissure defect
5. Determination of Fibre Saturation Point in Wood by Low Field Nuclear Magnetic Resonance Technology
6. Research of Narrow Molecular Weight Distribution Oilgochitosan Modified GD-DTPA MRI Complexes Synthesis Function and Properties
7. Inspect ion and Analysis on the Aging of Sill icone Rubber f or Composite Insulators
8. Low field NMR application in the hydrate formation of THF

2.2. 2Hardware

9. Development of variable-temperature probe using in Low-resolution NMR analyzer
10. Design of active shimming coils on mini-type permanent magnetic resonance imaging system
11. NMR applied research in liquid-solid-liquid interface contact angle measurement
12. Manuscripts Analysis on gender of Silkworms by MRI Technology

2.2.3 Food and Agriculture

13. Characterization of Water State and Distribution in Textured Soybean Protein Using DSC and NMR
14. Study on Solubilization Properties of NPES/AOT ReverseMicelles in Diesel Oil
15. Stabilization of soybean soluble polysaccharide on acidified milk drinks
16. Research on the Change of Moisture State in Rice during Soaking Process by LF-NMR
17. Preparation for Fermented Mineral Beverage from GynostemmaPentaphyllum
18. Effect of microbial transglutaminase on functionality of pork myofibrillar protein gel - a low field NMR method
19. Heat-Induced Gelation of Myofibrillar Proteins as Affected by pH——A Low Field NMR Study
20. Rapid detection of adulterated milk by low field-nuclear magnetic resonance coupled with PCA method
21. Development of Water’s State in Meat and Meat Products

22. Study on quality changes of goat meat under cold storage conditions with NMR
23. Determination of Water Content of Tea by Low Field Nuclear Magnetic Resonance Technology
24. Effect of microbial transglutaminase on NMR relaxometry and microstructure of pork myofibrillar protein gel
25. Study of Water Absorption of Mung Beans Based on Low-field Nuclear Magnetic Resonance Technology
26. Effects of blanching on water distribution and water status in sweet corn investigated by using MRI and NMR
27. Research on the Change of Moisture State in Zongzi during Cooking Process by LF-NMR
28. Study on Detecting Oil Content in Jatropha Curca Seed by Nuclear Magnetic Resonance Technique
29. Influence of Basic Tillering and Panicle Proportion on Absorption and Utilization of Nitrogen in Rice
30. Statistical Analysis for Low Field Nuclear Magnetic Resonance Batch Data of Sweet Corn
31. Optimization of Compound Phosphate Ratio of Water-holding Additive by Low-field NMR with Response Surface Methodology

2.2.4 Contrast Agent

32. Water-soluble super paramagnetic manganese ferrite nanoparticles for magnetic resonance imaging
33. Silica-Coated Manganese Oxide Nanoparticles as a Platform for Targeted Magnetic Resonance and Fluorescence Imaging of Cancer Cells
34. Silica-Coated Manganese Oxide Nanoparticles as a Platform for Targeted Magnetic Resonance and Fluorescence Imaging of Cancer Cells
35. Photosensitizer-conjugated magnetic nanoparticles for in vivo simultaneous magnet fluorescent imaging and targeting therapy
36. Detection of Ab Plaques by a Novel Specific MRI Probe Precursor CR-BSA-(Gd-DTPA)$_n$ in APP/PS1Transgenic Mice
37. One-pot synthesis of amphiphilic super paramagnetic FePt nanoparticles and magnetic resonance imaging in vitro
38. A gadolinium(III) complex with 8-amidequinoline based ligand as copper(II) ion responsive contrast agent
39. Preparation and magnetic properties of cobalt nanoparticles with dendrimers as templates
40. Research of Carbon Nanotubes as Magnetic Resonance Imaging Contrast Agents
41. Synthesis，Characterization and Evaluation of BSA-(Gd—DTPA)n as a MRI Contrast Agent Precursor
42. Preparation of GdIII / Quantum Dots Multimodal Imaging Probes for Disease Diagnosis