Development of a Nondestructive Inspection Method for Trees Using Cosmic Rays

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Abstract

We proposed the use of cosmic rays to investigate the interiors of giant trees. Cosmic rays can easily penetrate the interiors of trees having a diameter of 1.5 m or more, which are difficult to investigate using conventional methods. We conducted two experiments to demonstrate the feasibility of this method. In the first experiment, we detected the difference between the presence and absence of a 0.5 m cavity in a 1.2 m diameter wooden plate. In the second experiment, we measured a cedar tree with a circumference of 11 m, with an unknown internal condition, and compared the data with our simulations. The result predicted that there would not be any cavities larger than 1.0 m in diameter. The cedar tree was then cut and it was confirmed that there were no cavities that were larger than 1.0 m in diameter.

Keywords: tree, nondestructive inspection, cosmic-ray imaging, nuclear emulsion
DOI: 10.31526/JAIS.2022.251

1. INTRODUCTION

Techniques for the non-destructive inspection of huge structures, such as the Egyptian pyramids [1] and nuclear reactors [2] using cosmic rays that have high material penetration ability, have already been developed. In this study, we proposed a new application of this technique to the cavity exploration of trees.

Trees that have hollowed out due to decay have the potential to fall; hence, it is important to investigate the presence and size of internal cavities and assess the risk of falling in advance. The existing nondestructive tree diagnosis method is based on the penetration of gamma rays. However, this method cannot be used to evaluate trees larger than 1.5 m in diameter [3]. In contrast, cosmic rays are high-energy rays and can penetrate giant trees. The nondestructive inspection technique using cosmic rays was applied to trees for the first time, and the validity of this technique as a diagnostic method for giant trees was explored.

2. EXPERIMENT 1: WOODEN PLATES (WITH AND WITHOUT CAVITY)

A cavity measuring approximately 50 cm was created in a 1.2-meter-diameter wooden plate (zelkova or keyaki), and cosmic-ray imaging measurements were taken both with and without the cavity. Figure 1 shows the measurement setup. Measurements were taken for each of them over a period of 35 days, using a nuclear emulsion detector [4] with an active area of 125 cm^2. After the measurement, the nuclear emulsion was photo developed and read out by the scanning system [5] to estimate the muon flux. Figure 2 shows the comparison of the muon flux with and without the cavity, as well as the statistical significance of the difference. The wooden cavity was successfully detected by comparing the data.

3. EXPERIMENT 2: SHIN-MEI OSUGI (11 M IN CIRCUMFERENCE)

The measurement was carried out on the Shin-mei osugi (11 m in circumference, cedar tree) in Okute Town, Mizunami City, Gifu Prefecture, Japan, which fell due to heavy rains in July 2020. A nuclear emulsion detector [4] was installed at the base of the tree for 50 days from March to May 2021. After the measurement, the nuclear emulsion was photo developed and read out by the scanning system [5] to estimate the cavity size.

A 3D model of the cedar was made to simulate the cosmic-ray flux. Figure 3 shows the 3D model created by photogrammetry (with the software Agisoft Metashape). We assumed that the cavity passed through the central axis of the tree. The path length from the detector was calculated using the 3D model. In the root area, the path length is long and the cavity is short. After that,

FIGURE 1: A cavity of approximately 50 cm was created in a 1.2-m-diameter wooden plate, and a nuclear emulsion detector was installed at the bottom of the wooden tree, to measure the difference in cosmic-ray muon flux with and without the cavity.

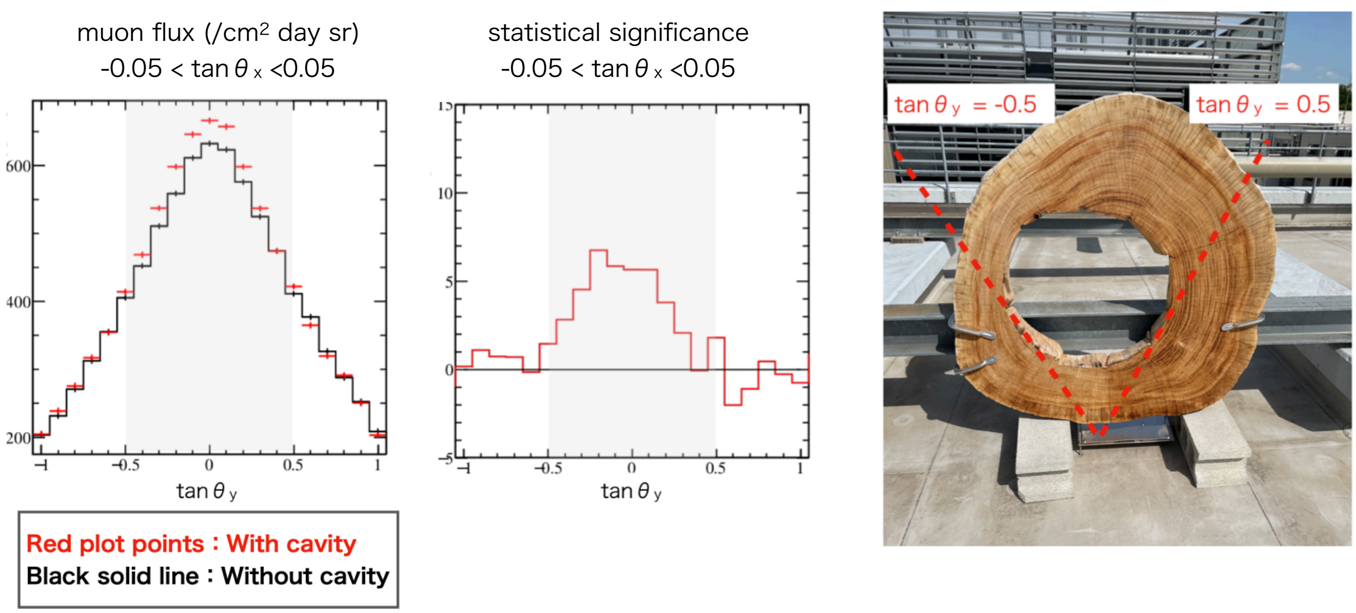

FIGURE 2: Comparison of cosmic ray muon flux with and without the cavity. muon fluxes were normalized using data from all angular ranges ($-1.0 < \tan\theta_{xy} < 1.0$). The wooden cavity was successfully detected by comparing the data.

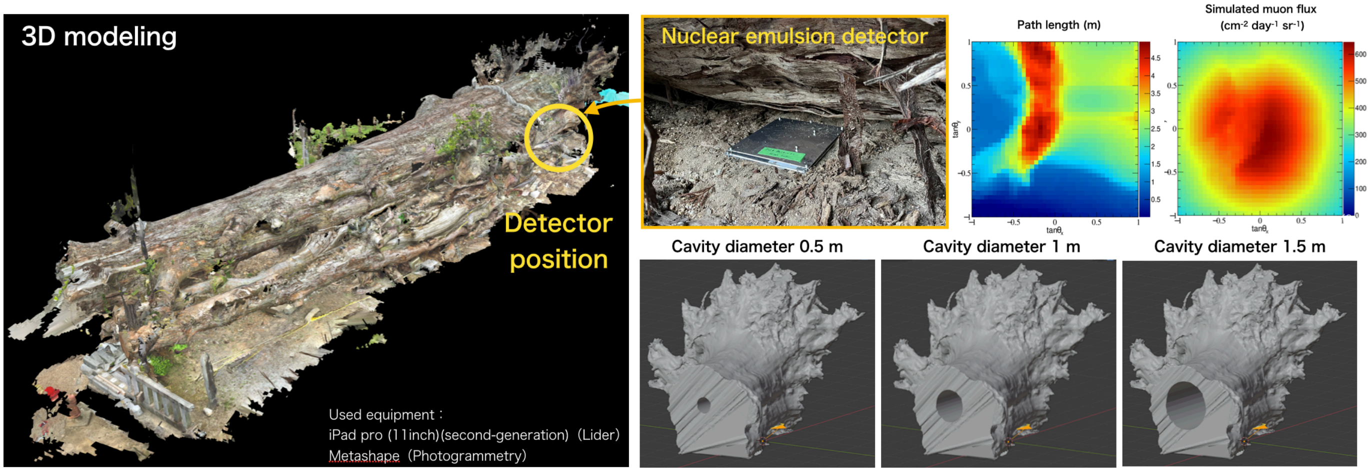

FIGURE 3: 3D models were created assuming the existence of a cavity; the cosmic ray muon flux for each of them were simulated.

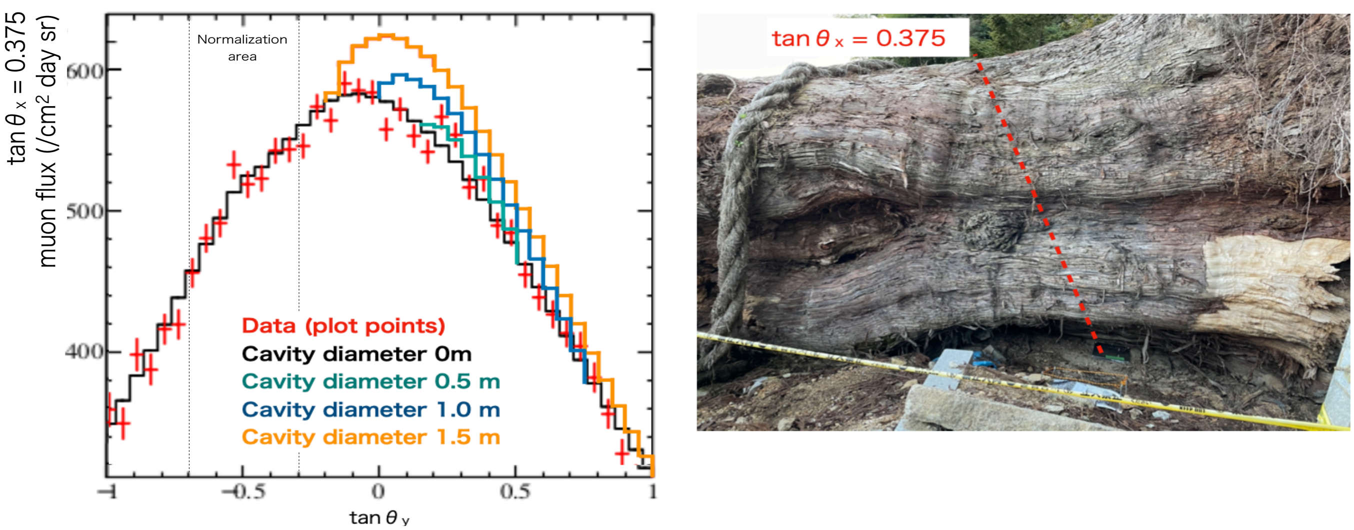

FIGURE 4: Comparison of a measured cosmic-ray muon flux with simulated fluxes, expected in the presence of a cavity (cross section of $\tan\theta_x = 0.375$). The cavity size was estimated to be between 0 m and 1 m in diameter.

FIGURE 5: The Shin-mei osugi cedar, which was cut near the root for preservation. It was confirmed that the cavity was in fact less than one meter in diameter.

the muon flux was simulated using a cosmic-ray flux model and the cedar density. The simulation was performed using the Guan muon flux model [6], Geant4 [7], material cellulose, and cedar density of $0.8\,\mathrm{g/cm^3}$ (Measured value).

The results of the cavity size estimation are shown in Figure 4. The muon flux is normalized by $-0.7 < \tan\theta_y < -0.3$, where the cavity is not affected. Comparing the data points with the simulation, the cavity size was estimated to be between 0 m and 1 m in diameter within the range of statistical error.

In November 2021, the Shin-mei osugi was cut near the root for preservation. The cavity was small; it was less than 1 m in diameter, as measured by the cosmic-ray imaging.

4. CONCLUSION AND FUTURE PROSPECTS

We developed a new method to investigate the internal cavity of trees, by using cosmic rays. Experiments were conducted on two targets. Firstly, a statistically significant cavity could be detected in a 1.2 m diameter wooden plate, with and without a 0.5 m cavity. Next, we measured a cedar tree having a circumference of 11 m, in Okute Town, Japan. By comparing the observed data with the simulated cosmic-ray muon flux from the 3D model, we concluded that the cavity was not larger than 1 m. The cedar tree was subsequently cut near the root for preservation and it was confirmed that the cavity was in fact less than 1 m.

Therefore, this study confirmed the feasibility of the cavity inspection method that uses cosmic rays for giant trees. It is expected that this method will be applied to standing trees and utilized as a tool for the conservation of giant trees.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

ACKNOWLEDGMENTS

We would like to thank Okute Town, Mizunami City, Gifu Prefecture, Japan, for providing the measurement field. This work was supported by JSPS, Japan KAKENHI (grant JP20K22589).

References

[1] K. Morishima, M. Kuno, A. Nishio et al. Nature, 552, 386 (2017).
[2] K. Morishima. Jour. of The Soc. of Phot. Sci. and Tech. of Japan. 79(1), 42–47 (2016).
[3] T. Yamada. Green Age 35.4 (2008): 10.
[4] A. Nishio et al. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 966, 163850. (2020).
[5] M. Yoshimoto et al. Progress of Theoretical and Experimental Physics. 2017(10) (2017).
[6] Mengyun Guan et al. "A parametrization of the cosmic-ray muon flux at sea-level." arXiv preprint arXiv:1509.06176 (2015).
[7] Sea Agostinelli et al. Nuclear instruments and methods in physics research section A: Accelerators, Spectrometers, Detectors and Associated Equipment 506.3 (2003): 250–303.