Extraction and Quantification of Burn Marks of War-Damaged trees Using the Reflectance from Terrestrial Laser Scanner

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ABSTRACT: In World War II, Japan was hit by repeated air raids by the US military on major cities across the country. 76 years have passed since the war, however there are still some War-damaged trees that have left the scars of the war. War-damaged trees have increased historical value and significance as they have a role in conveying the memories of the war. On the other hand, it has been promoted to preserve historically valuable heritage as 3D data in recent years. Terrestrial laser scanner(TLS) that can record almost complete shapes of features and can acquire highly accurate point cloud data without contact was applied in this paper. The purpose was to visualize the condition of war-damaged trees using the reflectance from the TLS point cloud data. Three types of damage have been confirmed on the War-damaged trees; burn marks, inclination, and hollow. Some of the previous studies using TLS on Atomic-bombed trees are cases focusing on inclination, and there are no studies focusing on burn marks and hollow. Therefore, focusing on burn marks, the purpose was to visualize the damage by using reflectance of TLS. As a result, the usefulness of reflectance was shown for the burn marks of the war-damaged tree. The extracted burn marks were confirmed up to the top of the tree. In addition, from the extracted burn, it was also possible to quantify by calculating the burn marks rate.

1. Introduction

Many war-damaged trees that were damaged in World War II are distributed throughout Japan. War-damaged trees are those that were damaged by fires caused by incendiary bombs during the Great Tokyo Air Raid. The historical value and significance of preserving these trees are increasing because they still retain their scars from the end of the war to the present.

As the number of people who experienced the war is getting older, Trees damaged in the war are considered to be a means of conveying the memory of that time. Therefore, By preserving the shape of the trees damaged in the war, thought possible to pass on the memories to future generations. (Negishi and Kanno,2015a) (Kannno and Negishi,2020a).

On the other hand, in recent years, the preservation of historical objects has been promoted. The Terrestrial Laser Scanner (TLS) can acquire almost complete shapes of geological objects as 3D point cloud data by using lasers swept from a device. TLS has also been shown to be useful for A-bombed trees damaged by the atomic bombs (Kumazaki et al. ,2019a). In this paper, an effective method for preserving the shape and visualizing the damage of war-damaged trees propose surveying by TLS

Previous research in this field has shown that war-damaged trees have burn marks, hollows, and inclination. The focus of this paper is the burn marks of war-damaged trees. The damage was the burn marks on the trunks of war-damaged trees. War-damaged trees were directly reflect damage caused by incendiary bombs. In recent years, the number of people who experienced the war has been aging and decreasing, so War-damaged trees urgent to preserve trees damaged in the war and to understand the damage in more detail.

In this study, the burn marks of the war-damaged trees were extracted from the 3D point cloud data by TLS, and quantification and visualization are performed. In addition, the current health status of war-damaged trees was discussed.

1.1 Position of this study

In Japan, research on war-damaged trees is limited. Negishi and Kanno (2015) clarified the survival status and morphological characteristics of war-damaged trees in the three wards of Joto, Tokyo, which were the targets of air raids by the U.S. military during the Tokyo Air Raids(Negishi and Kanno,2015a). Kanno and Negishi (2016) assessed the current status of unidentified war-damaged trees and discussed criteria for their future

conservation(Kanno and Negishi,2016a). Furthermore, Kanno and Negishi (2020) investigated the current status of unidentified war-damaged trees and discussed criteria for their future conservation(Kannno and Negishi,2020a).
Among the war-damaged trees, trees in Hiroshima and Nagasaki that were exposed to radiation from the atomic bombs (hereinafter referred to as "A-bombed trees") have been identified and are classified separately from war-damaged trees affected by incendiary bombs because of their uniqueness. Owaki et al. (2015), in a survey of A-bombed trees in Hiroshima City, clarified the inclination characteristics of the trunks of A-bombed trees existing within 2 km of the ground-zero, which were oriented toward the hypocenter area(Owaki et al, 2015a) . Furthermore, referring to the morphological characteristics of A-bombed trees revealed in Hiroshima City, A-bombed trees in Nagasaki City were searched for, which also suffered damage from the atomic bombing, and differences in the conditions for recognizing A-bombed trees and problems in preserving were discussed(Owaki et al, 2016a). These discussions are about the confirmation of the existence of war-damaged trees and A-bombed trees themselves, the understanding of their actual conditions, and the significance of their conservation, and therefore take a different perspective from this paper.
On the other hand, the example of visualization of morphological features of trees based on 3D information is a common viewpoint with this paper. Kumazaki et al. (2019) applied the TLS-QSM tree construction method to the A-bombed trees, quantified the slope characteristics of the A-bombed trees in Hiroshima based on the coordinate values obtained by TLS, and reconstructed and visualized them by constructing tree models using a 3D printer(Kumazal et al ,2019a). This suggests that TLS is useful for A-bombed trees.
This suggests that TLS can be an effective tool for visualizing more detailed morphological characteristics of war-damaged trees by using 3D data.
However, the only case in which the TLS was used to reveal the morphological characteristics of trees focused on the inclination of the tree trunk. As mentioned above, various other damage states have been identified in war-damaged trees. In order to visualize tree damage comprehensively, necessary to focus on other types of damage and to demonstrate their usefulness.

2. Research Method

2.1 Equipment used

The war-damaged trees were measured by using VZ-400i TLS manufactured by RIEGL, which is a time-of-flight system that can acquire 3D shapes as point cloud data based on the angle of the swept laser beam and the distance obtained from the elapsed time due to laser reflection(Figure 1). The point cloud data acquired by this system includes parameters such as color information (RGB), reflectance (Intensity) and the position coordinates (xyz), Furthermore, the TLS has the advantage of being able to acquire far-field and highly accurate 3D point cloud data. Of the information acquired by the VZ-400i, which is useful for the reflection intensity values that are effective in determining the condition of the object surface. Reflectance intensity values are useful for classifying material parameters, and for trees, in the case of trees, the method is used to classify point cloud data showing leaves (hereafter leaf point cloud) and point cloud data showing trunks and branches (hereafter trunk and branch point cloud). (Saito and Masuda, 2016b). However, the reflection intensity value tends to decrease in inverse proportion to the distance to the object. Therefore, the reflectance (dB: decibel), which is calibrated so that the degree of reflection does not depend on the distance, was used for the extraction of the burn marks(Figure 2).


Figure 1 VZ-400i


Figure 2 Reflectance of laser scanning

2.2 Quantification method

The purpose of this study is to extract the burn marks of war-damaged trees from the 3D information obtained by terrestrial laser surveying and to visualize the damage.
Extracted the burn marks were attempted to be quantified using the burn marks rate (Nakamura and

Morimoto,1999a), which is calculated from the ratio of the length of the area where the formation layer was scorched (burn marks length) to the length of the trunk circumference (trunk circumference), extracted at every 1m height of the tree. In general, the trunk circumference is measured with a tape measure stretched over the trunk regardless of its unevenness (Biodiversity Center ,2008b). However, war-damaged trees have caves and hollows caused by bombs. Using the TLS point cloud data, detailed the burn marks rate for war-damaged trees can be calculated.

3. Target trees

Deciduous and evergreen trees were selected from among the trees damaged by air raids in Tokyo. Four ginkgo trees (*Ginkgo biloba L.*) existing at Tobiki-Inari Shrine (Sumida-ku, Tokyo), Akasaka-Hikawa Shrine (Minato-ku, Tokyo), and Zempuku-ji Temple (Minato-ku, Tokyo) were selected as deciduous trees. In this paper, the two ginkgo trees at Akasaka-Hikawa Shrine will be referred to as A and B, respectively. As evergreen trees, The Sieboldii tree(*Castanopsis Sieboldii*) at the site of the Kyu-Hosokawa residence was selected. Figure 3 shows the target trees.

(a)Tobiki-Inari (b)Zempuku-ji (c)Akasaka-Hikawa A (d)Akasaka-Hikawa B (e)Kyu-Hosokawa

Figure 3 Target Trees

4.Expriment

4.1 Data Acquisition

The VZ-400i was set to a pulse repetition rate (PRR) of 1.2MHz and an effective measurement rate of 500,000 (measurements/second) to achieve a maximum measurement distance of 250m. The measurement resolution was set at 0.04° for both vertical and horizontal directions, which is similar to the setting used in this study because 80-90% of morphological information was obtained for a 10m tall Zelkova serrata by measuring from two diagonal points 10m distance from the tree(Honda et al ,2011a) in a tree measurement experiment using the same equipment with the same specifications. Therefore, the same setting was used for the measurement in this paper. The VZ-400i has a measurement accuracy of ±5 mm. The VZ-400i can be installed on a special tilt stand to tilt the instrument in the vertical direction at 15° intervals from 0 to 90°, making it effective for measuring the upper part of trees.

To obtain more detailed 3D shapes of trees, we set up several instrumentation points at each target tree as shown in Figure 4, and also made measurements by tilting the equipment around the target tree. Although the number of instrument points was greatly reduced due to obstacles and obstructions when measuring the ginkgo trees at the Tobiki-Inari Shrine. Therefore, such issue was resolved by using the War-damaged tree trunks as the main targets for measurement. Table 1 shows the measurement records of the number of instrument points, survey date, and weather conditions during the measurement of each target tree.

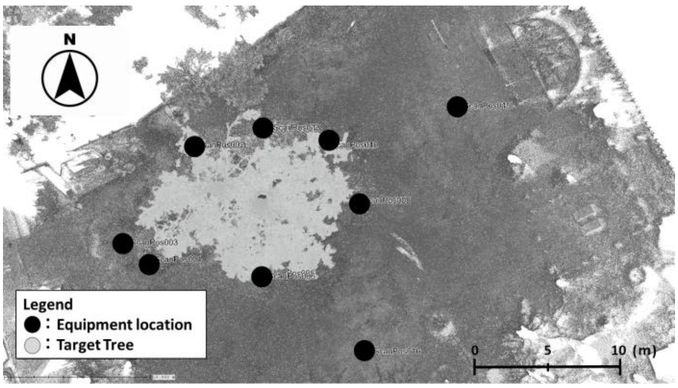

Figure 4 Equipment location

Table 1 Measurement record

	Target tree	Equipment location	Date	Weather
Deciduous tree	Tobiki-Inari Ginkgo tree	7	Aug/2/2019	sunny
	Zempuku-ji Ginkgo tree	46	Apr/22/2021	sunny
	Akasaka-Hikawa Ginkgo tree A	31	Apr/22/2021	sunny
	Akasaka-Hikawa Ginkgo tree B	31	Apr/22/2021	sunny
Evergreen tree	Kyu-Hosokawa Sieboldii tree	30	Jul/16/2021	sunny

4.2 Data Analysis

RISCAN PRO 64bit version2.9.0, a dedicated editing software, was used to analyze the acquired 3D data for data processing.
Since the 3D data acquired by the TLS is in relative coordinates with the TLS instrument point as the origin, data synthesis is required at each instrument point. In order to synthesize the data, the Automatic Registration 2 function of RISCAN PRO was used to automatically combine the data acquired at each instrument point. Therefore, only the target trees were manually extracted from the synthesized data.
The tree height, trunk circumference, and branching were then calculated from the extracted target trees. The tree height was calculated from the maximum and minimum height values of the point cloud data showing the target tree. The trunk circumference was measured by extracting the cross section of the tree trunk at 1.2m from the ground surface and using the measure function. The branching was also calculated using the same measure function as for the trunk circumference measurement. The tree information calculated from the target trees is shown in table 2.

Table 2 Tree information

	Target tree	Height(m)	Circumference(m)	Width(m)
Deciduous tree	Tobiki-Inari Ginkgo tree	15.25	6.12	13.44
	Zempuku-ji Ginkgo tree	21.40	17.71	27.89
	Akasaka-Hikawa Ginkgo tree A	21.99	6.78	20.46
	Akasaka-Hikawa Ginkgo tree B	18.83	4.99	19.53
Evergreen tree	Kyu-Hosokawa Sieboldii tree	11.19	10.95	11.94

4.3 Extraction

In order to extract the burn marks, the reflectance of each tree needs to be determined. For this purpose, from the extracted trees, point clouds showing each part of the war-damaged tree (normal trunk, burns, xylem, leaves, and lichens) were manually extracted, and visualized the reflectance of each part (Figure 5-9).
The reflectance values of the burn marks point cloud and normal trunks point cloud were clearly different, although there were individual differences in the burn marks of the trees. For this reason, burn marks were extracted by setting appropriate threshold values for the target trees.
By displaying the reflectance of the extracted trees, the reflectance of the trees can be visually checked. The burn marks were visually discriminated from the color information display, which consists of 12levels of color information in 1 dB increments from -10dB to 1dB.
When the burn marks were extracted by the above process, the point cloud data showing the burn marks (hereinafter referred to as burn marks point cloud) and the leaf point cloud showed almost the same reflectance. Therefore, after manually extracting only the trunk point cloud of the war-damaged trees, the data was processed by extracting only the burn marks point cloud from the extracted trunk point cloud data (hereafter referred to as trunk point cloud).
As a result, Classification of tree trunk point clouds and the burn marks point clouds was possible. In the classification of the threshold settings, the reflectance of tree trunks was almost the same as that of burn marks, point clouds that could be identified by their shape were removed, and only the burn marks point clouds were extracted manually. Since lichen point clouds could not be discriminated by shape in the case of reflectance display, by using the color information obtained from the TLS, the burn marks point clouds were classified.

The above process was applied to each tree. Figure 10-14 shows the trunk point cloud and the burn marks point cloud obtained by reflectance. As a result, for each target tree, the extraction of the burn marks was possible by reflectance (Figure15-19). The height of the burn marks from the ground surface (hereinafter referred to as "burn marks height") was confirmed for each target tree. The following burn marks heights were confirmed for each tree, 13.22 m from Tobiki-Inari Shrine, 18.60 m from Akasaka-Hikawa Shrine A, 11.05 m from Akasaka-Hikawa Shrine B, 17.52 m from Zempuku-ji and 8.84 m from Siebldii at the Kyu-Hosokawa.
The burn marks were, evaluated by using the reflectance values that indicated the shape of the burn marks that were clearly visible to the eye.

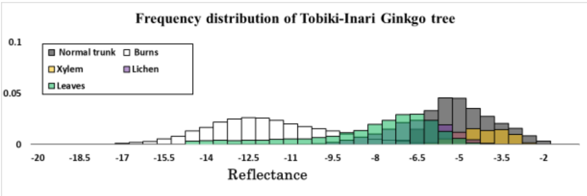

Figure 5 Tobiki-Inari shrine

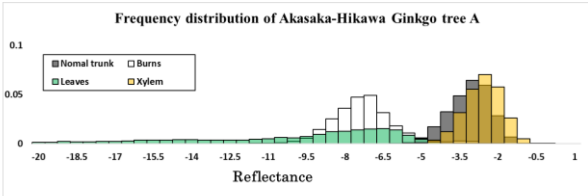

Figure 6 Akasaka-hikawa shrine A

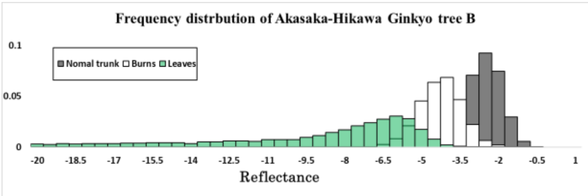

Figure 7 Akasaka-hikawa shrine B

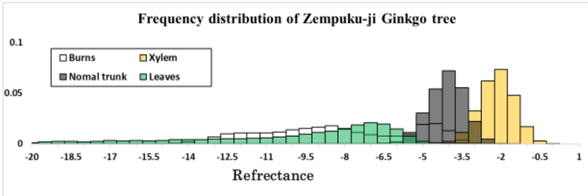

Figure 8 Zempuku-ji

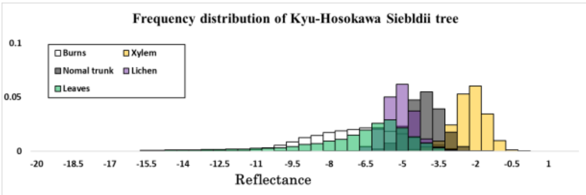

Figure 9 Kyu-hosokawa

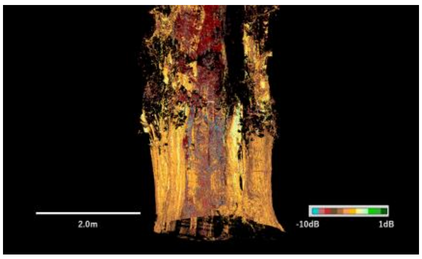

Figure 10 Tobiki-Inari

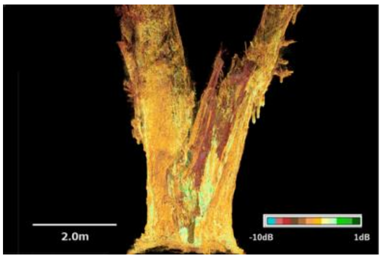

Figure 11 Akasaka-Hikawa A

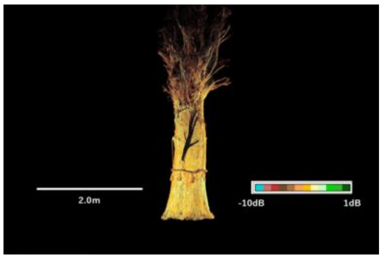

Figure 12 Akasaka-Hikawa B

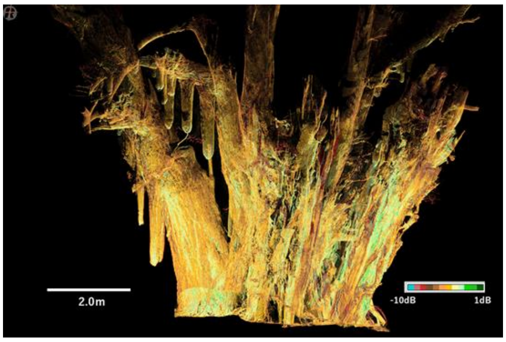

Figure 13 Zempuku-ji

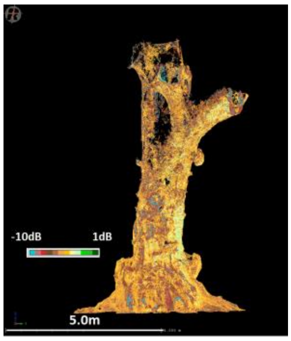

Figure 14 Kyu-Hosokawa

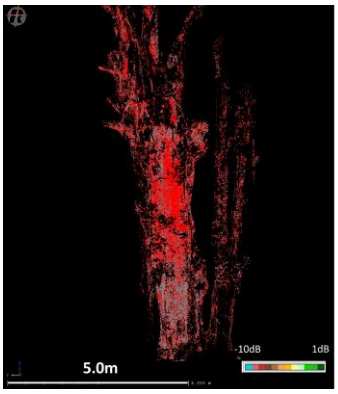

Figure 15 Tobiki-Inari

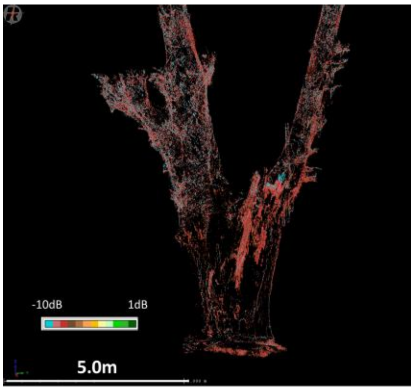

Figure 16 Akasaka-Hikawa A

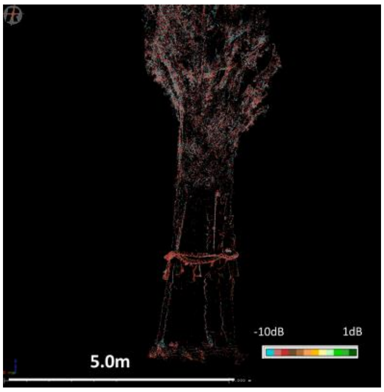

Figure 17 Akasaka-Hikawa B

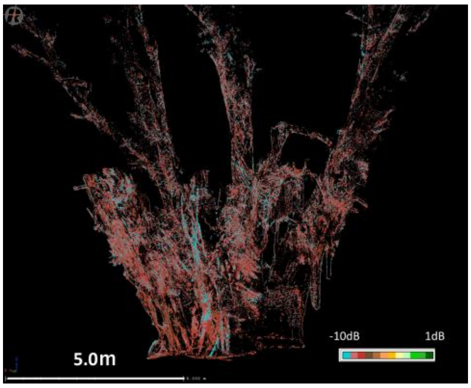

Figure 18 Zempuku-ji

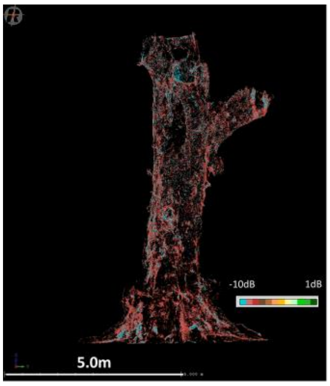

Figure 19 Kyu-Hosokawa

4.4 Quantification

In order to quantify the burn marks, tried to visualize it using the burn marks rate. Figure 20 shows the trunk cross-sections were extracted from the extracted target trees at every 1m height. The trunks extracted manually from the target trees and the burn marks extracted by reflectance were overlaid with different color displays, and the trunk circumference and the burn marks length were measured for each cross section extracted at 1m intervals using the measure function of RISCANPRO. Figure 21 - 25 show the burn marks rate of the target trees.

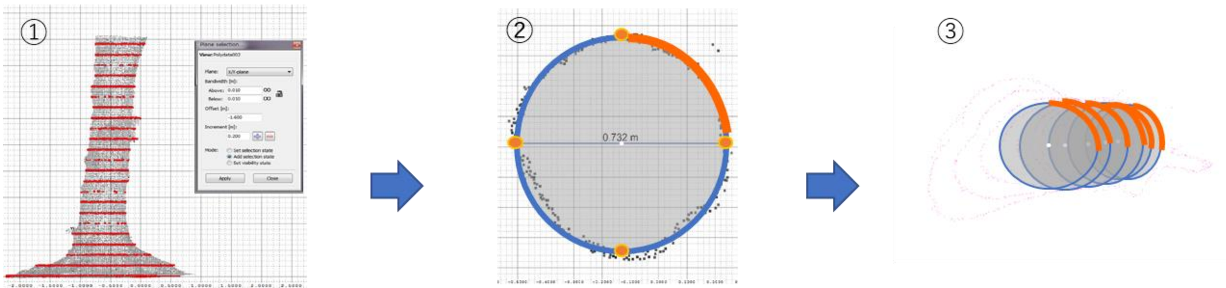

Figure 20 Calculation method of burn rate

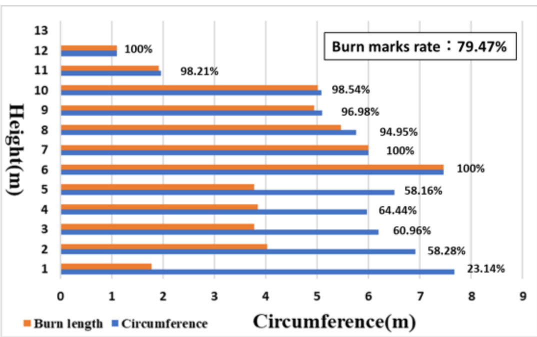

Figure 21 The burn marks rate of Tobiki-Inari

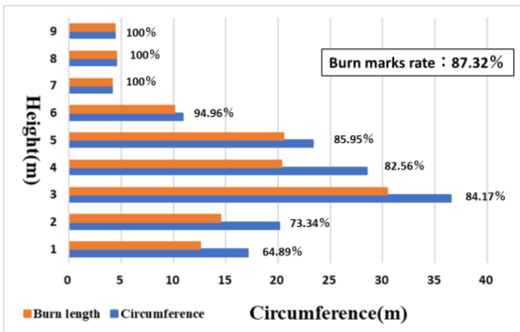

Figure 22 The burn marks rate of Zempuku-ji

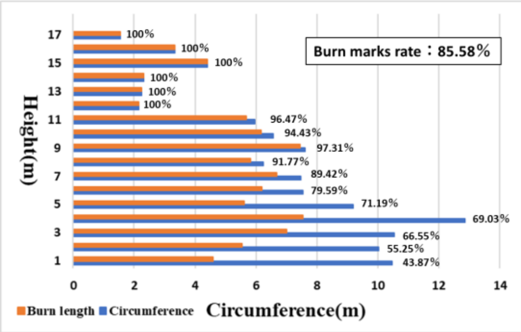

Figure 23 The burn marks rate of Akasaka-Hikawa A

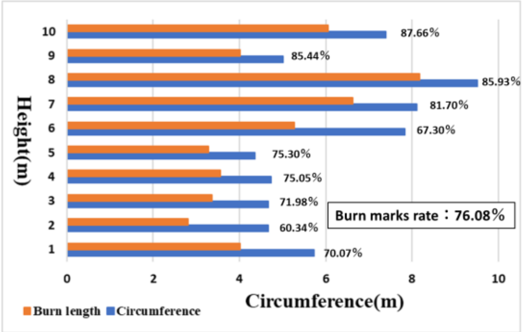

Figure 24 The burn marks rate of Akasaka-Hikawa B

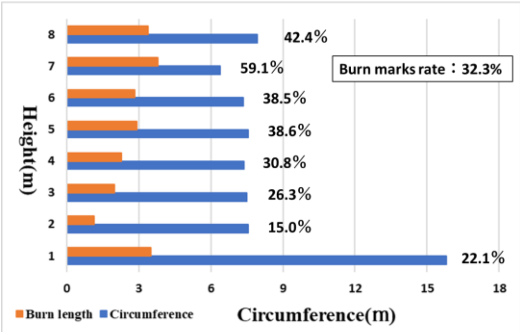

Figure 25 The burn marks rate of Kyu-Hosokawa

4.5 Statistical Analysis

As a result of attempting to quantify the burn marks point cloud extracted, the burn marks rate tended to increase toward the top of the trunk. Therefore, Correlation coefficients of the relationship between tree height and the burn marks rate were calculated from the measured values.

The burn marks height of the ginkgo tree at Tobiki-Inari Shrine was 13.22m. However, the main trunk of the tree could not be identified at a height of 13m due to lack of point clouds, so the correlation coefficient was calculated up to a height of 12m. For the same reason, correlation coefficients were calculated for Zempuku-ji Ginkgo up to a height of 9 m.

The coefficient of correlation for the ginkgo of Tobiki-Inari Shrine was 0.480 for the height of 12m, indicating a moderate positive correlation. The correlation coefficient for the 17m height of the ginkgo trees at Akasaka-Hikawa Shrine A was 0.833, indicating a strong positive correlation. The coefficient of correlation for the 10m height of the tree at Akasaka-Hikawa Shrine B was 0.968, indicating a strong positive correlation. The correlation coefficient of Zempuku-ji Ginkgo trees with a height of 9m was 0.987, indicating a strong positive correlation. The coefficient of correlation for the 8m height of the Sieboldii tree at the Kyu-Hosokawa was 0.295, indicating a weak positive correlation.

The calculated correlation coefficients were subjected to an uncorrelation test to verify the significance of the results. The results of the uncorrelation test showed that three of the target trees, Akasaka-Hikawa Shrine Ginkgo A, Akasaka-Hikawa Shrine Ginkgo B, and Zempuku-ji Ginkgo, met the 1% significance level, but the Tobiki-Inari Shrine Ginkgo and the Kyu-Hosokawa Sieboldii did not show any significance.

These results indicate that the burn marks rate of the three ginkgo trees, Akasaka-Hikawa Shrine Ginkgo A, Akasaka Hikawa-Shrine Ginkgo B, and Sieboldii at the former Hosokawa residence site, increased as the high position on the tree. In contrast, the tops of the trunks of two trees, Ginkgo Tobiki-Inari Shrine A and Sieboldii at the Kyu-Hosokawa residence, which did not show significance in the uncorrelation test, were affected by incendiary bombs and burned down. In the uncorrelation test, weak or moderate correlations were found, suggesting that the burn marks rate increases when the top of the trunk is not burned off.

5. Consideration

5.1 Considerations for burn marks

As a result of attempting to quantify the burn marks rate by calculating the burn marks rate, attempts to calculate and quantify the burn marks rate suggested that the burn marks rate tends to be higher at the top of the tree.

According to the calculated correlation coefficients, the correlation coefficients for the three Ginkgo trees met the 1% significance level. The main trunk and branches of trees become thinner as they reach the top of the main trunk. Therefore, the incineration rate may increase at the top of the trunk because the area of contact between the top of the trunk and the fire generated by incendiary bombs becomes larger.

The fire that reached the top of the tree trunks may have been affected by the time of the disaster and the attack plan by the U.S. military. The Tokyo air raid occurred in March 1945, and the ginkgo trees were presumably defoliated. During the defoliation period, the heat shielding power of ginkgo trees is reduced, and the fire prevention function is significantly reduced(Iwasaki et al ,2017a). In addition, since the air raid by the U.S. military was a clever attack plan that took into account the monsoon(Nagasaki,1998b), the fallen leaves and dead branches became combustible materials,(Nakagoshi and Touyama,1998a) and it is assumed that the fire reached the top of the tree trunk.

However, according to Harrington (1993), depending on the amount of photosynthetic products stored, trees recover better from fire damage during the dormant season (autumn) than during the growing season (late spring and midsummer(Harrington,1993a). This suggests that the fire had a greater impact on the trees at different times of the year, but that the trees healed naturally due to their recovery function.

According to Brown et al. (1987), in a survey of poplar trees killed by fire, an average of 75% of the trunk circumference was charred below 5m above the ground surface, and an average of 50% of the trees survived the fire(Brown,1987a), which is consistent with the results of this study.

The results of this study are in agreement with those of the present study. Since trees are thought to have undergone natural healing after being affected by the disaster, and that the trees are still in good health 76 years after the war.

5.2 Considerations for tree types

The common feature of both tree species was that there was a clear difference in the reflectance of each area found in the target trees. Therefore, although the visualization of the burn marks was tested on deciduous and evergreen trees, the usefulness of TLS was also demonstrated on different tree species.

In the present study, Ginkgo trees showed significance for the increase in the burn marks rate with tree height, while Sieboldii trees did not. This may be due to the loss at the top of the tree trunk, however, since the sample size was only one, the tendency of the burn marks was not completely understood.

In this study, Ginkgo was tested on multiple individuals, but only one individual was tested on Sieboldii tree. Therefore, increasing the number of specimens would help us to understand the burnability of evergreen trees.

The characteristics of ginkgo and Sieboldii trees are that they both have hard and strong trunks, and they have been planted as fireproof trees since ancient times. The fire resistance of both species is thought to be a factor in their continued existence today. Therefore, the damage caused by the incendiary bombs was presumably not enough to reach the formative layers inside the trunk. Since several species of trees were found in the war-damaged trees, In the future, verification of other types of trees is necessary to understand the trends of the burn marks.

5.3 Considerations for methods

In the study, TLS and reflectance were used for validation.

By using multiple instrument points for each individual tree, detailed data of the tree was obtained during data acquisition. Even with a small number of instrument points, detailed data on the burn marks could be obtained by measuring the main trunk as the main object.

One of the advantages of TLS is that it is effective for measurements from a long distance. The highest burn height of 19m was obtained. In the previous method, the burn marks rate was calculated by visual identification and measurement with a tape measure, but the TLS was also useful for burn marks on the top of the trunk, which is difficult to identify from the ground. This suggests that TLS is effective in preserving tree shape and visualizing burn marks even at high elevations.

The reflectance was used to extract the burn marks on the tree trunks. As can be seen from the reflectance frequency distribution map, the reflectance of each part of the tree was clearly different. However, since there was a difference in the reflectance values of each tree, the threshold value required for the extraction of burn marks from trees was considered to vary depending on the individual tree. This may be due to the severity of the tree damage. For example, when charring was observed on the exterior of a tree, the damage was considered to be severe, and the reflectance was lower. On the other hand, if the damage is light, such as soot left on the trunk surface, the reflectance value will be high and almost the same as that of the tree trunk point cloud. However, the fact that there was a clear difference in reflectance between the various parts of the trees suggests that reflectance may be useful for extracting burn marks.

In the extraction of trees and burn marks using reflectance, the leaf point cloud and burn marks point cloud showed almost similar reflectance values, so we manually classified each of them. The measurement data for deciduous

trees were scanned during the leaf setting period. Therefore, the use of measurement data from the deciduous season may simplify the task of classifying leaf point cloud and burn marks point cloud.
The burn marks were calculated and quantified for burn marks rate. This method was considered to be able to quantitatively visualize the burn marks on the whole trunk including the upper part of the trunk.

6. Future Prospects and Summary

As a future prospect, the following three points need to be pursued.
The first is the measurement method for deciduous trees. As mentioned above, the measurement for deciduous trees was done in the leaf-dressing season, but in the future, measurement in the deciduous season will simplify the analysis for the classification of leaf point cloud and stem and branch point clouds. In the future, a comparison of the results of analysis during the leaf-dressing and defoliation periods should be conducted to find the appropriate period for measurement.
Secondly, the number of samples. A total of five trees were preserved in three dimensions for shape preservation and the burn marks by TLS. However, A larger sample size of war-damaged trees is needed to understand trends in tree trunks damaged by incendiary bombs. In addition, the health of the target trees obtained can be studied by monitoring them over a longer period of time. Thirdly, the visualization of other types of damage in war-damaged trees should be considered. The visualization of the damage on war-damaged trees will reveal more detailed damage on each of the war-damaged trees. The use of 3D point cloud data allows us to understand the current morphological characteristics of trees, which may help us to consider the conservation of individual trees.
As an extension of the method used in this study, the information obtained by TLS may be applied not only to war-damaged trees but also to trees and buildings damaged by fire.
In summary, this study has shown the usefulness of visualizing the burn marks of war-damaged trees by using the reflectance of TLS point cloud data. Moreover, the extracted the burn marks could be quantified by calculating the burn marks rate. Therefore, an understanding of the current status and health of war-damaged trees was inferred.

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