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Study of Neutron CT with Micromegas as a Neutron Detector*

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Abstract: In this paper, the possibility using micromegas(Micro-Mesh Gaseous Structure) as neutron detector in 14 MeV neutron computed tomography(CT) has been simulated. The results show that the micromegas neutron detector has high spatial resolution and is a good candidate for neutron radiography. The three-dimensional images of plant roots in soil are successfully and clearly obtained by the 14 MeV neutron CT with micromegas as a neutron detector. In the present simulation, MCNP is employed for 14 MeV neutron transport in the sample and Matlab for the 3-D photograph reconstruction.

Key words: micromegas detector; neutron CT; image reconstruction; root visualization

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1 Introduction

Non-destructive examination(NDE) technique is of great importance for botanists to monitor the growth of a plant alive without removing soil and judge the health, growth and vitality situation of the plant, and to carry on their deeper research on the plant.

Among many NDE techniques available and capable of revealing the internal structure of an object, X-ray radiography has become widely used in many fields[1－5] including in botany. However, X-ray is not sensitive to hydrogen, whereas neutron is much more sensitive to hydrogen and consequently, the neutron radiography is expected to give better results for visualizing plant roots in soil. It is well known that CT technique is quite reliable to give clear 2D and 3D image. Neutron radiography with CT technique, i.e. neutron CT, may be treated as a more effective tool for qualitatively investigating the distribution of hydrogen in an object. The principle of Neutron CT and X-CT[6] is the same. The differences between them are from the interaction of X-ray and neutron with matter. Compared with X-CT, neutron CT develops slowly. One of the key problems which limit the development of neutron CT is the position-sensitive neutron detection technique.

Micromegas (Micro-Mesh Gaseous Structure) as a kind of micro-pattern gaseous detector has many outstanding features, such as good radiation resistance, excellent time properties, perfect spatial resolution, stability, high gain and counting rate. Although it was originally designed for charged particles and X-rays[7], it could also be used for neutron detection by adding a convert material[8－10] and have a good spatial resolution for

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neutron. All these excellent performances are just needed by neutron CT. The micromegas detector has been designed, constructed and studied since the beginning of 2006 by our group in Institute of Modern Physics, Chinese Academy of Sciences and the possibility of its being used in neutron CT system has being studied since then.

In this paper, based on the accelerator neutron source (T(d, n) ^{4}He, 3×10^{12} neutrons/s) of Lanzhou University and the micromegas as the position sensitive neutron detector, a prophase simulation of neutron CT for three-dimensional visualization of plant roots in soil is presented. This work would be expected to give some advisable information and firm confidence for further design of this radiography system planned to be developed in Lanzhou University.

2 High Spatial Resolution of Micromegas as a Neutron Detector

Micromegas detector was developed firstly by Giomataris[7] et al. in Dapnia of CEA (French Atomic Energy Commission) at Saclay in 1996. At present, it has been regarded as a robust one in the current and future physical experiments. The details of the detector used in the present simulation are shown in Fig. 1.

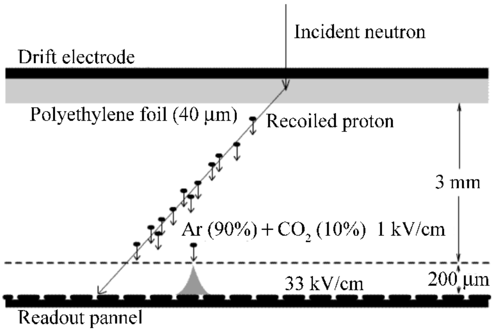

Fig. 1　Schematic of the Micromegas detector.

To study the performance of micromegas, two independent simulations have been done. In the first part, the drifting and multiplication of ionized electrons in the detector are simulated by Garfield. Its response functions in both time and space are obtained.

In the second part, the procedure of an incident neutron flying into the detector, leading a recoiled proton, which produces a lot of primary ionized electrons in the drift region, is simulated by a code based on Geant4. The efficiency of recoiled proton for per incident neutron is about 10^{-4}. The response of the detector for a good event is simulated.

After all procedures above, to get a higher spatial resolution, a new readout method called time coincidence technology has been developed. The main principle is that as the track of recoiled proton is not perpendicular to the detector plane, we only measure the original part of the track, which would be much closer to the position of the incident neutron. As a signal of a whole track lasts for a while, only the last part of it should be recorded. In such way, the original position of the recoiled proton is measured[11]. The final spatial resolution is shown in Fig. 2.

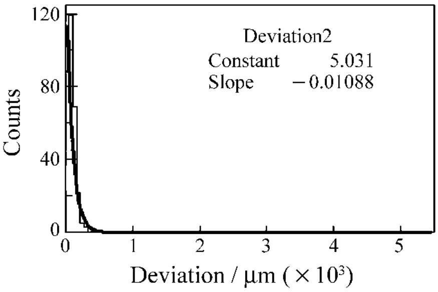

Fig. 2　Deviation under the new configuration.

An exponential decay in Fig. 2 shows that the spatial resolution for this detector configuration is only 91.9 μm, which is good for the need of neutron CT. Considered for some experimental factors, the spatial resolution was set to 200 μm in the neutron CT in our simulation.

3　Neutron CT

A transmission neutron CT setup at a radiography beamline consists of a position-sensitive neutron detector system and a rotary table. The sample under investigation is fixed on the rotary table in the collimated neutron beam and can be rotated with the rotary table in small angular steps over 180°. A slice of an object perpendicular to the axis of rotation of the rotary table is chosen to be analyzed in mathematics (see Fig. 3). The intensity of neutron beam along a straight line of response obeys the Beer-Lambert law:

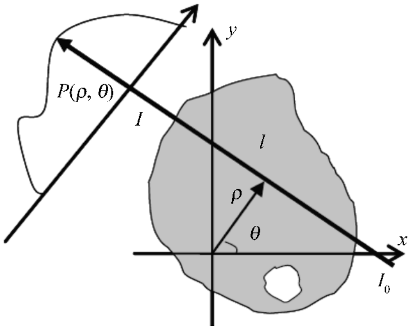

Fig. 3 Line of response in single slice projection.

$$I(\rho,\ \theta)=I(l)=I_0\mathrm{e}^{-\int_l^l \mu(x,\ y)\mathrm{d}l}. \tag{1}$$

The projection along the straight line of response parameterized by distance ρ and angle θ in the slice is defined as:

$$P(\rho,\ \theta)=\ln\frac{I_0}{I(\rho,\ \theta)}=\int_{l_0}^{l}\mu(x,\ y)\mathrm{d}l\ . \tag{2}$$

This is Radon transform of the unknown distribution of the linear neutron attenuation coefficient $\mu(x,\ y)$. The plane distribution of μ can be reconstructed from the projection $P(\rho,\ \theta)$ by inverse Radon transform:

$$\mu(x,\ y)=\int_0^\pi \hat{P}(x\cos\theta+y\sin\theta,\ \theta)\mathrm{d}\theta\ . \tag{3}$$

Eq. (3) is a short notation for the procedure called "filtered back projection", implementing the inverse Radon transform . By rotating the table , enough projections $P(\rho,\ \theta)$ can be obtained and used to calculate the $\mu(x,\ y)$ to get its 2D images. From the 2D images, the 3D matter distribution can be also reconstructed.

In reality, some implied assumptions are poorly fulfilled. Considering neutron transport through bulky sample, the biggest violation is due to neutron scattering. Firstly, Beer-Lambert law, i. e. Eq. (1), assumes that scattered neutrons should not reach the detector. But in fact, the scattered neutrons in neighboring lines of response lead to an additional contribution to the value of $I(\rho,\ \theta)$ measured in the detector. And the present detector can not distinguish direct source and scattered contributions. Secondly, Eq. (1) is valid for the mono-energetic neutrons only. Although the incident neutron beam can approximately have a single energy, the beam energy would decrease with neutron going deeper into the sample due to the neutron scattering. The detector measures the energy spectrum averaged neutron response. Due to the energy dependence of the neutron cross section values, this induces another deviation from the exponential attenuation law[6].

4 Simulation and Results

4.1 MCNP calculation

In the present work, MCNP is employed to simulate the transport of the neutron beam going through the soil sample and scanning the considerable section to get the projections $P(\rho,\ \theta)$. The simulation setup of neuron CT is shown in Fig. 4.

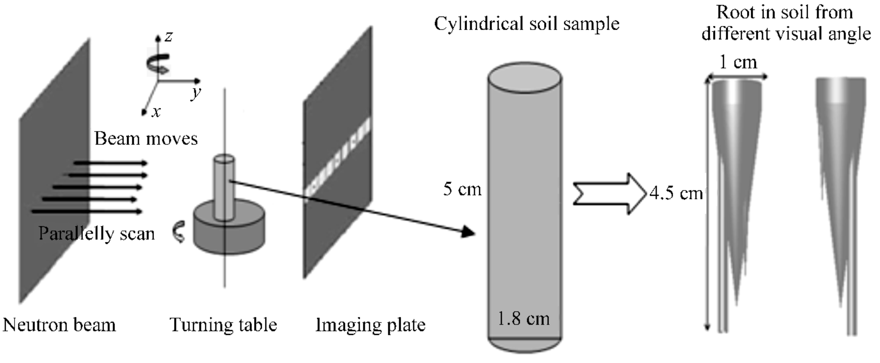

Fig. 4 Arrangement in MCNP.

As shown in left part of Fig. 4 the soil sample is a cylinder with a root in it. The weight fraction of different compositions in the sample is tabulated in Table 1. The compositions in root and soil are supposed to uniformly distribute, respectively.

The energy of neutron beam is 14 MeV. The imaging plate is actually the micromegas neutron detector with spatial resolution of 200 μm. The angle step of turning table is 3.6° from 0° to 180°.

Table 1　Composition of root and soil in MCNP input file　(wt%)

Composition	Root	Soil
H	11	3.2
C	5	4
N	4	2
O	75	40.8
Na	3	—
Al	—	10
Si	—	30
Ca	2	—
Fe	—	10

4.2　2D and 3D images

Using the projections $P(\rho, \theta)$ obtained with MCNP, a Matlab program was developed to run Filtered Backprojection Algorithm to get the 2D image of the sample. In order to get high quality 3D image, 250 cross section images were totally obtained. As an example, Fig. 5 shows two of them with area 1.2 cm ×1.2 cm each. The cross section image of the root in the soil sample is quite clear.

Furthermore, the 3D Medical Image Processing and Analyzing System (3DMed) was employed to get 3D image. This software system is expected to process and analyze the image data. 2D image data calculated with our Matlab code were used as an input of 3DMed. The 3D images of root in soil are shown in Fig. 6 (right part). In order to see how well the images got with neutron CT, the objects were put on the left of Fig. 6. From the Fig. 6, it is clear that the images of the root in soil taken by the neutron CT have very good quality.

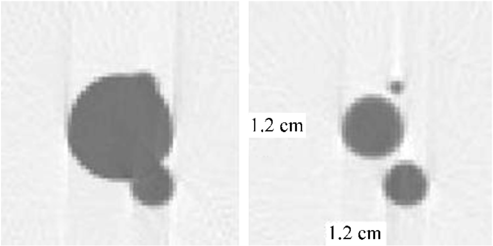

Fig. 5　Two selected section images with area of 1.2 cm × 1.2 cm.
Pixel is 200 μm×200 μm. The dark spots stand for roots with soil around.

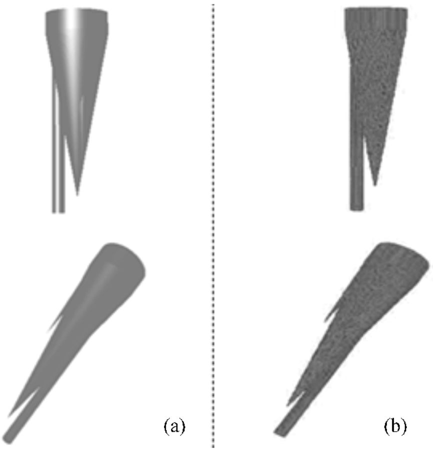

Fig. 6 (a) the 3D visualization of root tips in different visual angle; (b) their corresponding images taken with present neutron CT.

5　Conclusions and Outlook

According to our simulation, since Micromegas for neutron detection has high spatial resolution and neutron ray is very sensitive to hydrogen, the neutron CT with micromegas as a neutron detector can provide high quality image of a plant root in soil. This work is expected to be helpful for setting up neutron CT system based on the accelerator neutron source of Lanzhou University.

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基于 Micromegas 探测技术的中子 CT 可行性研究*

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摘　要：在培育新品种过程中能够实时掌握了解土壤中植物根系的形态以及其生长情况将为植物学家提供很多不可或缺的信息。对基于 micromegas 探测技术的中子 CT 在这一新应用的试验环境进行了仿真模拟，通过三维图像重建后，得到了令人满意的预期结果。首先通过 Geant4 和 Garfield 模拟计算利用聚乙烯薄膜作为中子转换层的 micromegas 中子探测器，得到了非常理想的位置分辨，说明基于 micromegas 探测技术建立中子 CT 照相系统的可行性。然后利用 MCNP 仿真模拟 14 MeV 中子 CT 的实验环境，最后由 Matlab 程序进行图像重建。

关 键 词：micromegas 探测器；中子 CT；图像重建；根系显影

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