Research Activities at National Institute of Radiological Sciences in Development of Radiological Apparatus

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ABSTRACT

This paper describes research activities at National Institute of Radiological Sciences (NIRS), Japan in development of radiological apparatus, which cover 4-dimensinal (4D) CT, next-generation PET and several progresses in heavy-ion irradiation system at HIMAC (Heavy Ion Medical Accelerator in Chiba).

Keywords: 4D CT, DOI-PET, Conformal irradiation, Respiratory-gated irradiation

1. INTRODUCTION

Progresses in radiology depend significantly on developments of hardware. For example everyone accepts that CT or MRI brought revolutionary progresses in radiology during the last quarter of 20 century. Developments in radiological apparatus have been so far led by western countries, especially by the United States. However in Japan a lot of efforts have been made to keep up with or to overcome them, among those I describe here research activities at National Institute of Radiological Sciences (NIRS) in developments of radiological apparatus, which cover 4-dimensional (4D) CT, next-generation PET and several progresses in heavy-ion irradiation system at HIMAC (Heavy Ion Medical Accelerator in Chiba).

2. 4-DIMENSIONAL (4D) CT

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, researchers at NIRS and Toshiba 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 [1]. Figure 1 shows a photograph of the 4D CT-scanner.

The x-ray detector for the 4D CT-scanner (Figure 2) 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 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 the multi-slice detector. 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.

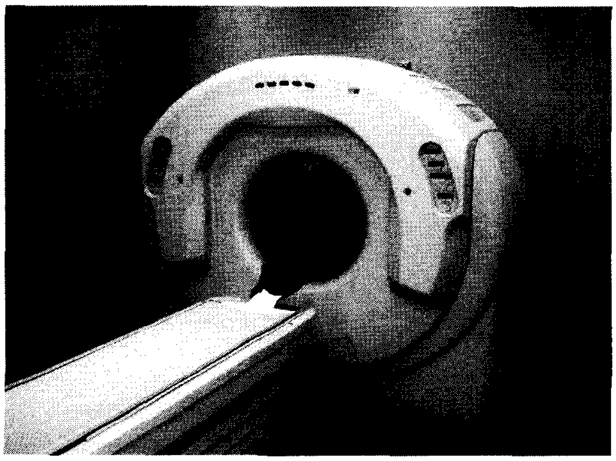


Figure 1. Photograph of the 4D CT-scanner.

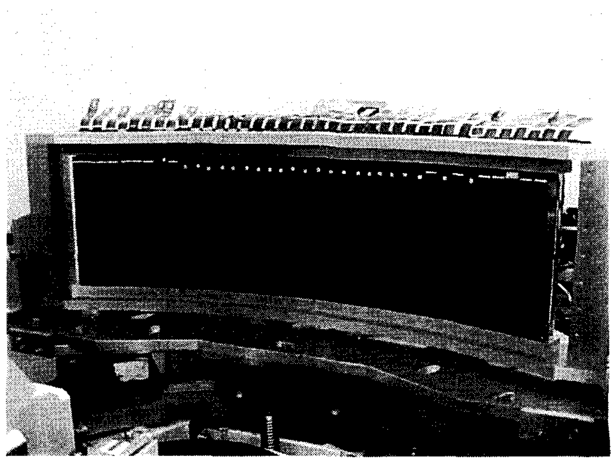


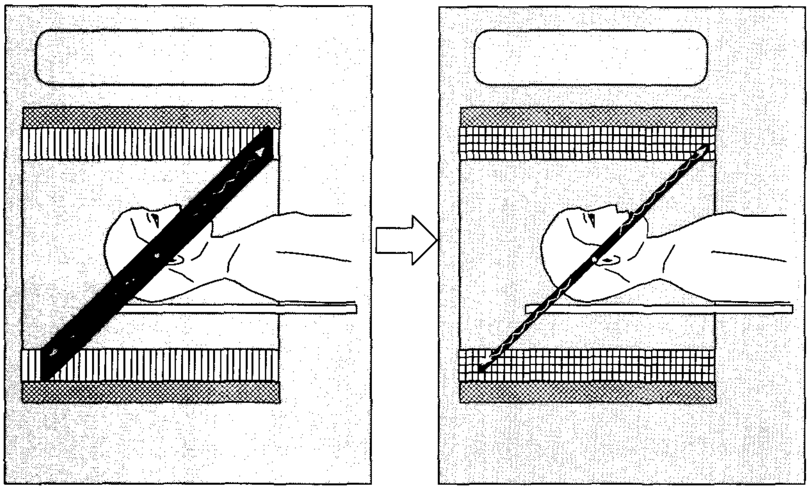
Figure 2. Photograph of the 2D detector.

Volume data of 512x512x256 voxels are reconstructed with FDK algorithm by parallel use of 128 microprocessors. It takes approximately 6 minutes to reconstruct 512x512x256 volume data.
Normal volunteers and patients with selected sites and diseases are now being studied. Because in the present 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. They are now constructing the second model that installs much faster reconstruction computer composed of the next-generation field programmable gate arrays (FPGA). This model will be completed in the end of 2003. The main differences in specifications between the present and the second model are reconstruction speed of 6 minutes vs. less than 1sec and scan time of 1.0 vs. less than 0.5 sec/rotation.

3. NEXT-GENERATION PET

There has been a strong demand toward higher resolution and higher sensitivity on PET. Typically this is achieved through the use of 3D mode acquisition and smaller scintillation crystal elements. Since the elements should keep a certain length in the radial direction to maintain their detection efficiency for photon attenuation, the resulting crystal becomes slender. This produces parallax error at the peripheral region of the field of view (FOV) in 3D mode acquisition (Figure 3A). The conception of depth of interaction (DOI) detector is one of the solutions to the problem (Figure 3B). DOI information will avoid the degradation of spatial resolution and permit one to realize the next-generation PET having the both high sensitivity and high resolution.

Murayama and his group has developed a novel DOI detector (Figure 4) which achieved 4-stages stacking of GSO crystals by making use of Anger-type position arithmetic calculation to determine the crystal of interaction, and doping different amount of Ce to change decay time constant depending on the stage of crystal [2]. His group will develop a prototype of next-generation PET with the DOI detector in the end of 2004.



A) Conventional PET B) DOI-PET

Figure 3. Concept of conventional PET (A) and DOI-PET (B).
(Through the courtesy of Dr. Murayama.)

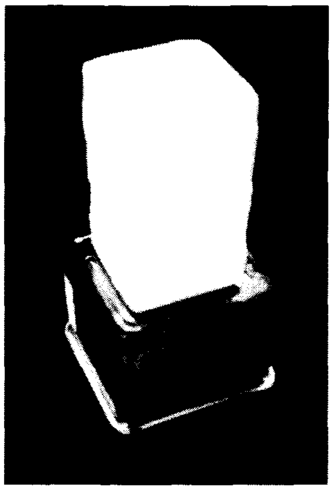


Figure 4. DOI detector.
(Through the courtesy of Dr. Murayama.)

4. IRRADIATION SYSTEM DEVELOPMENTS AT HIMAC

Since 1994, clinical trials of heavy-ion radiotherapy has been carried out with high-energy carbon beams using a medical accelerator complex HIMAC (Heavy Ion Medical Accelerator in Chiba) at National Institute of Radiological Sciences (NIRS). Over one thousand of patients have been treated. During 8 years of clinical trials, several developments have been made to its irradiation system, including respiratory-gated irradiation system and a conformal irradiation system using a layer-stacking method

4.1. Respiratory-gated irradiation system

In order to minimize the exposed dose to surrounding normal tissue during treatment of moving organs such as lung or liver, Minohara and his colleagues have developed respiratory-gated irradiation system that can allow irradiating a target with a repeated pulsed beam synchronized with the respiratory motion [3]. Figure 5 shows a timing chart of gated irradiation. A respiration waveform of the patient is measured by a position-sensitive semiconductor detector (PSD), which consists of a PSD camera and an infrared light-emitting diode (ir-LED). An ir-LED is attached to the patient's body and its motion with respiration is detected by the PSD camera. A gate-on signal is produced by applying a threshold to the respiration waveform. When the gate-on timing coincides with the flat-top timing of synchrotron operation pattern, the beam is extracted and then irradiated. They have found that with this system target margins are generally decreased to 5-10mm although the target moves twice or three times. This system has been used since 1996, and more than one thirds of patients are treated with the gated-irradiation.

4.2. Conformal irradiation system using a layer-stacking method

Since the beginning of clinical trials we have been using a passive irradiation technique (so called 2D irradiation) in which 100% dose level will be usually administered to the normal tissue peripheral and proximal to the target region. In order to avoid such irradiation, Kanai and his group have developed a conformal irradiation system using a layer-stacking method [4]. Figure 6 shows principle of the method. Uniform fields, as well as 2D irradiation, can be made by a pair of wobbler magnets and a scatterer. The Bragg peak of mono-energetic beam is slightly broadened by a ridge filter and its width was designed to be 2.5mm (Mini-peak). The mini-peak is swept longitudinally by inserting a range shifter for making a SOBP. The curved layer of mini-peak is made by the compensator just up-stream of the patient. Each layer is sequentially irradiated from the deepest one by the mini-peak. By this longitudinal sweep of the mini-peak SOBP can be made and covered the whole target volume. When irradiating the mini-peak by layer by layer, the irradiation field can be shrunk along the target volume by a multi-leaf collimator. By this procedure unwanted irradiation to normal tissue can be avoided. The whole system including treatment planning has been completed and clinical application will be started in the fall of 2002.

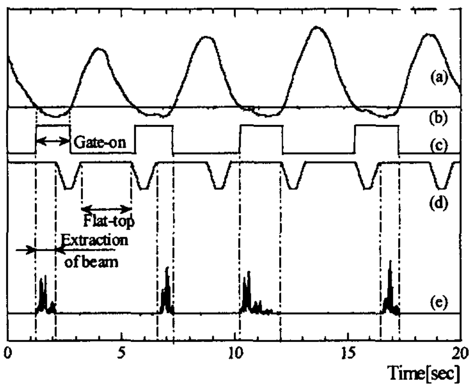


Figure 5. Timing chart of gated irradiation.
a) Respiration wave form. b) Threshold level.
c) Gate-on signal. d) Synchrotron operation pattern.
e) Signal of dose monitor.
(Through the courtesy of Dr. Minohara.)

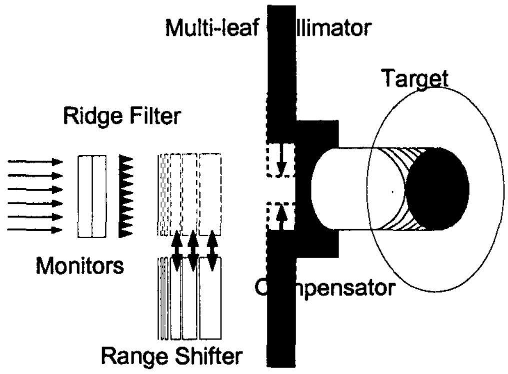


Figure 6. Principle of layer-stacking irradiation.
(Through the courtesy of Dr. Kanai.)

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