Cross-Sectional Imaging of Tree Stem Density Distribution using Gamma-Ray Tomography Technique

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Abstract. Cavities in the tree stem increase the potential of the tree to collapse and threaten the safety of people. The stem needs to be checked to determine whether the tree is safe or not. The option of tree stem inspection techniques without destructing it is still very limited. Gamma-ray tomography techniques was used to image tree stem density distributions. A collimated 2.96 GBq\textsuperscript{137}Cs emits gamma photons through the wood phantom as the object and received by the NaI(Tl) scintillation detector on the other side. The object was scanned with the parallel beam method. The data was built into the image using filtered back projection (FBP) algorithm. The results show the cross-sectional of the wood phantom include the cavities (holes) inside it. Density patterns of wood phantom can be observed. Finally, the use of gamma-ray tomography provided a non-destructive and accurate method for investigation of tree stem density distribution. The results in images form make it easier to be interpreted.

Keywords: Gamma-ray tomography, imaging, non-destructive testing, radioisotopes application, wood.

1. Introduction

High-density living also has negative impacts on urban living, such as stacked housing and crowded living with poor air quality and thermal discomfort [1]. Trees planting can improve air quality and stabilize ambient temperature. The deficiency of trees planting in the urban environment is that trees often collapse. There are many incidents of collapsed trees struck the vehicles and houses even causing casualties. Wooden density information is very important to ensure that the tree does not collapse. In many cases, density distribution of tree stem indicates the health condition of the plant. Cavities in wood increase the probability of the tree to collapse. Therefore, appropriate techniques are needed to check wood condition without destruct it.

Tomography is an advanced technique that has been continuously developed and used for diagnostic purposes throughout last 40 years not only in medicine but also in industry, biology and civil engineering [2]. It started with the theoretical justification of the possibility of reconstructing the distribution of a certain parameter across a planar section of an object from its projections [3]. Computed tomography (CT) aims at reconstructing the spatial distribution of physical parameter of object to be imaged (i.e., object function) from its projections acquired by an imaging device using some energy flue such as x-ray, gamma-ray, neutron, electron and so on [4].

The experiments of trees investigation using tomography technique has been attended previously. Abdullah et. al. has designed mobile gamma-ray tomography system for early detection of basal stem rot in oil palm plantations [5]. The mobile scanner has been successfully used for non-invasive early
detection of basal stem rot in a number of field tests in oil palm plantations in Malaysia. Hervé et. al. was using x-ray computed tomography to conduct the density mapping of decaying wood [6]. Putri et. al. was conducted the evaluation of incense-resinous wood formation using sonic tomography [7].

The attenuation of gamma-rays is highly correlated to the atomic number and density of materials [5]. Therefore, the non-destructive testing to get the density distribution of tree stem is very possible. In this experiment, $^{137}$Cs was used as the transmitter, NaI(Tl) scintillation detector as the receiver, and asoca tree stem as the object. The object is scanned with the parallel beam method, in which the radioisotope and the detector move simultaneously in a translation on a gantry flanking the object. It was the first projection data. Then, the gantry was moved to another angle to the next projection data. Furthermore, the set of data is built into image using filtered back projection (FBP) algorithm.

2. Material and Method

2.1. Phantom

The phantom was stem of Ashoka tree (Polyalthia longifolia). It is generally planted because of its effectiveness in reducing air pollution. It has lush leaves that make it often planted as street shade in urban areas. This plant is also a medicinally important tree of the Indian system of medicine [8].

The wood was perforated with a certain size as shown in Figure 1. There are five couples of holes with diameter 40 mm, 30 mm, 20 mm, 10 mm, and 5 mm. It aims to test which is smallest hole can be described by the tomography system. It is important to find out how sensitive the radiation source and the measurement system are to the cavities inside the wood.

![Figure 1. Wood phantom.](image1)

2.2. Tomography system

The parallel beam gamma tomography system was used in this experiment. Azmi et. al. has built the automatic parallel beam gamma tomography system [9]. The system consists of mechanical parts, computerized controlled module, a gamma ray source, a scintillation detector NaI(Tl), data acquisition and computer as shown in Figure 2. It was designed to conduct translational and rotational scan automatically.

![Figure 2. Gamma-ray tomography scanning system [9].](image2)
Gamma-ray source and detector collimators move translationally on the gantry. The collimators slit has diameter of 5 mm. Gamma-ray source collimator aimed to make gamma ray into narrow beam and for radiation safety purposes, whereas the detector collimator to block radiation scattering detected by detector. A set of translational scanning aims to obtain a projection data. The gantry is then through an angular increment until it has been rotated through a minimum of 180 degree.

Interaction of gamma radiation with medium of interest in the object will produce change intensity of the beam which correlated to the properties of the medium [10], [11]. If monoenergetic gamma ray are collimated into a narrow beam and allowed to strike a detector after passing through an absorber of variable thickness, the result should be simple exponential attenuation of the gamma ray [12] as shown in Fig 3. It can be expressed by the Beer–Lambert law:

\[ \frac{I}{I_0} = e^{-\mu t} \]

Where \( I \) is the intensity of radiation transmitted through the absorber. \( I_0 \) is the intensity of initial radiation. \( \mu \) is linear attenuation coefficient and \( t \) is the thickness of the absorber.

**Figure 3.** The exponential transmission curve for gamma ray measured under “good geometry” condition [12].

### 2.3. Experiment

The wood phantom was placed at the middle of the gantry as shown in Figure 4. The translational scanning was set to count the gamma photon every 2.5 mm. \(^{137}\)Cs with activity of 2.96 GBq was used as the transmitter. The radiation counted by the detector are about 18000 CPS at air medium (does not hit the phantom). Therefore, counting time is determined every 1 second.

The projection angular increment is 2.8125 degree (64 projections in 180 degree). It takes about 576 minutes to perform 2.5 mm translational step and 64 projections. If the translational scanning step is 5 mm then the required time is about a half of 576 minutes.

**Figure 4.** Experiment setup.

### 2.4. Image reconstruction

The 64 projections data object built into image using filtered back projection algorithm. The filtered back projection algorithm is a well-known classical technique, if the fast Fourier algorithm is use then the data should be obtained in 2n parallel rays and use of the radon transformation [13]. The radon transform is defined as [2]
\[ R(f) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \delta(x \cos \theta + y \sin \theta - t) \, dx \, dy \]  

(2)

The line integral along a line (gamma-ray beam) at an angle \( \theta \) from the x-axis and at a distance \( t \) from the origin. By rotating the coordinate system as shown in Figure 5:

\[ t = x \cos \theta + y \sin \theta \]  

(3)

\[ s = -x \sin \theta + y \cos \theta \]  

(4)

\[ x = t \cos \theta - s \sin \theta \]  

(5)

\[ y = t \sin \theta + s \cos \theta \]  

(6)

Image obtained by restoring the value of radon to the x,y-axis by using the inverse radon (iradon)

\[ \mu(x, y) = \int_{0}^{\pi} P\theta(t) \int_{-\infty}^{\infty} \delta(x \cos \theta + y \sin \theta - t) \, dt \, d\theta \]  

(7)

3. Result

The aim of this experiment is to test the gamma-ray tomography’s ability to recognize the cavities inside the wood. The 64 projections of data were then built into image. The sinogram of the data as shown in Figure 6. It shows that the projection data is symmetric.

The data were then made into 16 projections, 32 projections, and 64 projections for the 2.5 mm translation steps and also for the 5 mm translation steps. Data were built into image as shown in Figure 7. The results show the cross-sectional of the wood phantom include the holes inside it. Density patterns of wood phantom can be observed. The part having the highest density value is the inside of the wood shown by the reddish color. While the bark has a lower density is shown by the yellowish color.

Figure 5. Image coordinate system.

Figure 6. Sinogram of the data.

Figure 7 (a), (b), and (c) are the reconstruction images of 5 mm translational steps with 16, 32, and 64 projections, respectively. More number of the projections could produce smoother and higher contrast of the image. The 5 mm translational steps make the image pixel size represent 5 mm\(^2\). The resulting image size is 64 x 64 pixels (320 x 320 mm).
Figure 7. Reconstruction image, (a) 16 projections with 5 mm translational step, (b) 32 projections with 5 mm translational step, (c) 64 projections with 5 mm translational step, (d) 16 projections with 2.5 mm translational step, (e) 32 projections with 2.5 mm translational step, and (f) 64 projections with 2.5 mm translational step.

The translational steps of images in Figure 7 (d), (e), and (f) is a half from the previous images. It is 2.5 mm. It aims to improve the resolution of the resulting image. The image pixel now representing 2.5 mm$^2$ (128 x 128 pixels). There are more “artifacts” in the image with 2.5 mm$^2$ pixels size than images with 5 mm$^2$ pixels size. It could happen due to 2.5 mm and 5 mm measurements were using the same collimator that has 5 mm diameter of slit. There are overlapping of medium passed by radiation.

The cavities (holes) inside the wood phantom can be observed. Three of five pairs of holes can be clearly identified. They are holes with diameters of 40 mm, 30 mm, and 20 mm. While other holes (10 mm and 5 mm) appear vaguely indicated by the yellowish color. The 3D surface of the reconstruction image is shown in Figure 8. Translation step and size of the collimator slit greatly affect the image pixels produced. The 5 mm hole is only represented with 1 pixel in image with 5 mm$^2$ pixels size. This means it is very important to determine how is the pixel resolution it wants to produce and adjusted to the measurement system.

Low density value in the image was filtered as shown in Figure 9. The holes in wood phantom are now more clearly observed. The image with grayscale (Figure 9 (b)) looks easier to distinguish between solid phase and air (cavity) inside wood phantom, but it is more difficult to recognize the difference of density visually. It is easier to recognize the density distribution in the wood phantom visually using Figure 9 (a).

Finally, gamma-ray tomography system is one of the most effective methods to investigate the internal condition of tree stem. The results in images form make it easier to be interpreted. The cavities inside the wood are able to recognize. The density patterns are also observed clearly. Gamma-ray source $^{137}$Cs is effective to conduct wood tomography scanning. Its energy of 662 keV is strong enough to penetrate the wood and still bring the attenuation information if the wood. The higher energy may not be effective enough to be applied in terms of wood measurement. It has a high penetration power that can reduce the probability of interacting with wood so that it brings little information about the internal condition of the wood.
4. Conclusion
The use of gamma-ray tomography provided a non-destructive and accurate method for investigation of tree stem density distribution. The results in images form make it easier to be interpreted. The wood density distribution can be observed clearly. The highest density is shown by reddish color and the lowest density (air) is represented by the blue color default colormap. The cavities (hole) inside the wood can be recognized. Application of 2.5 mm translational steps using a 5 mm slit collimator did not produce better data than the 5 mm translation steps. There are overlapping of medium passed by radiation. The lack of this system is a relatively long measurement time. The system should be upgraded to multi-detectors (fan beam) method. The use of multi-detectors will shorten the measurement time.

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6. References
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