Raw Wood Fabrication with Computer Vision

Genki Furusho[a] and Yusuke Nakamura[a], Gakuhito Hirasawa[b]

[a]Graduate School of Science and Engineering, Chiba University, Japan
[b]Graduate School of Engineering, Chiba University, Japan
E-mail: ayua6112@chiba-u.jp, axaa4936@chiba-u.jp, hirasawa@faculty.chiba-u.jp

Abstract

Thinned wood, which is obtained as a result of pruning and thinning thick forests, is not widely used because of its small size and diameter. Thinned wood is not often used because conventional machines cannot leave enough cross-section for building materials. However, using computer vision technology to measure the shape of the wood and a fabrication machine that can adapt to the measurement results makes it possible to process the wood to retain a large cross-section and use it for construction. The developed workflow can be divided into three parts: 1) a database to handle wood inventory and shape data, 2) design of the desired shape, and 3) machining. Although it is difficult to reposition a discrete shape of raw wood during processing with the desired accuracy, the proposed method achieves repositioning of the wood with high accuracy. This research broadens the scope of raw wood processing and helps to utilize wood that was previously discarded and demonstrates a new processing method for irregular shapes.

Keywords –

Raw wood; Aruco Marker; Robotic Fabrication; Thinnings; Photogrammetry; Computer Vision

1 Introduction

Thinned wood is wood generated in the process of forest management, such as pruning and thinning. Because the wood from thinning is small in diameter or crooked, it is not easy to utilize and much of it is left in the forest and overstocked. Overstocking of thinned wood occurs worldwide; it increases the risk of tree disease, insect damage, and wildfires [1]. Therefore, some of the thinned wood is being used for engineered wood and biomass; however, the market value is so low that it is often not worth the cost of recovery. The number of forest businesses that carry out pruning and thinning is decreasing because of the high cost and lack of commensurate income, and some forests are left unattended. In Japan, measures such as offering subsidies to tree pruning companies have been implemented, but this problem has not yet been solved [2]. Construction materials account for a large percentage of the intended use of wood [3]. If small, thinned wood could be used as building material, the use of such wood could be promoted. Wood from thinning is not used because of its small diameter. Logs used for construction are usually cut into rectangular cross sections. When small thinned wood is processed into a rectangular cross section like standard lumber, it becomes too small to be used as a building material. However, three-dimensional (3D) CAD is now widely available, and it is possible to design posts and beams that do not have rectangular cross-sections. If the design retains as much of the cross-section of the thinned wood as possible, it will be sufficiently strong to be used as a building material. The processing of raw wood directly into the desired shape is good for the environment because there is no wasteful process of making standard lumber and then processing it, and the volume of cutting can be reduced. In this study, machining raw wood was realized by computer vision, shape-based design planning, and a machining machine with flexible motion. A staircase was made of raw wood as a practical application of the workflow. The parts that make up this staircase have parts to be machined on both ends and sides, making it difficult to machine without repositioning. However, machining an irregular surface by repositioning the material will cause a decrease in accuracy. A method was developed to estimate the position and orientation of the material to avoid the loss of accuracy.

2 Related Works

Design tools such as 3D CAD and arm-shaped robots have popularized fabrication projects that use wood to create complex shapes [4,5,6]. This high-mix, low-volume production is often fabricated from homogeneous wood products for process reasons. When dealing with non-homogeneous materials, the process is more difficult because the material needs to be handled more carefully than when dealing with homogeneous materials. However, if it can be processed from raw wood into the

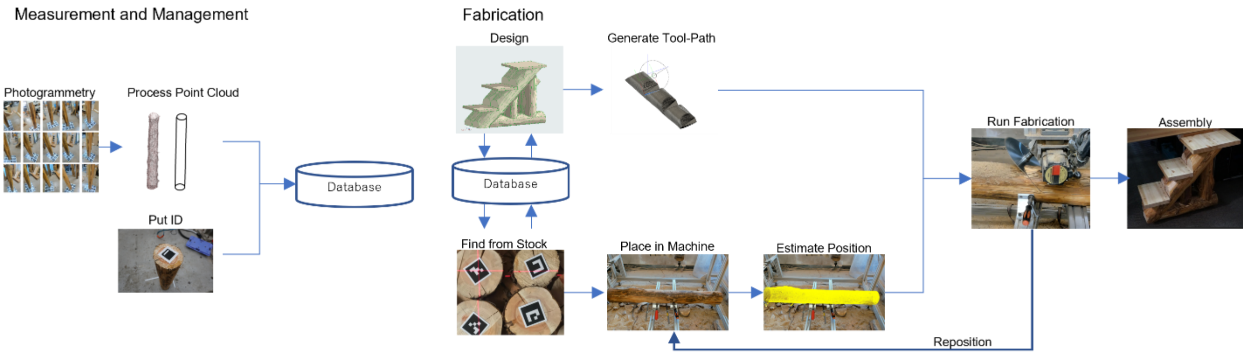

Figure 1 Workflow for registering wood measurement data and management IDs in the database (Left). Workflow for designing a staircase using raw wood to processing (Right).

desired shape without making it a homogeneous material, only one processing step is required, and cutting waste can be reduced. To process raw wood with an uneven surface, it is necessary to obtain raw wood shape data. Techniques such as laser scanners and photogrammetry have been used to measure shape.

The laser scanner measures the shape of the object using a system called time of flight (ToF), which measures the distance based on the time it takes for light to fly back from the measured object to the scanner. Siekański developed a system that can accurately acquire the shape of a log using six laser scanners [7]. Some projects use laser scanners to measure and process the shape of raw woods [8,9].

Photogrammetry is a technique used to obtain the shape of an object in images from multiple viewpoints. It can be performed with an ordinary camera, thus making the measurement relatively cost-efficient. Photogrammetry is also used in forked log processing projects because it is easy to increase the number of measurement positions needed to measure complex shapes [10,11].

In a project where raw wood is to be machined, the location of the shape data measured for design and the location of the raw wood when it is to be machined must be carefully handled. The simplest way to do this is to recreate the posture of the log at the time the shape data needed for the design was obtained.

This method is reliable, but it cannot change the fixed position; therefore, it can only be used in limited situations. To be able to change the posture, one solution is to add a fixture that can be tracked using optitrack [8] or Aruco markers [12]. These methods require the device to be attached to the wood, which may interfere with the fixing and cutting processes.

AR markers have a mechanism to estimate the position and orientation of the object from the features of the marker. In this study, focusing on the texture of a tree, a method to estimate the position and orientation of wood like AR markers using the texture of the tree was investigated. Kei developed a method to obtain the position and orientation of a camera and an object by mapping image features to 3D data [13]. By applying this mechanism, the position and orientation of the raw wood can be obtained using a single camera.

3 Method

3.1 Machine

Figure 1 shows the workflow for log processing using the position and orientation estimation technique proposed in this study. To investigate the usefulness of the proposed workflow, a demonstration of the staircase fabrication was performed using this workflow. However, the proposed workflow for processing can be applied to both arm- and gantry-type machines. In this study, a self-made gantry-type five-axis machine was used for the fabrication. It has three main spindles and two rotary axes; the XYZ axes have a range of 1100 mm, 1100 mm, and 400 mm, respectively, and the rotary axes have a range of motion of 360° around the z-axis and 180° around the y-axis (Figure 2). The main axis is an auto tool change (ATC) motor so that the tool can be changed. The tools selected for this project were straight bits, dovetail bits, and circular saws. (Figure 3). Because the position and orientation estimation technique requires a camera, this machine is equipped with a camera. The camera must measure the position of wood in the machine coordinate system to use it for position and orientation estimation. The camera position is measured by solving the perspective-n-points (PnP) problem [14], which is a method for obtaining the camera coordinates by matching the UV coordinates with the 3D coordinates. We created 26 combinations of UV coordinates and 3D coordinates in the experiment and solved the PnP problem to obtain the camera coordinates (Figure 4).

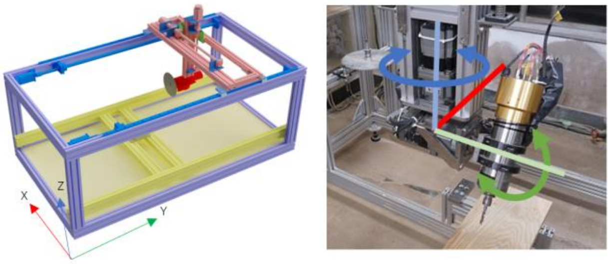

Figure 2 Overall view of the original gantry-type five-axis machine (Left). Rotation axis of the machine (Right).

Figure 3 Tools used for raw wood processing. Chip saw (Left). Spiral bit (Center). Dovetail bit (Right).

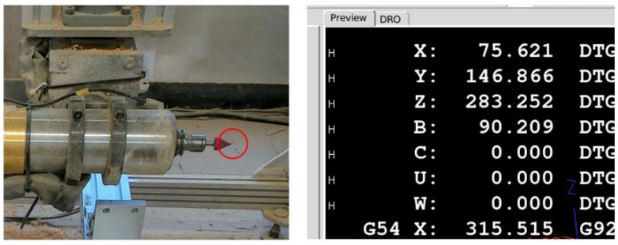

Figure 4 Tip of the tool, which is the reference point on the 2D side needed to solve the PnP (perspective-n-points) problem (Left). The coordinate values of the tool tip, which is the reference point on the 3D side (Right).

3.2 Database

The database manages raw wood shape data, length, diameter, management ID, and feature point information mapped to the 3D data, which were obtained by photogrammetry. For photogrammetry, OpenMVG and Colmap were used, which can acquire not only 3D data but also the position of the camera that captured the picture. Photogrammetry, by itself, does not provide an accurate scale. Conversely, using the Aruco Board, the camera position can be obtained at a relatively accurate scale (Figure 5). In this experiment, by matching the distance between cameras obtained by photogrammetry to the distance between cameras obtained by the Aruco Board, shape data were obtained at an actual scale. In addition, photogrammetry generates 3D maps of feature points during the process of creating 3D data. The 3D data of the feature points were stored in a database for use in estimating the position and orientation of the raw wood before processing. Photogrammetry includes not only the log but also the walls and the floor for processing reasons, but because the log is on the Aruco board, we trimmed the data to include only the top of the Aruco board, and the data of only logs was created automatically. The diameter and length of raw wood were obtained from shape data using Ransac Cylind, which was implemented in PCL. Aruco markers were placed at the cut end of the wood to link the acquired data to the logs. In this way, even if there is considerable stock, the camera can quickly find the raw wood to be used (Figure 6).

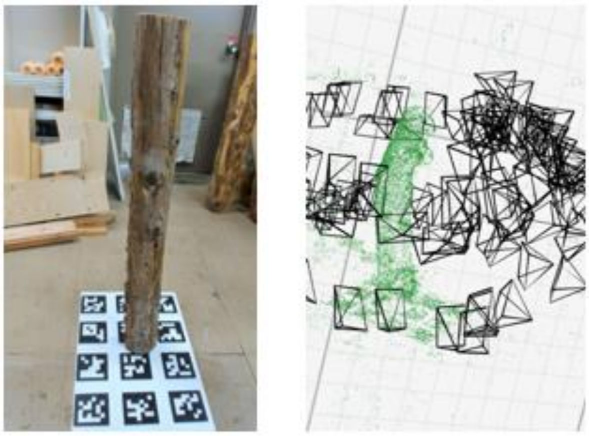

Figure 5 One of the photos for photogrammetry with the log on the Aruco Board (Left). Shape of the raw wood and the position and orientation of the camera acquired by photogrammetry (Right).

Figure 6 Application that finds logs to be used by Aruco Marker

3.3 Design

In the early stages of the design, a cylinder was used to study the shape. Once the shape is approximately determined, the diameter and length of the cylinder are used as inputs, and the appropriate wood is output from the database. The output wood shape data were reflected in the data designed with the cylinder. This application was developed as an add-on for ArchiCAD.

The staircase parts are designed to have joints in three directions on the sides and at the ends; hence, they need to be repositioned during machining (Figure 7,8,9).

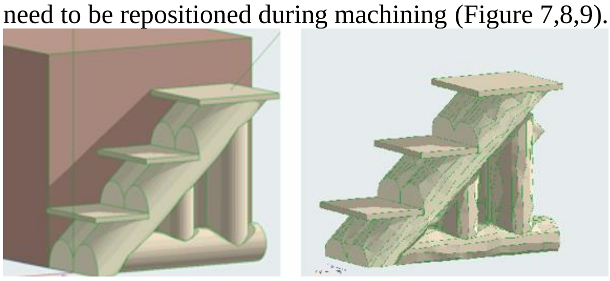

Figure 7 Staircase designed with cylinders (Left). Staircase with cylinders replaced by the shape of a raw wood (Right).

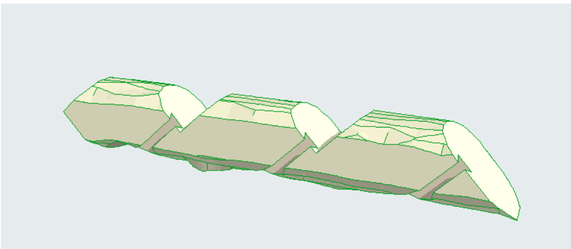

Figure 8 Design of diagonally placed components in the staircase.

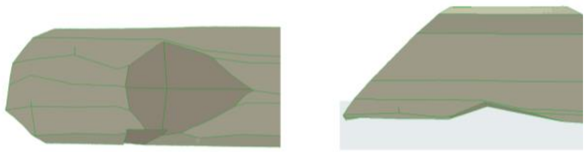

Figure 9 Enlarged view of the joint section.

3.4 Machining

3.4.1 CAM

The machining data is created in Fusion360; however, there is no function to generate the chip saw path. Hence, a plug-in was developed to generate the path for chip saw machining and to generate the machining path (Figure 10). The machining path was generated using the data designed in Section 3.3. The coordinate system used to generate the path matches the coordinate system of the raw wood shape data. Because the shape data of the raw wood are very uneven, a large distance is set for evacuation. This prevents unexpected contact.

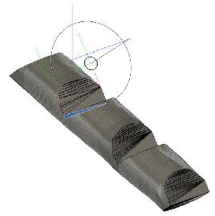

Figure 10 Plug-in to generate processing paths for chip-saw

3.4.2 Position and orientation estimation

The method of estimating the position and orientation after fixation can simplify the fixation tools. In this experiment, only two toggle vises were used; no special jigs were used. The estimation procedure involves taking a picture of the raw wood with the camera attached as discussed in Section 3.1 after fixing it and inputting it into the estimation application. The estimation application extracts feature points from the image and matches them with the image features with 3D positions of the log to be processed in the database. By solving the PnP problem with a combination of the UV coordinates of the matched input image features and the 3D coordinates of the database, the 3D data of the raw wood and the positional relationship of the camera are output. Because the position of the camera in the machine coordinate system was obtained in Section 3.1, it is possible to derive the position of the raw wood in the machine coordinate system. The results are presented in Figure. 11,12.

Figure11 Images taken from a camera installed in a processing machine and overlaid with the feature points used for position and orientation estimation. From top to bottom: before processing, once repositioned, twice, and three times repositioned.

Figure 12 Images taken from a machine with shape data overlaid according to the estimated position and orientation. From top to bottom: before processing, once repositioned, twice, and three times repositioned

3.4.3 Machining

Because the machining path generated in Section 3.4.1 is associated with the data of the original raw wood, the coordinate transformation is performed according to the position of the wood obtained in Section 3.4.2. As discussed in Section 3.3, this shape cannot be machined without repositioning. After machining, it was repositioned, the estimation was redone using the system in Section 3.4.2, and machining was repeated.

This position and orientation estimation method using image features loses its accuracy as it is machined and loses its original surface. Therefore, in this case, the order of machining was such that the uncut area was mostly in the direction of the camera. As a result, it was possible to estimate the position and orientation even after three repositioning.

4 Conclusion

Because the position and orientation estimation was realized without the use of any specialized jig, the replacement in the log processing was simplified. It is necessary to consider the order of processing because processing reduces the number of feature points to be referenced, and the accuracy of the estimation decreases. Compared to methods that require equipment such as the Aruco Marker, this method can reference the entire shape and is, therefore, more robust to occlusions.

One of the disadvantages of this workflow is that people must make decisions about fixing and rearranging materials. Owing to this drawback, full automation is difficult. However, as the repositioning of the materials, which was difficult in the past with fabrication using raw wood, has been realized, the amount of reworking in the workflow has been greatly reduced compared to the previous methods.

The applicability of the workflow proposed in this paper is not limited to raw wood; it can be adapted to all materials for which image features can be acquired and photogrammetry can be performed. It can also be said that the proposed workflow has a wide range of applications and is not limited to the processing machine used in this study, as long as it is capable of position control. In the future, we will conduct experiments on larger logs that are closer to the architectural scale.

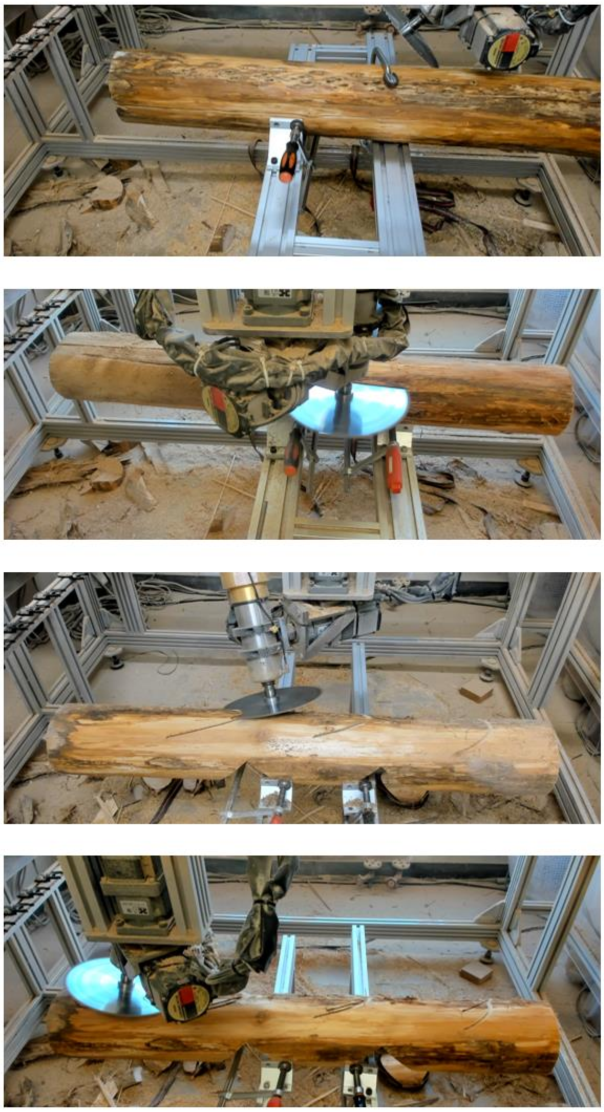

Figure 13 Images taken during processing. From top to bottom: No repositioning, once repositioned, twice, and three times repositioned

Figure14 Each part after machining.

Figure 15 Enlarged view of diagonally placed components of the staircase.

Figure 16 The staircase that was created.

5 Acknowledgements

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