Development of multiple regions tracking system to reduce inter and intra-fractional error for proton therapy

著者	TERUNUMA Toshiyuki, SAKAE T., ISHIDA M., SATO M., IKUMI S., YASUOKA K., KUMADA H., OKUMURA Toshiyuki, TSUBOI K., SAKURAI Hideyuki
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PTCOG49

Development of multiple regions tracking system to reduce inter and intra-fractional error for proton therapy

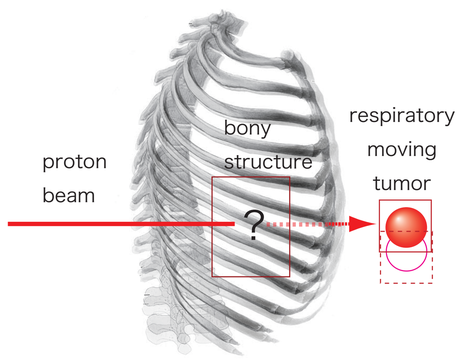
T. Terunuma, T. Sakae, M. Ishida, M. Sato, S. Ikumi, K. Yasuoka, H. Kumada, T. Okumura, K. Tsuboi and H. Sakurai
Proton Medical Research Center (PMRC), University of Tsukuba, 1-1-1 Ten-nohdai, Tsukuba 305-8575, Japan
E-mail : terunuma@pmrc.tsukuba.ac.jp

筑波大学 University of Tsukuba

1. Introduction

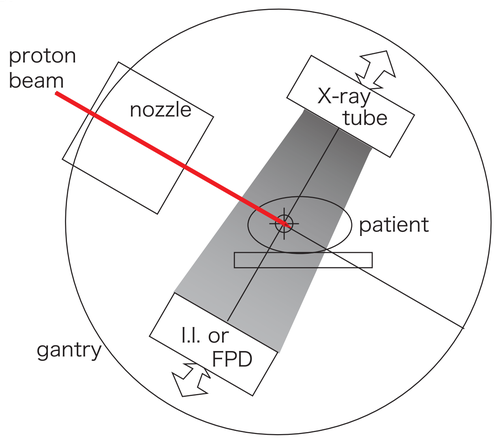
Is the irradiation accuracy enough when the tumor is just at the isocenter ? The position of a high-density structure in front of the tumor is also important, because the positional uncertainty of this structure on the proton beam path causes the proton range' s uncertainty. Both positions of the structure on the beam path and the tumor should be checked during patient setup and treatment to reduce inter and intra-fractional irradiation error.

The aim of this work is to study the possibility of multiple regions tracking.



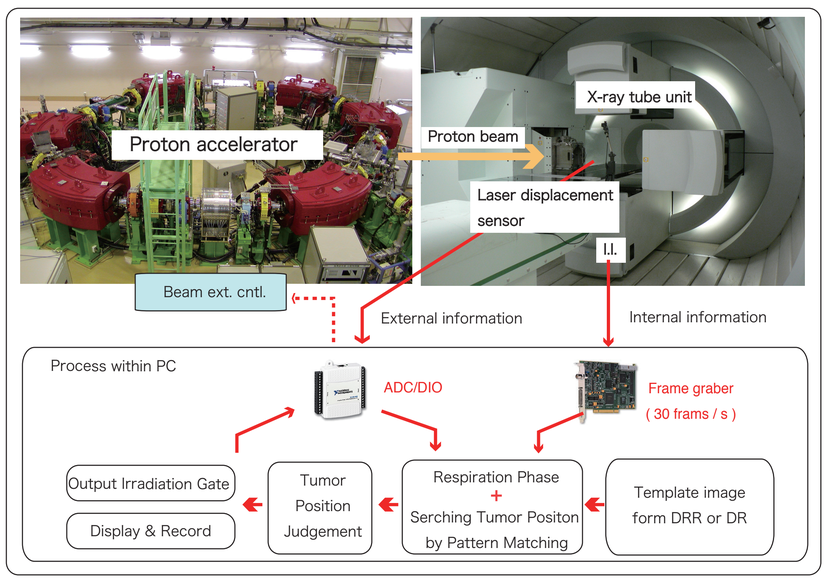
2. Concept

A X-ray device which can be rotated with a proton gantry is an appropriate arrange of the system to check both positions of the structure and the tumor. In this case, the X-ray direction is perpendicular to the proton beam direction. Therefore the X-ray projects the tumor and the structure, which is on the proton beam path, on an imaging device.



3. System

The developed real-time tracking system utilizes a fluoroscopic X-ray image and a patient' s respiratory waveform. The resolution of projected image around the isocenter is 0.3 mm/pixel. The position of tumor and the structure on the beam path are calculated by a pattern matching algorithm.

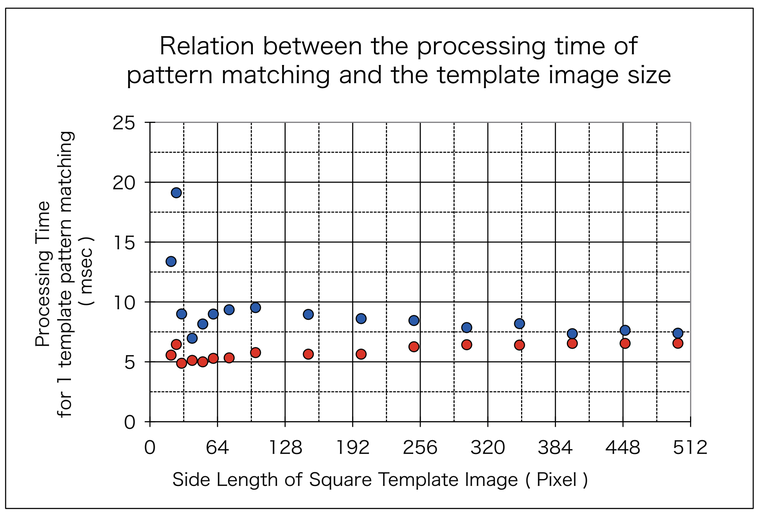


4. Pattern matching algorithm

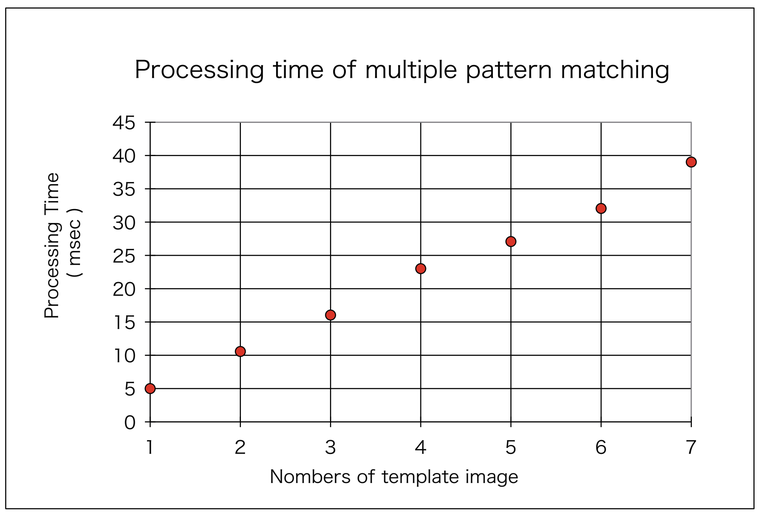
The developed pattern matching algorithm is based on searching a maximum position of the score which is calculated by using the normalized cross-correlation between the fluoroscopic image and the template image. This algorithm can calculate the position in sub-pixel (1/10) resolution, and can correspond to image changing in rotation (5 degree) and in expansion (10%).

$$S(i,j)=\frac{\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}(w(x,y)-\bar{w})(f(x+i,y;j)-\bar{f}(i,j))}{\left[\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}(w(x,y)-\bar{w})^2\right]^{\frac{1}{2}}\left[\sum_{x=0}^{L-1}\sum_{y=0}^{K-1}(f(x+i,y;j)-\bar{f}(i,j))^2\right]^{\frac{1}{2}}}$$

5. Performace of pattern matching



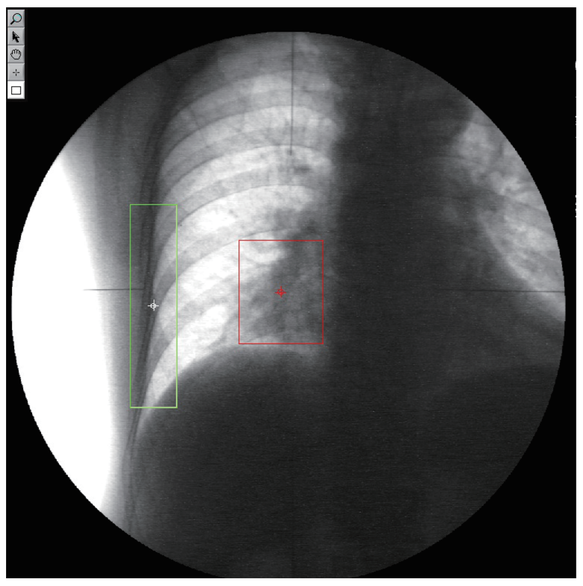
blue circle & red circle show the result of searching within full-area and within the template image size + 30mm margin.



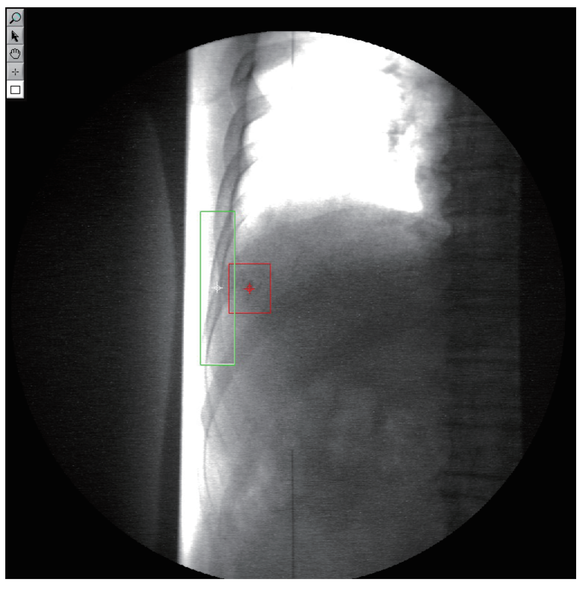
Up to 5 regions tracking are performed within the time interval of fluoroscopic image acquisition (33 msec).

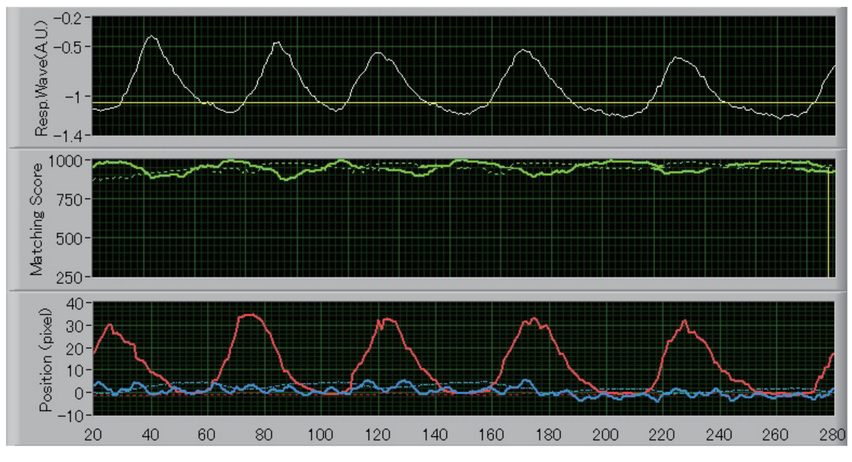
6. Result of multiple tracking

Lung
red: target
green:
rib on beam path



Liver
red:
a part of target
green:
rib on beam path

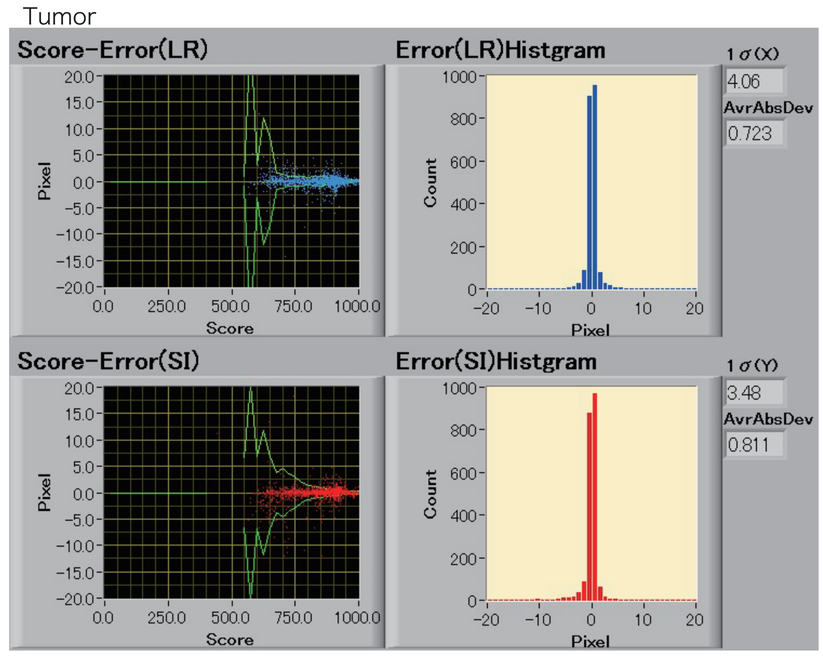




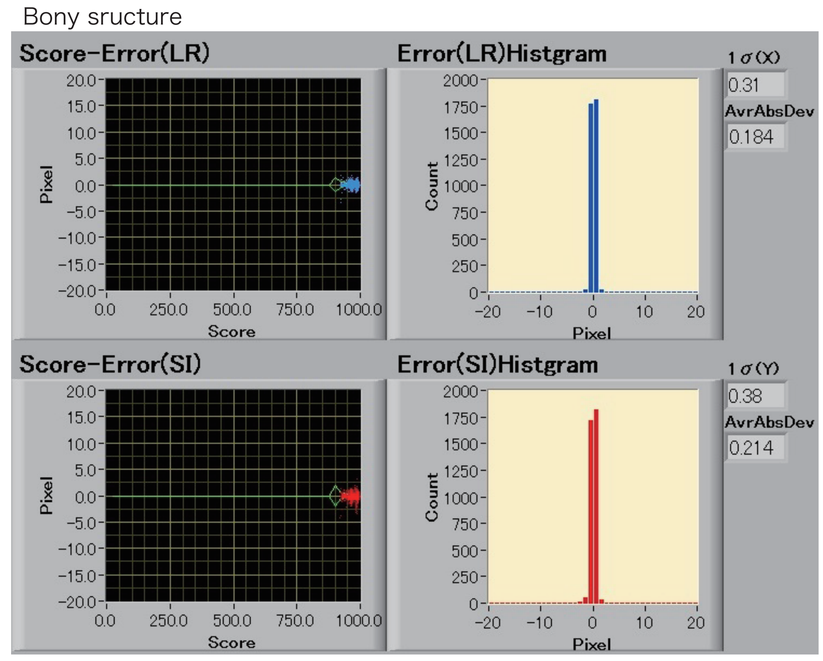
A example of tracking is shown. The image acquired during patient setup is used in this example. White line is respiration wave, green line and dashed line are the pattern matching scores of the tumor and the rib, red line and blue line are the trajectories of tumor in S-I direction and L-R direction, and red dashed line and blue dashed line are the trajectories of rib in S-I direction and L-R direction.

7. Analysis of traking error

Tumor



Bony sructure



In upper distribution maps, grren line shows the standard deviation of the positional errors for each tracking score which is normalized by 1000.

Fluoroscopic Images acquired during setup for 10 patients (5 lung cancer and 5 liver cancer) were analyzed. Tracking error (1sigma) of tumor and that of boney structure are 4.06 pixel and 0.38 pixel, and those are equivalent to 1.8 mm and 0.11 mm.

8. Discussion

The calculation time of pattern matching depends on the tamplate image size and the serching area. For typical size of template image, 5 regions tracking are performed in real-time.

The difference of tracking error between the tumor and the bony structure come from the difference of the elasticity of objects. The tumor is more deformed with respiration than the bony structure. Threfore lower correration score of the tumor between the fluoroscopy and the template image are calculated when inhale phase, because the template image are obtained in exhale phase. A wide distribution of the pattern matching score of tumor tracking shows the existance of lower correlation. However, the accuracy of multiple region tracking is enough whthin exhale phase.

A biplane X-ray system, one imaging device of which is inserted in the beam direction, is used for patient 3D registration. In this precedure, the multiple regions tracking is effective to determine the tumor position and the structure position on the beam path. Thus this function can reduce the inter-fractional irradiation error. During treatment, it is difficult to monitor object' s accurate 3D position, because no imaging device can insert in the beam line and arrangement of biplane X-ray system in gantry is difficult. The tumor mainly moves in S-I direction and the bony structure such as rib moves exterior due to lung infration. Therefore a single-plane X-ray system perpendicular to the beam direction can check the positional diference between the patient 3D registration and the treatment. Thus this function can reduce the intra-fractional irradiation error.

9. Conclusion

The function of the real-time multiple regions tracking was developed. The possibility to check the positional uncertainty of the tumor and the structure on the proton beam path is shown. Thus the inter and intra-fractional irradiation error can be reduced by using this system.