47

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Title: A PORTABLE 3-D COMPUTED TOMOGRAPHY SYSTEM

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A PORTABLE 3-D COMPUTED TOMOGRAPHY SYSTEM

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Abstract

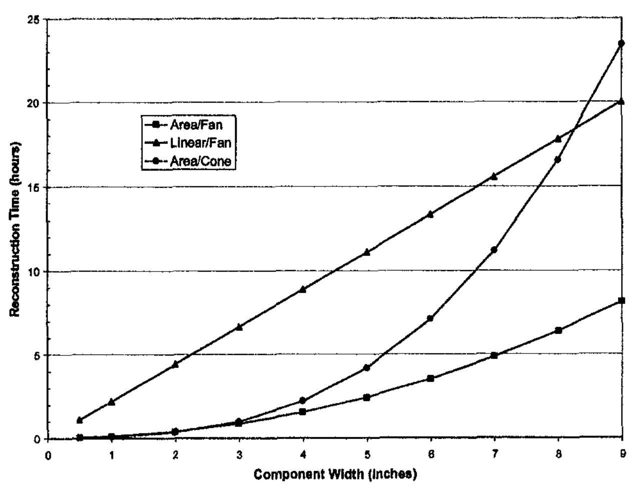
Through a Cooperative Research and Development Agreement between Los Alamos National Laboratory and HYTEC, Inc., a portable 3-D Computed Tomography (CT) system has been developed that dramatically reduces the overall complexity and time-to-completion for performing CT studies. The system incorporates an amorphous silicon flat-panel detector, coupled motion control and state of the art software to produce high quality CT results. All alignment, image calibration and radiation exposure monitoring is handled in software, thereby, eliminating the need for precise mechanical positioning during setup or a highly stable source of radiation. The image acquisition hardware occupies a minimal 30" X 48" footprint and is mounted on a portable cart for transportation between multiple X-ray sites. The software is built on the Windows NT/2K operating system for maximum flexibility in today's industry, and offers an unprecedented user interface designed for technicians and operators who have minimal computer training. Multiple reconstruction methods (parallel, fan and cone beam) are provided and can be run in a parallel-processed mode on any number of Windows NT/2K computers to decrease reconstruction time. Visualization software offers 2-D and 3-D viewing including slice animation and volume rendering of entire objects.

Introduction

Radiographic testing facilities at Los Alamos National Laboratory (LANL) are comprised of numerous shielded radiation bays spread across the 43 square mile complex, X-ray sources ranging from 160 kV microfocus to 20 MeV accelerators, neutron sources and various amorphous silicon and image intensifier detector packages. Inspectors are faced daily with a wide range of applications that often require multi-modality testing approaches to solve. In 1998, LANL decided to add 3-D computed tomography to its NDE arsenal but realized that choosing a single system platform would not afford the flexibility required to address the full range of applications they encounter. A Cooperative Research and Development Agreement (CRADA) was formed with HYTEC, Inc. to develop a portable 3-D computed tomography system based on a few underlying design philosophies. First, the system was to exclusively utilize commercial-off-the-shelf (COTS) hardware, which could be easily upgraded as better and faster components, became available, and highly scalable to handle unknown future applications. Second, the system needed to be compact enough to be transported between X-ray bays, work with any available X-ray or N-ray source and require minimal mechanical setup and alignment to reduce overall operational complexity. Third, the system software had to be intuitive and easy to use for line technicians, yet incorporate enough options to handle all applications.

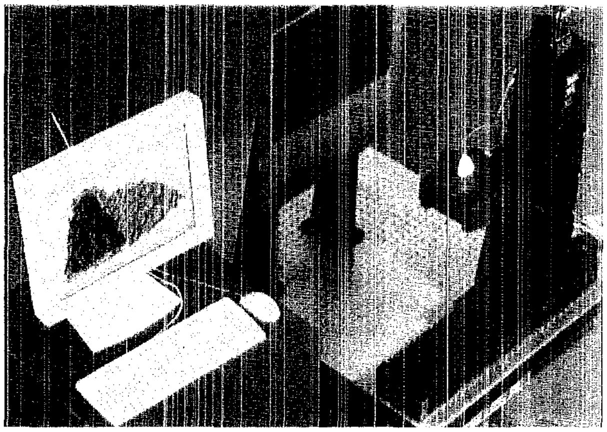
System Design

One of the first design elements, which had to be decided upon, was the choice between a traditional linear array approach and an area detector. The advantages of linear arrays include good high-energy sensitivity, high dynamic range (16 bit digital data) and improved resistance to scatter. The advantages of area detectors include faster volumetric data acquisition, better Z dimension resolution (linear arrays are generally taller than they are wide) and a simpler projection radiographic imaging process. Figure 1 shows a simulated comparison of total acquisition and processing time between an area detector utilizing both fan beam and cone beam reconstructors, and a linear array. The analysis is based on a 6-inch high component and assumes that full radial sampling is met by acquiring one



projection per pixel of width (e.g., a 3 inch part projected 1:1 on a detector with 0.005" pixels will be 600 pixels wide and, therefore, require 600 radial projections). The linear array is assumed to run at 30 frames per second and the area detector at 1 frame per second. Both the linear array and area detector simulations assume the data is reconstructed on a single 1.7 GHz CPU. The cone beam reconstruction is simulated using a 16 machine cluster of 1 GHz processors. The linear array results assume that the previous slice is reconstructed while the next slice is being acquired, and as such, are dominated by acquisition time. Conversely, area array results are dominated by reconstruction time since all data is acquired in a single rotation of the component before reconstruction begins. In general this analysis shows that the area detector approach is faster for small to moderate sized components. Even when the component aspect ratio is high requiring cone beam reconstruction, utilizing a computing cluster and parallel process algorithms, the total time to acquire and reconstruct the data is on the order of the time required by a linear array approach. Additionally, since the reconstruction process is performed after data acquisition and can be run as an unattended batch operation while operators are off-shift or performing other work, the cost of labor is reduced.

Figure 2 shows a photograph of the 3-D CT system implemented at LANL. The design incorporates a dpiX FlashScan 30 amorphous silicon flat panel imaging plate and high-resolution manipulator mounted on a breadboard atop an electric lift cart.



LANL was one of the first organizations to begin experimenting with amorphous silicon, flat panel, digital detectors developed at Xerox (dpiX) and now manufactured by Varian. The design of these detectors offer excellent operational flexibility by accommodating scintillator changes and allowing complete control over the frame integration time via external TTL signals. LANL has employed these detectors on numerous DR applications (microfocus, megavolt and neutron radiography) and found them to be portable and durable. Their compact packaging, lightweight and commercial availability made them an ideal candidate for the portable 3-D CT system.

Since the intent of this system was to utilize any available radiation source, the decision was made not to integrate source control with the CT system. This raised the issue of how to best work with unstable sources of radiation to ensure each image had received the proper dose. The data acquisition system was designed with a radiation monitoring feature whereby a predefined region of each image is evaluated against a user defined tolerance band. If the digital image values are within tolerance, the acquisition process continues as normal, if the source has failed causing the digital values to fall outside of the tolerance band, the exposure is repeated until acceptable. The data in this region is also used to determine the incident radiation on a per image basis for calculating the attenuation image needed for CT reconstruction. This open loop approach ensures accurate attenuation data without requiring communication with the radiation source.

Emphasis towards COTS hardware drove the design of the manipulator system. A Galil motion controller, IDC drives, stepper motors and translation hardware were chosen due to their high precision, reliability and commercial availability. However, after considerable use in high radiation an unexpected observation was made. The standard petroleum based lubricant was breaking down and actually gumming up the bearings and slides. By switching to a carbon based lubricant this problem was resolved and the positioning hardware has functioned well for many hours.

Given that the system was required to work under a wide range of radiographic setups, it was not feasible to implement only a single reconstruction method that would work in all situations. The system software was implemented with parallel, fan and cone beam reconstruction algorithms to address this problem. For many high-energy applications, the radiation source has enough output that the source-to-detector distance can be reasonably made 6-10 feet, and still accommodate frame integrations on the order of 1-3 seconds. For objects up to 16 inches in diameter (the maximum width of the amorphous silicon detectors) accurate results can be achieved with the parallel or fan beam reconstructors which offer $O(n^2\log(n))$ speed. However, for high magnification microfocus applications, the cone beam reconstructor delivers better spatial accuracy but at the cost of speed since this algorithm is an $O(n^3)$ problem. The ability to easily choose any of the available reconstructors on any data set, in addition to subsampling the input data allows the end-user to perform extremely quick single slice and sub-volume reconstructions for preliminary evaluation and then batch process the reconstruction at full resolution.

For use as a portable system, it was necessary to devise a mechanism for quickly and easily establishing alignment of the source focal spot to manipulator center of rotation and image centerline. Numerous concepts for mechanically and optically aligning the system were considered but not selected in the final design due to the time and complexity to perform the operation. The simplest approach was determined to be a complete software solution whereby the operator is given the ability to remotely manipulate the component in front of the detector, crop the input projection radiographs to a region of interest, and automatically determine the correct center of rotation on an image-by-image basis from an analysis of the sinogram. This approach proved to be the most efficient, accurate and repeatable process for quickly setting up and determining the necessary alignment parameters for CT reconstruction.

Finally, since it was anticipated that large reconstructions would be common for LANL applications, the system was also designed to take advantage of multiple computers linked via a local area network or across LANL's intranet. Computing power is becoming an increasingly affordable resource so LANL purchased a bank of ten Pentium III, 500 MHz computers, each with 256 MB of RAM and a 100-Base-T Ethernet card. The total cost of this computing cluster was less than $10,000 and provided order of magnitude improvements in reconstruction time.

Conclusions

A portable, 3-D computed tomography system has been developed for use at Los Alamos National Laboratory, which offers NDE engineers a powerful tool for volumetric imaging of internal structures and complex assemblies. The system can be easily transported, works independently of the source of radiation, can be operated in multiple configurations (parallel, fan or cone beam) and can be highly parallelized to reduce the data processing time of large components.

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