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DYNAMIC TESTING Los Alamos

Image Analysis for Dynamic Weapons Systems

Introduction

Image processing and analysis in support of the nuclear weapons research and development program have been pursued at this laboratory for more than a decade. In M Division, radiographs of various sizes are produced by PHERMEX—a pulsed, high-energy x-ray source—as part of dynamic explosives experiments. The fundamental mission of our image analysis is to quantify the dynamic behavior in the radiographed object to determine the positions of surfaces and to provide both a qualitative visual perception of the distribution of the materials and a quantitative estimate of the material densities. The techniques used to fulfill this mission are edge localization and x-ray computed tomography. These techniques are based on the assumption that the object has axial symmetry, which is characteristic of many of the objects radiographed at PHERMEX and elsewhere. The edge localization technique uses a physical model of the object, incorporating the radiographic system, to estimate parameters that describe the positions of the object's surfaces and material densities. The other technique, x-ray computed tomography, provides both a qualitative visual perception of the distribution of the materials and a quantitative estimate of the material densities in the object.

Radiographic Recording System and Analysis Hardware

To make the radiographic films of the static and dynamic experiments computer compatible, we digitize them on Perkin-Elmer flatbed microdensitometers. A microdensitometer converts the film density into 10 bits (which gives a film density range of 0-5 density units) for each 200-μm-square picture element (pixel). A typical digitized radiograph consists of a 1300×1300 array of pixels. A film pack may contain from one to a dozen or more registered films for a given experiment because each film captures only a small portion of the incident x-ray flux. Experiments have been conducted to increase film efficiency by averaging the digitized images from up to 20 registered films. The images on each developed film are similar (Figs. 1a and 1b), but the grain noise is different and nearly independent. When the films are digitized and the averaging complete, the result is a greatly reduced image noise. This is dramatically shown by comparing Figs. 1a and 1b with the averaged image in Fig. 1c, where 20 registered films of a step wedge are used to reduce the image niose by approximately $\sqrt{20}$.

To analyze the composite radiographs, we use software tools on an integrated network of computers and image display hardware. Typically the software tools are on a Digital Equipment Corporation VAX 11/780 or a CDC 7600; the display and some additional analysis are carried out on a COMTAL Vision One/20 connected to a VAX 11/780.

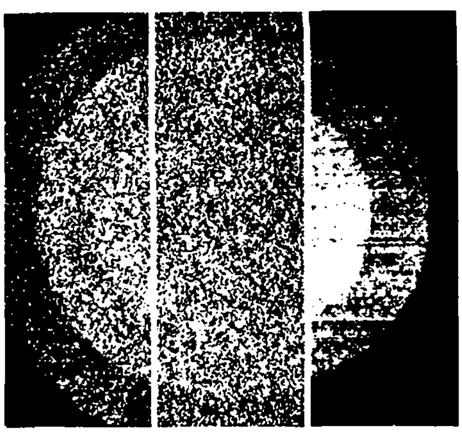

Fig. 1. *Image of step wedge from stack of 20 KK films: (left) first film; (center) last film; (right) average of all 20 films.*

As noted above, the individual high-speed radiographic film yields very grainy images, and the system point-spread function (PSF) caused by the finite size of the x-ray source and by the film pack internal scatter makes the images blurred. In addition, the spatially variant blur caused by the motion of the object's surfaces further degrades the image quality. This combination of blurs plus the superposition of overlying material impedes (1) measurement of various radii, lengths, widths, and relative locations; (2) visual perception of material distribution; and (3) estimation of material densities. Traditional deconvolution techniques of removing the image blurs are impractical because the film grain noise would be grossly amplified.

Edge Localization of Axially Symmetric Objects

A major obstacle in the analysis of radiographs of weapons or other complex objects is the superposition of the overlying structures: the three-dimensional object is projected onto the film in only two dimensions. In edge localization, the superposition of overlying material is circumvented by a one-dimensional radial model of the object that takes into account the x-ray linear attenuation coefficients associated with the overlying structures. In addition, the model incorporates the blur of motion in the dynamic object and the blur of the radiographic system caused by the

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x-ray source and film pack. The amount of expected motion blur, which can be calculated from the basic physics of the dynamic experiment, is approximated by a linear blurring function. The PSFs of the x-ray source and film pack blur can be estimated by calculating what is called the modulation transfer function (MTF) of an edge from a step wedge of dense material placed in the same geometry as the experiment. Once we know the estimated MTF, an analytic functional form can be used to approximate the x-ray and film pack PSFs. The one-dimensional model of the planar geometry projection is then blurred with the appropriate motion and x-ray and film pack PSFs. Figure 2 shows an example of a one-dimensional projection through a hollow sphere, the blurring process, and the correction for radiographic film response and film fog. The resultant blurred and modeled data are fitted to the radiographic data by means of a least squares technique. Figure 3 indicates that the fit can take into account a nonuniform film background. Figure 4 shows an example of a radiograph of a hollow shell of depleted uranium. The inner surface of the shell remains unobscured by a large collimator that obscures the outer surface. The collimator shows up as the very dark ring at the periphery of the figure. We are interested in estimating the location of the inner surface of the uranium shell with the greatest precision our measurement system will allow. Pie-shaped sections of the data are extracted and collapsed to one-dimensional averaged data sets. This is done by first determining the center of the object and then transforming the data from Cartesian coordinates to polar coordinates. An example of a line at 0° is shown in Fig. 5. Figure 6 shows a least squares fit to a limited section of the data to determine the inner edge of the hollow sphere when we used a one-dimensional model for the sphere's structure. The accuracy of determining the inner diameter of this hollow sphere was approximately ±0.1mm.

The edge localization method can be used to estimate the edge position of a static object to ±0.1mm and that of a dynamic object to ±0.3mm.

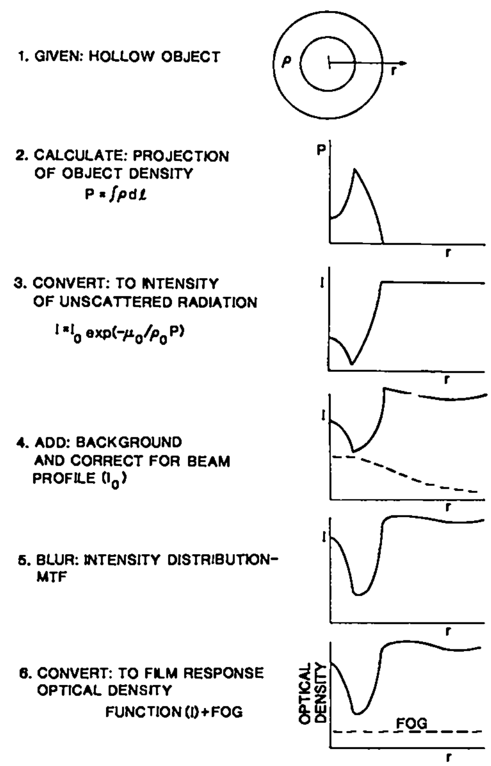

Fig. 2. *Radiographic model.*

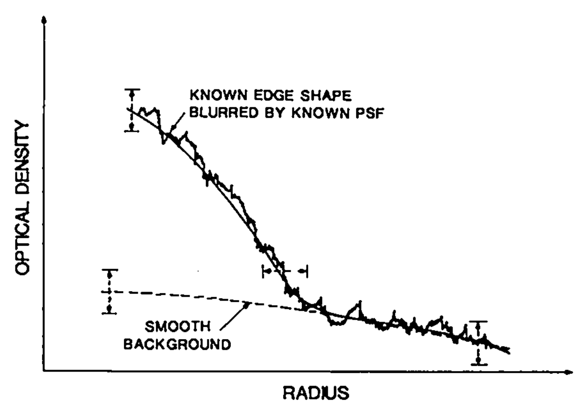

Fig. 3. *Fitting concept.*

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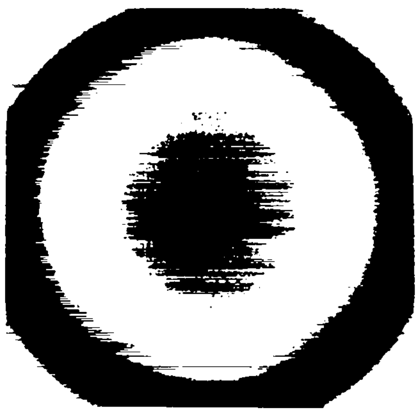

Fig. 4. *Radiograph of a hollow spherical shell of depleted uranium.*

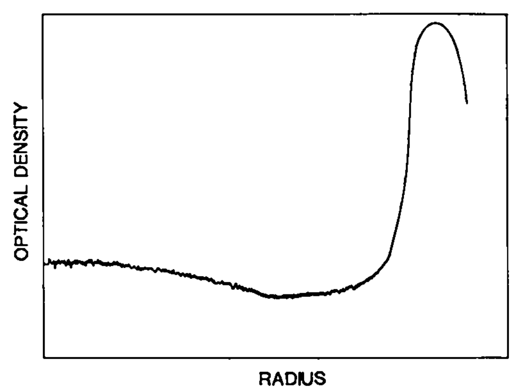

Fig. 5. *Radial dependence of radiographic film density of Fig. 4 at 0°.*

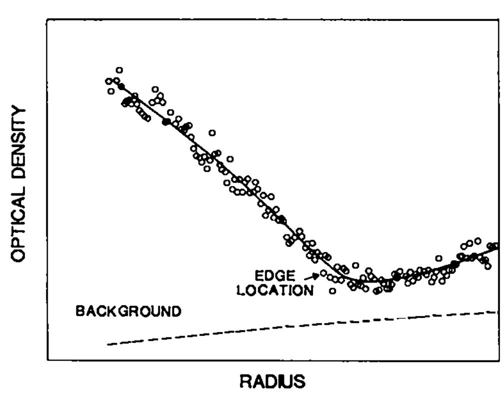

Fig. 6. *Fit of spherical shell model to data at 0°.*

X-Ray Tomographic Reconstruction of Axially Symmetric Objects

As in the case of edge localization, a major obstacle in the analysis of weapons radiographs is the superposition of the overlying structures. The superposition problem has been completely eliminated by the introduction of computed tomography (CT). This field has had its most notable and publicized successes in medicine, where most people are familiar with the term CAT Scan (Computer-Assisted Tomographic Scan).

The idea behind x-ray tomographic reconstruction (XTR) is fairly simple: given x-ray views from enough different directions of a two-dimensional object, one can reconstruct the complete two-dimensional distribution of the object's x-ray linear attenuation coefficient distribution, $\mu(x,y)$. The function μ relates the incident intensity I_0 of the x rays to the intensity I of the x rays at the film or detector. By moving the source and film around the object, we obtain a series of views of the object. In a typical CAT Scan, hundreds if not thousands of views are taken.

In our dynamic testing program, we radiograph the object from only one direction, which is not sufficient to reconstruct an arbitrary three-dimensional object. However, if the object is essentially axially symmetric, a characteristic of many of our test systems, a single radiograph taken normal to the axis of symmetry is adequate to obtain an XTR of the object. Since the object is assumed to be axially symmetric, each scan line normal to the axis of symmetry is a one-dimensional projection of a plane through the object. The standard method of reconstruction we use for weapon radiographs is a one-dimensional simplification of a well-known method called filtered back-projection. This method is used to reconstruct the radial dependence of the x-ray linear attenuation coefficient. After each line of the image has been reconstructed, a cross-sectional display of the object is created (Fig. 7). This method effectively eliminates any superposition of material that is caused by the projection of the radiographic image onto the film, provided the object has axial symmetry.

Several examples showing the value of this XTR technique are described below. The reconstructed profiles of each line of an axially symmetric steel object in Fig. 8a are combined to form the image shown in Fig. 8b. The computation time to obtain this result was 1.4 min of computer time on a CDC 7600. The reconstruction closely resembles the cross section of the object in Fig. 8a, but the grooves, which were very difficult to observe in the original radiograph, are now easily seen.

As another example, the static object whose radiograph is shown in Fig. 4 is reconstructed in Fig. 9. Only that portion of the uranium shell that was unobscured by collimation was reconstructed. The figure gives an accurate representation of a cross section of a spherical shell of constant density. The inner edge of the uranium shell is much better defined than in the original radiograph (Fig. 4), which has been contrast-enhanced to bring out the inner edge position.

It should be possible to measure the positions of reconstructed surfaces in dynamic radiographs to ±0.3mm, just as with the edge localization technique.

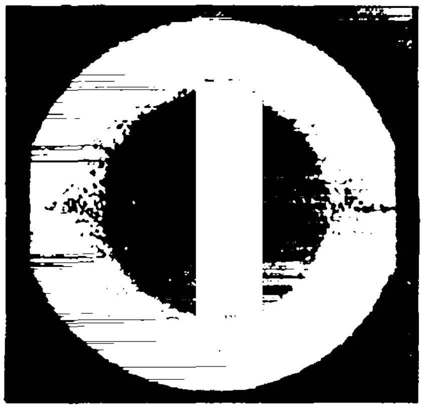

Fig. 9. *Reconstruction of a cross section of the spherical shell of constant density shown in Fig. 4.*

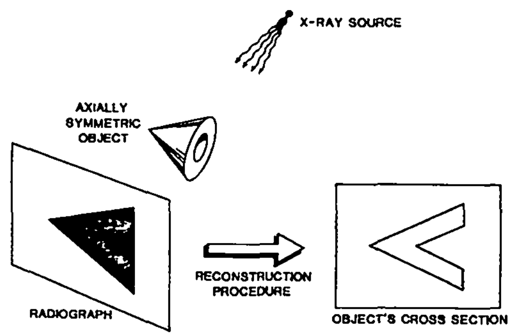

Fig. 7. *Overview x-ray tomographic reconstruction method.*

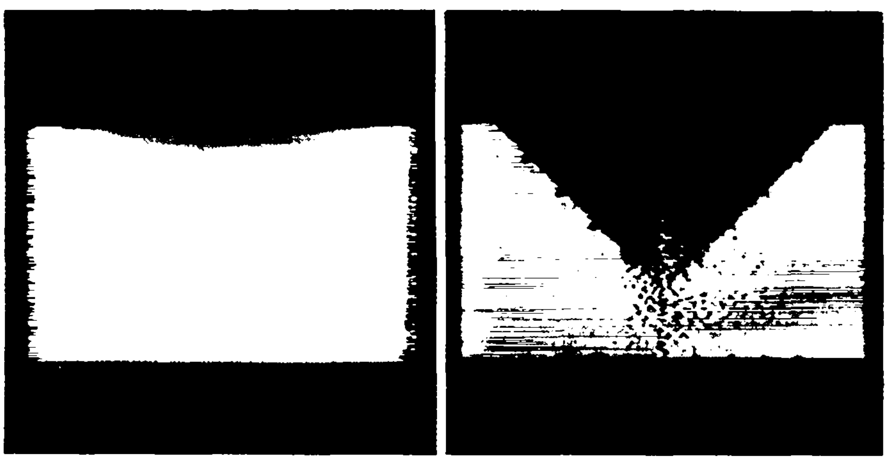

Fig. 8. *(left) Radiograph of an axially symmetric steel object taken with a ^{60}Co source. The AA film was sandwiched between two 0.25-mm-thick lead screens. (right) Display of the reconstruction of the object's cross section derived from Fig. 8a. The 2-mm × 2-mm grooves machined in the inside cone are readily apparent. These grooves were almost invisible in the original radiograph.*

Future Developments

We are investigating the characteristics of various film/screen types using noise-power spectrum analysis and MTF measurements to arrive at a technique applicable to combinations of the various film types. This film averaging allows one computer-generated pseudoimage to combine the attributes of each film type into one having a very large dynamic range and increased signal-to-noise ratio. This has been accomplished on a modest scale for some of our dynamic weapons experiments.

This brief news note on image analysis at Los Alamos has been provided to give an insight into this very interesting and challenging research area. If you have questions or would like more information on this subject, please contact Rollin Whitman (M-4, 7-7542), Kenneth Hanson (M-4, 7-1402), or Karl Mueller (M-4, 7-6470). Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36. The Laboratory is an affirmative action/equal opportunity employer.