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ARTICLE

Development of a Signal Processing System to Control a Tumor Positioning System Based on Annihilation Gamma-rays Measured using Several Pairs of Scintillation Detectors

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The authors have been studying a new tumor tracking system for stereotactic radio surgery, composed of several pairs of scintillation detectors that detect annihilation gamma rays from radioactive medicine, such as ^{18}F-FDG, in tumor tissue. For that purpose, a signal processing system was developed based on an ASIC (MPX-08, Nova), which can output the logical pulses when the signals from the photomultiplier tubes (PMTs) are above the preset discrimination level. Results obtained experimentally using a ^{22}Na point source show that the system can control erroneous irradiation outside the expected region to less than 1.8%, even when the source moved with speed of 15 mm/s. Moreover, the computer simulation showed that the system can work with erroneous irradiation of less than several percent, even for volumetric sources, considering the three-dimensional distribution of ^{18}F-FDG near a lung tumor.

KEYWORDS: radiotherapy, scintillation detectors, tumor tracking, ASIC

I. Introduction

Because tumor radiotherapy is known to be effective, it has been applied to many patients[1)]. To enhance therapy efficiency, some respiration-gated radiotherapy techniques using information of peritoneum pressure or body surface movement have been developed [2), 3)]. However, results have demonstrated that those techniques have insufficient accuracy. To overcome the problem, Shirato et al. developed a new technique with a gold target set beside the tumor position, which enables measurement of the tumor position[4)–6)]. The system enhanced the accuracy of tumor tracking, and it has been applied to radiotherapy of the patients. However, because this system presents the disadvantage that setting the gold target inside the patient body is a great burden, the feasibility of a new tumor tracking system has been investigated to improve the problem[8)]. In the system, the annihilation gamma rays from the ^{18}F-FDG are used to measure the tumor position. The technique obviates the gold target, thereby reducing the patient burden. However, the spatial resolution and the possibility of increasing the unwanted irradiation of normal tissues can be a problem. As described herein, the authors have developed a signal processing system to control the new tracking system and have investigated the feasibility of the technique.

II. Developed signal processing system

1. System configuration

For measuring the annihilation gamma rays emitted from the ^{18}F-FDG and outputting the ON/OFF signal to an LD which simulated the X-ray generator for therapy, we developed a signal processing system with the signal flow presented in **Figure 1.** For the system, we adopted a commercial Application Specific Integration Circuit (ASIC, MPX-08[7)]; NOVA R&D Inc.) to process signals from the photomultipliers (PMTs). The ASIC outputs logic signals when charges from the PMTs are above a pre-set threshold level by the digital to analog convertor (DAC). Using the logic ICs, we realized the coincidence measurements of the annihilation gamma rays. The microcomputer in the system calculates the count rate of the coincident signals, which outputs the ON/OFF signal to the LD.

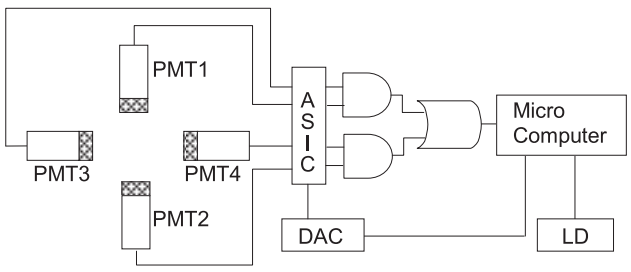

Fig. 1 Developed signal processing system.

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2. Measurement to check the system function

Using a pair of scintillation detectors, we conducted a simple experiment to determine the threshold level of the ASIC to output the logic pulse. The experimental setup is presented in Fig. 2. The source was set at the same height as the detectors. By changing the output from the DAC, we measured the pulse height distribution with and without the coincidence circuit for ^{22}Na gamma rays. **Figures 3 and 4** respectively show results for cases with and without the coincidence circuit. We can observe that the peak at the DAC output of 400 disappeared when the coincident function was on. Based on the results, we inferred that the peak was correspondent to the annihilation gamma rays and set the threshold just below the peak.

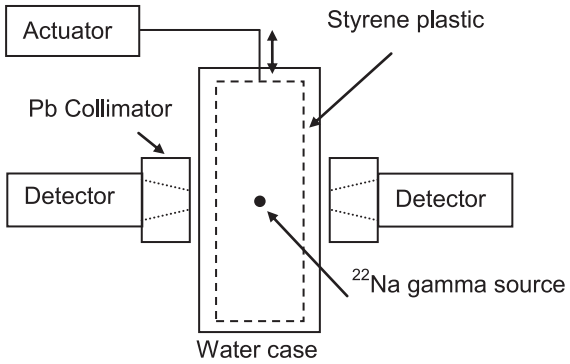


Fig. 2 Experimental setup used to determine the threshold level set by the DAC. The ^{22}Na gamma source can be moved with the styrene plastic inside the water case.

III. Experimental

1. Experimental setup

The experimental setup is the same as that presented in **Figure 2**. The ^{22}Na source was moved up and down using an electrical actuator. The count rate at each position was measured. **Figure 5** presents the results. We set the irradiation range as -5 mm to + 5 mm around the source position. The microcomputer was programmed to output the ON signal to the LD when the measured count rate was higher than those at the boundary of the interval. Because of the extension of the string which suspended the source, the count rate distributions differed between moving-up and moving-down periods. The threshold levels were set independently of the direction of movement.

2. Measured ratios of Errors of two types

In this experiment, errors of two types were defined as follows:

Error-1:

Errors where the output signal was set ON when it should not be set ON.

Error-2:

Errors where the output signal was not set ON when it should be set ON.

Error-1 includes unwanted irradiation of normal tissues. Error-2 results in lowering the efficiency of irradiation of the tumor.

In the experiments, the moving speeds of the ^{22}Na gamma source were set to 2, 5, 7, 10, and 15 mm/s. The counting period in the microcomputer was set to 50 ms or 100 ms, where after each period, the output was determined to be ON or OFF.

Table 1 presents values of Error-1 and Error-2 for each experimental condition. In this table, the output of LD is compared with the physical position of the actuator. It is apparent that the higher source velocity caused larger values for both Errors. Only in the case in which the velocity was 2 mm/s and integration period is 50 ms was the value of Error

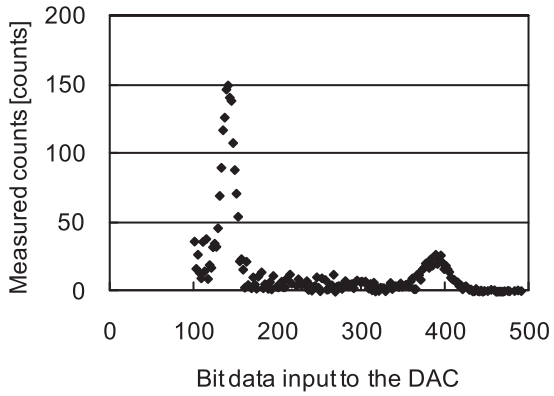


Fig. 3 Measured pulse height distribution without the coincident function.

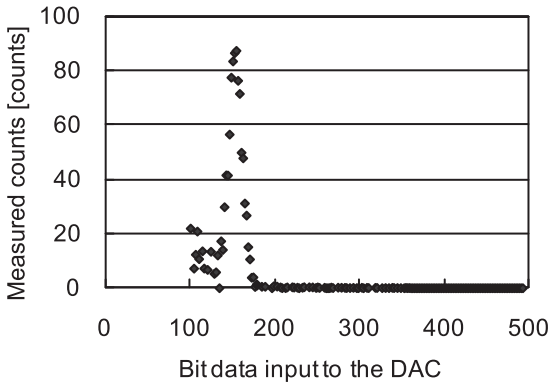


Fig.4 Measured pulse height distribution with the coincident function.

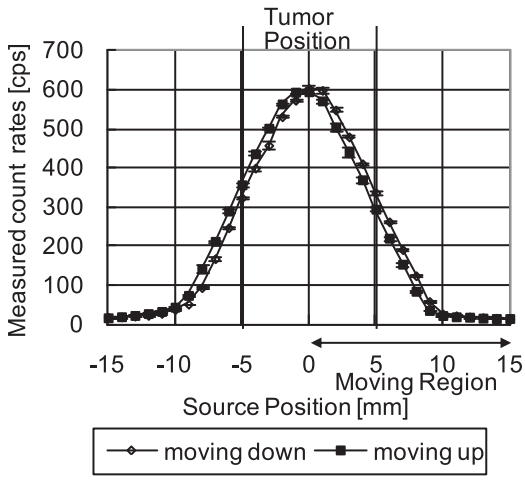


Fig. 5 Measured distribution of counts over the threshold level set by the DAC in the experimental system shown in Fig. 2.

2 larger for the integration time of 100 ms, which was caused by the balance between the three parameters, which are (1) the time when the source was moving at the boundary region of the tumor and the normal tissue, (2) the time response of the system, and (3) the statistical errors of the measured counts. In other cases, shorter integration time reduced the errors because the system response speed was improved. From these results for a point source, Error-1 especially can be made sufficiently low.

Table 1 Measured errors for the point source experiments.

Integration Time	100 [ms]		
Velocity of the source [mm/s]	Success [%]	Error-1 [%]	Error-2 [%]
2	76.51	0	23.49
5	84.71	0	15.29
7	90.85	0.14	9.009
10	80.10	0.83	19.07
15	90.25	1.76	7.990
Integration Time	50[ms]		
Velocity of the source [mm/s]	Success [%]	Error-1 [%]	Error-2 [%]
2	78.42	1.18	20.40
5	82.02	1.85	16.13
7	83.82	1.34	14.84
10	80.23	0.75	19.01
15	77.51	0.21	22.28

IV. Simulation

1. Function of the simulation code

Based on the experiments described above, for a point source, results demonstrated that the present signal processing system can control the therapy system with fairly low Error-1 values.

However, to investigate the applicability of the system, we must consider various cases of volumetric sources for several experimental parameters. For this purpose, we developed a simulation code that can calculate two errors under various conditions.

The flow chart of the developed code is depicted in Fig. 6. First, the code reads in the averaged count rate distribution for the experimental system, which had been measured or calculated beforehand. Subsequently the source position was moved, simulating the breathing of the patient. At each position, according to the pre-read averaged count rate and Poisson statistics, the count during the integration time was estimated. By comparing the value with the preset threshold, the irradiation flag of the therapy X-rays was changed. Comparison between the simulated results and the experimentally obtained results for a point source case showed that the simulation code can estimate the errors accurately.

2. Simulation condition for a volumetric source

As a volumetric source, we assumed a case of lung cancer with tumor diameter of 50 mm and with distance between each detector pair as 500 mm. The standardized uptake value (SUV) of ^{18}F-FDG was assumed to be 5. Under these conditions, the count rate distribution was calculated using another simulation code[8]. The result is portrayed in Fig. 7. In our simulation, the threshold level in the simulation code was set such that the irradiation flag was set ON when the source position was from -25 mm to +25 mm, corresponding to the tumor size.

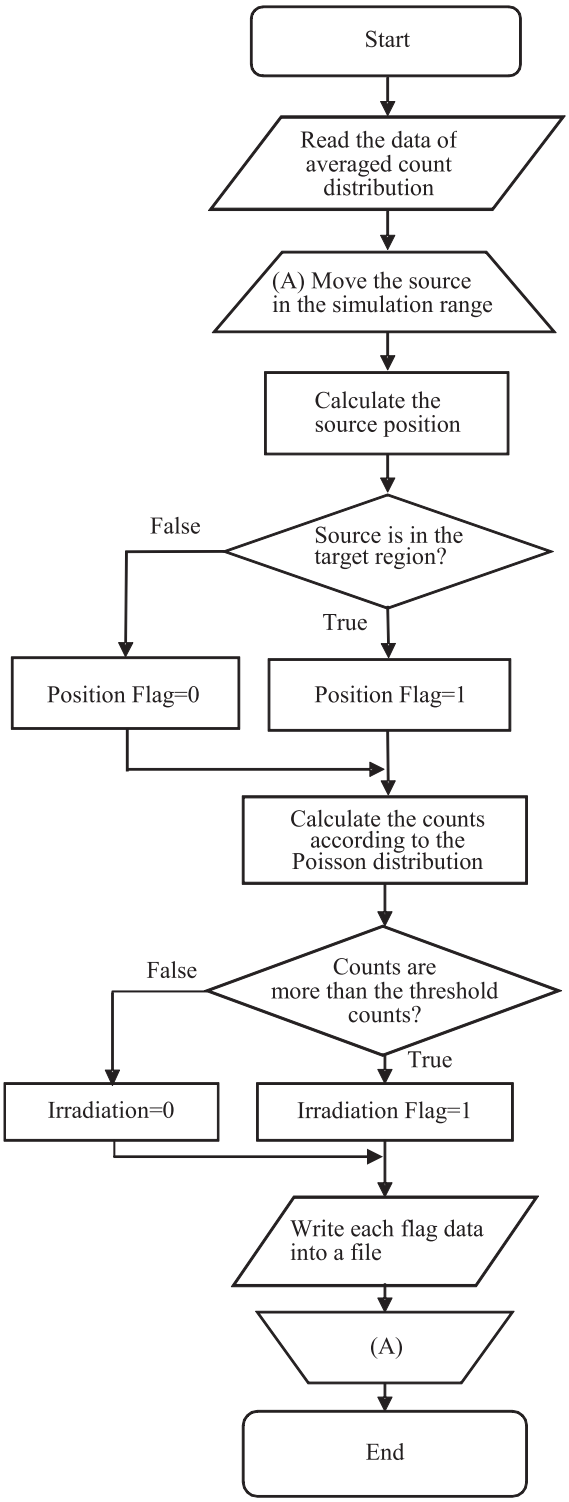


Fig. 6 Flow chart of the developed simulation system.

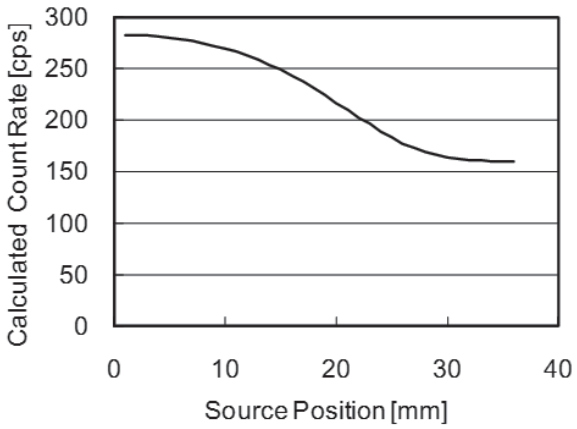


Fig. 7 Calculated count rate distribution for a volumetric source assuming a lung cancer[8].

3. Simulated results

Figure 8 presents results for cases when 4 or 5 sets of detectors are used in the irradiation system presented in Fig. 1. The detector pairs are assumed to be set around the body with their focus points on the tumor position. In those cases, one or two more ASICs are necessary with the signal diagram shown in **Figure 9**. Coincidence measurements are assumed to be conducted by the AND gates between the detector pairs, and counts from the AND gates are summed using an OR gate and a microcomputer. Figures 8(a) and 8(b) show results for the Error-1 and Error-2: it is apparent that the average values of Error-1 are small, although the Error-2 values are larger. Therefore, although the irradiation efficiency to the tumor is low, the probability of unwanted irradiation to the normal tissue can be low. However, the dispersions of both Errors are revealed to be large. To reduce the dispersions of the Errors, we tried averaging the simulated results 10 times. **Figure 10** portrays the results for Error-1. As expected, 10-times averaging reduced the dispersion of the Error-1 considerably. In the current system, the statistical errors of the measured counts are determined by the accumulated radioactivity inside the tumor region and the counting periods. To increase the source strength, a new medicine with higher SUV is necessary. However, a longer counting period results in slower system response and increases the value of Error-1. Therefore, it can be said that it is difficult to reduce the statistical error markedly. In this situation, if we carry out the therapy at high dose rate, then large doses of unintended irradiation might occur in each irradiation shot. However, if the irradiation is conducted repeatedly at a lower dose rate, the probability of Error-1 is averaged and its dispersion becomes low. Consequently, by irradiating the therapy X-rays many times at a low dose rate, tumor therapy conducted using this system can be done with stable and planned probability of unwanted irradiation of normal tissues.

V. Conclusions

A signal processing system was developed to investigate the feasibility of the new tumor tracking and therapy system. Experiment and simulation results demonstrated that the tracking system can function with fairly low unintended irradiation of normal tissues. During therapy, repeating irradiation at a low dose rate can reduce the average and dispersion of the errors.

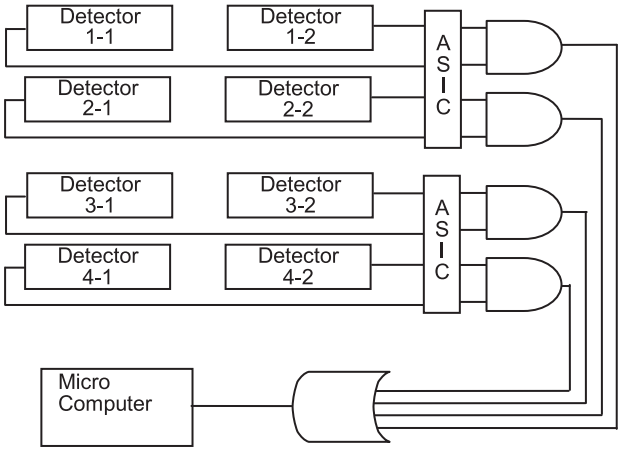
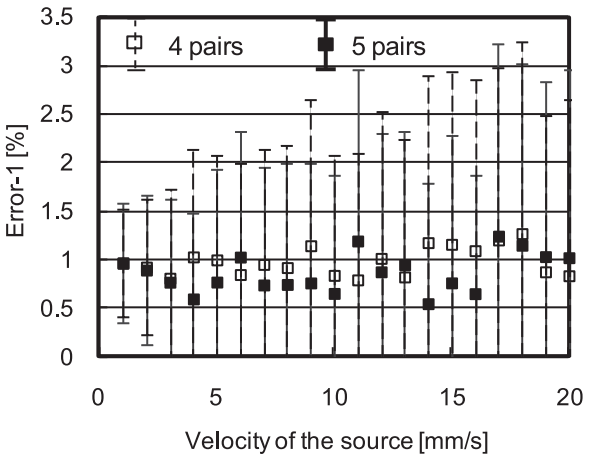
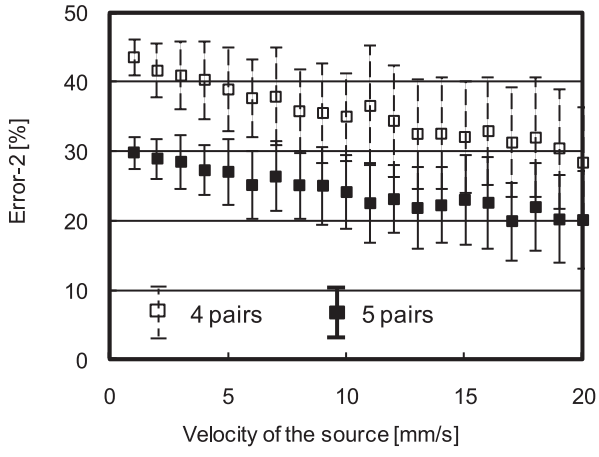


Fig. 8 Signal diagram assumed in the simulation.



(a) Simulated results of Error-1.



(b) Simulated results of Error-2.

Fig. 9 Simulated errors for the 4 and 5 detector pairs, where (a) and (b) respectively denote the results for Error-1 and Error-2.

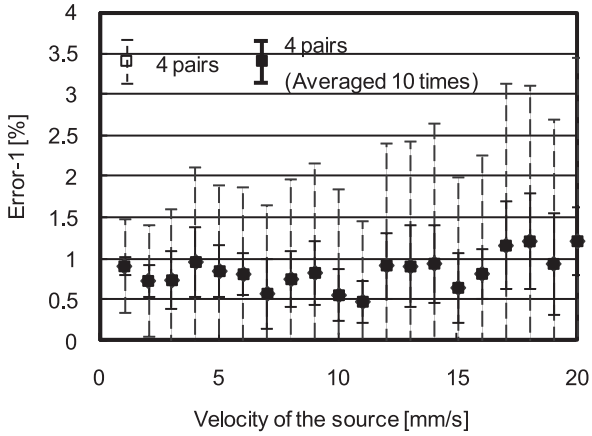


Fig. 10 Comparison ofthe Error-1 values between the cases of without averaging and with 10-times averaging.

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