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ORIGINAL ARTICLE

# Nondestructive tree-ring measurements for Japanese oak and Japanese beech using micro-focus X-ray computed tomography

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## Abstract

The purpose of this study is to establish technology for utilizing images taken by micro-focus X-ray computed tomography (CT) to perform nondestructive tree-ring measurement of wooden cultural properties. This paper covers two experiments conducted using Japanese oak as a typical example of ring-porous wood and Japanese beech as a representative example of diffuse-porous wood. In the first experiment, images of thin strip specimens of Japanese oak and Japanese beech taken by micro-focus X-ray CT are compared against those taken by soft X-ray radiography, the method conventionally used in dendrodensitometry. A discussion then follows in regard to image quality and tree-ring width measurement resulting from the two methods. In the second experiment, tomograms are taken of folk art articles made of Japanese oak and Japanese beech, demonstrating that it is possible to use nondestructive means to visualize the tree-rings of three-dimensional objects. The results show that micro-focus X-ray CT offers much promise of widespread utilization in the tree-ring dating of wooden cultural properties.


***Keywords:*** Micro-focus X-ray CT; Nondestructive; Cultural heritage; Tree-ring; Japanese oak; Japanese beech

## Introduction

Tree-ring measurement has played an important role as a means of age determination in the study of wooden cultural properties. The most generally used method of measuring tree-ring width is to take the measurements on the specimen surface using a lens, photography, etc. (Okochi and Mitsutani, 2004). However, in cases where the surface is coated with such matter as paint, lacquer, or gold leaf, or when the degree of deterioration is such that it is impossible to see the tree-rings clearly, ring width measurement becomes exceedingly difficult. Sampling methods are sometimes used such as boring to take samples from the object of interest (Stokes and Smiley, 1968), or grinding down a portion of the area to be measured. Nevertheless, nondestructive methods are ideal in the study of wooden cultural properties. The materialization of a method for measuring the tree-rings inside specimens has been a much awaited development.

X-ray computed tomography (CT) is a method widely used for the nondestructive imaging of the interior of specimens. Studies have been performed by numerous researchers on the use of X-ray CT to create images of the interior of wood materials, including living trees (Onoe et al., 1983, 1984; Tsao and Onoe, 1983; Miller, 1988), logs (Onoe et al., 1982; Funt and Bryant, 1987;

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Aoki et al., 1998a, b; Rinnhofer et al., 2003), wood chips (Hattori et al., 1985a, b; Ekevad, 2004), and cultural properties (Reimers et al., 1989; Iwamoto et al., 1999, 2002; Ohashi et al., 2002; Ohashi, 2004; Kawai, 2004; Sakuraba, 2004). However, their insufficient spatial resolution makes X-ray CT scanners incapable of fully resolving tree-rings less than 1 mm in width, which are often the most important in tree-ring dating.

Recent years have seen the development of devices such as X-ray tubes with small focal spot size, high-sensitive image intensifiers, and high-resolution CCD cameras. The spatial resolution of X-ray CT scanners has seen a remarkable improvement. Some studies have used these high-resolution X-ray CT devices to observe anatomical structure of the wood (Lindgren et al., 1992; Illman and Dowd, 1999; Kobayashi, 2002; Kobayashi and Okochi, 2003; Okochi et al., 2003). However, in such studies, in order to achieve high-resolution images, it was often necessary to use specimens cut into small measurement-practical pieces.

The purpose of the present study is to establish technology for performing tree-ring dating by utilizing high-resolution micro-focus X-ray CT to image the interior portion of wooden cultural properties and using the tomograms thus obtained to take measurements of tree-ring width. In this paper, the Japanese oak (*Quercus crispula* Blume) is used as a typical example of ring-porous wood, and the Japanese beech (*Fagus crenata* Blume) as a typical example of diffuse-porous wood. The reasons these species were chosen are that both the Japanese oak and the Japanese beech are already proven to be appropriate species for tree-ring dating (Tanaka et al., 1990), and that the authors are in the process of constructing master chronologies for these species in Japan (Hoshino et al., 2002, 2005; Fujii, 2004). In addition, given the current status of the oak (*Quercus petraea* Liebl., or *Quercus robur* L.) and beech (*Fagus sylvatica* L.), which are both vigorously studied in European dendrochronology (Eckstein, 1972; Baillie, 1982, 1995; Sass and Eckstein, 1995; Piovesan et al., 2003), it was chosen to investigate their two Japanese counterparts as the focuses of this study.

## Materials and methods

This paper presents the results and discussions relating to two experiments. The first experiment compares images taken of thin strip specimens of Japanese oak and Japanese beech by micro-focus X-ray against those taken by soft X-ray radiography. The second experiment is an attempt to take micro-focus X-ray CT images of three-dimensional (3D) objects made of Japanese oak and Japanese beech.

### Comparison of images of thin strip specimens of Japanese oak and Japanese beech taken by micro-focus X-ray CT and those taken by the conventional method of soft X-ray radiography

Out of three individual Japanese oak trees felled in Wakayama Prefecture, Japan in 2003, and five individual Japanese beech trees felled in Miyagi Prefecture, Japan in 1989, one individual tree of each species was selected for having the narrowest tree-rings, and the two trees were used to make the specimens in our experiments. From disks of Japanese oak and Japanese beech, the following slices were taken: Japanese oak, 2.4 cm × 10 cm; Japanese beech, approx. 2.5 cm × 14.8 cm. Both slices encompassed the entire range of tree-rings, from the pith to the outermost ring. Thin strip specimens with a uniform thickness of 1.8 mm were then prepared from these slices, as shown in Figs. 1 and 2A, to be subjected to soft X-ray radiography.

Soft X-ray radiography is widely used in tree-ring dating as a means for densitometrical analysis of wood materials. Because the irradiation by X-rays occurs parallel to the axis of the wood tissue, there is a need for the thin strip specimen to be made as thin as possible and of uniform thickness (Parker and Meleskie, 1970; Parker and Jozsa, 1973; Schweingruber, 1988). In this experiment, the imaging by soft X-ray radiography was performed using an in-motion radiography device (HX-60MWS, Hitex Co., Ltd.) designed specifically for the densitometrical analysis of wood materials. In this device, a molybdenum anode X-ray tube with a focal spot size of 0.4 mm is positioned at a distance of 43 cm from the specimen surface, and structured to take radiographic images of the thin strip specimen that is in contact with film. The exposure conditions in this experiment were as follows: X-ray tube voltage 12 kV, X-ray tube current 2.5 mA, and irradiation time 12.8 s. The film used in the experiment was industrial X-ray film (IX50, Fuji Photo Film Co., Ltd.). Following exposure, the film was developed in an automatic film processor, after which it was rendered into digital data using a flatbed scanner (ES-8000, Seiko Epson Corporation) under the following conditions: input resolution 1200 dpi and quantization level 8 bits. Under these photographic conditions, each pixel of the image is equivalent to 21 μm. In order to convert the light and dark contrast of the image into density, a standard sample was also captured in the photograph as a stepped gradation. However, the density was not quantified in the present experiment.

By contrast, in micro-focus X-ray CT, the tomograms are obtained by the geometric arrangement of the X-ray source, test object, and detector along a cross-sectional plane that is perpendicular to the axis of the object. Since the above scan geometry, and hence the provision of tomographic planar images, is possible with any