STUDY ON CREATING CROSS SECTION OF THE OLD GIANT OLD TREE'S TRUNK FOR ACQUISITION OF SONIC TOMOGRAPHY

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ABSTRACT:

This study aimed to improve the usefulness of 3D scanning as an alternative to the biased measurement method for getting tree trunk geometry using a calliper in sonic tomography for tree health diagnosis. To this end, this study constructed geometry information using PiCUS Calliper and a 3D scanner on an old giant tree located in Buyeo-gun and compared the results with sonic measurements.
Of the two instruments, the 3D scanner has the advantage of realizing the geometry of the object more closely than the calliper, which uses the principle of three-point surveying. Provided that Section A produced through the 3D scanning is more similar to the actual geometry, and the error range of the data acquired by the 3D scanner is within 1-3cm, the deviation of -0.2-+0.9% in the perimeter of the two geometries is insignificant, and the section based on 3D scanning is more similar to the actual tree trunk than the calliper. However, while the calliper-based section was not significantly different from the 3D scanning-based section geometry, the problem of exaggeration and distortion in the bumpy parts of the tree was identified. This confirms that 3D scan data can be used as a tool to accurately realize the section geometry of the tree trunk. On the other hand, the sonic tomography results obtained based on the two geometries also showed a difference in the total area and the area where the symptom appeared. However, to accurately calculate the extent of the symptom, a quantitative comparative analysis of the actual sonic velocity value in addition to the area is required, which is a limitation that was not covered in this study.

1. INTRODUCTION

In recent years, tree damage has been increasing due to the occurrence of heavy rainfall and typhoons caused by extreme weather events. In particular, old giant trees that have survived for hundreds of years are structurally vulnerable due to aging and weakening tree vigor. In addition, due to their large dimensions, such as height and diameter at breast height, tree breakage causes large-scale damage to neighboring buildings, pople, and property. In 2019, a fir tree, a natural monument at Hapcheon Haeinsa Temple in South Korea, fell during Typhoon Lingling. The tree fell sideways and damaged part of the surrounding fence.

The destruction of the old giant tree poses a deadly threat due to its internal hollows and decay, which are usually difficult to see with the naked eye. Recently, the Cultural Heritage Administration has been conducting sonic tomography of trees to preserve the old giant tree and diagnose damage in advance. Sonic tomography is a method of getting the tree trunk section geometry to be measured, inserting a measuring point (MP) shallowly into the xylem of the tree, and measuring the generated sonic velocity (Son et al., 2022). Since it can diagnose hollows and decay inside the tree non-destructively, it is often used as basic data to check the condition of old giant trees. Thus, it is very important to acquire accurate section geometry of trees in sonic tomography.

However, for old giant trees, there are limitations in getting accurate sections using a calliper, which is commonly used for sonic tomography, because the section geometry of the tree trunk is diverse and large. In addition, it is cumbersome to repeatedly measure the section geometry of the tree trunk at each height to perform sonic tomography. Thus, this study aimed to explore the applicability of 3D scan data used for recording and monitoring the geometry of heritage sites, in getting the section geometry of the tree trunk required for sonic tomography, considering the geometric characteristics of old giant trees and site workability.

2. MATERIAL AND METHODS

2.1 Materials

Figure 1. Research Subject

The subjects of the study were 32 *zelkova* trees over 300 years old, which are managed as protected ones in Buyeo-gun, South Korea, and were selected based on their location, general

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geometry of the tree, whether or not they had tree surgery, and their size. The tree selected finally was a zelkova located at 304 Baekjemun-ro, Gyuam-myeon, Buyeo-gun, with a height of about 6.7m and a crown of about 8.2m wide (Figure 1).

2.2 Methods

The study was conducted in three main steps(Figure 2). First, reference points were set in the site to acquire the section geometry of the tree trunk using a 3D scanner and a calliper. The reference points were marked with markers at three points forming a triangle centered on the tree. Using a leveler, sensors(measuring point, MP) were attached at 90, 120, and 150cm height of the tree trunk that is horizontal and perpendicular to the markers and assigned a unique number of 1. Sensor 1 had a styrofoam ball attached to it so that it could be distinguished from the other sensors in the data acquired by the 3D scanner.
Second, the section geometry of the tree trunk was acquired using a 3D scanner and a calliper, respectively. The point cloud acquired by the 3D scanner was aligned and denoised. Then, points were extracted from the three heights of the tree trunk where Sensor 1 was attached. The extracted points were converted into section lines using Rhino3D and Grasshopper to create the section geometry of the tree trunk (hereinafter referred to as 'Section A'). At the same time, the section geometry of the tree trunk was acquired using a calliper. At this time, several sensors were installed equidistantly at the same height of the tree trunk based on Sensor 1, and the section geometry was acquired by the three-point survey method (hereinafter referred to as 'Section B').
Third, sonic tomography was conducted using IML's PiCUS Sonic Tomography based on the section geometry of the tree trunk acquired by the two measuring devices. Lastly, this study conducted a comparative analysis of the differences in the perimeter and area of the section geometry of the tree trunk acquired by each measuring device and the distribution of the decay measured by sonic tomography.
Geo Slam ZEB-GO was used for 3D scanning. CouldCompare, Rhino3D, and Grasshopper were utilized for processing and handling the scan data.

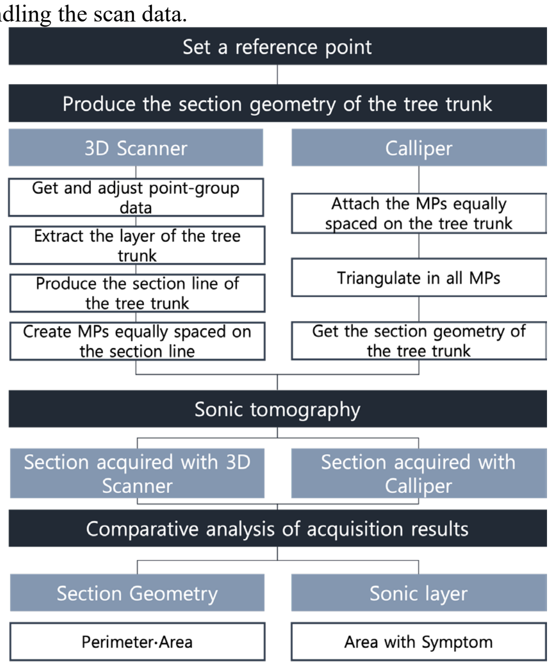


Figure 2. Research flowchart

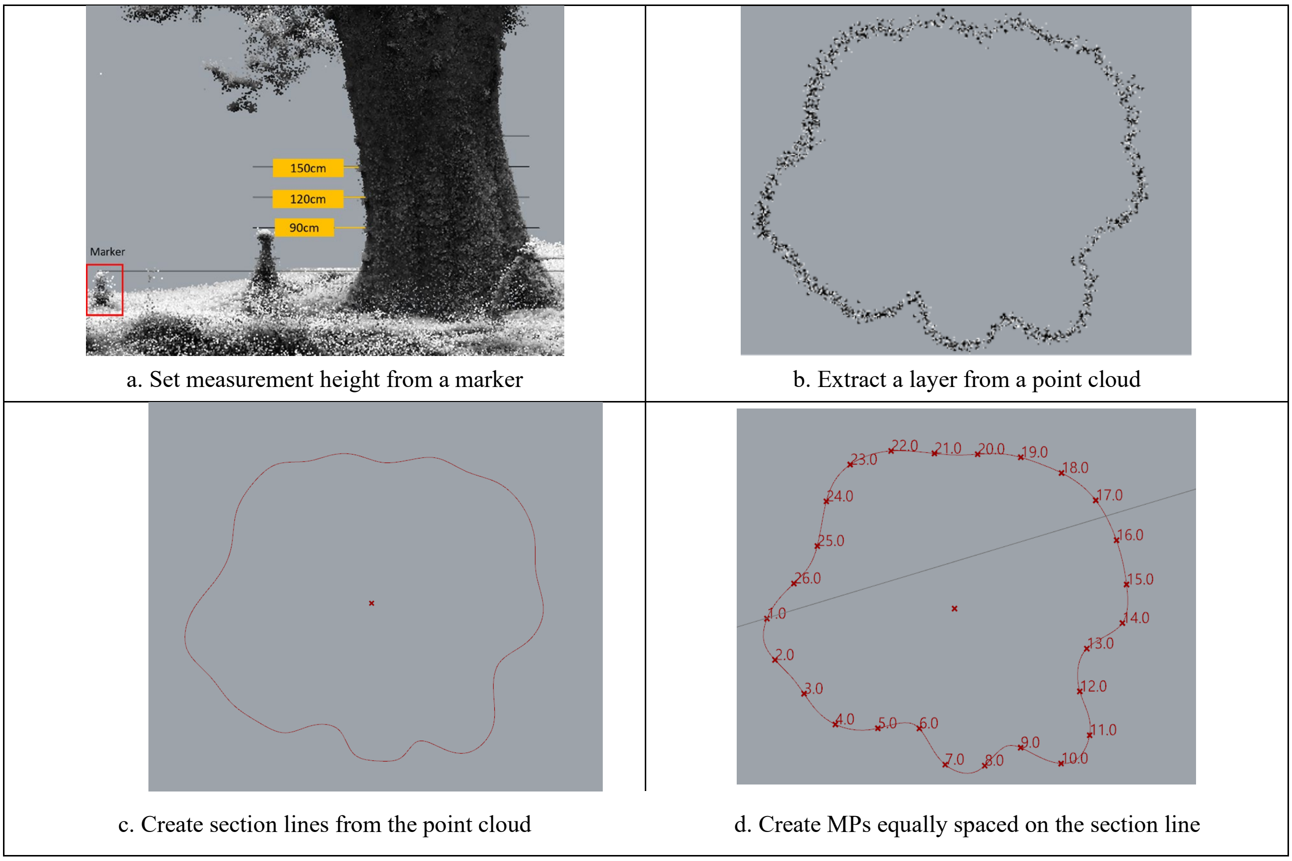
3. RESULT AND CONCLUSION

3.1 Acquiring cross section of the trunk using 3D scanning and sonic tomography

3D scanning is a fundamental tool used to record the precise section of heritage objects. It is increasingly being used to acquire the geometry of natural heritage such as old giant trees. In addition, data acquired with high precision can accurately realize irregular geometry such as that of trees, and it has the advantage of being able to extract information on the desired area or point with a single data acquisition. This study attempted to create a section geometry of the tree trunk that can be applied to the sonic tomography of trees using 3D scanning.
First, reference points were set up on the site, including a marker and MP1 for comparison at the same point as Section B. The marker was placed at the vertex of a triangle centered on the tree to be used for matching the scan data and locating the MP. MP1 was then placed at heights of 90, 120, and 150cm from the marker, horizontally and vertically, respectively, on the tree trunk before 3D scanning (Figure 3). Styrofoam was attached to MP1 to distinguish it from the other MPs in the acquired data.


Figure 3. Getting Sectional geometry of the tree using 3D Scanning

The acquired 3D scan data were denoised in CloudCompare, and section geometry was created using Rhino3D and Grasshopper. In the point cloud, a line perpendicular to gravity was specified based on the marker (Figure 4a), and points were extracted at 90, 120, and 150cm height of the tree trunk to create a section based on MP1 (Figure 4b). This study used Grasshopper's cull duplicates component to remove duplicate data From the point c loud extracted at each height and extracted the average point to create an outline (Figure 4c).
Along the outline, this study specified the location of the MPs to be used in the site during sonic tomography (Figure 4d). For sonic tomography, the PiCUS manual recommends installing MPs with appropriate equal spacing between 12 and 15cm for optimum data acquisition. Thus, MPs were set to be equally spaced using the “Divide Length” component in the created section (Figure 5). For example, at the 90cm height of Section
A, the perimeter is 442.8cm, so this study set 34 MPs at 13.3cm spacing. At the 120 and 150cm heights, this study set 32 MPs at 13.4cm and 13.5cm spacing, respectively (Table 1).



a. Set measurement height from a marker

b. Extract a layer from a point cloud

c. Create section lines from the point cloud

d. Create MPs equally spaced on the section line

Figure 4. Process of creating a sectional geometry of the tree trunk from the point cloud

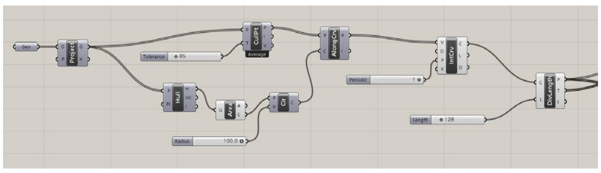


Figure 5. Algorithm for generating MP

Measurement height (cm)	90	120	150
Tree trunk perimeter (cm)	442.8	430.9	432.6
Spacing of MPs	13.3	13.4	13.5
Number of MPs	34	32	32

Table 1. Perimeters and MPs of Section A based on the measured height

Section A with MP positioning was entered into the PiCUS software for sonic tomography. However, an error occurred in the coordinates of the MP entered into the software.

Generally, sonic tomography results are visualized on Axes X and Y with the origin at 0,0. However, the MP coordinates of Section A were arbitrary values generated by Grasshopper and needed to be converted to a coordinate system compatible with PiCUS software. Thus, the lowest value of the X and Y coordinates of the MPs was set to 0,0, and the coordinate values of all MPs were converted based on this (Figure 6).

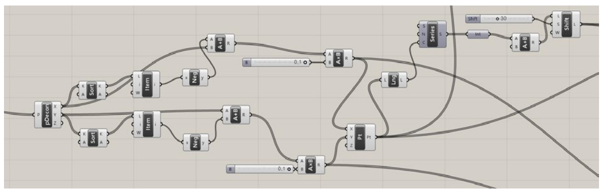


Figure 6. Algorithm for transforming MP’s Coordinate

At this time, the coordinate values of the MPs were reduced by 10 times in Grasshopper since they had been enlarged by about 10 times when entered into the PiCUS software. The coordinate values of the MP with the coordinate system and size converted were inserted into a .pit file and imported into the PiCUS software to recreate the section. Based on the inputted tree section geometry, sonic tomography was conducted using PiCUS Sonic Tomographic.

3.2 Acquiring cross section of the trunk using a calliper and sonic tomography

A calliper was used to acquire the section geometry of the tree trunk at 90, 120, and 150cm heights (Figure 7). Since the number of MPs and their spacing can affect the section geometry of the tree trunk and the sonic tomography results, this study set the same acquisition conditions as the number and spacing of MPs set in Section A. Thus, 34, 32, and 32 MPs were installed at 90, 120, and 150cm heights, respectively. The MPs were numbered sequentially in a counterclockwise direction with MP1 in the north as the reference point, and after getting the section geometry of the tree trunk, sonic tomography was performed using PiCUS Sonic Tomographic.

Figure 7. Getting the sectional geometry of the tree trunk using a Calliper

3.3 Comparison of measurements results

The geometry of Sections A and B and sonic tomography results were compared and analyzed.

The sectional geometry of the tree trunk acquired using the two instruments showed differences depending on the measurement height. The perimeter of the tree trunk showed the smallest difference at a height of 90cm, with the perimeter of Section B being about 0.9cm less than that of Section A. On the other hand, at heights of 120 and 150cm, the perimeter of Section B tended to increase slightly by 2.9 and 4.1cm over Section A, respectively.

Of the two instruments, the 3D scanner has the advantage of realizing the geometry of the object more closely than the calliper, which uses the principle of three-point surveying. Provided that Section A produced through 3D scanning is more similar to the actual geometry, and that the error range of the data obtained by the 3D scanner is within 1-3cm, the deviation of -0.2 to +0.9% in the perimeter of the two geometries can be considered insignificant (Table 2).

The perimeter of the section was correlated with the sectional area. In the comparison, at heights 90 and 120cm, the change rate of Section B compared to Section A was about 0.5-0.9%, showing that the two geometries were similar. However, at the height of 150cm, the total area of Section B was about 434.79 ㎠ smaller than Section A, showing the largest difference. This is likely because the section geometry of the tree trunk has a more curved geometry at 150cm than the section at other heights. For example, MP 5 to 9 at 90cm, MP 23 at 120cm, and MP 5 to 6 at 150cm were characterized by a more distorted Section B than the geometry of the actual tree trunk (Table 3). It is judged that this has occurred because the calliper's characteristic of measuring the distance between two points with a fixed rod limits its ability to realize highly curved geometry. Thus, old giant trees are more atypical than young giant trees, where the crown of the tree is smooth, suggesting the efficacy of using 3D scanning to acquire the section geometry of the tree trunk.

Next, this study compared the results of sonic tomography acquired using the sectional geometry of Sections A and B (Table 2). The results of sonic tomography are visualized in the section diagram of the tree trunk as relative values by calculating the difference in the transmission velocity of sonic waves according to the state of the medium inside the tree trunk. A color close to brown in the section diagram is interpreted as a relatively healthy interior of the tree trunk. On the other hand, green is the early stage of the symptom, and it is judged that the symptom has developed toward blue.

The analysis showed that the area with a symptom decreased in Section B compared to Section A at all three heights. In particular, at the height of 90cm, the symptom area in Section B

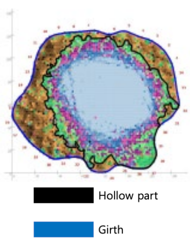
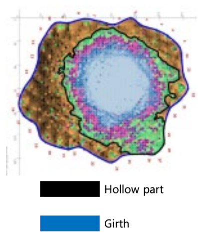
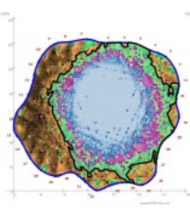
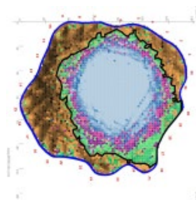
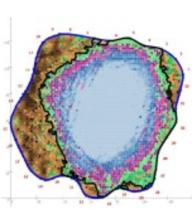
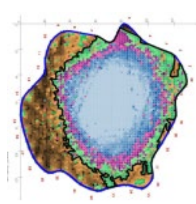
<table>
<tr><th>Classification</th><th>A</th><th>B</th><th colspan="2">Classification</th><th>A</th><th>B</th><th>A-B</th><th>Change rate(%)</th></tr>
<tr><td rowspan="3">Height 90(cm)</td><td rowspan="3">
</td><td rowspan="3">
</td><td colspan="2">Perimeter(cm)</td><td>442.8</td><td>441.9</td><td>0.9</td><td rowspan="3">▼ 0.2</td></tr>
<tr><td rowspan="2">Area (㎠)</td><td>Whole</td><td>13464.26</td><td>13338.04</td><td>126.22</td></tr>
<tr><td>Symptom</td><td>9283.33</td><td>7670.46</td><td>1612.87</td></tr>
<tr><td rowspan="3">Height 120(cm)</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2">Perimeter(cm)</td><td>430.9</td><td></td><td>-2.9</td><td rowspan="3">△ 0.6</td></tr>
<tr><td rowspan="2">Area (㎠)</td><td>Whole</td><td>13126.01</td><td>13048.55</td><td>77.46</td></tr>
<tr><td>Symptom</td><td>8441.63</td><td>7896.63</td><td>545</td></tr>
<tr><td rowspan="3">Height 150(cm)</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2">Perimeter(cm)</td><td>432.6</td><td>436.7</td><td>-4.1</td><td rowspan="3">△ 0.9</td></tr>
<tr><td rowspan="2">Area (㎠)</td><td>Whole</td><td>12828.88</td><td>12394.09</td><td>434.79</td></tr>
<tr><td>Symptom</td><td>9319.52</td><td>8541.27</td><td>778.25</td></tr>
</table>

Table 2. Differences in the geometry between Section A and Section B

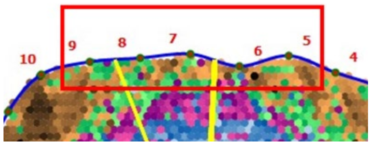
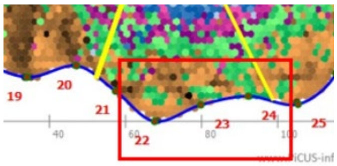
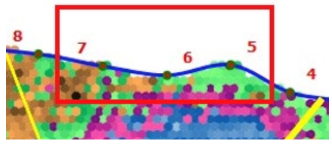
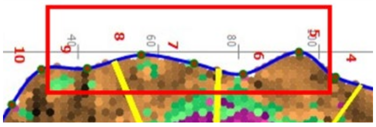
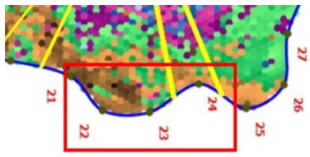
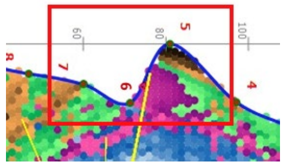
Classification	Height 90cm	Height 120cm	Height 150cm
Actual Geometry			
Section A			
Section B			

Table 3. Differences in the geometry between Section A

was reduced by about 1616.87 ㎠ compared to Section A, showing a clear change. However, this is a mapping of the velocity of sonic waves acquired from each tomography relative to the section, and it is not possible to accurately diagnose the extent of the symptom by simply comparing the area. In this case, it is possible to compare the sonic velocity values of the neighboring points mapped as symptoms in the section and identify the points where the sonic velocity changes rapidly. In this study, an accurate comparison of sonic tomography results should be accompanied by the analysis of sonic velocity values for each point. However, this was not done in this study due to the time-consuming process of getting and processing tree geometry data.

In addition, sonic tomography results are also affected by the experience and skill of the site operator, even for the same tree. For example, the depth of the sensor attached to the tree trunk, the strength of the hammer striking the sensor, etc. varies from one operator to another, and even when the same operator measures the same tree at different heights, the installation conditions or circumstances of the equipment may change, so it is necessary to consider these site conditions.

To sum up, the perimeter change rate of the section processed with the 3D scan data and the section measured by the calliper was -0.2-0.9%, which is a very small difference, considering the measurement error of the two measuring instruments. Nevertheless, in the measurement using a calliper, the bend of the tree trunk was found to be unrealizable or distorted. Meanwhile, the section processed from the 3D scan data showed a high similarity to the actual section geometry, confirming the feasibility of using it as an instrumentation tool to accurately acquire the section geometry of the tree trunk.

In the sonic tomography acquired based on the two sections, the areas showing symptoms were somewhat different. And yet, there were limitations to the analysis of characteristics. In this case, it was necessary to diagnose the extent of the symptom through the process of comparing the area and the sonic velocity values around the symptom.

4. CONCLUSION

This study aimed to improve the usefulness of 3D scanning as an alternative to the measurement method biased toward getting tree trunk geometry using a calliper in sonic tomography for tree health diagnosis. To this end, this study constructed geometric information using PiCUS Calliper and a 3D scanner on an old giant tree located in Buyeo-gun and compared the results with sonic measurements.

The sectional geometry based on 3D scanning was more similar to the real tree trunk compared to the calliper. The section based on the calliper did not show much difference from the sectional geometry based on 3D scanning, but the problem of exaggeration and distortion in the bending part of the tree was identified. This confirms that 3D scan data can be used as a tool to accurately realize the geometry of the tree trunk. On the other hand, the sonic tomography results obtained based on the two geometries also showed a difference in the total area and the area where the symptom appeared. However, for an accurate calculation of the extent of the symptom, a quantitative comparative analysis of the actual sonic velocity value in addition to the area is required, which is a limitation that was not covered in this study.

In a follow-up study, 3D scanning that considers the tree surgery area and the supplementation of the algorithm for freely adjusting the position of the MP would be required. In addition, it is necessary to quantitatively reveal the reliability of the sonic tomography results of the section acquired using 3D scanning. This is expected to improve the accuracy of the data and improve the speed of fieldwork.

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