

Computational Requirements in NMR Image Reconstruction

Ian J. Curington
Floating Point Systems, U.K. LTD.

INTRODUCTION

Nuclear Magnetic Resonance (NMR) Systems hold promise for providing significant information to the diagnosis of diverse medical conditions. NMR imaging techniques can be used to generate both anatomic and physiologic images. Because entire sections of the patient's body can be scanned at the same time, NMR is inherently three-dimensional. This forces a very large quantity of data upon the processing system. Although future NMR systems may provide direct views of three dimensional structures, commercially viable systems are directed toward two dimensional images. This paper outlines the computational requirements of the reconstruction process.

THE DATA COLLECTION PROCESS

The scanning process takes several minutes due to physical and signal-to-noise considerations. First, body protons are aligned with the axis of the main system magnet. The application of a second field causes proton spin to precess at a frequency directly proportional to the strength of the applied field (termed the Larmor frequency). When the second field is abruptly shut off, the protons emit a radio frequency signal during their decay to the background state. This signal, termed the free induction decay (FID), forms the basis for generating the NMR image. By controlling the strength and timing of the fields at various positions, FID signals are obtained which correspond to specific tissue characteristics. Magnetic field sequences are designed to enhance certain types of fluid flow and proton density.

The NMR magnet, signal sources, power supplies and control systems, provide the environment for the scanning sequence through the subject. As the magnetic field is varied, signals are captured by the radio frequency antenna. After detection by the antenna coils, the input signal is frequency shifted before being digitized. The result of this process is a sequence of complex numbers representing a line through the volume. The system scans through the body tissue, collecting data over an axis of interest, sending data to the reconstruction process.

NMR PROCESSING SYSTEM ARCHITECTURE

A typical NMR processing system consists of a general-purpose minicomputer with attached subsystems dedicated to the functions of data collection, reconstruction, analysis, and display. The reconstruction and analysis processor is typically an Array Processor (AP), such as the Floating Point Systems FPS-5000. The minicomputer controls the flow of data through the system, including an image library on a magnetic disk. Any tasks that involve intensive calculations such as image reconstruction and analysis, are carried out in the AP.

COMPUTATIONAL REQUIREMENTS

The computational phase consists of data collection, image reconstruction, and image analysis. These are performed sequentially or overlapped, depending on the structure of the processing system. The data acquisition system collects phase-frequency format data, thus requiring Fourier Transforms to generate images. Two dimensional Fast Fourier Transform (2-D FFT) algorithms are used for optimal efficiency. The sequence of operations is given below:

- Phase 1.
1. Frequency Shift and A/D Conversion
 2. Weighted Average Over N Data Lines
 3. Noise Filter
 4. Row FFT's and Interpolation

- Phase 2.
5. Intermediate Data Storage (Disk)
 1. Column FFT's and Interpolation
 2. Magnitude Evaluation Function
 3. Image Enhancement and Scaling for Display
 4. Processed Image Library Storage (Disk)
 5. Image Analysis and Display

The elapsed time between successive scans is approximately 20 milliseconds due to proton relaxation and stability of the magnetic field. The reconstruction process is divided into two phases. The first can proceed during the data acquisition interval; the second must be delayed until all data from one scan has been acquired. The first phase of image reconstruction includes averaging (to improve the signal to noise ratio), scaling (to remove sensor bias), noise filtering, row FFT's, and intermediate data storage. Once the first line is digitized, the first phase of reconstruction can begin and continue while subsequent lines are acquired.

The second phase of reconstruction must wait until the complete slice is buffered in intermediate storage, as the second pass in the 2-D FFT requires access to data in column order. Reading the data back from storage, column FFT's with interpolation are performed, followed by scaling to display format and storage in the processed picture library. Once the scan and reconstruction processes are finished, the operator can display, compare, and analyze the stored images. Typical analysis operations vary, but may include ratios, multipliers, contrast enhancement, volume, area, and contour measures.

COMPUTATIONAL ANALYSIS

To estimate the total time required for image reconstruction on a given computer system, or to determine the performance needed to achieve a given response time, the total number of arithmetic operations are totaled. The number of floating point additions, multiplications, divisions, and square-roots is approximated with image resolution as:

Samples/Line	Image Size	Operation Count
256	256	4,200,000
512	512	18,000,000
1024	1024	77,000,000

As roughly half of the operations occur in each of the two phases, AP performance of at least one million floating point operations per second (MFLOPS) is required to overlap the first phase with acquisition (at 512 point resolution). In systems with performance exceeding 4 MFLOPS, the ability to efficiently retrieve data from intermediate storage becomes critical. With modern winchester disks and an 18 MFLOP AP, reconstruction times of 4 seconds per slice (at 512 point resolution) are possible.

CONCLUSION

Identifying the algorithms required for NMR image reconstruction is the key to selecting processing equipment and for estimating processing times in new systems. The demand for higher image quality will force computational complexity to grow. The analysis shown here forms the minimum required functions in the design of new systems and for the evaluation of commercially available NMR imaging systems.

REFERENCES

- [1] NMR Image Reconstruction with the FPS-5000 Series Distributed Array Processor. CHECKPOINT Vol 2, No 1, January 1984, Floating Point Systems, Portland Oregon.