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TITLE: SIMULATION AND PRELIMINARY PERFORMANCE CHARACTERISTICS
OF A COMPUTED TOMOGRAPHY DEVICE FOR INDUSTRIAL APPLICATIONS

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Abstract

A computed tomography system designed to function in an industrial environment is being constructed. The modular design maintains the flexibility necessary in an environment where source strength and energy, as well as detector size, could change with each application. The static nature of industrial objects also allows economies of design not possible where dynamic objects are to be analyzed. Completion of the device has been completed and selected image qualities obtained.

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Computed transverse axial tomography has been applied to such diverse fields as geology, radio astronomy,² and most notably, nuclear medicine,^{3,4} and medical radiography.⁵ The latter instance has included a new dimension for the discipline in the form of the production of an image of a cross section slice through an object at a desired depth, rather than a projection of that object. Inspection of several such cross-sectional images has demonstrated the ability to make cross-sectional slices through anatomy without the use of a knife. The technique has proven invaluable in medicine.

[illegible]

A significant advantage was the fact that the subjects who attended the "workshop" received a more complete and detailed description of a "real" situation than the subjects who did not attend the "workshop".

[illegible]

System Architecture: [unclear]

The basic inputs needed for the computer simulation include the basic physical properties of all materials at a specified radius; the number of particles per unit volume; the number of particles per unit volume; the projection of the particles; the number of particles per unit volume; the number of particles per unit volume; the number of particles per unit volume; and the number of particles per unit volume.

These microprojectors are used in a number of ways. They can be used to form the cross-sectional estimate of the population of interest.

$$f(n, j) = \sum_{i=1}^n \tilde{f}_{i,j} \cos \frac{2\pi i}{n} x, \quad x \in \mathbb{R}^1, \quad (1)$$

where x, y, z , are all discrete and

$$\bar{p}_1(r) = \frac{1}{2} \sum_{n=0}^{N-1} p_{1,n}(r) e^{i\pi n r / N} \quad r = 1, \dots, N \quad (2)$$

$\tilde{p}_1$ is the forward Fourier transform of p_1 and $\tilde{p}_1(r)$ is the rho-filtered (u) representation of $p_1(r)$. Typically, one is given experimentally derived values of σ^2 and γ_0 . An effective noiseless path length ($\tilde{p}_1$) through the system is then computed

$$\hat{\theta}_1(r) = \int_0^1 \hat{\theta}_1(r) dr = 1.42 \quad r = 1.0 \quad (3)$$

This facility allows either a monoenergetic source spectrum $I(\lambda, \lambda_0)$ or the integration over an energy range via experimentation to form

$$u = C \int \frac{dx}{x^2 \sqrt{1-x^2}} \quad (4)$$

This yields a constant estimate of σ^2 . Therefore, σ^2 is estimated, thus, along with the incident number of source photons n_i , is used to compute the standard deviation σ_{n_i} of each projection point.

$$-\dot{\bar{p}}_1(r) = \left(\frac{\partial \bar{p}_1(r)}{\partial r} \right) \quad (5)$$

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15. המנהל מודאג כי המעורבות של הציבור בפרויקט תהיה רחבה, וייתכן כי תהיה צורך להעביר את המידע למנהל המחוזי.

(8)

values of σ_R between 2 and 3 with $\sigma = 3.5$ have been shown to allow a 50% detection probability, of small (4 pixel area) σ_R shifts in video totals.

As an example, let us theoretically reconstruct a simulated 24-m diameter plutonium cylinder with $w = 180$ evenly spaced projections over 2π rad. There will be 4.750 pixels/projection, a 0.1 m-square aperture, a 1-MeV source, and the σ of detector will equal 0.16 m⁻¹. Within the cylinder are eight circular air voids $w = 0$, ranging in diameter from 0.2 mm to 0.4 mm. Since σ_p is signal-dependent, we will estimate

the maximum number of incident photons n_i per aperture needed to produce a reconstruction with a minimum SNR of 4. This will yield a reconstruction where the smallest air void will be just above the 50 percent detectability threshold.

$$\sigma_R = \frac{\mu}{SAR} = \frac{0.16}{4} = 0.04 \quad (9a)$$

$$\max \sigma_p = \frac{\sigma_R \sqrt{N}}{K} = \frac{(0.04) \sqrt{780} (1.1)}{0.5} = 0.1073 \quad (9b)$$

$$\max \bar{p} = \int_0^{24} 0.16 \, dz = 3.84$$

$$\max N_0 = \frac{\sigma_{\bar{p}}}{\sigma_p^2} = \frac{3.84}{(0.1073)^2} = 2546 \quad (9c)$$

$$\min N = N_0 e^{-\bar{p}} = 2546 e^{-3.84} = 55 \quad (9d)$$

Therefore, with $N_0 = 2546$ incident photons, one should expect not fewer than $N = 55$ exit photons incident on the x-ray detector. The SAR = 4 should allow 0.16-mm diameter air voids just detectable. Figure 1a shows the resultant 156-ct. 256 reconstruction (1.1) small void just above the large central void is 0.4 mm in diameter. The 0.3-mm void to the left of center is a so quite detectable. The 0.2-mm void to the right of center is barely detectable, thus reinforcing the just explained detectability criteria. As a comparison, Fig. 1b shows the same phantom with an order of magnitude higher incident flux (corresponding to a SAR = 16). As predicted, all voids are easily detected.

These initial simulations demonstrate a realistic range of image qualities possible using the prototype system under design.

Specifications of the Industrial Tomographic System

The tomographic scanner hardware is being designed as a modular system. The source, scanner, and detector are each separate modules mounted on a common stand. In this way, the system can be tailored to meet sensitivity and operational requirements to be customized for a particular application.

A schematic of the detector collimator is illustrated in Fig. 2. One of each pair of plates is movable, permitting the collimator aperture to vary from a central spot 1 mm in diameter to a 2-cm diameter. The detector itself is simply placed behind the plates and can be a scintillation detector, a GM detector, or a proportional counter depending upon the application. A lead or lead-equivalent bulk shield is necessary to shield the detector from stray scattered radiation.

The scanner assembly moves the object under inspection back and forth through the radiation field. The scanner assembly rotates at between scans. The assembly is built from essentially variable linear and rotary motion modules. The total linear travel is about 75 cm horizontally and has a vertical displacement of 10 cm. The rotary motion is continuous with an angular precision of 0.1 degrees. All axes are driven by three separate stepping motors controlled by the PDP-11/40 computer. Figure 3 illustrates the mechanical design of the system.

The source module is a table that permits any type of source to be mounted with it. Isotopic sources are inserted inside a cylindrical shield with an insert that collimates the beam to a cone with a fixed diameter at the detector collimator. If the source detector distance is changed from the nominal, the source collimator insert may be changed to maintain the 2-cm diam base. Figure 4 illustrates a typical isotopic source holder.

All three modules are mounted on a stand that permits the source and detector modules to move along the beam axis. In this manner, we have the greatest flexibility in adjusting the various tomographic parameters.

The tomographic system interface controller which connects the PDP-11/40 computer to the mechanical tomographic scanner assembly is also designed in a modular fashion. This will permit a high degree of flexibility and ease of modification for particular applications. A block diagram of the controller is shown in Fig. 5. The connection to the PDP-11 can be via a standard DEC 6411 general device interface card which allows parallel transfer of 16-bit words in or out. This interface will be used when the scanner hardware is located in the same building as the PDP-11. To accommodate special radiation sources such as the LASL 14-MeV neutron located remotely from the PDP-11, provisions are also made for interface through a DEC 6411 asynchronous serial line interface at 9600 baud. This interface uses either coaxial cables or wideband telephone lines. This potentially makes possible a portable tomographic system which could be quickly set up at a remote site.

The interface logic chassis is organized around a bus concept with eight card slots. Any of these slots can be used for either positioning electronics or data acquisition modules. A positioning module permits one to control a single mechanical motion with a stepping motor. Provisions are made for reading the absolute position from encoders, controlling speed via software over a 100 to 1 range with a stability of 0.01%, controlling acceleration and deceleration of the motor, detecting limit switch closures, and generating interrupts.

or start data take signals at increments from 1 to 511 motor steps. Initially we will be controlling two translational axes of motion and one rotational axis. If in the future it were desired to position very large assemblies, it would be possible to use the same system with electrohydraulic stepping motors which are available in multihorsepower ratings.

The data acquisition module is designed with up to eight analog channels multiplexed into a single analog to digital converter. Alternatively, it can also be used with a single analog to digital converter on each card. Initially two 16-bit analog to digital converters with 4 μ sec digitizing time will be used. One of these will record intensity, position, rotation and the other will record x-ray transmission through the object being scanned. In normal operation, the current will be integrated between data takes. The end of conversion signal from the analog to digital converter can be programmed to generate a computer interrupt. With the interrupt generated, the computer program can be considered as a background job, and the majority of the time on the PDP-11 can be used for the integration of the detector while detection gathering is still going on. The provision for multiple analog to digital converters and for multiple data acquisition modules will allow the use of a multi-detector system. This will reduce the scan time required. It could also allow the use of a multiple energy x-ray source, energy source and an energy discriminating detector to allow gathering of information about the composition of systems, as well as the density of the sample element. The latter technique, which is referred to as dual energy, requires the attenuation of each x-ray, which acts as a function of its linear absorption coefficient, by fitting the two separate attenuation values into an empirical function that can be used to determine the composition of the material as a function of its element. The absorption of at least one of the x-rays is due to a significant photoelectric interaction and thus exhibits a strong dependence on atomic number.

Most of the interface hardware is implemented with standard 14 power supply, TTL integrated circuits, built on plug-in boards and connected to the host hardware of a PDP-11. The boards are used for power supply and the interfacing to the computer and the control panel in the interface allows monitoring the system for initial and subsequent problems.

The filtered x-ray beam is generated by a source of ^{241}Am and is collimated under the shield. The system is so built that the x-ray source can be removed from the system, along with the interface board, tomographic hardware will allow a change of reconstruction and projection gathering.

Conclusions

An industrial computer for image reconstruction has been designed and is being constructed for the design and construction of a tomographic system. The system will be able to handle large volumes of data and will be able to handle a large number of data points and will be able to handle a large number of data points.

Acknowledgment

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Fig. 1a. Plutonium cylinder reconstruction with 2546 incident photons/projection print.

Fig. 1b. Plutonium cylinder heterodyne image with 25261 incident photons/projection print.

Fig. 2. Variable detector collimator.

Fig. 3. Tomographic system mechanical subsystem.

Fig. 4. Typical isotopic source holder.

Fig. 5. Tomographic system electronic controller.