ELSEVIER Nuclear Instruments and Methods in Physics Research A 467–468 (2001) 1326–1328

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Integrated image presentation of transmission and fluorescent X-ray CT using synchrotron radiation

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Abstract

We have developed a computed tomography (CT) system with synchrotron radiation (SR) to detect fluorescent X-rays and transmitted X-rays simultaneously. Both SR transmission X-ray CT (SR-TXCT) and SR fluorescent X-ray CT (SR-FXCT) can describe cross-sectional images with high spatial and contrast resolutions as compared to conventional CT. TXCT gives morphological information and FXCT gives functional information of organs. So, superposed display system for SR-FXCT and SR-TXCT images has been developed for clinical diagnosis with higher reliability. Preliminary experiment with brain phantom was carried out and the superposition of both images was performed. The superposed SR–CT image gave us both functional and morphological information easily with high reliability, thus demonstrating the usefulness of this system.

PACS: 87.59.F; 78.70.E; 07.85.Q; 87.62

Keywords: Transmission X-ray CT; Fluorescent X-ray CT; Synchrotron radiation; Superposition; Image understanding

1. Introduction

Recently, superposition of functional images on morphological images, i.e. single photon emission computed tomogram (SPECT) on 3D X-ray images has been studied for clear image understanding with high reliability [1]. We have developed a CT system with synchrotron radiation (SR) by detecting fluorescent X-rays and transmitted X-rays simultaneously [2–7]. Both transmission X-ray CT (TXCT) and fluorescent X-ray CT (FXCT) can describe the spatial distribution of target materials with higher spatial and contrast resolutions as compared to conventional X-ray CT. FXCT, particularly, is able to depict small amount of specific materials. The sensitivity of FXCT is about 70 times better than that of TXCT [5]. In our present FXCT system, 0.025 mg/ml iodine solution was detected with $0.2 \times 0.2\,mm^2$ spatial resolution [6]. Therefore, the understanding of physiological function by using small amounts of non-radioactive contrast materials has come in our hands. However, since FXCT only describes the distribution of target material without tissue structure image, it

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0168-9002/01/$ - see front matter
PII: S0168-9002(01)00658-1

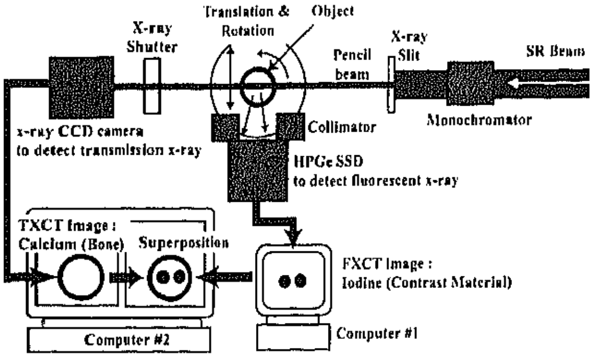

Fig. 1. Schematic diagram of the SR–CT system to detect fluorescent X-ray and transmission X-ray simultaneously.

becomes necessary to superpose FXCT image on TXCT image for quantitative image understanding.

In image superposition, we need a reliable image registration procedure and an effective human interface for easy manipulation of the image data on the computer. In our system (Fig. 1), the information of position of FXCT image and TXCT image are obtained simultaneously in a synchronized observation system. Thus, the image registration procedure is quite simple.

Preliminary experiment with brain phantom was carried out to examine the possibility of quantitative image fusion of SR–CT image with both functional and morphological information.

2. Materials and methods

2.1. SR–CT system for FXCT and TXCT

The imaging experiment was carried out at the bending magnet beam line of BLNE-5A of the Tristan accumulation ring (AR; 6.5 GeV, 20–40 mA) in Tsukuba, Japan. As shown in Fig. 1, this system consists of a Si (1 1 1) double-crystal monochromator, an X-ray slit, a collimator for detection, a table for scanning the object, a highly purified germanium solid state detector (HPGe), a rotating X-ray shutter, an X-ray CCD camera, and computers for system control and image processing.

The incident monochromatic X-ray beam was collimated to 0.5 mm × 0.5 mm (horizontal and vertical, respectively) size and X-ray energy was 37 keV.

Fluorescent X-rays emitted isotropically from excited contrast materials along the line of the incident beam were detected by the HPGe placed perpendicular to the incident beam. The projection data along the scanning line were measured from counts of the iodine Kα fluorescence line.

The transmission X-rays were detected and converted into digital data by an X-ray CCD camera with 1152 × 1242 pixels. The pixel size was 22.5 μm × 22.5 μm. The area size of incident transmission X-ray (0,5 mm × 0.5 mm) corresponded to 22 × 22 pixels on the detector, so intensity of one pixel of the observed image was integrated over 22 × 22 pixels of the CCD.

Thus, fluorescent X-ray and transmission X-ray were detected on the system simultaneously without special image registration procedure. Sixty projections were acquired at 3° steps using a translation–rotation motion of the object. The TXCT image was reconstructed by filtered back projection method. The FXCT image was reconstructed by a least-squares method using singular value decomposition [7]. Both TXCT image and FXCT image were composed of a 51 × 51 matrix.

2.2. Brain phantom for experiment

A cylindrical acrylic brain phantom was prepared for the evaluation of the image superposition. The phantom was filled with iodine solution (0.1 and 0.2 mg/ml) from two holes at the center and calcium powder was filled in the outside cavity (Fig. 2). The iodine solution, the calcium powder and the acrylic cylinder are assumed to represent the tracer material, bone and soft tissue, respectively.

3. Results and discussion

In the TXCT image shown on the upper left of Fig. 3, the acrylic cylinder and the calcium powder were clearly displayed, but the holes filled with iodine solution were not depicted. On the other hand, in FXCT image shown on the upper right in Fig. 3, the two holes were depicted, but the acrylic

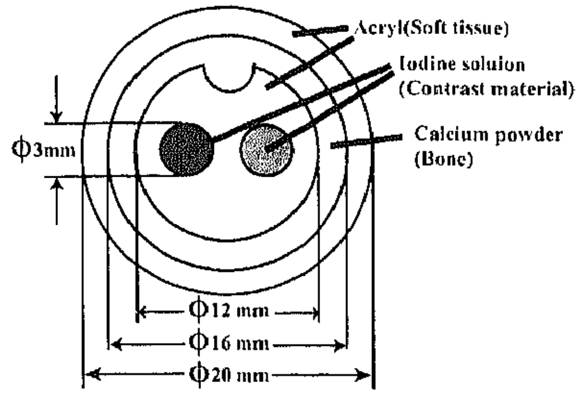

Fig. 2. A cylindrical acrylic brain phantom (20 mm in diameter). Two holes (3 mm in diameter) filled with iodine solution (0.1 and 0.2 mg/ml), Outside ditch (2 mm in width) with calcium powder.

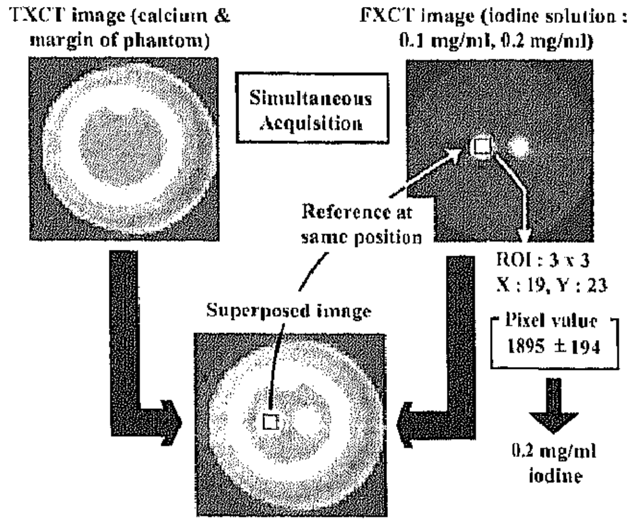

Fig. 3. Superposition of the TXCT image and the FXCT image. Interactive manipulation of superposed image for quantitative image understanding.

cylinder and the calcium powder were not imaged. The image shown at the bottom of Fig. 3 was obtained by superposing FXCT image on TXCT image. All three viz. the iodine solution, calcium and acrylic cylinder were displayed on the superposed image.

From this result, it follows that the superposed image can provide the analyst the exact spatial information of small amount of target materials. It is also pertinent to mention that the image could be obtained immediately after the data acquisition and CT reconstruction without special image registration procedure.

Thus, an interactive data-handling tool has been prepared. To demonstrate this tool a quantitative image obtained by this system is shown in Fig. 3. When a region of interest (ROI) is selected on the superposed image, the ROI of the same position on FXCT image is referred. The pixel value with standard deviation on the ROI on FXCT image is denoted. By using this tool, the observer can obtain the concentration of the target material on the superposed image.

4. Conclusions

It was confirmed that the superposition of TXCT image and FXCT image was realized effectively by this SR–CT system. This system can be used for quantitative image understanding conveniently. The superposed image with functional and morphological information will be useful for image diagnosis with high reliability.

Acknowledgements

This research was partially supported by Grant-in-aid for Developmental Science Research (#10557084, #11450156) from the Japanese Ministry of Education, Science and Culture. This study was performed under the auspices of High Energy Accelerator Research Organization (Proposal No. 99G124).

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