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# X-ray Computed Tomography on Larger Diameter Timber than Digital Detector*[1]

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## ABSTRACT

X-ray computed tomography is a very powerful nondestructive technique in safety inspection of historic timber building. But, in field, various testing condition makes it difficult to carry out X-ray CT testing. Limited size in X-ray digital detector is one of the problems. In this study, a pitch pine disk with two holes was used to know how imperfection in X-ray projection affects CT image resolution. Using various number of projections, CT image was reconstructed by filtered back projection method, and then it was investigated how many projection is required to identify the holes in different location.

Two artificial holes could be differently detected according to their location in cross section of specimen. One hole in center part of specimen was identified using more than 9 radiographs, but the other one which located in outer part of cross section could not be detected until more than 36 projections were used. Even though there is data missing in outer part of cross section due to limited size of detector, the center part of CT image could be reconstructed well and the resolution of outer part became higher with increase of the number of projections. For field application, the number of projections for CT image reconstruction needs to be decided with consideration of another nondestructive testing and the location of interest.

*Keywords* : Computed tomography, X-ray, Digital detector, Number of radiographs, Nondestructive technique

## 1. INTRODUCTION

X-ray radiography is one of the most powerful nondestructive techniques. Because it can provide internal view of an object, X-ray radiography is used in various industries as well as medical examination. For wood, Oja *et al.* (2000) showed that the X-ray log scanner can be used to predict both the strength and stiffness of boards based on X-ray scanning of green logs. Schajer (2001) developed a statistical model for stress grading using X-ray scanner. Oh *et al.* (2009) developed a method to predict knot area ratio in a cross section by a single X-ray radiation. He also developed an X-ray model for bending strength prediction

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(Oh *et al.*, 2008, 2010 a b). Kim *et al.* (2006 a b) investigated the attenuation of X-ray radiation for timber building safety inspection. Kim *et al.* (2011) developed a portable X-ray CT apparatus which acquires projection images during the rotation of the object itself for small wooden cultural property such as small Buddhist statues and Tripitaka Koreana, and he reconstructed cross sectional images by Filtered Back Projection (FBP) algorithm. Recently, X-ray radiation technology has been improved considerably. The state-of-art digital detector can provide lots of advantage in X-ray application; faster, high sensitivity, less dose, more convenient and portable. This digital detector increases the feasibility to apply X-ray CT technique for safety inspection of historic timber building. However, there are very few researches to report the possible problems in field application of X-ray CT by digital X-ray detector. Many efforts to overcome the limitation in field application have not been made.

Most of historic heritage buildings in Korea was made of wood. The wood members can be damaged by various biological attacks. The damages can threaten the safety of the building. In this situation, X-ray technique can be used to find the damaged member in safety inspection of history timber building, and computed tomography (CT) can visualize cross sections with high resolution. However, X-ray CT could make a health problem to inspectors due to radiation exposure. Because the heavy shield cannot be installed in field unlike medical CT, the inspectors need to be away from X-ray source and the apparatus has to be remotely controlled. Besides, because all equipment should be portable, the CT apparatus, which makes X-ray tube and detector turn around the object, needs to be light and easy to assemble.

Currently, two different types of detector are used to inspect historic buildings; radiographic film and two dimensional digital detector. The radiographic film is much cheaper than digital detector and two or more film can be used at a radiography in case that the object is large. But when radiographic films were used for reconstructing CT image, it takes long time to reconstruct a cross section because many radiographic films need to be developed and digitalized. On the other hands, digital detector with scintillators made it much easier and faster to take X-ray images. Because numerous X-ray projections are required to make a CT image, the use of digital detector can provide lots of advantages, compared with film, such as convenience of inspection and saving time.

However, in case of historic building inspection, most of Korean historic timber buildings have large diameter column, especially important building such as palace. In such that case, the digital detector is not large enough to obtain a full size X-ray image of the large diameter column by a single radiography. It is possible to obtain a full size projection image by stitching 2 or more X-ray images in the same manner as radiographic film. But when reconstructing X-ray CT image with the digital detector, it is difficult to make the apparatus which lets the detector move without any angle change to obtain two or more radiographs for a projection angle. Besides, the apparatus should make the X-ray tube and the detector turn around the test member and it should be remotely controlled. Moreover, it need to be disassembled and portable. As well as difficulty to make the apparatus, double or more time will be spent to obtain a set of 360 degree projections.

Because of difficulties in stitching method, an alternative method was attempted in this study. The alternative method was based on a hypothesis that the missing data in projections can be compensated by more number of projections.

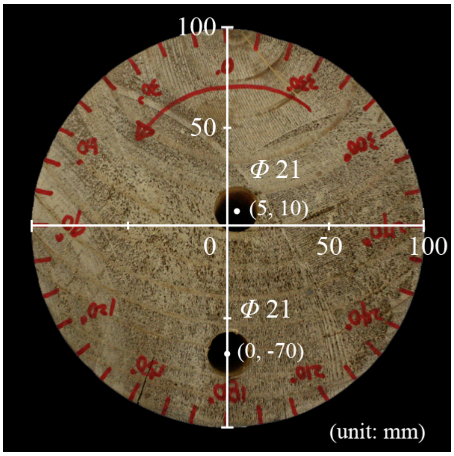


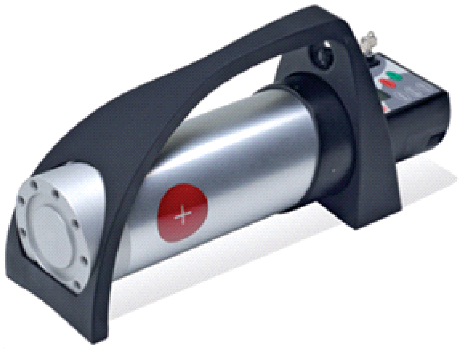

Fig. 1. Specimen preparation.

Therefore, in this study, more projections were obtained than typical X-ray CT experiments for safety inspection and every X-ray projection has data missing caused by smaller detector size than the specimen. Because of the imperfection in X-ray profile of each projection, the CT image might not be reconstructed properly. Therefore, in this study, the feasibility of X-ray CT image reconstruction for large cross section wood member with limited size of digital detector was investigated and the best method to detect internal defect was found in practical viewpoint.

## 2. MATERIALS and METHODS

### 2.1. Specimen

A pitch pine (*pinus radiata*) disk was prepared for the test. The diameter of specimen was 200 mm. Two holes were made at center and near the edge of specimen to decide the accuracy of X-ray CT, and the diameter of both hole was 21 mm. Moisture content and oven-dry specific gravity was 18% and 0.5, respectively. Fig. 1 shows the size and location of the hole.



(a)


(b)

Fig. 2. Test equipments (a : Portable X-ray tube, b : 2-dimensional digital detector).

### 2.2. Test Setup and Method

#### 2.2.1. X-ray Apparatus

A portable X-ray tube, CP 120 (ICM sa, Belgium, Max 120 kVp and 1.5 mAs) was used as X-ray source (Fig. 2). Tube voltage and current of 60 kVp and 1.5 mAs were used and the intensity of this X-ray was weaker than that of typical medical examination.

A 2-dimensional digital detector, NX06 (RF Co., ltd., Japan), was used as an X-ray detector (Fig. 2). This type of detector composed of scintillators and charge coupled device (CCD). The size of digital detector was 254 mm by 206

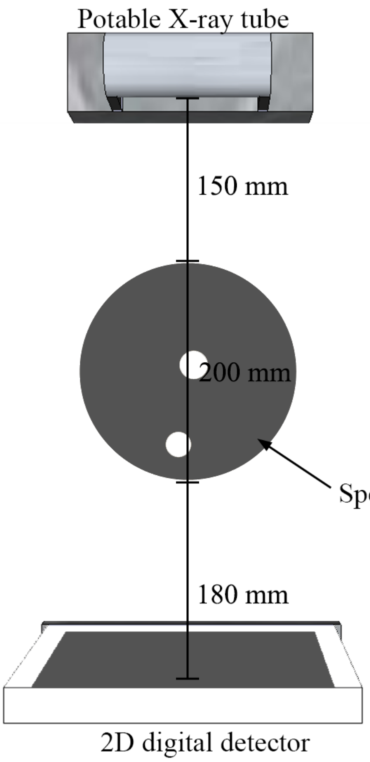



Fig. 3. Experiment set-up.

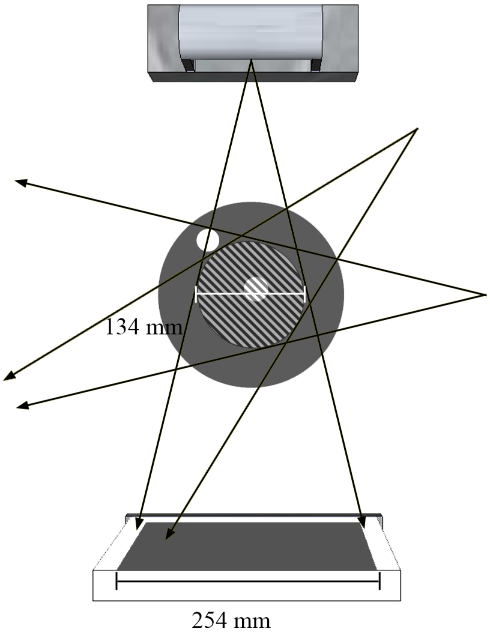



Fig. 4. Schematic drawing for effect of detector size on CT reconstruction.

mm. The exposure time was 1 second and the X-ray image was automatically digitalized and transferred to laptop computer.

#### 2.2.2. CT Installation

As Figs. 3 and 4 showed, the experiment in this study was intended to reproduce the situation that the diameter of specimens is larger than the detector size. Specimen was placed on a turn table and the distance from the source to the detector was 530 mm. Seventy two projections were captured with 5 degree turn table rotation. The diameter of specimen (200 mm) was smaller than wide width (254 mm) but some outer part of the specimen could not be captured by the detector because the fan X-ray beam was used in this study (Fig. 4). As Fig. 4 shows, only shaded area (diameter 134 mm) have 72 projections but the other had less than 72 projections.

#### 2.2.4. Reconstruction of CT Image

Seventy two projection images for a cross section (2,540 pixel by 1 pixel) was extracted from the original X-ray radiographs. Because of limitation in the memory of computer, it was converted into 400 pixel by 1 pixel. Then a CT images were reconstructed by filtered back projection (FBP). To compare the resolution of CT image according to the number of projection, CT image with 9, 18 and 36 projections was also reconstructed as well as CT with full number of projections (72 projections). The FBP algorithm was programmed using Matlab (R2007, Mathworks inc. USA, Kim *et al*. 2006).

Table 1. Predicted diameter of the artifact defect according to the number of projections

| Location of hole | Diameter of hole (mm) | | | | |
|---|---|---|---|---|---|
| | The number of projections | | | | Actual size |
| | 9 | 18 | 36 | 72 | |
| Center part | - | 17.66 | 20.51 | 21.08 | 21 |
| Outer part | - | - | 18.80 | 21.08 | 21 |

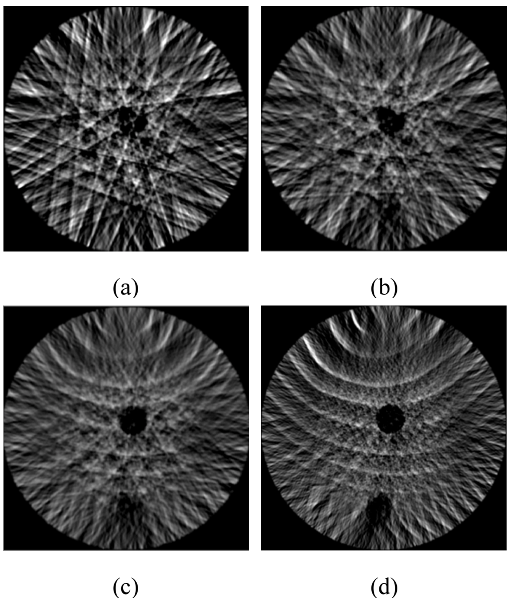



Fig. 5. The CT image reconstructed by FBP method according to the number of projections (a: 9 projections, b: 18 projections, c: 36 projections, d: 72 projections).

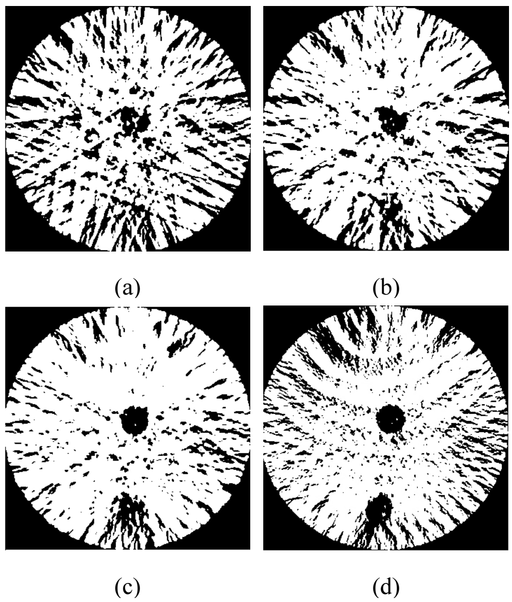



Fig. 6. The threshold-applied CT image according to the number of projections (a: 9 projections, b: 18 projections, c: 36 projections, d: 72 projections).

# 3. RESULTS and DISCUSSIONS

## 3.1. Resolution of CT Image According to the Location of Defect.

In field application, the number of projection would be very important because adding more projections are almost impossible after reconstructing the CT image. Therefore, the number of projections has to be decided before obtaining X-ray profile for projections. At first, CT images were reconstructed by FBP method with 9, 18, 36 as well as 72 projections. These reconstructed CT images were compared with each other.

As Table 1 and Figs. 5 and 6 shows, more than 18 projection provided enough resolution to identify 21 mm-diameter artificial defect in center. Even only 9 projections were used, the hole could be identified (Figs. 5a and 6a). This result is very similar to Kim *et al*. (2006) which carried out with no problem in detector size. Based on this comparison, it was found that the center part can be inspected by the FBP and regular projection acquisition method and at least 9 projections are required to identify defects located in center part.

However, the cases of 9 or 18 projections could not identify the hole located in outer part of specimen (Figs. 5a, 5b, 6a and 6b). If the outer part is interesting in field, defects would not be found by 9 or 18 projections CT. Fortunately, when more projections were used in CT reconstruction, the resolution of the outer part became higher and the hole in outer part could be more clearly identified. The 72 projections provided enough resolution to identify the defect located in outer part as Figs. 5d and 6d shows.

### 3.2. Feasibility to Reconstruct CT Image with Smaller Detector than Object Size

In this study, two holes were made to consider the effect on the detectability of defect location. One hole was made at center, and the other hole was made at the outer part. Imperfections in projections, which were caused by the limited size of detector, were related to this outer part. The minimum number of projections was investigated on the two holes in different location.

As Figs. 5 and 6 shown. CT image resolution of center part was much better than that of outer part at every CT image according to the number of projections. Using only 36 radiographs, not only artificial hole but annual ring could be identified at center part of CT image (Fig. 5). When CT image was reconstructed by 72 radiographs, the other artificial hole, which was located at outer part of specimen, also could be detected. This result indicated that smaller detector than object can be used to reconstruct CT to inspect the inner part of object.

The shaded area in Fig. 4 had 72 projections, but other part than this shaded area has some data missing in X-ray profile of each projections. This data missing is the main cause of the lower resolution in the outer part. Even though there was data missing in the outer part, CT image could be reconstructed up to the level to be capable of detecting defects, when more projections were obtained than the case without problem in detector size. If the more projection are used in CT reconstruction, the outer part can be inspected by the conventional FBP algorithm without costly apparatus for stitching and stitching pre-process.

In addition, CT inspection on outer part can be less important because it can be inspected by other nondestructive technology such as simple tapping. Before CT test, the importance of the outer part CT inspection need to be evaluated and the number of projection should be decided with consideration of other applicable NDT. For example, if another NDT which can inspect 10~20 mm depth from the surface will be applied to the large member and its diameter is just little bit larger than detector size, 36 projection CT could be chosen.

## 4. CONCLUSIONS

This study was carried out to investigate the feasibility to reconstruct CT image with imperfect projections due to limited size in digital detector. From this study, the below was concluded.

1. Conventional FBP algorithm can be used, even though X-ray profile of each projection does not have some of outer part information in case that the detector size is not large enough to inspect the test object.

2. The resolution was varied according to the distance from the center. The required number of projection depends on the location of interest in a cross section. In field application, the number of projections needs to be decided with consideration of the location of interest.

3. Because there is no X-ray profile missing in the center part, the hole in center part could be identified when only 9 projections were used in reconstruction, as Kim *et al*. (2006) reported. But more projections provided the higher accuracy in prediction of the size.

4. More projections are required when the outer part is inspected. At least 36 projections are required to inspect the outer part of member. But more than 72 projections provide much higher accuracy in measuring the size of defect.

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