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Research Paper

APPLICATION OF MICROWAVE BACKSCATTERING TO MONITOR THE STATE OF CHANGE IN TRUNCATED PALM TREES

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The remote-sensing technique microwave backscattering is known to be applied to determine various vegetation conditions, such as the growth of trees. However, the technology is mainly applied for studying geographic topologies from long distances, with measurement systems installed in satellites or aircraft. The rapid evolution of microwave technologies in recent years, such as the miniaturization of radar apparatus and reducing the power required to operate them, supports the thought that anyone may be able to use such systems someday. The ability to use ground-based equipment to monitorchanges occurring in vegetation could contribute to resolving agriculture and environmental problems considering a number of aspects such as cost, convenience and effectiveness. For this study, the authors developed a scatterometers capable of taking high-speed measurements of various frequencies of microwaves irradiated at palm tree trunks positioned at a relatively short distance. They also applied the properties of microwave fading and radar cross-sectionanalysis to backscattering results obtained at different times over a period of approximately three months.This paper introduces the experiment, apparatus and analytical procedures, and validation that microwave backscattering can be utilized to measure the internal change in truncated palm trees over time.

Keywords: Microwave backscattering, Remote sensing, Palm trees, Scatterometer, Microwave fading

INTRODUCTION

Changes in ecosystems and regional climates believed to be caused by global warming and environmental pollution are key topics of discussion around the world. In Europe, it has been reported that flowering, leaf development and the fruition time of vegetation have abnormally quickened in 78% of 542 species of plants in the past 30 years (i.e., 1971 to 2000; and Menzel *et al.*, 2006). In China, the number of bamboo trees—the panda's main diet—has drastically decreased, and the possibility of the extinction of wild pandas has become a major concern (Kim, 2012). In Africa, the Sahara Desert continues to

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expand southward, with 1.5 million hectares of land moving towards desertification per year (Darkoh, 1989). Economically weak and developing countries tend to suffer the most from the changing global environment, leaving them susceptible to food shortages and agricultural damage due to droughts, floods and other extreme conditions.

As one of the agricultural issues, the damage caused to palm trees in regions ranging from the Middle East to Northern Africa is well known. Healthy palm trees contain a large amount of water in order to survive in the dry desert environment. This abundant water supply, however, attracts the red palm weevil (i.e., *Rhynchophorusferrugineus)*, and when this pest infests the trees, it burrows in and begins depleting the water source and eating the tree from the inside out.

As a result, tree health weakens, the trees become dehydrated and finally die (Murphy and Briscoe, 1999; Faleiro, 2006; and Mozib and El-Shafie, 2013). This damage became a serious issue over a decade ago, and there are reports of heavy damage to the growth of date palm trees, which are a major form of agricultural income in the Middle East. Measures to save the agricultural product need to be introduced as soon as possible.

One means for preventing damage to agricultural products due to pest infestation is chemical spraying. However, this method has dangerous aspects, such as the physical influence of the chemicals on farm workers exposed to it and the possible health risks involved for those who consume the chemicals accidentally by, for example, insufficient cleansing of the item after harvesting. Unlike fruits such as bananas and oranges, which are eaten after peeling off a thick skin, in cases where the skin of the vegetable or fruit such as potatoes, grapes or datesis consumed, the use of chemicals for pest control should be avoided. Therefore, in order to halt the damage caused by insects, there is a need to devise a means of continuously monitoring vegetation in its natural growing environment. In the case of the date palm, the trees grow in vast desert fields, and it is difficult to carefully control the state and quality of each one. Therefore, a method capable of monitoring the state of these scattered trees and other agricultural products cultivated in vast fields is required. The authors therefore set out to prove that microwave-based remote sensing is a promising method for solving problems related to the aforementioned issue.

Various approaches have been introduced to detect and monitor changes in the global environment and the resulting damage to agriculture using microwaves. A few examples are monitoring precipitation and managing water resources (Messer and Sendik, 2015), measuring and monitoring soil moisture (Ulaby and Batlivala, 1976; and Vernieuwe *et al*., 2011), monitoring deforestation (Frolking *et al.*, 2012) and vegetation management such as desertification (Nicholson, 2001). However, the methods applied to dateare not ideal for the close-range remote sensing required for monitoring such things as changes in the surface and internal conditions of trees.

Synthetic Aperture Radar (SAR), which is commonly utilized for vegetation monitoring systems, has evolved rapidly in recent years owing to advancesin mobile phone technologies and the ongoing application of radar in the automobile industry and transportation infrastructure. One example is that small private enterprises can now obtain SAR equipment and components relatively easily and at lower cost. As a result, radarsystems that were applied in large-scale, high-cost programs utilizing satellites and large aircraft several years ago are becoming available for use in smaller, lower-budget projects.

Microwave backscatteringis known to be able to reveal various features of an object, including surface shape and internal structure. But the authors found literature regarding the use of microwave backscattering to determine the characteristics of tree trunks. It is assumed that this is partly due to the common practice of using unidirectional angle and single-point measurement procedures, which ends in poor results when conducting monitoring measurements at closer distances (e.g., several meters to hundreds of meters). For this study, the authors developedscatterometers capable of capturing tens-of-thousands of measurements in less than one minute and utilize it to measure the microwave backscattering from palm tree trunks irradiated with microwaves from all sides.

The tree species chosen as the object for measurement is the Sago palm (i.e., *Cycas Revoluta*), which is a tree found in Japan that is similar in structure to the date palm trees of the Middle East. Wanting to simulate the conditions of when a date palm tree is infested by the red palm weevil, for the experiment, the trunks of healthy Sago palm trees were harvested and truncated, and then subjected to microwave irradiation periodically for three months. The measurements of backscattered microwaves recorded over the experimental period were then analyzed to determine if changes in the tree trunks are detectable.

RELATED STUDIES

Generally, there are two methods for applying the use of microwaves to monitor vegetation: microwave transmissionwhere the radio waves permeate and travel through the plant and are received on the opposite side, and microwave backscattering where the microwaves are reflected off the surface of the plant and other internal matter capable of reflecting the microwaves. The former method has already been put to practical use; one example being moisture meters that measure internal moisture by applying the dielectric constant of matter in the plant and attenuation of the microwaves transmitted. This method is commercially applied in various ways; for example, controlling the quality of wood, fruits, grains, etc., since the moisture contained inside an object can be measured accurately. However, due to complicated installation requirements resulting from the configuration of the device used and other conditions required to conduct measurements, it is not suitable for use in the field.

The other method, using microwave backscattering, is utilized for the remotesensing and monitoring of vegetation and the environment via systems mounted in satellites or aircraft. These systems also have some fundamental issues that need to be resolved if devices utilizing similar technologies are to be applied on a smaller scale.

The first problem is that there is a substantialdistance between the sensors and the area/object being measured (e.g., tens to hundreds of miles). Therefore, the accuracy of the measurement information received for a specific object at such a distance becomes questionable (Ouma *et al.*, 2008). Additionally, system applications are limited; in particular, the distance between the sensor and the area/object being measured is fixed. Accordingly, the measurement area and time revisited cannot be changed freely (Tarchi *et al.*, 2003). Moreover, since measurements are conducted from above the object, an appropriate incident angle is essential for obtaining successful measurements (Ulaby, 1975). Finally, satellite and airborne radar systems generally measure large-scale areas, making it difficult to measure and monitor smaller-scale areas and distinguish between adjacent objects, such as two trees.

A number of methods can be utilized for analyzing measurement data, and various SAR algorithms have been applied in order to construct SAR images (Brown and Bennett, 1999; and Zhou *et al.*, 2004). RCS and backscattering coefficients can also be calculated when monitoring objects and measuring microwave reflection intensity, and these parameters contribute to determining the detectability of the object being measured (Mougin *et al.*, 1993; and Oh *et al.*, 2002). Ulaby and Dobson conducted extensive research of terrain applying microwave backscattering, collecting hundreds of thousands of data points derived from measurements by both airborne and ground-based scatterometer systems. Those data points were compiled into reference tables and a database, the latter which has commonly been referenced by other researchers. The information has been used as a standard not only for calibration accuracy and measurement accuracy, but also for detailed category identification. In addition, the measurement results have been analyzed using statistical methods and are considered to be a reliable information source, which has contributed to confirming the characteristics of objects such as rocky soil, vegetation, snow, ice, artifacts (city), etc., can be determined utilizing microwave backscattering. While many researchers assumed measurements in natural environments, there was no data found referencing experiments conducted in the laboratory (Ulaby and Dobson, 1989).

It is also known that radar backscattering has a variation factor called “fading.” Microwaves induce a fading affect as a result of complex reflections and repeated scattering due to the shape and size of, and various environmental factors around the object to be radiated. Therefore, it is known that it is difficult to unambiguously determine the reflection intensity. Furthermore, since fading changes greatly due to delicate differences such as antenna position and object position, complete reproduction of the measurement results is also difficult. In order to monitor changes inside an object based on backscattering, this fading fluctuation must either be eliminated or applied in calculations. In order to eliminate the influence of fading, all associated factors must be clarified. This is difficult in a natural environment outdoors where conditions are constantly changing. Therefore, the authors chose to include fading in their experimental analyses.

The goal of this study is to confirm whether or not changes that occur in tree trunks over a period of time due to some influence can be measured remotely using microwave backscattering. If it is proven that this is possible, the changing state of trees can be monitored remotely, doing sonon-invasively without causing physical damage or harm to the trees.

The remainder of this paper is organized as follows: The Materials and Methods section explains the objectives of the experiment, materials utilized, and experimental design and processes. The Results and Discussion section outlines the measurement results and discusses the experiment findings, and the Conclusions section offers the authors‘ conclusions and issues for future work.

MATERIALS AND METHODS

To confirm whether or not changes that occur in a tree trunk due to some influence can be measured remotely using microwave backscattering, it is necessary prepare a technique that enables the intensity of microwaves backscattered from an object to be measured. The specific requirements and measurement methods are described below.

First, it is necessary to set the frequency of the microwaves used. It is known that microwaves have different penetration depths depending on the wavelength of the wave irradiated. Longer wavelengths penetrate deeper, and there is a high possibility of detecting internal changes happening inside the tree trunk. For this reason, the L band microwave frequency is chosen. Additionally, shorter wavelengths, like X or Ku band microwaves, are suitable for capturing changes in shape at the surface. Each of these wavelengths is known to have intrinsic characteristics, and the three frequencies are the most commonly used bands in the remote-sensing field.

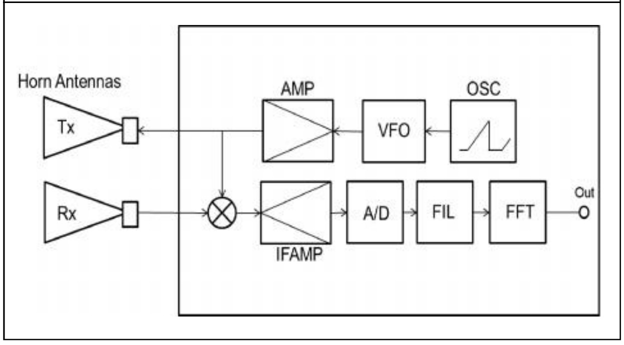
Next, in order to measure only backscattering from a specific object, it is necessary to minimize the reflection of radio waves from objects other than the one being measured. This is achieved by carrying out all measurements in an anechoic chamber. Moreover, by using the time domain method for measurements, it is possible to extract only the reflection intensity from a specific distance. For this experiment, measurements were taken carefully, ensuring that no radio waves other than those reflected from the object existed at equidistant positions between the antenna and the object in the anechoic chamber.

The last item to be considered is the issue of fading. The influence of fading always appears when taking measurements using microwaves. Multipath fading caused by the object being measured is caused by complicated microwave reflection and scattering due to the surface shape and/or internal structure. By analyzing the fading pattern, it is possible to observe changes in the object measured. Therefore, in this experiment, the multipath fading caused by the shape and internal structure of the object was measured by analyzing the measurement data of the entire circumference while rotating the object on a turntable. To enable this feature, the measuring apparatus used in this experiment must be able to measure backscattering continuously at a very high speed.

Three scatterometers, one each for the L, X and Ku bands, were specially made for this experiment. The devices designed—based on a FMCW microwave transmission/reception unit developed for airborne SAR—enable high-speed measurements to be carried out at close range. This makes it possible to measure objects that are at a distance of one meter to several kilometers away. Additionally, the minimum resolution range is 170 cm in the L band and that for the X and Ku bands is about 50 cm, thus making it possible to cover the measurement conditions required for this experiment. An illustration of the scatterometer configuration is shown in Figure 1.

One feature of the scatterometers developed is that they allow for time-domain measurement,

Figure 1: The Scatterometer Architecture Used



which is the method of transforming the frequency domain into time domain. This method is convenient for calculating the distance of the object being measured, and thus enables the tree position to be known. Another feature of the scatterometers is the use of Frequency-Modulated Continuous Wave (FMCW) transmission technology. This is useful in that it makes rapid and continuous measurement possible for objects in motion; a beneficial feature since the trunks measured in this experiment were placed on a rotating platform.In practical terms, the rapid measurement of objects while in motion is required since trees, while stationary, could be swaying due to the presence of wind and this could affect measurement accuracy. Other advantageous features of using a scatterometer for this experiment include low-power transmission/consumption, small weight and ease of portability. Low power consumption via a battery source will enable use of the scatterometers outdoors in future experiments. Small and lightweight equipment is useful for ease of mobility and contributes to affordable operating cost.

Table 1 provides a comparison of the characteristics for the scatterometers utilized and those of existing Vector Network Analyzers (VNAs), thereby clarifying the reason for using scatterometers rather than VNAs. As can be seen by the characteristics of the scatterometers, fast operation of 1,250 measurements per second is ideal for measuring objects in motion. Accordingly, the use of scatterometers may be viable for backscattering measurements in the field.

Table 1: Comparison Between Use of Scatterometer and Common VNA

	Scatterometer	VNA
Speed	800 microsec operation: 1,250 measurements per second Continuous measurement: Ideal for measurement when the object is in motion (for this experiment, rotation of the palm tree during measurement)	Operation: 0.1-1sec + processing time Stop-and-Go measurement: Time consuming to measure the object from different angles. Can't measure the object in motion. Object must be stationary for each measurement
Transmission technology	FMCW	STEP FM (Not suitable for radar)
Transmission power	100 mW	10 dBm = 10 mW
Frequency bands	Ku-band = 17 GHZ	Open
	X-band = 9 GHZ	
	L-band = 1.2 GHZ	
Bandwidth	Ku-band = 300 MHz	Based on antenna and measurement time
	X-band = 300 MHz	
	L-band = 85 MHz	

As shown in Figure 2, three scatterometers, each equipped with a different frequency band (L, X and Ku), were prepared for this experiment. As previously mentioned, the bands each unique characteristics and different penetration levels. Each scatterometer was connected to horn antennas designed to be polarized vertically VV and horizontally HH when rotated 90º, except for the Lband, for which only VV was used due to the limited size of the chamber and the large size of

Figure 2: The Scatterometer Systems: Top Left, Ku-Band System; Top Right, X-Band System; and Bottom, L-Band System

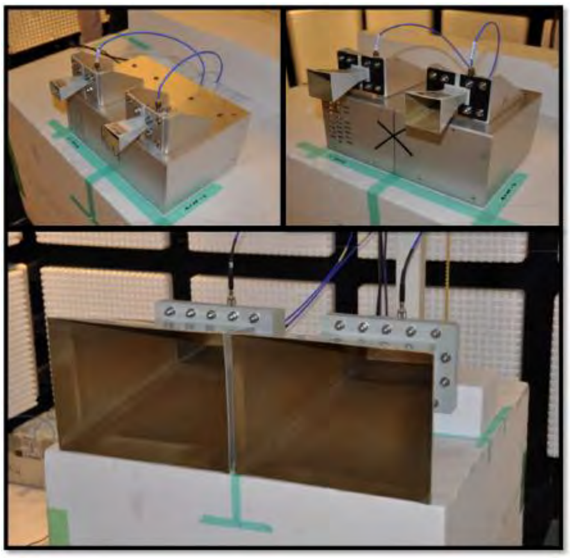


Table 2: The Specifications of the Horn Antennas Used

	L-Band	X-Band	Ku-Band
Size[mm] W×H	384×284	42×35	32×23
Antenna gain [dB]	14.52	11.29	14.62

Table 3: Palm Tree Trunk Weights on Dates Measured (Unit: kg)

Tree	Day			
	0	18	53	74
1	11.05	10.49	8.26	7.18
2	13.79	13.25	10.39	9.13
3	19.59	18.74	15.62	13.89
4	17.82	16.87	13.7	11.75
5	24.24	22.95	17.99	15.12
6	18.08	17.4	15.12	14.07
7	20.33	19.3	14.91	11.76
8	24.92	23.68	18.64	15.98
9	29.51	28.09	22.35	19.23
10	21.38	20.17	17.29	15.78

Table 4: Tree Trunk Measurements

Tree	Diameter (cm)	Length (cm)
1	0.18	0.485
2	0.2	0.59
3	0.18	0.645
4	0.195	0.58
5	0.195	0.755
6	0.185	0.61
7	0.2	0.675
8	0.22	0.655
9	0.23	0.72
10	0.205	0.635

the antennas. Table 2 lists the specifications of the horn antennas for all three of the frequency bands utilized in this experiment.

The trunks of Sago palm trees were chosen as the target. It is difficult to artificially introduce sudden changes in the state of a living tree, such as damage caused by pest infestation. Therefore, as a compelling measure to simulate such a state, the palm trees were truncated, thereby cutting off the ability of water to continue entering the tree via the root system. In addition, two holes were bored the length of the tree trunk from the center of the top to the center of the bottom, thereby promoting the drying process. Because each tree has its own characteristics (e.g., size, weight, humidity, etc.), a total of 10 tree trunks were prepared. The average characteristics of the sago palm and individual trees were compared. Furthermore, to measure changes occurring in the tree trunks, each tree trunk was weighed every few days and the weight was recorded. Table 3 shows the results of mass loss for each tree trunk over the period of the experiment. Additionally, at the time of preparing the tree trunks, the stem diameter and length of each tree trunk were measured, as shown in Table 4.

Experiment Design and Process

Ten Sago palm tree trunks were prepared, transforming them into testable trunks by removing stems, leaves and roots. In order to detect the variation in internal conditions of the trees trunks, three scatterometers equipped with different frequency bands (L, X and Ku) were used to irradiate the tree trunks and the microwave backscattering from each trunk was measured. The backscattering intensities from the tree trunks were each captured, recorded and analyzed for the purpose of determining changes in the characteristics of the surface and internal structure over a period of approximately three months.

Each palm tree trunk was set on a turntable and rotated a full 360º for a period of one minute during measurement. This enables the influence of fading to be taken into account by measuring microwave backscattering from the entire surface of the tree and conducting a statistical analysis of the results.

In order to determine the position of the tree trunk during each measurement, the scatterometers can measure backscattering applying the FMCW time domain measuring method. The bandwidths were set to 85 MHz for the L band and 300 MHz for each the X and Ku bands. Therefore, the range pixel size is 1.7 meters for the L band, and 0.5 meters for each the X and Ku bands.

The scatterometers were set for one measurement per 800 microseconds (μS). Since measurements were continuous, 1,250 data points per second were obtained. This enables the effects of measurement and noise to be investigated, and the variance and median of the data to be measured. Furthermore, this level of data collection contributes to ensuring the accuracy of measurement results.

As mentioned above, VV and HH polarization were also utilized. However, due to space limitations for antenna placement in the anechoic chamber, the large size of the Lband antennas made it impossible to use them in an ideal position for HH polarization. Placing them close to each other would cause antenna-to-antenna coupling and interfere with the measurement results. Thus, HH polarization for the L band was not conducted.

At the time of taking measurements, the scatterometer was connected to a laptop computer that controls scatterometer operation and records the data measured.

All of the measurements conducted were carried out in an anechoic chamber to prevent the interference of other microwaves/radio waves from the surrounding area. Figure 3 shows a configuration of the experimental setup inside of the anechoic chamber. The specifications of the anechoic chamber are provided in Table 5.

Each palm tree trunk was placed on the rotator platform located 2.9 meters in front of the

Figure 3: The Experiment Configuration

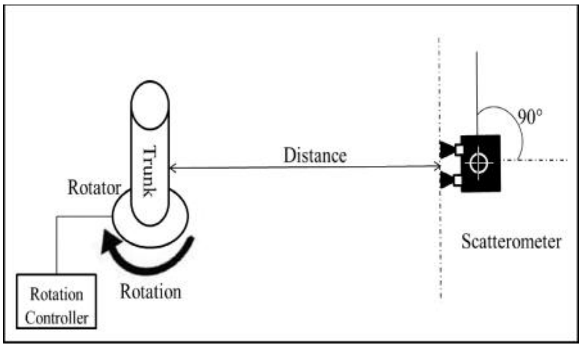


Table 5: The Anechoic Chamber Specifications

Manufacturer	**TDK-EPC Co., Ltd.**
Model	DA15133
Available frequency	150 KHz - 12 GHz
Diameter (meters)	5(L) × 3(W) × 1.9(H)

scatterometer horn antennas. During measurement, the trunk was rotated 360º in 60 seconds to obtain measurements for the entire surface of the tree trunk and collect data from all angles. In order to be able to measure the direct reflection, the antennas were set at an off-nadir angle of 90º.

Measurements

To begin the experiment, the three scatterometers were calibrated using a trihedral corner reflector with a surface area of 0.1 meters. After that, palm tree trunks were placed on the rotator one at a time and measured separately using each frequency band and both polarizations, except for L-band HH polarization. During measurements, the raw data measured was recorded and collected using custom-made software. It was then processed to determine the received power S_R, which was later used to calculate the RCS for each palm tree trunk.

The objective throughout the experiment was to obtain the RCS values for each palm tree trunk at different times and determine the conditions of the tree trunks based on those values. To achieve this, as stated above, the three scatterometer systems were calibrated before starting the experiment and the calibration values obtained were used as reference data when calculating the RCS.

The following equation was used to calculate the RCS:

$$RCS = \frac{S_R(4\pi)^3 R^4}{A.\, G_t.\, G_R.\, \lambda^2}$$

where, S_R is the received power, *A* is the receiver gain, *G* is the antenna gain, *R* is the distance between the antenna and the target, and ^{a} is the wavelength of the radar.

Data Processing

All three scatterometers were set for a backscatter sweep of 800 microseconds (µS) to measure distance, and bandwidths were set to 300 MHz for the X and Ku bands and 85 MHz for the L-band. Therefore, during a 60-second rotation, approximately 75,000 data points were recorded per pixel range. Additionally, the data received underwent specific processing until the final data was plotted.

First, the data received (i.e., reflection intensity from the object) is transformed from time scale to distance scale using Fast Fourier Transform (FFT). Next, the palm tree trunk's position is determined based on the distance between the antenna and the target. This distance (in meters) was measured manually in the chamber prior to the experiment. The position of the tree trunk in the data is displayed in pixels, with the pixel range being 1.7 meters for the L-band, and 0.5 meters for each the Ku and X bands.

Next, the intensity of the microwaves reflected is calculated. The data received are very complex numbers, totaling the summation of the microwaves reflected from every point on the object. The sum of the intensities from each palm tree trunk at specific angles is determined by calculating the absolute value of the amplitude. The data measured is then converted into RCS values using the reference data obtained from the corner reflector during scatterometer calibration. Finally, the RCS values calculated are plotted to display the distribution of values and the changes in the conditions of each palm tree trunk on the various experiment dates are compared.

A total of 75,000 data points (RCS values) were generated and recorded. If only the average of the RCS value is calculated during rotation, it may not be possible to clearly observe and account for meaningful differences in the values measured. Therefore, to prove the validity of the data, the RCS value distribution of measurements, not the average RCS value, is plotted for this experiment.

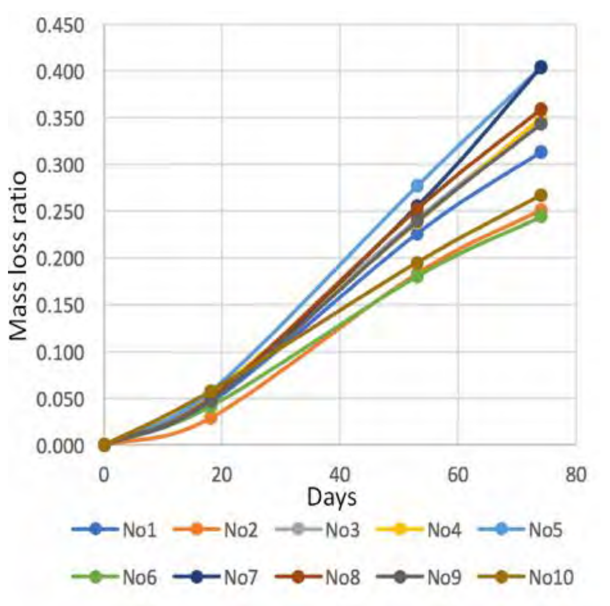
RESULTS AND DISCUSSION

Due to the similarity of the results for VV and HH polarizations, only VV polarization graphs are used. Additionally, it should be noted that failed measurement attempts were experienced for the first three palm tree trunks (i.e., 1, 2 and 3) using the Ku-band scatterometer on day 53 and for all of the palm tree trunks using the Ku-band on day 74. In addition to histograms, RCS maximum (max), mean (mean) and minimum (min) values are used to show the distribution of RCS values.

Figure 4 shows the results of plotting the number of days on the horizontal axis and the change of the mass for each palm tree trunk on the vertical axis. According to the results, although there are some differences in each data, mass loss was almost linear for all tree trunks. Although there is a difference in reduction rate, considering the difference in volume and mass, the loss is almost the same for each trunk.

The values obtained reveal smaller mass, and this is believed to be related various factors such as loss of moisture. In the graph shown here, it can be seen that the mass of each palm tree trunk decreased almost linearly during the three months after the trees were cut.

Figure 4: The Mass Loss for the Palm Trees During the Experiment Period



Evaluation Conditions

The following issues were considered when evaluating the measurements:

1. All of the measurement data was converted into RCS values and the results were displayed in a linear-scale graph. As comparing the results of each measurement is a vital component of the experiment, all measurement results were converted into RCS values. Generally, radio-wave measurements are displayed logarithmically; however, in this study the memory is displayed utilizing linear-scale order for the purpose of comparing shapes using a histogram.
2. In order to obtain the most accurate measurement results possible, the decision was made to make evaluations utilizing maximum value (max), minimum value (min)

and mean value (mean), and a histogram of the results measured using the entire surface of each tree trunk. When conducting radio-wave measurements, depending on the positional relationship between the object being measured and the measuring device/antenna, it is possible that measurement results can fluctuate due to the influence of fading. The authors utilized a method to suppress the influence of fading, doing so by collecting a large amount of data through rotating each object 360º and analyzing the results applying dispersion.

3. Measurements were conducted four different times over a 74-day period. The first set of measurements was conducted on the first day, the second set on the18th day, the third set on the 53rd day, and fourth and final set on the 74th day. The same procedure was followed for each set of measurements. In order to simulate a natural setting as much as possible at the time of measurement, the tree trunks were stored in a well-ventilated dark place with stable temperature and humidity. Since it was expected that a period of time between measurements would be required to allow the moisture content to fall based on natural evaporation, measurements were conducted at intervals of two to five weeks.

Exclusion of Inconclusive Measurement Data

The graphs of each band plotting the change in maximum, mean and minimum values of RCS for the ten tree trunks are shown in Figure 5. The measurement dates are plotted on the horizontal axis. Based on the results plotted in the graph, the L-band measurementsshow a tendency among the results. Looking at tree trunks No. 1 and No. 6, the RCS values are slightly lower than the others. In considering the possible reasons for this, it is thought that a shorter and/or thinner physical size result in a generally smaller projected area.Tree trunk No. 1 is visibly thinner and shorter than the other tree trunks, and it is therefore understandable that the RCS values measured are smaller. However, regarding tree trunk No. 6, although the RCS values measured were small on average, there is little difference in size compared to the other trees. Accordingly, the reason for the smaller values is unknown. As the measurement values for tree trunks No. 1 and No. 6 showed a different tendency in the graph plotting RCS and elapsed days, they are excluded from further discussion.

Comparison of Measurement Results Over Experimental Period

As seen in Figure 5 (D – I), regarding the measurement results for the X and Ku bands, all measurements were distinctively well separated and it is difficult to depict a trend. Fig. 5 (A – C) shows the results for Lband irradiation. From this, except for tree trunks No. 1 and No. 6, the maximum value is relatively the same, the minimum value decreases, and the median value decreases slightly. Even when plotted in a graph showing the measurement results, the amplitude of the tree trunk measurements plotted in the graph increases downward over time. It is therefore clear that there is a relationship between the passage of time and the lower minimum value. Additionally, as previously discussed, the internal change caused by moisture loss and other factors confirmed through monitoring the change in the mass of the palm tree trunks. Based on these two factors, it was found that there is a relationship for Lband measurement results: “the backscattering minimum value decreases over time” as the tree trunk loses its mass.

Figure 5: The RCS Max, Mean and Min Values for the 10 Palm Tree Trunks Irradiated Utilizing Three Frequency Bands at Separate Times

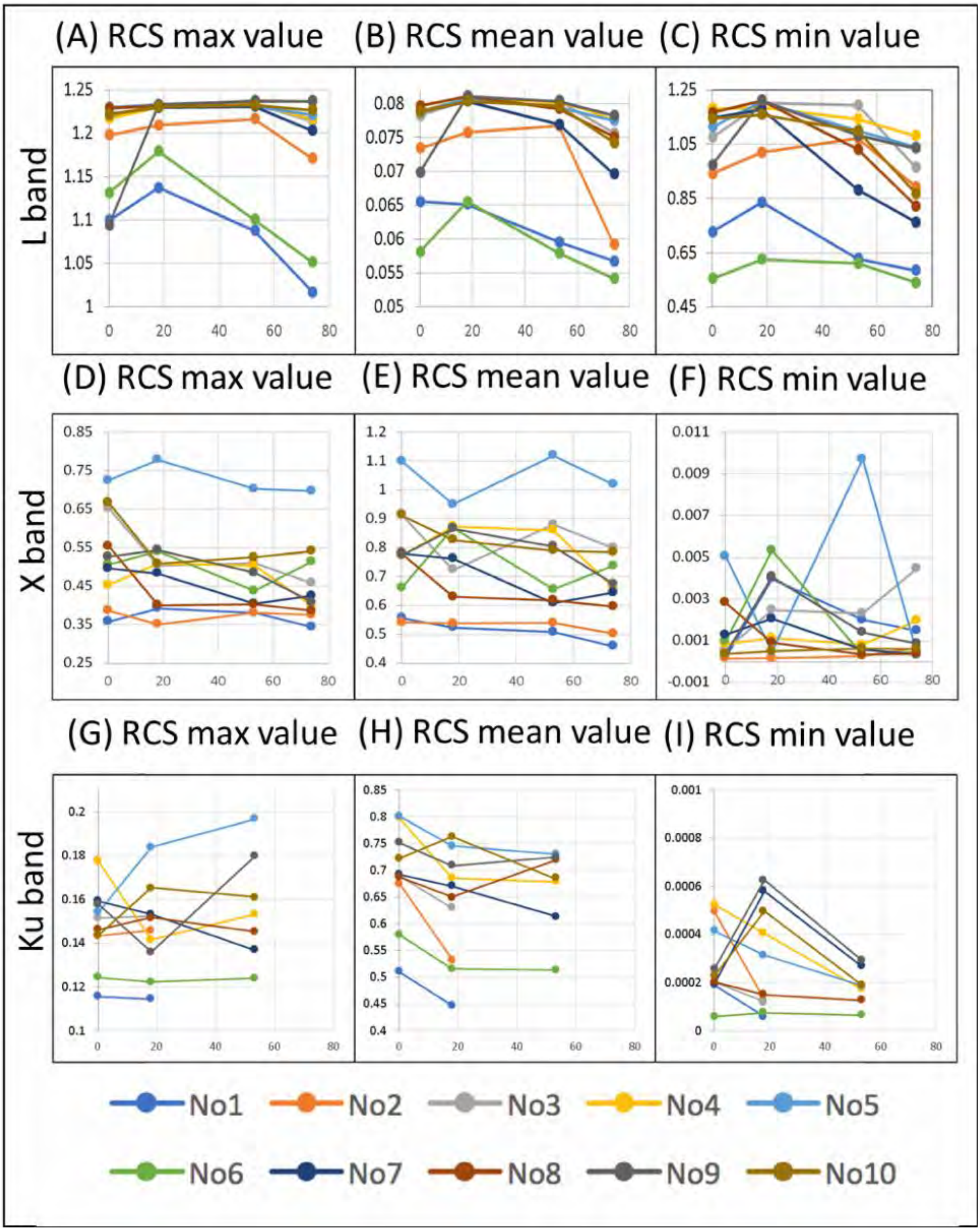


Figure 6: Fading Variation and Pattern for Tree 7 L Band During a 360° Rotation

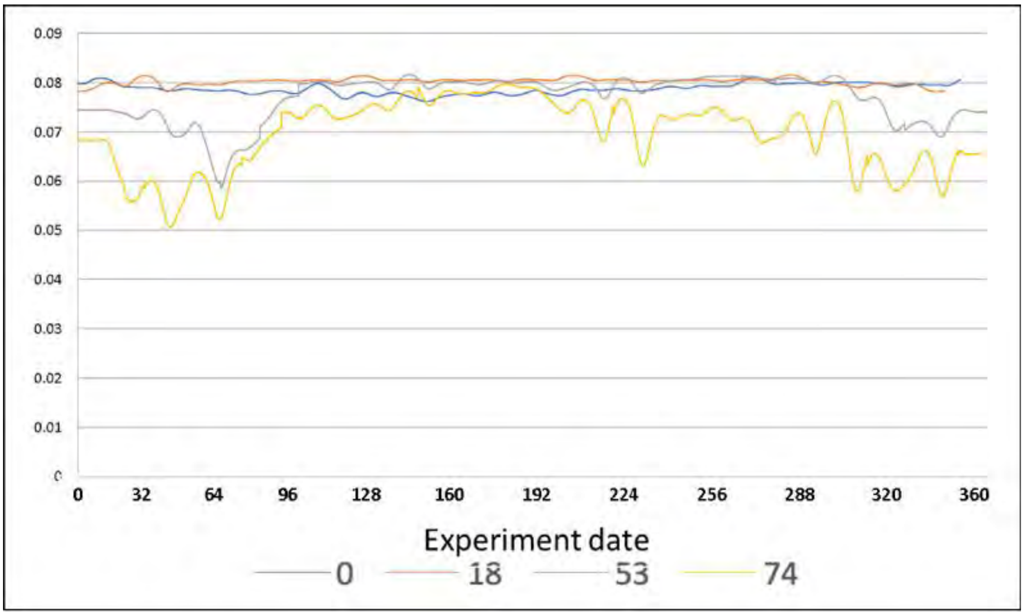
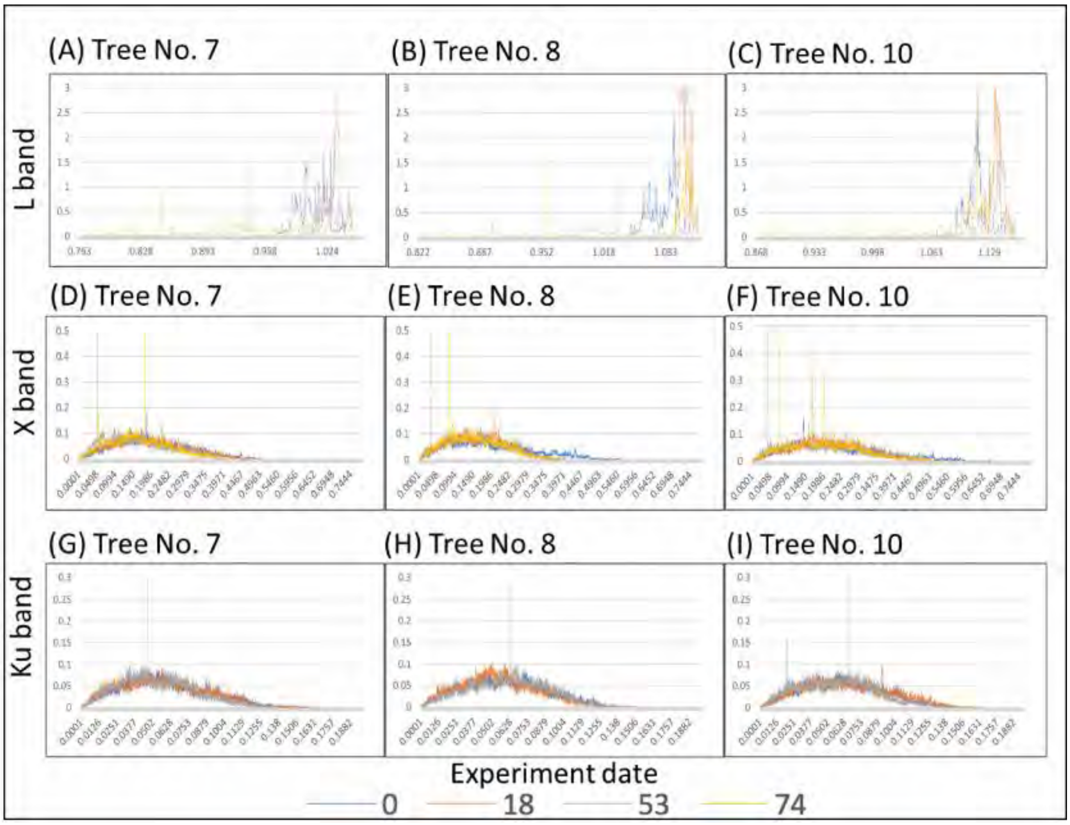


Figure 7: The Histograms of Tree Trunk Nos. 7, 8 and 10 for the L, X and Ku Bands



The reason for this phenomenon is that the mass loss in the various palm tree trunks does not occur equilaterally among all trees; some trees may lose mass easily and others may retain it for a longer period of time. This results in unequal mass loss inside the palm tree trunks, which causes multipath fading and is possibly due to changes in fading variation and pattern as shown in Figure 6. Other reasons could be the biological changes that occur inside the palm tree trunks after they have been cut down, such as the destruction of tree cells and infection by bacteria or decay.

Histogram Observation

In order to better clarify the results, the measurement results of each band are presented in histograms. Figure 7 shows the histograms of palm tree trunks Nos. 7, 8 and 10 for the L, X and Ku bands. From these results, almost no change in the histograms for the X and Ku bands can be seen over time in Figure 7 (D – I). A Gaussian distribution or Rayleigh distribution are always apparent; however, only the L band shows a distinctive shape for all measurement results, where it can be seen that lower scattering increases as time passes. This Lband characteristic was also observed for the other palm tree trunks, and similar results are provided in Figure 7 (A, B and C).

CONCLUSION

Through the experiment conducted and analysis of the resulting measurements, it was found that for the X and Ku bands, it is difficult to determine change in the internal structure of palm tree trunks over the passage of time. Based on the characteristic measurement results using short-wavelength microwaves such as the X and Ku bands, in terms of scattering properties of the tree trunk surfaces, the conclusion is that the Sago palm tree is covered by a thick (hard bark) epidermis.

The results of the Lband measurements suggest interesting possibilities. Irradiating microwaves in the Lband or lower frequencies, it was shown that changeinside an object, even a thick-barked tree like the Sago palm tree used in this experiment, can be determined. In particular, it is expected that a method for recognizing a pattern, or patterns, rather than just a numerical value using histograms may be practical. This will become more viable as advancements are made in the rapidly developing area of pattern recognition technology.

The objective of the experiment in this study was to measure the state of change in trees using only microwave backscattering. This was achieved by showing the relationship between the direct microwave backscattering results obtained utilizing the Lband frequency and the loss of mass in the palm tree trunks measured. This relation is assumed to be a characteristic effect of microwaves.

However, the reason for why the change in multipath fading occurred is only an assumption. In the graphs plotted using number of days elapsed and median values (Figure 5), there are many instances showing a sudden change in the latter half of the measurements taken. This may be related to some change other moisture loss; for example, destruction of tree cells, decay, etc. In a future study, it is necessary to clarify this issue by increasing the accuracy of the measurements taken.

Additionally, this was the first attempt at displaying a large amount of data utilizing multipath fading in a histogram. Therefore, it may be possible to determine the internal structure tree trunks in detail by improving the pattern analysis method. For future research, it is desirable to investigate new methods of analysis.

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