Development of radiation imaging system for nutrient distribution in sapling

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Abstract. Radioactive tracer in plant commonly uses X-ray films or imaging plate for study nutrient distribution, which cause radioactive waste. We developed a real-time imaging system for radiotracer in sapling to reduce a large number of samples and radioactive waste. The main components of the developed system consist of the radiation imaging detector, the mechanical part, and the operating software. We used 4 × 4 channel array of Silicon Photomultiplier (SiPM) model ArrayC-30035-16P from SensL coupling with plastic scintillator array of 3 × 3 × 5 mm³ pixels as a radiation imaging detector. The signals from the detector were amplified and noises discriminated then transfer to the operating software on a personal computer (PC). The area scanning unit and mechanical parts were modified from MicromakeC1 3D printer with customised control board and controlled by operating software on PC interfacing via USB to RS232. Furthermore, the LabVIEW base system control software was developed to control the movement of motors in X, Y and Z directions of the mechanical control board in associated with the counting signals transferring from the developed detector board. Each counted data from the scanning process was transformed into rainbow scale image. The developed system could measure a sample with a maximum size of 300 × 300 mm², and the precision of motors was ± 0.1 mm. The control software is able to change parameters of the time for counting, a pitch of motors and scanning area of a sample. Finally, the developed system was tested by run through the process of radiotracer in the maize sapling growth for 30 hours. The result showed satisfactory rainbow color scale image of accumulation and distribution of radioactive tracer in sapling.

1. Introduction

Plant nutrition is necessary elements for plant growth and metabolism which plants must obtain from their growing medium. Analysis of nutrients in plants has been developed primarily to provide information on the nutrient contents and distribution in plants as a guide to nutrient management for optimal plant production [1].

To trace a path of nutrient commonly use radioactive isotopes as a tracer [2][3][4]. Typically, X-ray film or imaging plate are used to study nutrients in plants with a method of an autoradiograph [5][6]. However, this method needs to dry plant samples that cause a large number of sample, more radioactive waste, and error from different samples.

Silicon Photomultipliers (SiPM) are solid-state devices which have a compact size, high gain with the low bias voltage, and also insensitive to electromagnetic fields. SiPM has a pixelated structure which consists of an array of Geiger-mode avalanche photodiodes and quenching resistor pixels on
common silicon substrate [7]. SiPM has been widely used as radiation detectors [8][9][10]. It is also extensively used as a radiation detector on the Positron Emission Tomography (PET) system due to its properties and compact size [11][12][13]. Moreover, SiPM also has been used as radiation detectors for the radiation imaging system for radiotracer technique in plant nutrition management. [14][15]

The purpose of this paper is to describe the development of a real-time imaging system for nutrition distribution detection in sapling growth using radioisotope tracer technique in order to reduce a large number of samples and error form different samples of plant nutrition research.

2. Material and Method

2.1. The configuration of the imaging system

2.1.1. Detector unit. The detector was considered according to the radioisotope has been used in the research. In this case, Phosphorus 32 ($^{32}$P), a pure beta-emitter ($E_{\text{max}}$ 1.71MeV), was used as labeling tracer. Plastic scintillator Model BC-408 was used for the scintillation detector. The scintillator size of $3 \times 3 \times 5$ mm$^3$ was wrapped with Teflon tape as a scintillating light reflector and coupled to a SiPM array model ArrayC-30035-16P-PCB from SensL (Figure 1). The SiPM array has 4 × 4 channel (pixelate) with pixel size of $3 \times 3$ mm$^2$. The assembled detector with a total size of $16.6 \times 16.6$ mm$^2$ operates at a low bias voltage of 27 V. The SiPM signals were fed into the detector circuit board which each signal form SiPM array was individually amplified by high-speed amplifiers (AD8054) and discriminated electronics noise by low voltage comparators (LMV339). The summed output signals from the detector circuit board were transferred to measure radiation events at interrupt pins of the microcontroller (MCU) model PIC32MZ2048EFH100 to measure radioactivity from each pixel. Figure 2 shows the assembled pixelated scintillation detector with a circuit board.

![Figure 1. A 3 × 3 × 5 mm$^3$ of plastic scintillators coupled with 4 × 4 channel of 3 × 3 mm$^2$ SiPM array PCB](image1)

2.1.2. Mechanical unit. The detector unit was fixed in vertical scanning plane (Y, Z coordinate axes) to the mechanic part of the developed system which modified from MicromakeC1 3D printer. Three units of stepper motor were controlled their position in each axis by A4988 on the customised control board. The area scanning unit was directly controlled by the MCU which received the commands from the operating software via USB port.

![Figure 2. Assembled detection unit on the area scanning unit](image2)
2.1.3. Operating Software. The operating software was developed on the LabVIEW program and interfaced with the MCU to received count signals from the detector unit and communicated with the mechanical unit. The operating software could also facilitate the system to move the motors and measure radiation in both manual and automatic mode. Figure 3 shows the sequence of the automatic mode in software. In automatic mode begin with initialed imperative parameters which are counting time, size to scan, pitch of detector unit and auto timer. When the software run in automatic mode, it will start with transferring commands to the detector unit to count radioactivity of nutrient distribution at the started position. After finish counting, the MCU on the detector unit will send back a total count at each pixel coordinates to the PC which will process to recompense the radiation decay then pass through larger averaging operators image processing [16] and generate rainbow scale image. After that, the software will update the position of the detector and check for the next command. If the index position of the detector is lower than the size of the scanning area, it will send another command to move motors to the next position and start the counting in another cycle. However, if the next position is higher than the size of the scanning area, the software will finish the process and save the image of nutrient distribution. The software will keep checking on the auto timer to run the process all over again. For Image processing of grayscale and rainbow scale was done by divided count signals to 256 scales which the minimum count and maximum count were 0 and 256 scale, respectively.

![Flow chart of image scanning and image processing sequence in automatic mode](image)

Figure 3. Flow chart of image scanning and image processing sequence in automatic mode

2.2. Testing with Sapling growth
The developed system was accomplished by testing with the sapling growth in a realistic condition of the experiments. Maize sapling was grown in a growing rack for seven days with a natural light condition and then treated with NaH$_2$PO$_4$ 12 µCi of activity. The radioactively-labeled nutrient in sapling was monitoring with the developed system continuously for 30 hours by counting the nutrient activity in every 6 hours. After the experiment, the sapling was managed and disposed as radioactive waste by stored in the shield for 8 half-lives (114 days) then discard with regular waste following the delay and decay method.
3. Result and Discussion
The assembled detector generated signals with an average height of 150 mV applied to the amplifying circuit to gain signals to approximately 1.5 V. The amplified signals could be discriminated by Threshold Level Discriminator (TLD) in adjusting range from 0 – 100 mV to generate logic pulses for interrupt pins of MCU. The area scanning unit has been constructed with a working area of 300 × 300 mm² and precision of motor is ± 0.1 mm with a safety limit switch in each axis. The developed system could receive a maximum count at 100,000 counts per second and the sensitivity of the developed system is 101 cps/µCi measure by using the same method as Vaska (2003)[17] with a 0.51 µCi ⁹⁰Sr point source. Calculated counting signals are converted into a rainbow scale image with color scale ranging from 0 to 255.

In the experiment with the sapling, from the beginning, it took around 1 hour for a cycle. Therefore, we will not compensate for the radiation decay in each position in the cycle because there is no statistically significant. At the beginning of experiment the sapling height was 20.5 cm, and after 30 hours of an experiment, the sapling growth height had been changed to 24 cm which revealed that the sapling had grown during the experiment. Figure 4 shows the distribution and accumulation of ³²P in the maize sapling growth at 0, 6, 12, 18, 24, 30 hours after starting the experiment which has satisfactory image quality similar to Kawachi (2016) and Yamamoto (2013).

The results of this experiment showed the mobility of ³²P trend towards increasing absorbed and accumulated by maize sapling during the experiment time.

![Figure 4. ³²P distribution in maize sapling in rainbow scale image](image)

4. Conclusion
According to the system testing, the developed imaging system can run through the process of the radioactive tracer of nutrient in sapling growth with the maximum size of the sample at 300 × 300 mm². The operating software can change parameters setting of counting time, pitch, scanning area, and run continuously in automatic mode. Therefore, the developed system provides a rainbow scale image that shows accumulation and distribution of radioisotope nutrient in the sapling. Furthermore, it was found that the amount of radioactive waste in this experiment was lower than our previous study with the conventional autoradiographic technique.

In summary, we suggest that 2 factors could be applied for image quality improvement. Firstly, improve image contrast could be done by increasing detection time in each position to get more radiation recorded count and expand the value of rainbow scale level from 8 bits to 24 bits. Secondly, improve image resolution could be done by using more than 16 channels of SiPM.

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