Development and Performance Evaluation of the First Model of 4D CT-Scanner

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ABSTRACT

4D CT is a dynamic volume imaging system of moving organs with an image quality comparable to conventional CT, and is realized with continuous and high-speed cone-beam CT. In order to realize 4D CT, we have developed a novel 2D detector on the basis of the present CT technology, and mounted it on the gantry frame of the state-of-the-art CT-scanner. In the present report we describe the design of the first model of 4D CT-scanner as well as the early results of performance test. The x-ray detector for the 4D CT-scanner is a discrete pixel detector in which pixel data are measured by an independent detector element. The numbers of elements are 912 (channels) x 256 (segments) and the element size is approximately 1mm x 1mm. Data sampling rate is 900views(frames)/sec, and dynamic range of A/D converter is 16bits. The rotation speed of the gantry is 1.0sec/rotation. Data transfer system between rotating and stationary parts in the gantry consists of laser diode and photodiode pairs, and achieves net transfer speed of 5Gbps. Volume data of 512x512x256 voxels are reconstructed with FDK algorithm by parallel use of 128 microprocessors. Normal volunteers and several phantoms were scanned with the scanner to demonstrate high image quality.

Keywords: 4-dimensional computed tomography (4D CT), dynamic volume imaging, 2D discrete detector.

1. INTRODUCTION

Since the advent of computed tomography (CT) in 1973, dynamic imaging of moving organs in a living person has been one of the biggest dreams in this field[1]. The concept is simply called as 4D CT because it takes 3-dimensional (3D) image with additional dimension of time. With 4D CT one could carry out not only new diagnoses but also provide new interventional therapy by real-time observation of its procedures. Because volume data (3D data) can be acquired by cone-beam CT using a rotation of the cone-beam[2,3], continuous rotation of the cone-beam allows dynamic volume data (4D data) to be acquired. In order to realize 4D CT, we have developed a novel 2D detector on the basis of the present CT technology, and mounted it on the gantry frame of the state-of-the-art CT-scanner (Toshiba Corp. Aquillion) [4]. In the present report we describe the design of the first model of 4D CT-scanner as well as the early results of performance test.

2. DESCRIPTIONS OF SCANNER SYSTEM

2.1. Gantry

The detector and x-ray tube pair is mounted on the gantry frame of the state of the art CT-scanner (Toshiba Corp. Aquillion). Figure 1 shows the geometry of the scanner, and Figure 2 shows a photograph of the gantry. The scanning mechanism can assure a rotation speed of up to 0.5 sec/rotation. However the first model employs 1.0sec/rotation as the maximum speed due to acceleration limit of x-ray tube that covers a wide cone-angle. The x-ray tube is slightly tilted to the rotation axis to cover a wide cone-angle.

2.2. Detector

The detector is a discrete pixel detector in which pixel data are measured by an independent detector element. The number of elements is 912 (channels) x 256 (segments), and the element size is approximately 1mm x 1mm. Data sampling rate is 900views(frames)/sec, and the dynamic range of A/D converter is 16bits. The detector element consists of a scintillator and photodiode. The scintillation material is the same as that for a multi-slice CT detector, and the photodiode is made of a single-crystal silicon, the same as for the multi-slice detector.

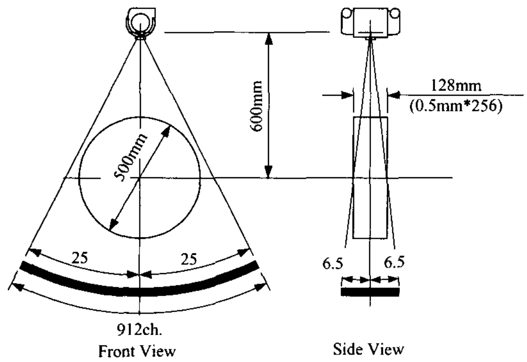

Fig. 1. Geometry of the scanner

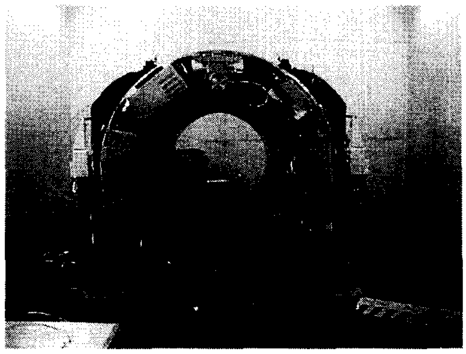

Fig. 2. Photograph of gantry

Because the size of a single-crystal silicon wafer is limited, the detector system has been realized by tiling detector blocks. One detector block consists of 24 (channels) x 64 (segments) = 1,536elements, while one detector system consists of 38x4=152 blocks. Figure 3 shows the construction of the detector. The 2D detector has an anti-scatter collimator that is assembly of thin molybdenum blades equally spaced. The collimator blades are adjusted to parallel to the rotation axis, and the pitch of the blade is identical to the detector element pitch. The collimator ratio is approximately 30:1, where it is the height of the blades divided by the length of the gap. The data acquisition system is different from that of theconventional CT-scanner, and is rather similar to that of a flat panel detector (FPD). Much faster readout-speed than that of FPD is achieved by the circuits on the single-crystal silicon as well as one-to-one bonding of each data line to readout electronics.

2.3. High-speed data transfer system

In the present system projection data should be transferred from the rotating part to the stationary part. Since the transfer rate is determined by multiplying the required net rate of 3.4Gbps (=912x256x900x16) by a redundant factor of 1.3-1.4, where the redundant factor is necessary for adding error correction codes, transfer control codes etc, it becomes approximately 5Gbps. This requirement is realized by parallel use of 12 sets of a laser diode – photodiode pair, each of which has a transfer rate of 622Mbps. The difference between the required 5Gbps and maximum transfer rate of 7.4Gbps (=622Mbpsx12) is a design margin that accounts for dead time of the data transfer system caused by gaps between light-concentrating devices for the photodiodes

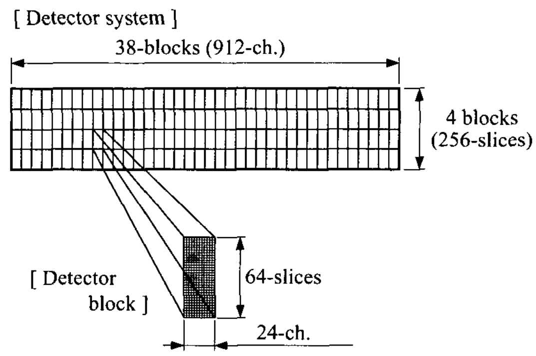

Fig. 3. Construction of the detector

2.4. Image reconstruction computer

Volume data is reconstructed with the FDK (Feldkamp-Davis-Kress) algorithm [5]. Image reconstruction computer consists of 128 digital signal processors (DSP), each of which has the maximum computation speed of 400MFLOPS. Reconstruction time is 6 min for 512x512x256 from 900views in the precise mode.

3.EXPERIMENTS

Several phantoms were scanned with this scanner to examine image characteristics including image noise, spatial resolutions, image distortion, high contrast and low contrast detectabilities. Several volunteers were scanned with this scanner. The study protocol was approved by the ethics committee of the National Institute of Radiological Sciences, and each subjects gave written informed consent prior to participating in the study.

4.RESULTS AND DISCUSSION

Figure 4 shows results of the resolution phantom that consists of several sets of three wires separated twice of diameter from the adjacent ones. The diameters were 0.5 (stainless steel), 1.0, 1.6, 2.0 and 3.0mm (aluminum), respectively. In the figure wires are placed perpendicularly to the image planes, while Figure 4a) shows a transaxial plane and Figure 4b) shows a longitudinal plane. In the both figure 0.5mm wires separated. However in the longitudinal plane (Figure 4b)) the separation is more clear and this might be attributed to anisotropic features of FDK algorithm. Figure 5 shows transaxial images of a normal volunteer, which demonstrate low contrast resolution comparable to commercial CT-scanners. Because in the first model reconstruction time is 6 minutes for full size matrix and much slower than the scan time, it may be an obstacle in clinical applications, especially in the application to interventional therapy. We are now constructing the second model that installs much faster reconstruction computer composed of next generation field programmable gate arrays (FPGA). This model will be completed in the end of 2003.

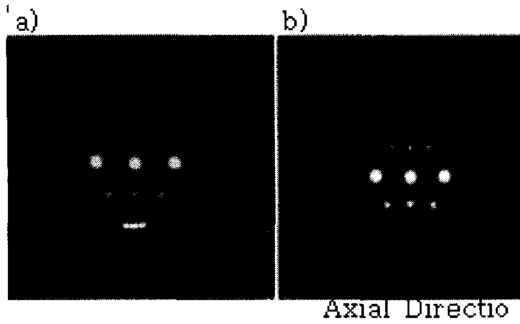

Fig. 4. Images of resolution phantom.
(a) transaxial, b) longitudinal plane)

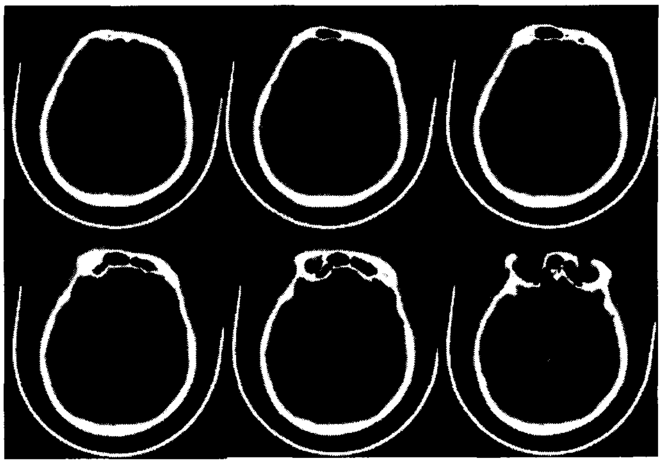

Fig. 5. Head images of a normal volunteer.

ACKNOWLEDGEMENT

This work is supported in part by the NEDO (New Energy and Industrial Technology Development Organization), Japan.

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