

COBRA: CONE BEAM COMPUTED TOMOGRAPHY (CT)

RECONSTRUCTION CODE IN INTERACTIVE DATA LANGUAGE (IDL)

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INTRODUCTION

In support of stockpile stewardship and other important missions, Los Alamos is continually looking for fast and effective ways of inspecting and evaluating industrial parts. Thus, Los Alamos is continually striving to improve our radiography and computed tomography (CT) capabilities. Cormack [1] and Hounsfield [2] received the Nobel Prize in 1979 for their pioneering work in computed tomography that led to the development of medical scanners. Copley et al. [3] provides a good history of the development of industrial CT systems. The early systems collect data via a single detector or linear detector array. While CT offers greatly increased spatial resolutions over radiography, CT inspections with a linear array are slow and costly. To improve the viability of CT for NDT applications, Feldkamp, Davis, and Kress [4] reported a cone beam reconstruction technique that speeds up the CT process by using image data rather than data collected by a linear array. Because it potentially offers processing speeds up to 10 times faster than CT systems that use a linear array, we are building a cone beam CT for use with our 20 MV x-ray source and Los Alamos Neutron Science Center (LANSCE) neutron sources. Our software, called CoBRA, is a portable cone beam reconstruction code for CT applications that efficiently and rapidly reconstructs large data sets. CoBRA applications include both x-ray and neutron inspections using x-ray phosphor screens coupled to either a CCD camera or flat-panel amorphous silicon arrays. Photographs of two amorphous silicon arrays (128 x 128 and 1600 x 200) are shown in Figure 1.

Speed and efficiency were key design components built into the software along with the cross-platform portability offered by CoBRA's Interactive Data Language (IDL) coding. We chose to develop CoBRA in IDL not only because of its portability between IBM-PC, Mac, and UNIX platforms, but also because it provides convenient debug and graphics-handling capabilities that promote rapid code development. Because CoBRA is well documented and easy to use, we plan to make the resulting software available via a Web page for free (but unsupported) distribution to the NDT community.

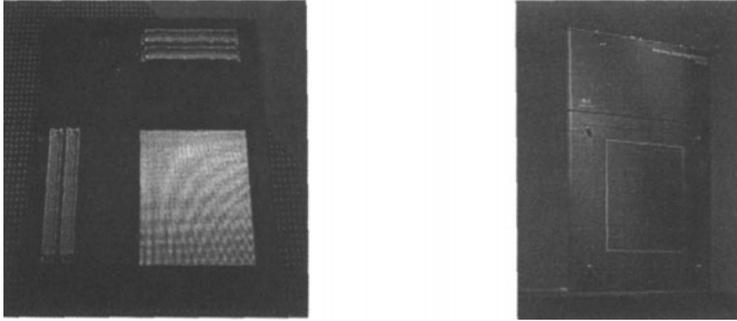


Figure 1. A 128 x 128 amorphous silicon detector array (left) and a 1600 x 2000 amorphous silicon detector array used to take Cone Beam Radiographs from both x-ray and neutron sources.

CoBRA's execution time is proportional to n , the total number of pixels in all the input images. To reduce execution time (a common issue when writing codes in interpreted languages), we calculate trigonometric relationships before back projecting the data into the reconstruction volume and reduce the back projection operations to simple additions. We also use the geometric properties of a cubic reconstruction volume to speed up code execution. CoBRA enables us to reconstruct a full three-dimensional volume from 72 images in only 40 minutes on a 166 MHz Pentium computer, where each input image consists of 128 x 128 pixels and where the reconstruction volume is 128 cubed voxels. We save the calculated trigonometric relationships for use with other data sets using the same experimental setup.

CoBRA DEVELOPMENT

Cone beam reconstructions follow three basic steps: capture images at several known angles, filter the images, and back-project the filtered images at the angles of capture.

For CoBRA, during step one, the images are captured at $360/4n$ equally spaced angles where n is an integer ≥ 1 . Step two filters the data using the RamLak, Sheep Logan, Hamming, or LP Cosine filters. During step three, CoBRA performs an ordinary back-projection, and, for each pixel on every image, a ray must be calculated from that pixel on the detector, through the reconstruction volume to a point source (Figure 2). The pixel value is added to each voxel intersected by the ray. This step involves the evaluation of several trigonometric expressions for each pixel.

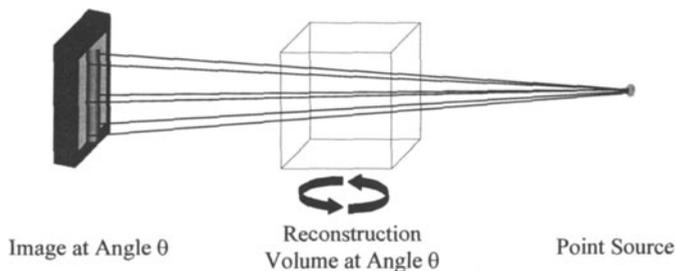


Figure 2. Back-projecting filtered images at the angles of capture.

To speed up the back projection, CoBRA first evaluates all the trigonometric equations required for one horizontal component of pixel traces (Figure 3a) and one vertical component of pixel traces (Figure 3b) rather than all the individual pixels. This information is stored on the hard drive and is reused for all CT scans that use this geometry, thus saving the calculation time in subsequent scans. The horizontal and vertical pixel traces are used to calculate which pixels are added to each voxel. As a result, only simple addition is needed in the voxel-filling stage, greatly reducing reconstruction time (Figure 4). We also use the geometry of the cubic reconstruction volume to speed up the back projection.

The input data consists of an array of 128 x 128 pixel filtered sinograms. An additional program reads in 16-bit 128 x 128 pixel images and converts them into this array. The 128 x 128 pixel limit is only temporary and will be removed once CoBRA begins distribution.

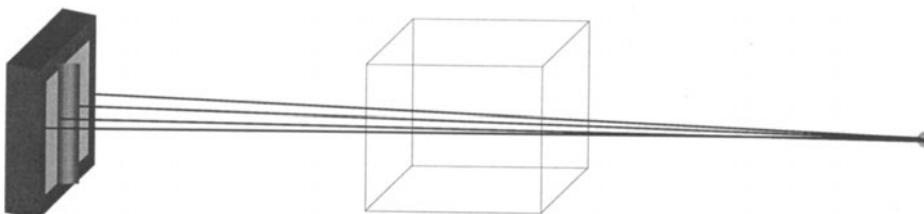


Figure 3a. Horizontal component of pixel traces.

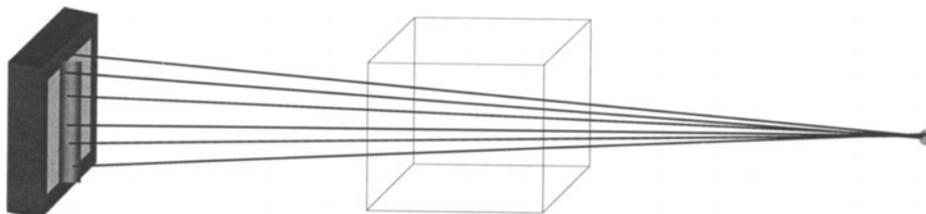


Figure 3b. Vertical component of pixel traces.

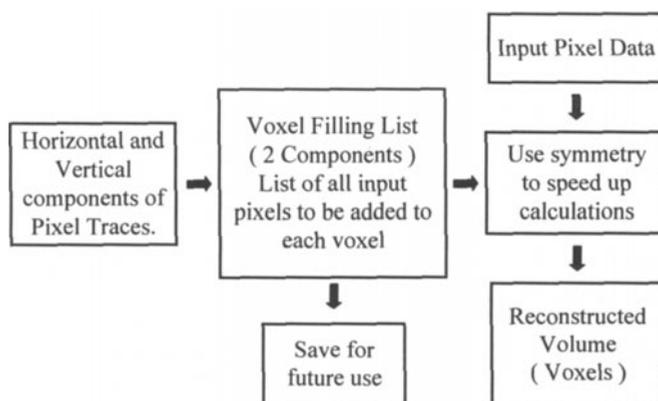


Figure 4. Reconstruction algorithm.

RESULTS

Several test pieces have been reconstructed using CoBRA. In the first test, we radiographed a Microsoft computer mouse (Figure 5a), collecting 72 angles worth of data, and then reconstructed it (Figure 5b) using CoBRA. The radiographs were taken on a 450 KV x-ray source using the 128 x 128 pixel amorphous silicon detector array. The ball, wiring, and rollers can be seen clearly in the Isosurface display.

In the second test, we radiographed an iron step wedge (Figure 6a shows a sample radiograph) and reconstructed it (Figure 6b) using CoBRA. These radiographs were captured on a 6 MV x-ray source (Scanditronix M22 Microtron). A CCD camera was used to capture the images at 1024 x 1024 pixel resolution, which were then resized to 128 x 128 pixels. We used a Spectra Source Instruments CCD camera, Model MCD1000, which operates with a Tektronix TK1024 CCD chip. The steps are clearly visible in the resulting Isosurface rendering.

In the third test, we radiographed a brass phantom (Figure 7a), a piece of polished brass with three empty drilled holes and two drilled holes filled with epoxy. We used the 1536 x 1920 pixel amorphous silicon detector array to capture the radiographs (Figure 7b), taking again 72 angles worth of data. We then used a $5.0 \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$ neutron beam at LANSCE to expose the radiograph. Finally, we resized the radiographs to 128 x 128 pixels. The reconstruction (Figure 7c) shows the epoxy-filled holes of the brass phantom as bright spots inside the disk. The dark spots are the empty holes, and the bright spots at the bottom of the disk represent the plastic base, which heavily scatters neutrons.



Figure 5a. Computer mouse radiograph.

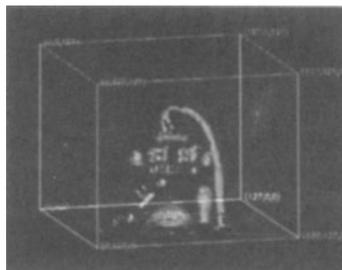


Figure 5b. Isosurface of a reconstructed computer mouse.

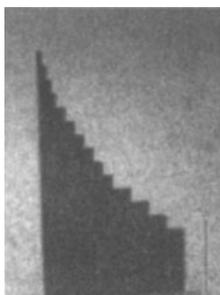


Figure 6a. Iron step wedge radiograph.

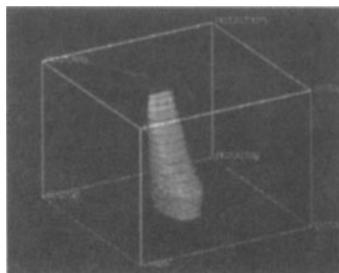


Figure 6b. Isosurface of a reconstructed step wedge.

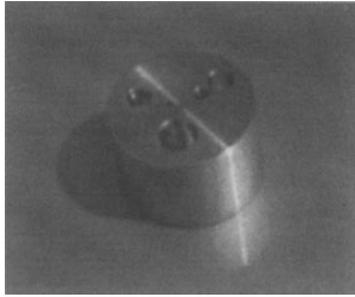


Figure 7a. Brass phantom.

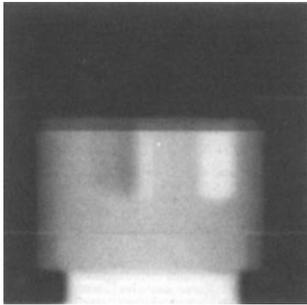


Figure 7b. Neutron radiograph of the brass phantom.

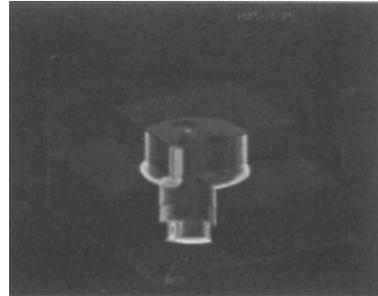


Figure 7c. Sliced volume rendering of the reconstructed brass phantom.

PERFORMANCE

A 128 x 128 x 128 pixel volume with 72 input images takes approximately 45 minutes to reconstruct on a Pentium Pro 200 with 128 MB of memory. However, a system this powerful is not needed to perform successful reconstructions. CoBRA was designed to run using less than 10 MB RAM. Processing time is decreased with greater amounts of RAM. In order to make it possible to reconstruct large volumes, all I/O is conducted to and from the hard drive, making the processing algorithm slower than it might otherwise be.

INTERFACE

CoBRA supports a friendly user interface (Figure 8) written with IDL's widget libraries. The interface is project-based, so the geometry calculations for similar test objects can be used repeatedly if necessary. Additionally, the interface is consistent in any IDL environment and across the above-mentioned platforms. The interface also provides time and status indicators as to how long the reconstruction will take.

AVAILABILITY

CoBRA will be made available for distribution via the Web at <http://www.nde.lanl.gov/cobra> for non-commercial applications. The most up to date distribution is available at <http://www.nde.lanl.gov/cobra>.

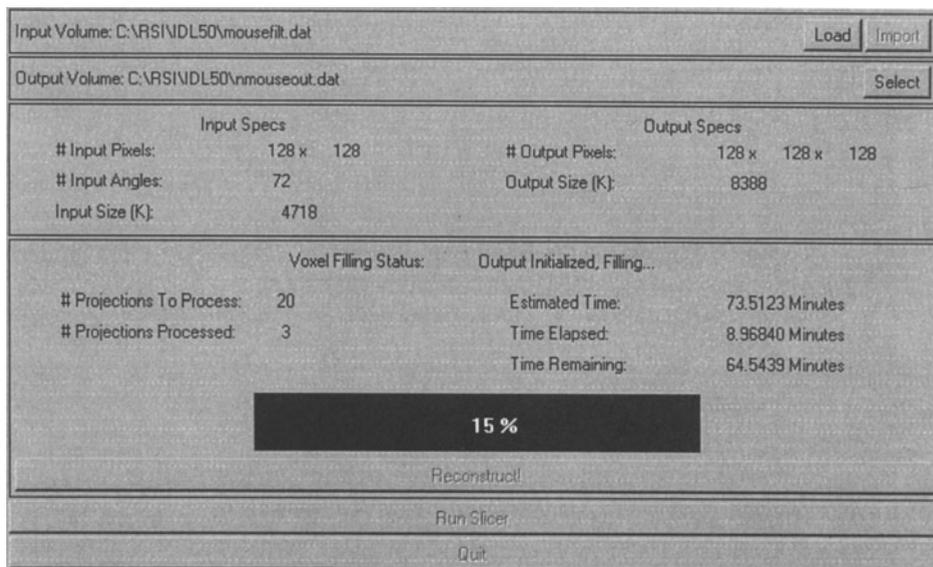


Figure 8. Project data entry screen.

FUTURE WORK

We plan to make several enhancements to CoBRA in the future, including accelerating processing times by making more efficient use of data. We will also test CoBRA's precision and will modify the code to ensure accurate measurements. By adding an import wizard, we hope to allow users to process data arrays in any size and in a number of different formats. Finally, we are considering adding a port to C++ to enhance speed.

CONCLUSION

CoBRA provides a cross platform method of performing cone beam CT reconstructions, includes a user friendly interface, and can perform large reconstructions with minimal computer hardware requirements. CoBRA will soon be freely available to the public for testing.

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