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Research on data smoothing and singular value removal algorithm in proton beam detection

Mingyan Sun, Ning Lv

Institute of nuclear. Rocket Force University of Engineering, Xi'an, 710025, China

Abstract

Proton therapy is a method of radiotherapy for tumors, which has good therapeutic effect and less damage to the treatment. The detector that measures the beam position contains multiple data channels. In order to solve the problems of multi-channel data transmission and partial channel data loss, an algorithm including data smoothing and singular value removal is proposed and implemented on the host computer. The background data and signal data are used for testing, and the results are better.

Keywords

LabVIEW Data smoothing Singular value removal.

1. Introduction

Radiotherapy is one of the main methods of tumor treatment. According to data provided by the Particle Therapy Co-Operative Group, as of February 2021, there are 9 particle therapy centers under construction in China, of which 8 are proton therapy centers. Radiation therapy mainly uses the deposited energy of rays in the human body to accurately irradiate tumors. Radiation destroys the structure of tumor cells and then kills tumor cells. The rays used in radiotherapy include α, β, γ, X-rays, electrons, protons, and Carbon ion beam current, etc.[1-3]

By adjusting the energy of the proton beam, the position of the Bragg peak of the proton can be controlled, so that the maximum dose deposition position acts on the target organ, thereby achieving precise irradiation of the tumor. Due to the Bragg peak effect of the proton beam and the general tumor location is located inside the human body, when protons enter the human body, less energy is released and has little impact on normal organs. The energy of the proton beam is adjusted to make the Bragg peak in the tumor. At the location, to achieve the purpose of precise irradiation.[4]

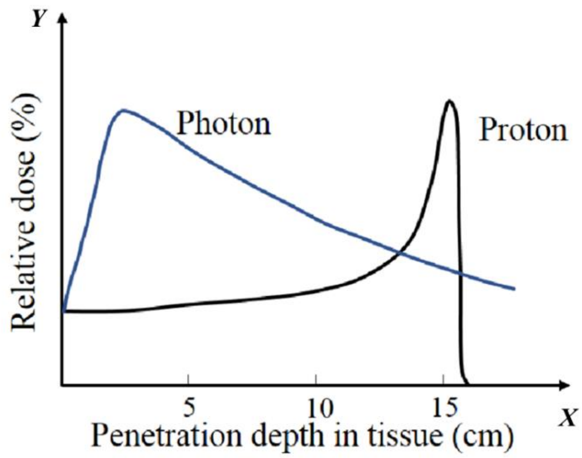

Figure 1 Dose depth curves for different rays and particles in the human body

2. Research Background

2.1. Main methods of proton therapy

The width of the Bragg peak of a single-energy proton beam is only a few millimeters, which is on the order of millimeters, while the size of clinical tumors is usually on the order of centimeters. Therefore, in the process of proton radiotherapy, the proton beam needs to be expanded horizontally and longitudinally and conformed to the tumor in order to be treated.

The Bragg peak generated by the proton beam will only have a width of millimeters when it is not expanded. However, the size of the tumor detected by PET-CT is usually more than 1 cm, even up to 10 cm. Therefore, in the process of tumor radiotherapy, the beam needs to be broadened to expand the size of the proton beam in all dimensions. For proton beam broadening, there are currently two main technologies, namely passive scattering irradiation technology and pencil beam scanning irradiation technology (active scanning irradiation technology). [5-7]。 The difference between passive scattering illumination technology and pencil beam scanning illumination technology lies in the beam width released before reaching the patient.

Figure 2 is a schematic diagram of a passive scattering irradiation system, which is mainly expanded by the reaction of protons with matter. In the horizontal direction of the beam, the proton beam passes through the First Scatterer and the Second Scatterer to achieve the scattering of the proton beam.[8]

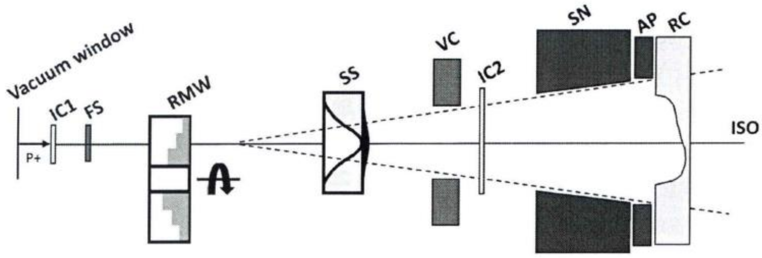

Figure 2 Diagram of the passive scattering irradiation system

Figure 3 is a schematic diagram of a pencil beam irradiation system. Different from the passive scattering irradiation technology, the pencil beam irradiation system does not use the beam to expand through the scatterer, but directly operates the beam emitted by the accelerator. The deflection direction of the beam is controlled by a magnet placed vertically at the beam outflow port, combined with information such as the location and size of the tumor, and point-by-point scanning is performed hierarchically.

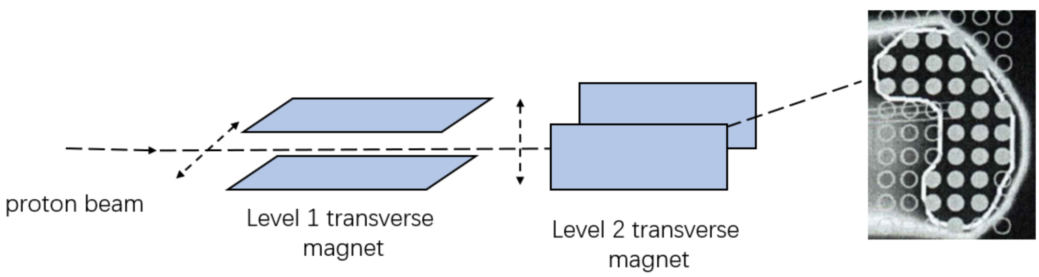

Figure 3 Schematic diagram of pencil beam irradiation system

2.2. Two-dimensional detector array

The two-dimensional ionization chamber detector array is composed of multiple ionization chambers. In order to detect the position distribution of the beam in the horizontal direction,

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the ionization chambers in the detector array are only uniformly distributed in the horizontal direction, and not superimposed in the longitudinal direction. The difference between the detector array and the multi-layer flat panel ionization chamber is that the two-dimensional ionization chamber array is generally composed of square or rectangular small ionization chambers as shown in Figure 4. Before the ionization chamber is used, it is necessary to clarify the position information of each detector. In the process of use, combine the signal collected by the detector and the position of the receiving signal detector to determine the distribution of the beam in the horizontal direction. At the same time, according to the data processing, information such as the peak value and peak width of the beam can be obtained. To improve the resolution of the detector and obtain more precise beam position information, it is necessary to reduce the size of a single detection unit at the hardware level, increase the number of detection units, and improve the resolution by optimizing the structure of the detector.

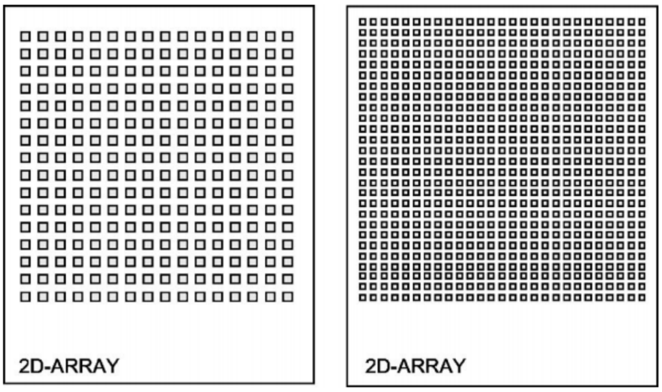

Figure 4 Schematic diagram of two ionization chamber array structures produced by PTW

The IMRT MatriXX dot matrix system produced by German IBA is composed of flat panel detectors, electronics systems and analysis software. The panel size is 31.5 cm×31.5 cm×4.0 cm. The dot matrix system consists of 1024 air ionization chambers. Each ionization chamber has a diameter of 4.5 mm, a height of 5 mm, and a sensitive volume of 0.07 ml. The distance between the centers of adjacent ionization chambers is 7.62 mm. All ionization chambers are arranged to form a 32×32 plane matrix, and the effective measuring point is 3 mm from the front surface of the detector.[9] The IMRT MatriXX point matrix system has been studied and imitated by many scholars as the current detector array with better detection effect. Many scholars around the world use IMRT MatriXX to conduct experimental measurements and carry out research on the performance indicators of detectors in different detection environments.

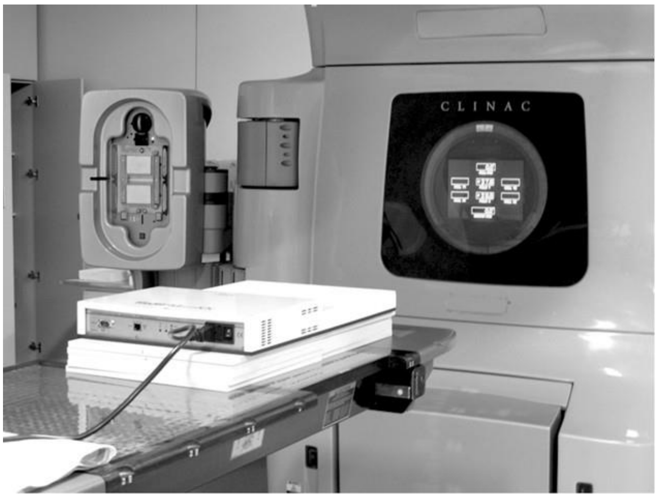

Figure 5 MatriXX two-dimensional ionization chamber dot matrix

3. Introduction of data smoothing and singular value removal algorithm

The two-dimensional ionization chamber array is usually composed of multiple air ionization chambers with the same size and similar structure. The problem that the ionization chamber array needs to deal with in the detection process is the coordination of multiple signals. For example, the ionization chamber array produced by PTW includes 729 small ionization chambers, and subsequent signal processing needs to be performed around 729 signal processing. In the process of multi-channel signal processing, there are two problems that need to be solved. The first is that the ionization chamber corresponding to each channel may cause different noises in the electronic system due to the process or installation steps. This situation will cause large fluctuations in the ionization chamber signal below the background level. The second problem is that in actual use, due to too many signal channels, some signals may be missing. Aiming at these two possible problems, a combined data smoothing and singular value removal algorithm is proposed and tested by simulating 256 channels.

3.1. Data smoothing method

At present, there are a variety of data smoothing methods. In order to perform simulation tests, the GetData software is used to obtain the data collected by the multi-collecting electrode flat ionization chamber. Use different smoothing methods to test. Including "simple five-point smoothing", "simple three-point smoothing", and "weighted moving average".

$$P_i = \frac{\sum_{i-1}^{i+1}(P_{i-1}+P_i+P_{i+1})}{3} \quad (1)$$

Formula 1 is a simple three-point smoothing calculation method, whereP_i is the data collected by the i-th channel;

$$P_i = \frac{\sum_{i-2}^{i+2}(P_{i-2}+P_{i-1}+P_i+P_{i+1}+P_{i+2})}{5} \quad (2)$$

Formula 2 is a simple five-point smoothing calculation method, whereP_i is the data collected by the i-th channel;

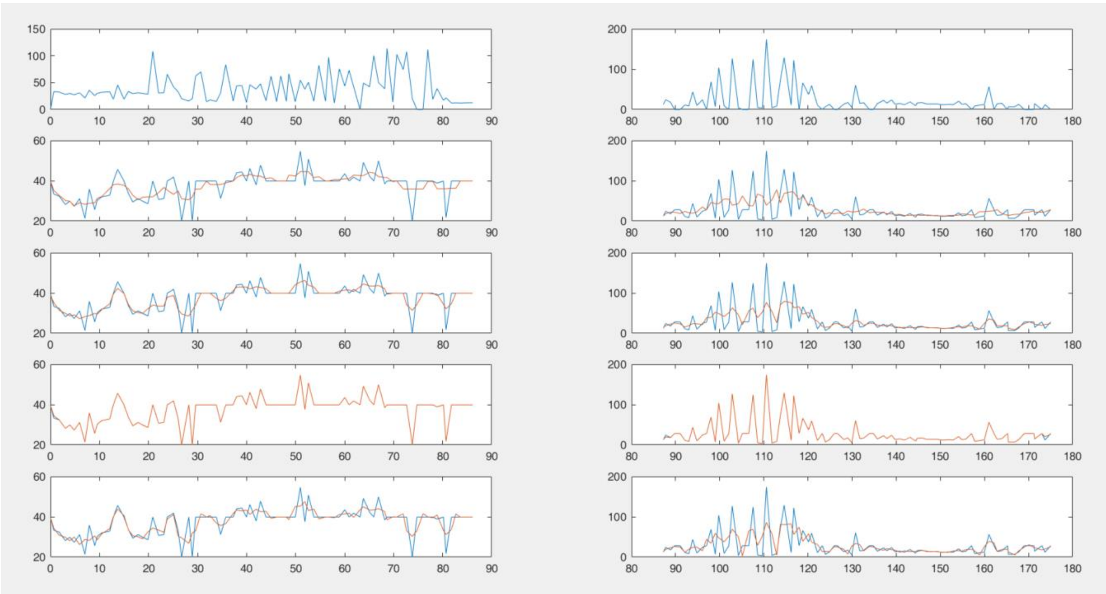

Figure 6 Test results of multiple data smoothing methods

The smoothing result is shown in Figure 6. The left and right sides are the data processing results of the X and Y direction channels, respectively. From top to bottom are the initial data and four different smoothing methods. From the results, it can be seen that too much smoothing will lead to the lack of peak information, such as the left side 2, 3; too small a smoothing degree will lead to signal fluctuations Too large, such as 4, 5 on the left. After comparing various smoothing results, a simple 5-point smoothing was finally selected.

3.2. Outlier removal method

In view of the possibility that the electrode strip data is missing or the signal of a single channel is too large, the singular value removal function is performed on the basis of data smoothing. The data singular value processing flowchart is shown in Figure 7.

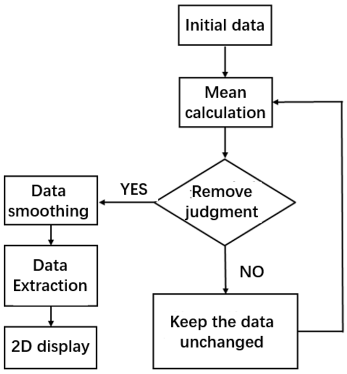

Figure 7 The data singular value processing flowchart

First, in a passive environment, the average value of all channel data is collected, and the average value fluctuates 75% as the normal data filtering range, and the channel where the abnormal value is located is extracted. After the outlier channel extraction is completed, the average value of the normal data channel is calculated, and this average value is assigned to the outlier channel, and finally the X-axis data and the Y-axis data are superimposed to obtain two-dimensional data. Finally, the singular value removal function of multi-channel data is realized.

4. Host computer production based on LabVIEW software

4.1. LabVIEW software introduction

LabVIEW is a program development environment, developed by National Instruments (NI), similar to C and BASIC development environments, but the significant difference between LabVIEW and other computer languages is that other computer languages use text-based languages to generate code, And LabVIEW uses the graphical editing language G to write the program, and the generated program is in the form of a block diagram.

LabVIEW software is the core of the NI design platform, and it is also an ideal choice for developing measurement or control systems. The LabVIEW development environment integrates all the tools that engineers and scientists need to quickly build various applications, and is designed to help engineers and scientists solve problems, improve productivity, and continue to innovate.

LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications. Traditional text programming languages determine the order of program execution according to the sequence of statements and instructions, while LabVIEW uses data flow programming. The data flow between nodes in the block diagram determines the execution order of VIs and functions. VI refers to virtual instrument, which is a program module of LabVIEW.

LabVIEW provides many controls that look similar to traditional instruments (such as oscilloscopes and multimeters), which can be used to easily create user interfaces. The user interface is called the front panel in LabVIEW. Using icons and wires, objects on the front panel can be controlled through programming. This is the graphical source code, also known as G code. LabVIEW graphical source code is similar to a flowchart to some extent, so it is also called block diagram code.

4.2. Host computer introduction

For multi-channel signals, first enter the data, take into account the subsequent data interaction with electronics and other systems, use Ethernet for data transmission, increase the transmission rate while ensuring the transmission effect, and use TCP as the protocol for data transmission. This part of the programming is shown in the figure below.

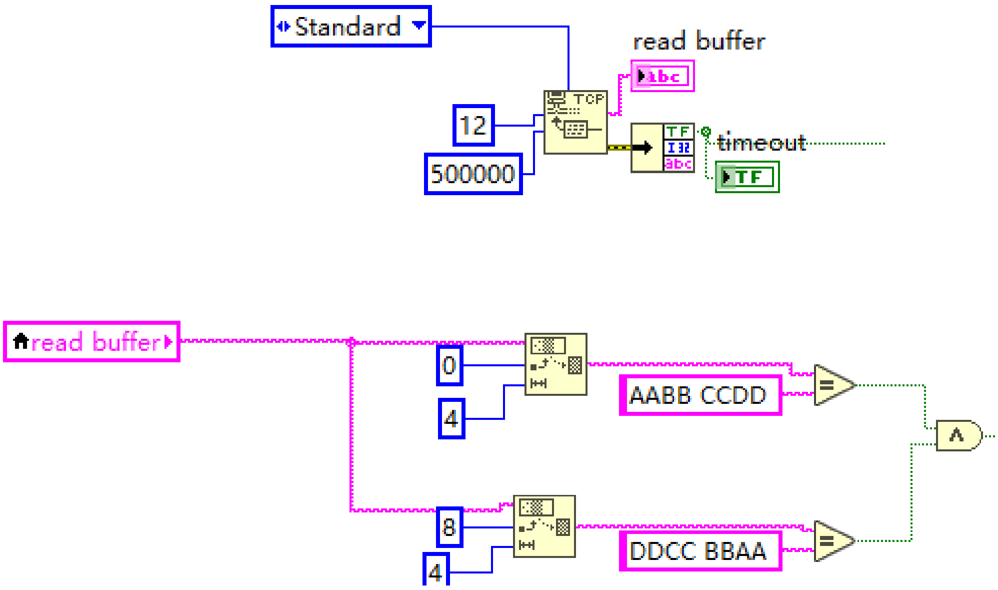

Figure 8 The data singular value processing flowchart

It can be seen from Figure 8 that the accuracy of the collected data is guaranteed by the TCP protocol, and the TCP protocol can increase the accuracy of data transmission while ensuring the transmission speed.

The second is the production of the host computer interface and its logical relationship. The host computer interface is shown in the figure below.

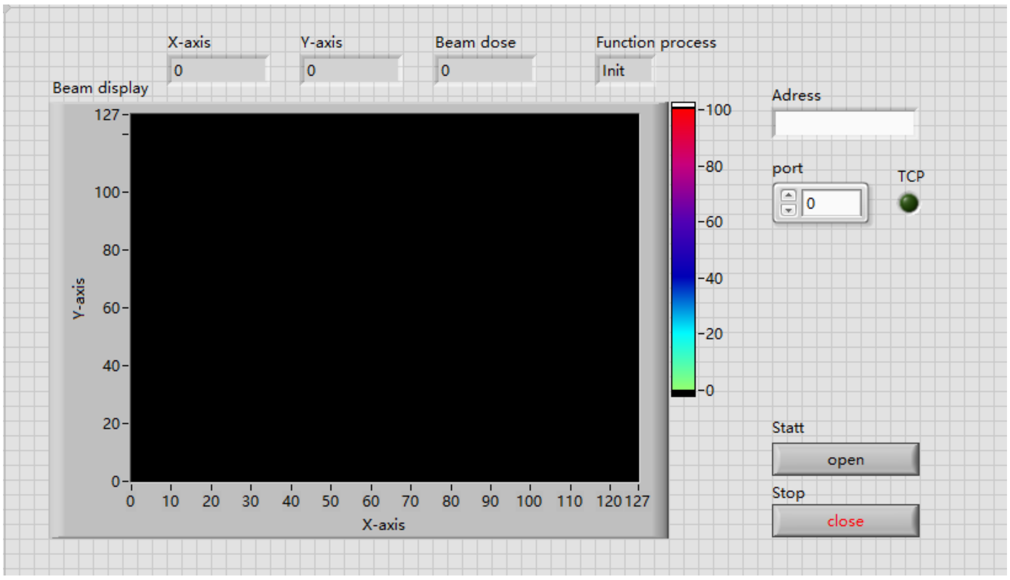

Figure 9 The interface of the host computer

It can be seen from Figure 9 that the host computer includes functions such as beam two-dimensional position display, network address input, X, Y direction peak search, beam dose, program progress display and other functions. It can better meet the beam current measurement in subsequent applications.

5. Algorithm application results

In order to test the reliability of the algorithm, the final test is carried out for two different situations, one of which is the electronic background noise. In the case of a small mean value, there are more specific channels with larger signals. Experiment with the algorithm in the upper computer, use the network transmission assistant to transfer the data to the upper computer, extract the final processed data, and the processing result is shown in Figure 10.

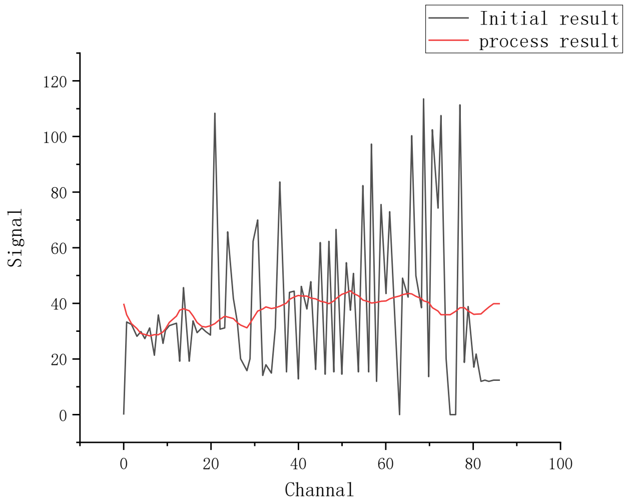

Figure 10 Data comparison under background conditions

It can be seen from Figure 10 that in a local environment with a small mean value, the result after processing by the singular value removal algorithm is better than the initial result. While smoothing the data, it removes channels with obvious error values. better.

From the above results, it can be seen that for the detector, the test results are relatively ideal under background conditions. Next, deal with the situation where a single peak signal is detected. Outside the peak channel, there are some channels with data errors. Use the network assistant to transfer the data to the upper computer, extract the data for processing, and the result is shown in Figure 11.

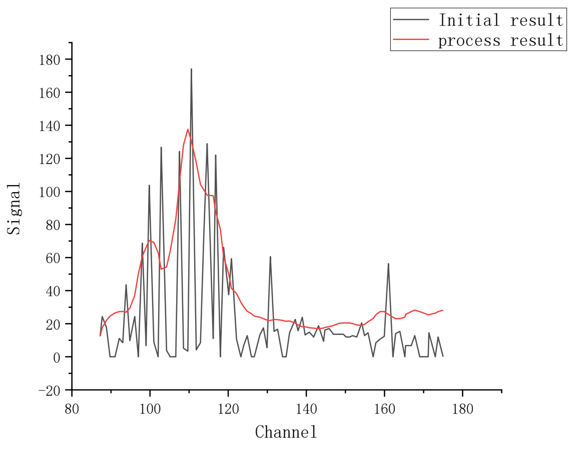

Figure 11 Data comparison under peak conditions

It can be seen from Figure 11 that although the processed signal also has a small peak due to the singular value, compared with the initial signal, both the overall trend and the smoothing effect are greatly improved. The test results once again proved the feasibility of detection.

6. Summary and outlook

This paper proposes an algorithm that combines data smoothing and singular value removal, and introduces its application in proton beam detection. From the results, the algorithm uses singular value removal to improve the effect of data smoothing. It was successfully presented on the host computer and tested with beam current data, and the results were good. The algorithm processes multi-channel data, adapts to a variety of multi-channel detectors that detect information such as position, and provides theoretical support for subsequent multi-channel ionization chamber detection.

References

[1] Vidal M, Moignier C, Patriarca A, et al. Future technological developments in proton therapy - A predicted technological breakthrough[J]. Cancer radiotherapie: journal de la Societe francaise de radiotherapie oncologique, 2021, 0:1-11.
[2] Nie Qing, Jingbo Kang. Progress of proton therapy for malignant tumors[J]. Medical and health equipment, 2005, 07:89-92.
[3] Weiming Cai, Xiangkui Mu. Proton Therapy of Tumors: Current Status and Prospects at Home and Abroad[J]. Journal of Practical Oncology, 2007, 22:475-478.
[4] Wei Jie, Xueqing Yan, Junjie Wang. Tumor Proton Therapy and Progress: A New Strategy for Precision Therapy[J]. Cancer Progress, 2016, 14:834-839.
[5] Yajun Jia, Liu Ming, Shu Hang, et al. Design of position control system for proton point scanning irradiation[J]. Nuclear Technology, 2018, 41:1-8.
[6] Jianguo Yu. Beam expansion system of proton therapy device[J]. Accelerator Center, 1996, 08:1-7.
[7] Yajun Jia, Yongjiang Li, Zhang Xiao, et al. Simulation of point scanning irradiation technology in proton therapy[J]. Nuclear Techniques, 2016, 39: 13-20.
[8] Zhikai Liang. Design and optimization of deenergizer system for proton therapy [D]. 2019.
[9] Arjomandy Bijan, Sahoo Narayan, Ding Xiaoning, Gillin Michael. Use of a two-dimensional ionization chamber array for proton therapy beam quality assurance[J]. Medical physics, 2008, 35:1-9.