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3D Stacked Radiation Collimator

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— Abstract —

Multileaf collimators whose Pb leaves are moving in two-dimensional directions have been used. We propose a different concept three-dimensional (3D) collimator with 3D shape that is automatically changeable to modulate the radiation dose even for complex tumors in real time. A voxel collimator, including a hinged Pb plane and a 3D assembly of many voxel collimators, was used. In each frame rotation axis, a motor, which was controlled by a circuit with field-programmable gate array (FPGA) board connected with computer, was operated according to a predetermined plan. Simulations of that, which are generally used for planning, were performed and compared with experimental results.

Key Words : 3D assembly of many voxel collimators, three-dimensional collimator, FPGA

Ⅰ. Introduction

In order to collimate high energy radiation for therapy of a tumor located near a radiosensitive organ, multileaf collimators whose Pb leaves are moving in two−dimensional (2D) directions have been used[1)]. we propose a different concept 3D collimator with a 3D shape that is automatically changeable to modulate the radiation dose even for complex tumors in real time. This device was an assembly of many unit collimators stacked in 3D directions and controlled by a prescheduled program[2)]. In order to demonstrate the feasibility of this different concept collimator, we developed a prototype device with 27 unit voxel collimators assembled in a cubic pattern. The experimental and simulation results of the 3D collimator under various conditions were compared.

Ⅱ. Material and Method

A voxel collimator comprising a hinged Pb plane and a 3D assembly of many voxel collimators is shown in Fig. 1. A driving motor rotating the Pb plane was attached to each cubic voxel, and if it received a forward or reverse current from a power supply via control circuits (cf. Fig. 1), the Pb plane connected to the driving motor was opened or closed depending on the direction of current, as shown in the top of Fig. 1. In order to cover a wide energy range of incidence radiation and collimate the radiation to a region of interest, each collimation unit operating independently was stacked up to construct a large 3D collimator. As shown in Fig. 2, the 3D collimator consists of independently operating collimation units controlled by an FPGA

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(XILINX, SPARTAN XCM-001-400, Singapore) as programmed from a computer with planning data, so that the total thickness and overall shape of the 3D collimator could be varied to collimate the radiation to a complex geometry with various intensities that could be changed in real time.

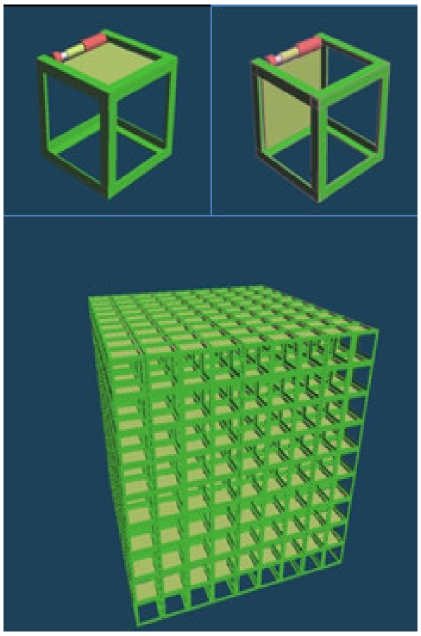


Fig. 1. Design of a closed (top left) and opened (top right) voxel collimator, and a 3D assembly (below) consisting of many voxels.

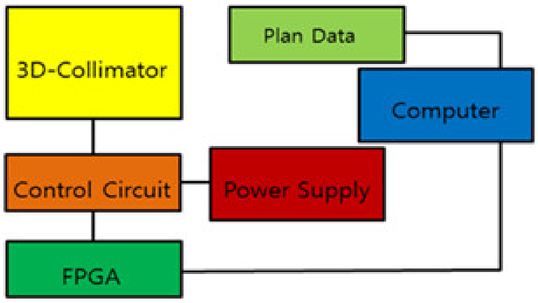


Fig. 2. Simple block diagram of the 3D collimator entire operating system introduced. As the plan data, the operation information could be changed to FPGA code language. The power from supply will be provided to collimator by control circuit connected with FPGA.

Fig. 3 shows photos of the 3D collimators and electronics. The 3D collimator consisted of 27 (3×3×3) unit collimators, each of which consisted of Al frames and a Pb plane cover (cf. Fig. 3 (a)). The inner and outer areas of the frames were 30×30 mm and 46×46 mm, respectively, and the area of the Pb cover was 30×30 mm. The thickness of the frame and cover were all 0.25 mm and 0.15 mm, respectively. In each frame rotation axis, a DC motor, which was controlled by a circuit with an FPGA board connected with a computer via JTAG (platform cable, XILINX, Singapore) (cf. Fig. 3 (b)), was operated according to a predetermined plan. If 5V voltage was supplied, the open and closing time of the lead cover was 0.1-0.3 sec. In order to evaluate the hardware performance, three kinds of experiment were performed: wedge filter modulating radiation intensity, intensity-modulated radiation control with the radiation attenuation depending on various positions[3], and image-guided radiation technique modeling with the exposure region changed over time as prescheduled by a computer. The experimental results were compared those of the simulation under the same conditions.

For the simulation, the Monte Carlo method (MCNPX) was used as shown in Fig. 4[4,5]. The size of the squarely shaped plane photon source was 9×9 cm and the dimensions of the simulated collimator were equal to those of the experiment. The detector located below the collimator consisted of 45×45×1 voxels and the size of the whole detector and each voxel was 9×9×2 cm and 0.667×0.667×20 mm respectively. The source-to- collimator and collimator-to-detector distances were both 20 cm, which was identical to the experimental conditions. A spectrum processor (SRS-78, Birch and Marshall, Institute of Physics and Engineering in Medicine, 1997, York, United Kingdom) was used to simulate the X-ray source with a continuous energy spectrum depending on the target and filter of the X-ray tube.

In the experiment, radiation fluoroscopy equipment (Model: Digital X-ray system CLASCAN-600, Listem,

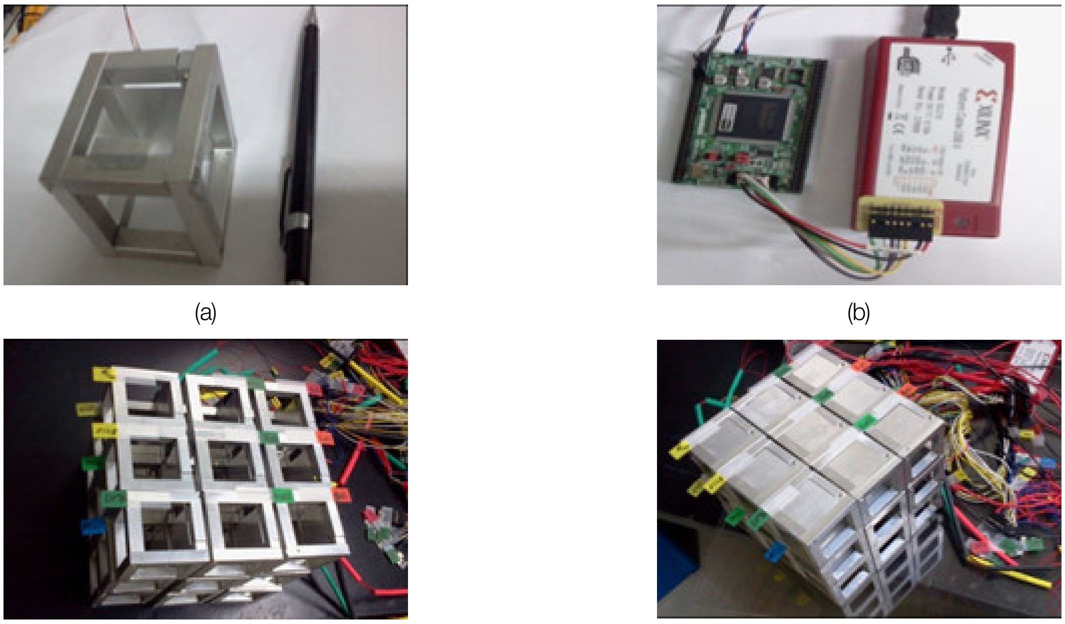

(a)
(b)
(c)
(d)

Fig. 3. Photos of 3D collimators and electronics: (a) Voxelized unit collimator, (b) FPGA board with JTAG, (c) 3D collimator assembly (opened) and (d) 3D collimator assembly (closed)

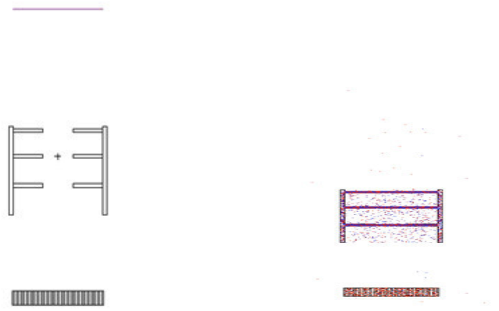

(a)
(b)

Fig. 4. Simulation of 3D collimator assembly and 45×45 detectors using Monte Carlo method: (a) Simulation structure: source (top), collimator (middle) and detector (bottom) and (b) Display of photon interaction.

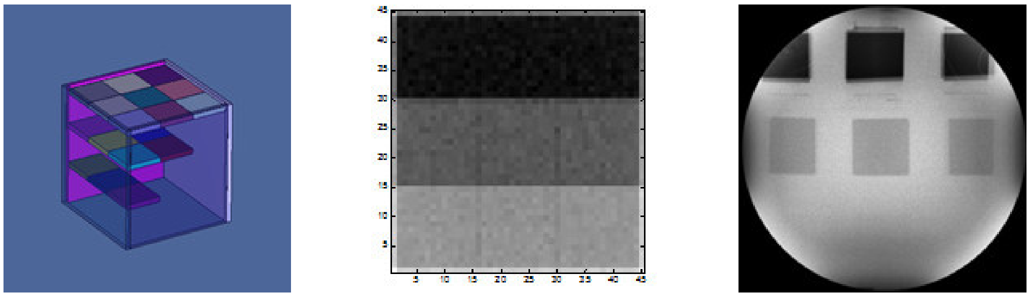
Fig 5. Fluoroscopy instrument for X-ray exposure and imaging in Korea university

Kangwon, Republic of Korea) was used as shown in Fig. 5. The exposure condition was set as 42 kVp, 320 mA and 250 msec (80 mAs). The experimental conditions of the X-ray source, distance and field of view were identical to the simulation conditions$^{6)}$.

Ⅲ. Result

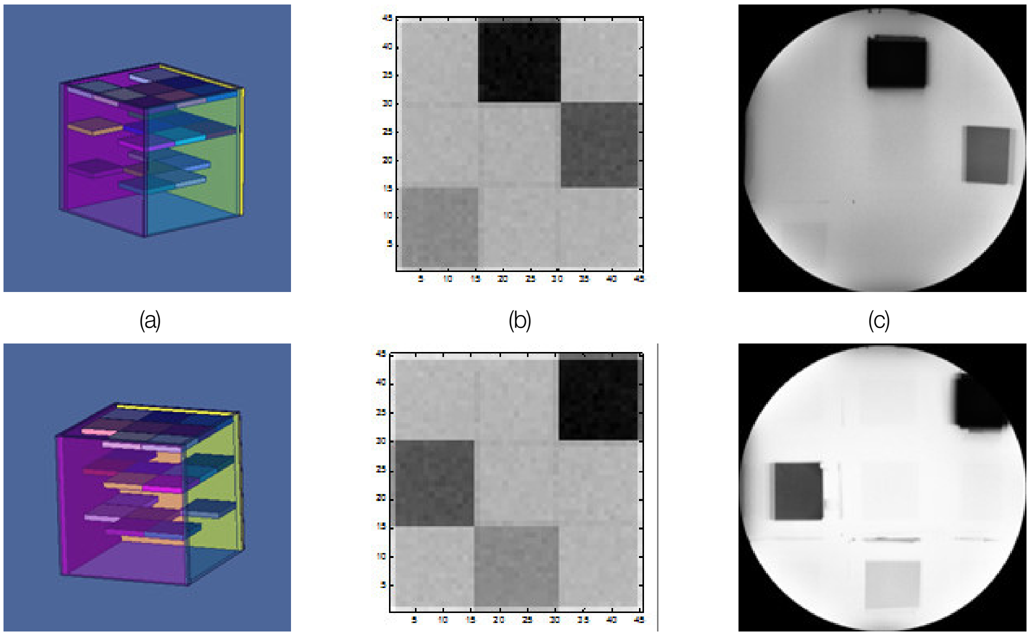
The simulations of the 3D collimator, which were generally used for planning, were performed and compared with the experimental results. The first experiment used a wedge filter, as shown in Fig. 6.

In order to realize the pattern of the wedge filter, the 3D collimator was constructed in a terraced shape. Since the attenuation of the radiation was proportional to the number of closed collimators aligned with the incident direction of the radiation, the area shielded by a single Pb layer was the darkest and that shielded by all three Pb layers was the brightest. The simulation and experimental results were well matched, which demonstrated the effectiveness of the 3D collimator assembly. Due to the limited size of the image intensifier tube, there were cut-offs in the experimental image. Self-shielding of the Al frames of each unit collimator was also shown in the image. However, with our 3D collimator, both the position and the intensity of the radiation can be automatically changed in real time as controlled and planned by an FPGA and a computer7). Fig. 7 shows the experimental and simulation results of real time modulation by the 3D collimator. The brightness of each area was proportional to the number of collimation layers. The modulation process was automatic once the



(a) (b) (c)

Fig. 6. Images for simulation and experiment using a wedge filter: (a) Visualization of simula-tion design, (b) Simulation image and (c) Experimental image.



(a) (b) (c)

(d) (e) (f)

Fig. 7. Images for simulation and experiment for intensity-modulated radiation technique. Before the motion: (a) Visualization of simulation design, (b) Simulation image and (c) Experimental image After the motion: (d) Visualization of simulation design, (e) Simulation image and (f) Experimental image.

therapy plan was run by the computer, and the simulation and experimental results were also well matched.

For image guided radiation technique, if the gantry head is rotating with the collimator (e.g., radiation tomotherapy) and the radiation is selectively exposed with consideration for the patient' s movement such as respiration or cardiac impulse, then the collimator has to be changed to an appropriate pattern related to the patient' s movement in real time. For this application, our 3D collimator controlled by an FPGA with operation software could be useful (cf. Fig. 8) because the 3D collimator can change its shape in synchronization with electronic triggering from a gantry movement or an electrocardiogram for precise exposure in radiation therapy[8].

Ⅳ. Discussion and Conclusion

Multileaf collimators have been mainly used for radiation therapy in actual field. In order to treat tumors with complex shape near critical organs, a different concept 3D collimator was developed. This

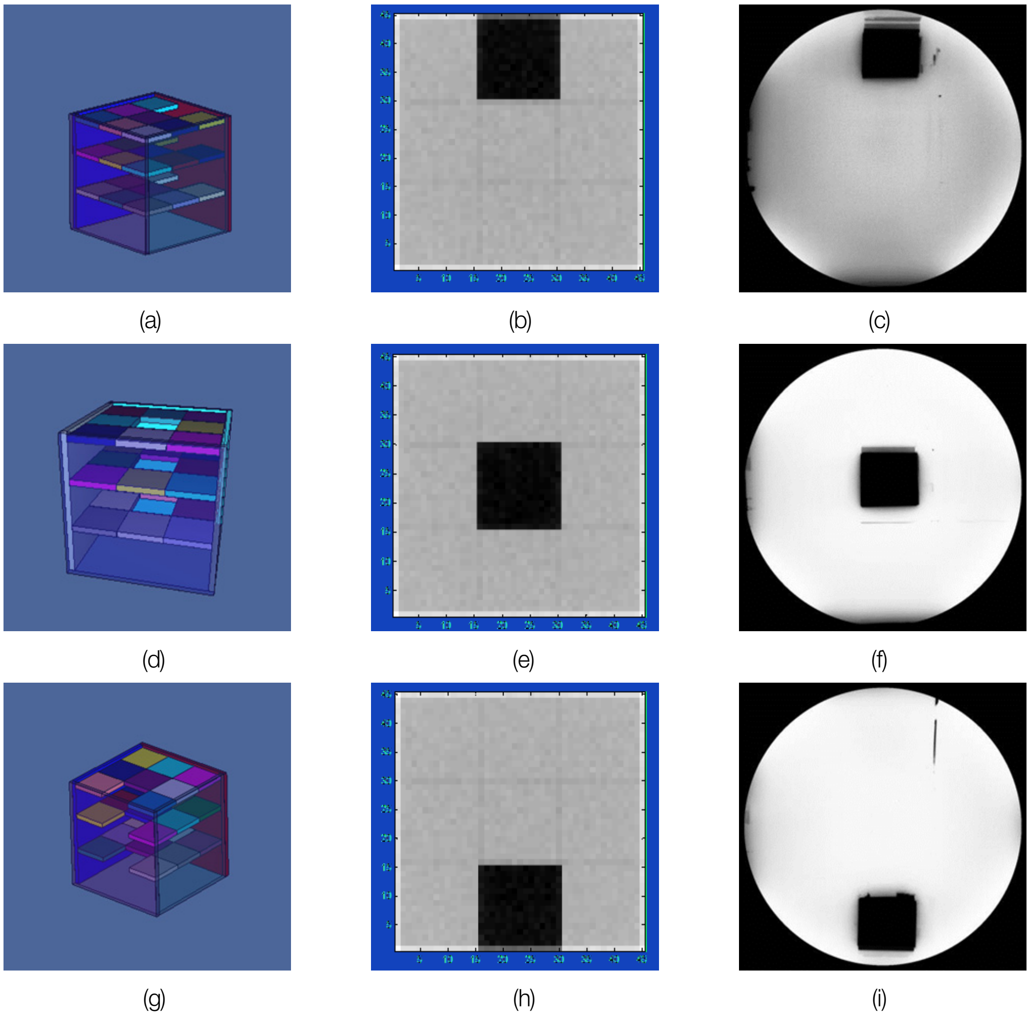

(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

Fig. 8. Images for simulation and experiment for image-guided radiation technique. Top position: (a) Visual-ization of simulation design, (b) Simulation image and (c) Experimental image Middle position: (d) Visualization of simulation design, (e) Simulation image and (f) Experimental image Bottom position:(g) Visualizat-ion of simulation design, (h) Simulation image and (i) Experimental image.

3D collimator consists of many unit collimators for modulating the radiation intensity depending on the positions in real time controlled by an FPGA according to a predetermined computer plan. The performance of the 3D collimator assembly was verified by both experiment and simulation, in which the results were well matched showing the feasibility of the 3D collimator.

In this study, the feasibility of clinical application was confirmed by simple experiment. This model could not be applied to clinical directly and needs more refined construction to field application. This collimation system could not be avaliable to be compared with other collimator model like MLC and further steps required to be clinical application. First, the finite size of the motors and frames, which has their own radiation attenuation, can cause additional shielding or leakage of radiation preventing precise radiation exposure to patients. Second, since the lead cover open and close vertically, the 3D collimator requires relatively large volume for the rotating cover, which limits the compactness and finiteness of the system compared to widely used MLC[9]. In the further study, we will apply smaller motors and frames using current micro-technology to minimize the attenuation effect, and develop a different method to move the lead cover space-wisely followed by the comparison of the performance of conventional MLCs.

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Reference

1. Eric E. Klein, Daniel A. Low, Jerry Markman, Mallinckrodt Institute of Radiology, St. Louis MO "Periodic Testing for Dynamic Multileaf Collimation" Proceedings of the 22"d Annual EMBS International Conference, Chicago IL, 23-28, 2000
2. Gert 0. de Meerleer, Cristina M. T Defue, R.N. Luk Vakaet, Ludwig G. Fortan, M Sc., Bart K. G. Mersseman. "Execution of a Single-Isocenter TJBtEE-Field Technigue, using a Multileaf Collimator or Tray-Mounted Cerrobend Blocks-Effect on Treatment Time" Int. J. Radiation Oncology Biol. Phys.. 39(1), 255-259. 1997
3. Brenda G. Clark, Tony Teke, Karl Otto "Penumbra evaluation of the varian millennium and BrainLAB M3 multileaf collimators" Int. J. Radiation Oncology Biol. Phys. 66(4), S71-S75, 2006
4. Lijun Ma, A.L Boyer, C.-M Ma, L Xing "Synchronizing dynamic multileaf collimators for producing two-dimensional intensity-modulated fields with minimum beam delivery time " Int. J. Radiation Oncology Biol. Phys. 44(4), 1147-1154, 1999
5. Matjaž Jeraj, Vlado Robar "Multileaf collimator in radiotherapy" Radiol Oncol 38(3), 235-40, 2004
6. Andrew W Beavis, Paul S Ganney, Viv J Whitton and Lei Xing. "Optimisation of MLC orientation to improve accuracy in the Static field delivery of IMRT" Proceedings of the 22nd Annual EMBS International Conference, Chicago IL 23-28, 2000
7. E.M. Fernandez, G.S. Shentalla, W.P.M. Maylesa, D.P. Dearnaley "The acceptability of a multileaf collimator as a replacement for conventional blocks" Radiol Oncol. 36, 65-74, 1995
8. Maarten L.P. Dirkx, Ben J.M. Heijmen, Gert A. Korevaar, Marjolein J.H. van Os, Joep C. Stroom, Peter C.M. Koper. "Field margin reduction using intensity-modulated x-ray beams formed with a multileaf collimator" Int. J. Radiation Oncology Biol. Phys. 38(5), 1123-1129, 1997
9. Glenn F. Knoll: Radiation Detection and Measurement 4th ed. Wiley, Hoboken, 336, 2010

•국문초록

적층구조의 3차원 콜리메이터

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2차원 방향으로 납을 이동하여 방사선 세기를 조절하는 기존의 다엽콜리메이터와는 다른 방식으로 고안 된 3차원 콜리메이터를 개발하였다. 3차원 콜리메이터는 복잡한 기하학적 구조에 방사선 조사에 있어 실시간으로 선량을 변화 할 수 있다. 3차원 콜리메이터는 정육면체 구조로 이를 구성하는 각각의 복셀화된 콜리메이터는 모터와 납으로 연결되어 있다. 각각의 프레임은 컴퓨터로 코딩된 FPGA 신호를 회로에 전달하여 계획대로 개별적으로 움직일 수 있다. 여러 가지 복잡한 기하학적 구조를 몬테칼로 시뮬레이션을 이용하여 결과를 도출하고 직접 실험한 결과를 비교 분석 하였다.

중심 단어 : 3차원 적층구조의 복셀화된 콜리메이터, 3차원 콜리메이터, FPGA