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Microtomography with 3-D Visualization

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ABSTRACT

A facility has been developed for producing high quality tomographs of order one micrometer resolution. Three dimensional volumes derived from groups of adjacent tomographic slices are then viewed and navigated in a stereographic viewing facility. This facility is being applied to problems in geological evaluation of oil reservoir rock, medical imaging, protein chemistry, and CADCAM.

Keywords: microtomography, tomography, visualization, stereographic display, 3D, x-ray imaging, synchrotron light

OVERVIEW

Staff at Brookhaven National Laboratory, in collaboration with researchers at GTE Government Systems and Mobil Oil, have developed a facility for producing high quality tomographs on the order of one micrometer resolution. This facility is based on data collected from the x-ray ring at Brookhaven's National Synchrotron Light Source. Three dimensional volumes derived from groups of adjacent tomographic slices are then viewed and navigated in a stereographic viewing facility.

The initial application of this facility has been for geological evaluation of oil reservoir rock. Other applications are on the horizon, especially for the visualization subsystem. They are in the areas of medical imaging, protein chemistry, and CADCAM.

The conceptual design of the system is shown in Figure 1.

EXPERIMENT CONFIGURATION

The National Synchrotron Light Source operates an X-Ray Ring and a VUV (Vacuum Ultra Violet) Ring. X-Ray, ultraviolet and infra-red radiation from the storage rings is guided into over 83 beamlines, or experimental stations, where it is used in many fields of research. Microtomographs for this effort were produced using beams of radiation in the x-ray spectrum. The very high flux of x-rays delivered to the target by the Light Source makes possible rapid tomographic measurements with micrometer resolution.

To obtain data for a reconstructed slice, the x-rays transmitted through a single slice of the sample are recorded on a linear array of detectors. The sample is rotated, with the axis of rotation perpendicular to the plane of the incident beam, by a discrete angular interval determined by the linear resolution. The transmission of each ray through the sample, along a line from the source to the detector is recorded; the detected signal is proportional to a line integral of the attenuation coefficients along this ray. The procedure is repeated for each angular view until the sample has been rotated by 180 degrees in the x-ray beam.

The apparatus incorporates a cooled charge-coupled device (CCD) camera with 1317x1035 pixels, Kodak's KAF-1400 chip. Each row of pixels constitutes one linear detector array and provides the data to reconstruct one 2-D slice of the sample. The CCD records the data to reconstruct over 1000 horizontal slices simultaneously. Instead of detecting x-ray transmission directly onto detectors, which would limit spatial resolution to the detector size, a thin high-resolution YAG scintillator placed behind the sample converts each x-ray attenuation map to a visible image, which is then magnified and reimaged with conventional optics onto the CCD array.

The use of imaging optics allows the flexibility to make a simple lens change and view larger samples with lower magnification, as desired. To date, a continuously variable .75x to 3x lens, a 4x lens, and a 10x lens have been used to collect data from various samples, ranging in size from .5 to 12mm. To protect the camera optics and detector array from direct exposure to x-rays, the camera is positioned at 90 degrees to the incident beam. The visible image produced by the scintillator is then folded into the camera by a flat mirror, as shown in figure 2.

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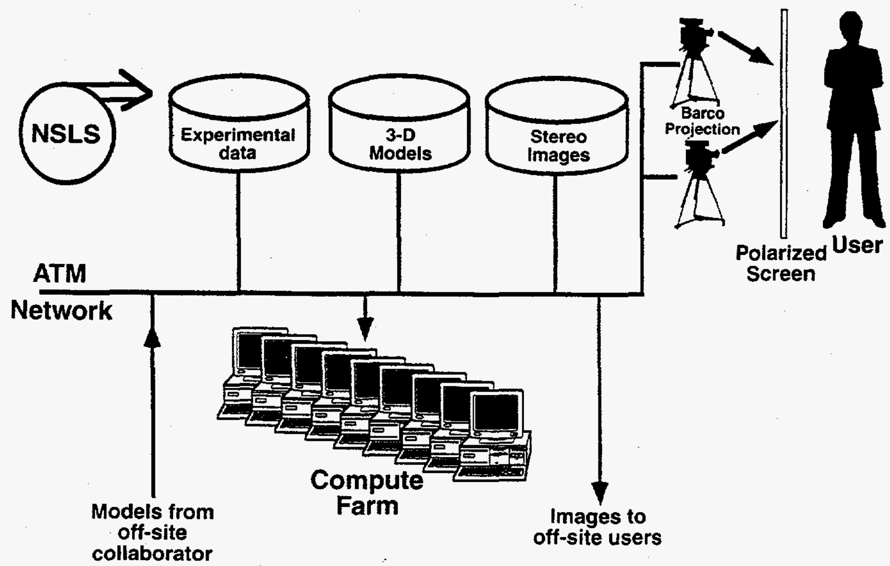

Figure 1. Visualization Facility: Systemic View

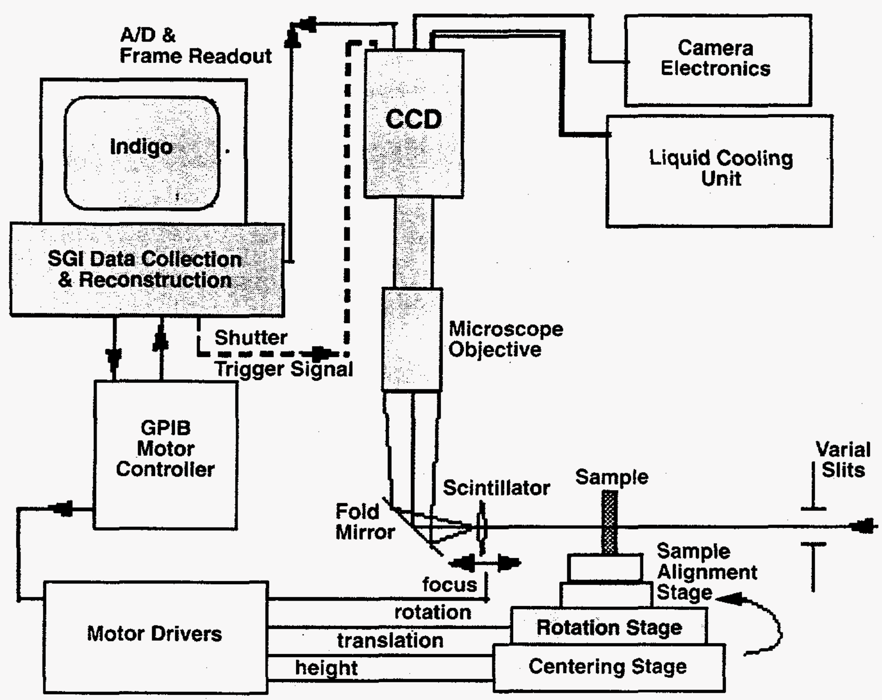

Figure 2. Microtomograph Experimental Apparatus

DATA ANALYSIS AND PROJECTION

Referring to figure 1, the data collected at the NSLS Beam Line is processed in the following steps. The data is first normalized against a known background "white field". Median filter codes are used to remove the effect of noise spikes in the raw data. A "sinogram" of the data, which is a plot of intensity versus projection angle, is then produced. The sinograms are then corrected to align the axis of rotation with the center pixels. The result is processed using a filtered back-projection algorithm, which produces over 1000 tomographic image slice. Resolution is currently on the order of 1 micrometer. The backprojection algorithm used is the one provided by the RecLBL program, graphical representation and volume rendering is performed with standard visualization software.[1,2]

Three dimensional volumes derived from adjacent tomographic slices are then viewed and navigated in a stereographic viewing facility. The display system is driven by a Silicon Graphics Reality Station with a single CPU and Reality Engine, two Raster Managers, and a Multi-Channel Option to create dual viewports. The stereo effect is achieved in a conference room setting by projecting two polarized images using high resolution, high brightness, digital projectors with low-persistence phosphors. The image is projected on a specially designed 10 foot (diagonal) screen, which is treated to retain light polarization, then viewed through ordinary polarized glasses. The image that is produced appears to be in the room with the viewer with a striking degree of realism. The system was designed for ease of replication and high-speed network interaction so that the visualization can occur at several locations simultaneously by collaborative teams.

There are several advantages of this time-parallel approach over the more common time-multiplexed method used for stereo viewing. On a cost basis, while the initial investment may be greater because of the need for two projectors; this is compensated for by the extremely low cost of the lightweight polarizing glasses, which makes possible a large audience in a room-sized facility. This system offers twice the screen resolution of time-multiplexed systems because two full screen left and right eye images are drawn with 1024 lines each. The three-dimensional sensation appears to be superior to that of time-multiplexed system, in that the image is brighter and more vivid, and appears situated directly in front of the viewer, hovering in space. Finally, because two normal display windows are drawn, it is possible to do `real time' stereo modeling from within an application, without resetting the monitor during the viewing session. To provide further flexibility, the system can be configured to run a single projector in the usual time-multiplexed manner for applications that are already `stereo enabled' in this

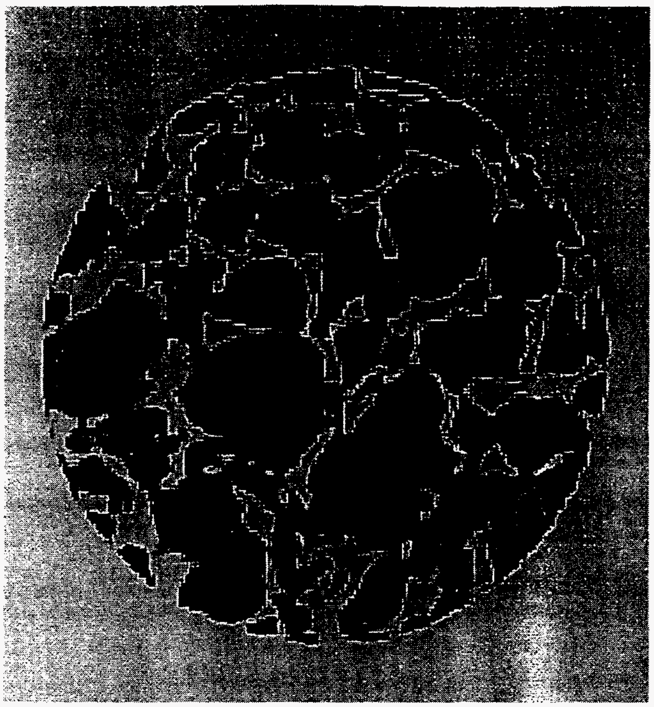

Figure 3. Microtomograph of Reservoir Rock

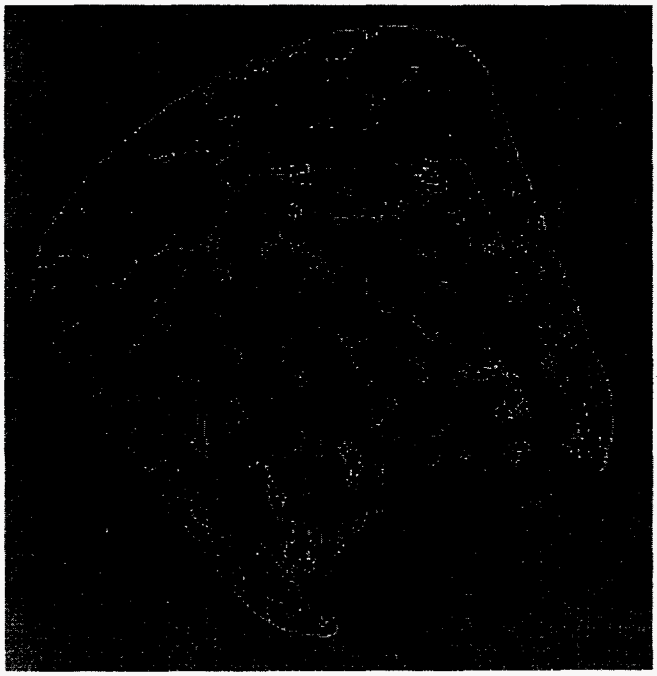

Figure 4. 3-D Image of Reservoir Rock

modality; however only a limited number of goggles would be available for viewing in this case.

Among the application tools currently used are the Silicon Graphics Inventor/Performer suite, and IBM Visualization Data Explorer (DX). Performer provides a real-time rendering library optimized for the graphics hardware. Data files must first be prepared in a 3D object file format such as Inventor. The 3D scene graph is controlled by a trackball with function keys for fine adjustments. Frame rates of up to 30 frames per second are easily achieved for polygon counts of up to 250,000 triangles.

DX provides an extensible, modular programming environment in which programs are constructed as visualization networks via a Motif-based GUI. Three dimensional animations can be edited in stereo using the DX Visual Program Editor.

APPLICATIONS

Determination of the macroscopic properties of porous materials has been a long-standing problem of great interest to the oil industry. Synchrotron X-ray computed microtomography has been utilized to determine structural characteristics and fluid flow within reservoir rock.[3] Visualization apparatus of a quality sufficient to display and lend insight to this data and relate it to the relevant theoretical analyses, both on microscopic and larger scales, provides a firm foundation for studies in oil reservoir management. This technique has been applied with considerable success to reservoir rock core samples and work is currently underway to perform analogous analyses on seal rock, whose porosity is several orders of magnitude smaller, thus presenting a far greater challenge in terms of fineness of resolution. A microtomogram of reservoir rock appears in Figure 3. A three dimensional rendering of a core sample appears in Figure 4.

Originally designed for the geoscience applications, the visualization facility also promises to demonstrate its usefulness in other diverse scientific applications.[4] It appears to be a useful tool in analyzing three-dimensional representations of molecules from Brookhaven's Protein Data Bank, which is a repository of protein molecules referenced world-wide.[5] It has also shown value in projecting 3D images of a large nuclear physics detector called Phenix, currently in design, which will be used to gather massive amounts of data from a particle accelerator called the Relativistic Heavy Ion Collider. Finally, the technology appears most promising in medical imaging, and is being investigated for use in co-registration of structural and dosage images in a Boron Neutron Capture Therapy facility.[6]

SUMMARY AND FURTHER WORK

This system is already beginning to show its value in lending insight to a variety of scientific investigations. In addition to its scientific value, the system has had considerable impact in technology demonstrations, and has also been one of the more popular and entertaining scientific facilities. Further work will center on three critical areas. Greater computer power and interconnect bandwidth must be applied to perform real-time manipulation of graphic images whose size can approach 4 Gigabytes. Instrumentation and display improvements are needed to increase the resolution of the images into the sub-micrometer range. And techniques such as head-tracking and multi-wall projection must be incorporated to improve the fidelity and immersive effect presented to the viewer. All of these improvements are either in progress or in the planning stages at this time.

REFERENCES

1. Herman, Gabor T., Image Reconstruction from Projections, Academic Press, 1980, pp 90-107.

2. Huesman, R. H., Gullberg, G. T., Greenberg, W. L., Buddinger, T. F., RECLBL Library Users Manual, Lawrence Berkeley Laboratory, University of California, 1977.

3. Coles, M. E., Spanne,P., Muegge, E. L., and Jones, K. W., ``Computed Microtomography of Reservoir Core Samples'', presented at the 1994 Symposium of The Society of Core Analysts, Stavanger, Norway, Sept. 1994.

4. Jones, K. W., Peskin, A. M., Siddons, D. P., Andrews, B. and Dowd, B., ``The BNL Geoscience X-Ray Imaging Project (GXRIP)'', presented at the 1996 Spring Meeting of The American Geophysical Union, Baltimore MD, May 20-24, 1996

5. Abola, E., Manning, N., Prilusky, J., Stampf, D., Sussman, J., ``The Protein Data Bank: Current Status and Future Challenges'', Journal of Research of the National Institute of Standards and Technology, Vol. 101 No. 3, 1996

6. Selcow, E. C., Capala, J., Andrews, A. B., Wheeler, F. J., Peskin, A., ``A Methodology for Evaluating the Efficacy of the Radiation Therapy of Brain Tumors Using Multi-Modality Imaging'', presented at the 38th Annual Meeting of the American Association of Physicists in Medicine, Philadelphia PA, July 21-25, 1996