Discrimination Method between Prolate and Oblate Shapes of Leaves Based on Polarization Characteristics Measured with Polarization Film Attached Cameras

Kohei Arai [1]
Graduate School of Science and Engineering
Saga University
Saga City, Japan

***Abstract*—Method for discrimination between prolate and oblate shapes of leaves based on polarization characteristics is proposed Method for investigation of polarization characteristics of leaves by means of Monte Carlo Ray Tracing: MCRT is also proposed. Validity of the proposed discrimination method is confirmed with MCRT simulations. Also field experiments are conducted. Through field experiments at the tea estates situated in Saga prefecture, a validity of the proposed method is confirmed. Also discrimination between prolate and oblate shapes of leaves is attempted. The results show that the proposed method is valid and discrimination can be performed.**

***Keywords*—polarization; Monte Carlo Ray Tracing; prolate and oblate shapes of leaves**

I. INTRODUCTION

Plant identification is very complex and required an appropriate background with significant experience. Also the number of researchers who can identify medicinal plants is very limited. Generally, identification process of medicinal plants has been done manually by a herbarium taxonomist using guidebook of taxonomy/dendrology. The proposed method is designed to help taxonomist to identify leaf medicinal plant automatically using a computer aided system.

In particular, it would be better to identify leaves by using airborne based radiometer data Although spectral reflectance can be estimated with the radiometer data, it is difficult to identify the leaves in concern by using only the spectral reflectance. The method proposed here is to use spectral polarization camera or radiometer. It is obvious that polarization characteristics are different between needle leaves and broad leaves [1]-[10]. Therefore, it may be possible to identify the leaves in concern based on the polarization characteristics.

There is another strong demand to discriminate between vertically standing leaves and horizontally laying leaves. For instance, new borne and young leaves are vertically standing leaves while elder leaves are horizontally laying leaves. In order to determine the most appropriate harvesting timing for tealeaves, such the discrimination is needed. Spectral characteristics between both young and elderly tealeaves are not so easy to discriminate. Obviously, although Bi-Directional Reflectance Distribution Function: BRDF are different between young and elderly tealeaves [5], it does costly for measurement. Therefore, the proposed discrimination method with polarization characteristics measurements is useful. It is effective and relatively easy as well as comparatively cheap. Only instrument required for this is cheap camera with polarization film.

As the first step, the method which allows discriminate needle leaves and broad leaves is proposed. The proposed method is also possible to distinguish between prolate and oblate shapes of leaves even if the size and scale of the leaves in concern are same.

The following section describes the proposed method and system including basic concept of the proposed method, scientific background together with Monte Carlo Ray Tracing: MCRT simulation method for validation of the proposed method [2],[7],[9]. Then simulation results and field experiment results are described followed by conclusion with some discussions.

II. PROPOSED METHOD AND SYSTEM

A. Proposed System

Only thing required for the proposed system is polarization film attached camera. Major specification of the camera Cannon S-100 used for the experiment is shown in Table 1.

TABLE I. MAJOR SPECIFICATION OF S-100

Resolution	13.3million
Detector	CMOS
F_No.	2-5.9
Shutter_Speed	1-1/2000
Sensitivity	ISO80-6400
Focal_Length	30mm

At the optical entrance of the camera, polarization film has to be attached. The camera has to be set-up at the relatively high pole or tower. Most of farm areas have lighting poles or fan attached tower for air convections for avoidance from the frosting damage. In particular, tea farm areas have fan attached poles with electricity supply. Therefore, the camera can be amounted on at a high position. The recommendable observation angle is 55 degrees. Tealeaves surface is used to be covered with oily materials and water. In order to acquire their polarization characteristics, Brewstar angle between air and water or oily materials (55 degrees) is recommendable. Camera acquired data can be transferred through WiFi or wireless LAN communication links. Figure 1 shows the proposed system.

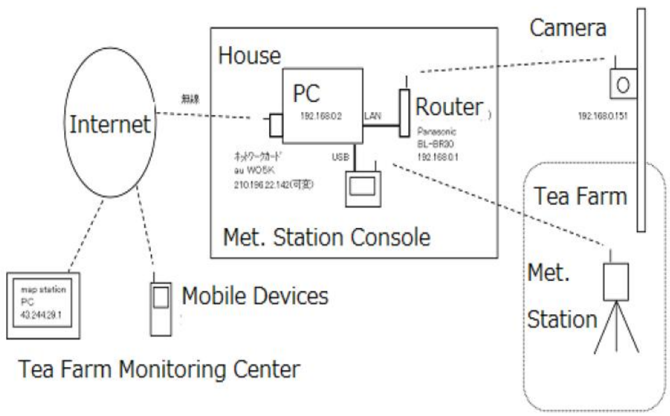


Fig. 1. Proposed system with polarization film attached camera mounted on the relatively high position which allows look down the farm area with 55 degree of Brewstar angle.

Proposed system consists of the polarization film attached camera mounted on the relatively high position which allows look down the farm area with 55 degree of Brewstar angle and meteorological station. Camera data and meteorological data are gathered through WiFi or wireless LAN communication links at farmers' houses and the farm area monitoring center through Internet

B. Process Flow

The proposed method in this paper uses polarization radiometer data of leaves in concern which is acquired with airborne based polarization radiometer. p and s polarization of reflectance of the leaves in concern is observed. Then Degree of Polarization: DP which is represented as equation (1) is calculated.

$$DP=(Rp-Rs)/(Rp+Rs) \quad (1)$$

where Rp and Rs denote surface reflectance for p polarization and that for s polarization, respectively. DP depends on the shape of leaves in concern obviously.

Therefore, discrimination between prolate and oblate shapes of leaves as well as distinguishes between needle leaf and broad leaf becomes available results in identification of medicinal leaves. In order to validate the proposed method, simulation study with Monte Carlo Ray Tracing model is conducted together with field experiments.

C. Monte CarloRay Tracing Simulation

In order to validate the proposed method, MCRT simulation study and field experimental study is conducted. MCRT allows simulation of polarization characteristics of sea surface with designated parameters of the atmospheric conditions and sea surface and sea water conditions. Illustrative view of MCRT is shown in Figure 2. Photon from the sun is input from the top of the atmosphere (the top of the simulation cell). Travel length of the photon is calculated with optical depth of the atmospheric molecule and that of aerosol. There are two components in the atmosphere; molecule and aerosol particles while three are also two components, water and particles; suspended solid and phytoplankton in the ocean. When the photon meets molecule or aerosol (the meeting probability with molecule and aerosol depends on their optical depth), then the photon scattered in accordance with scattering properties of molecule and aerosol.

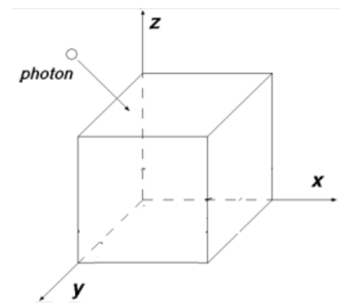
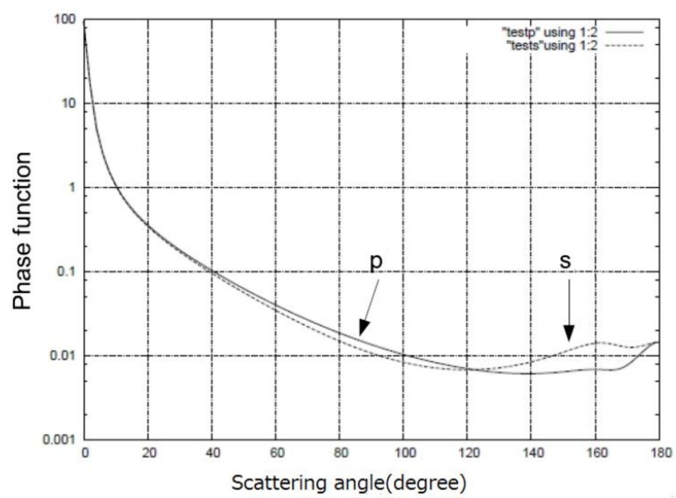


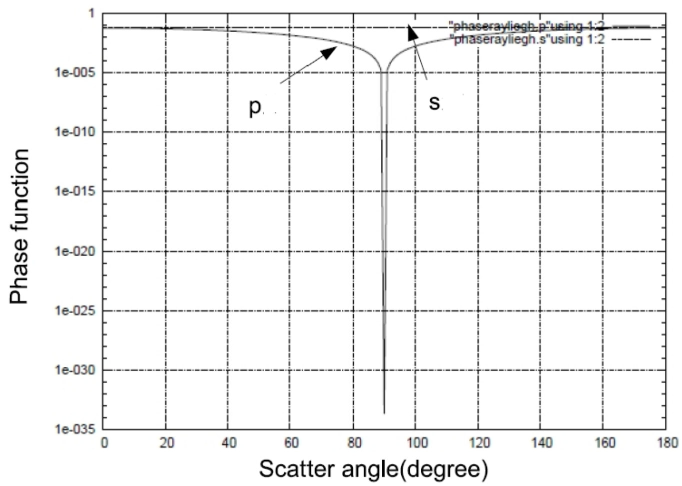
Fig. 2. Illustrative view of MCRT for the atmosphere and sea water

The scattering property is called as phase function[1]. In the visible to near infrared wavelength region, the scattering by molecule is followed by Rayleigh scattering law [11] while that by aerosol is followed by Mie scattering law [11]. Example of phase function of Mie scattering is shown in Figure 3 (a) while that of Rayleigh scattering is shown in Figure 3 (b).



(a)Mie scattering (aerosol)

[1] http://ejje.weblio.jp/content/phase+function



(b)Rayleigh scattering (Molecule)

Fig. 3. Phase functions for Mie and Rayleigh scattering

In the atmosphere, there are absorption due to water vapor, ozone and aerosols together with scattering due to the atmospheric molecules, aerosols. Atmospheric Optical Depth: AOD (optical thickness) in total, Optical Depth: OD due to water vapor (H2O), ozone (O3), molecules (MOL), aerosols (AER), and real observed OD (OBS) are plotted in Figure 4 as an example.

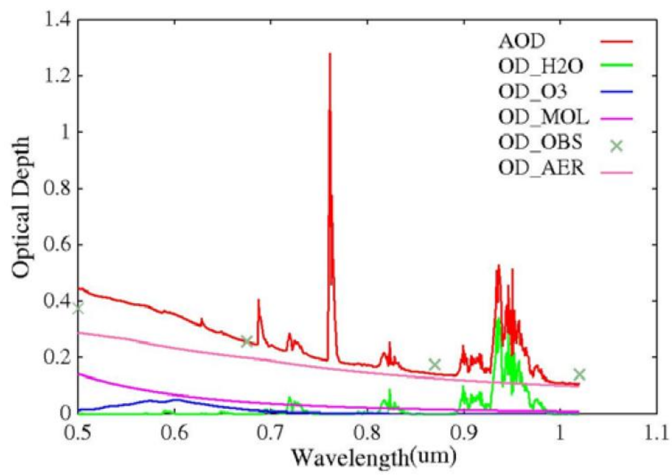


Fig. 4. Example of observed atmospheric optical depth in total and the best fit curves of optical depth due to water vapor, ozone, molecules, and aerosols calculated with MODTRAN of atmospheric radiative transfer software code..

For simplifying the calculations of the atmospheric influences, it is assumed that the atmosphere containing only molecules and aerosols. As shown in Figure 4, this assumption is not so bad. Thus the travel length of the photon at once, L is expressed with equation (2).

$$L=L0\ \mathrm{RND}(i) \quad (2)$$

$$L0=Zmax/\tau \quad (3)$$

where $Zmax$, τ, RND(i) are maximum length, altitude of the atmosphere, optical depth, and i-th random number, respectively. In this equation, τ is optical depth of molecule or aerosol. The photon meets molecule when the random number is greater than τ. Meanwhile, if the random number is less than τ, then the photon meats aerosol. The photon is scattered at the molecule or aerosol to the direction which is determined with the aforementioned phase function and with the rest of the travel length of the photon.

D. Ground Surface with Slopes

When the photon reaches on the ground, the photon reflects at the ground surface to the direction which is determined by random number. Lambertian surface [11] is assumed. Therefore, reflectance is constant for all the directions (from all the aspects). The reflected photon travels with the rest of travel length. Flat Lambertian surfaces are assumed.

E. Top of the Atmosphere: TOA Radiance Calculation

If the photon reaches on the wall of the simulation cell, the photon disappears at the wall and it appears from the corresponding position on the opposite side wall. Then it travels with the rest of travel length. Eventually, the photons which are reached at the top of the atmosphere are gathered with the Instantaneous Field of View: IFOV of the Visible to Near Infrared Radiometer: VNIR onboard satellite. At sensor radiance, I+ with direction and IFOV of μ, $\mu 0$ can be calculated with equation (4)

$$I+(\mu, \mu 0)=I\ N+(\mu, \mu 0)/Ntotal \quad (4)$$

where $N+$ is the number of photons which are gathered by VNIR, $Ntotal$ denotes the number of photons input to the simulation cell. Also I denotes extraterrestrial irradiance at the top of the atmosphere.

F. Leaf Surface Model

Prolate and oblate shapes of leaf surface models are created as shown in Figure 5.

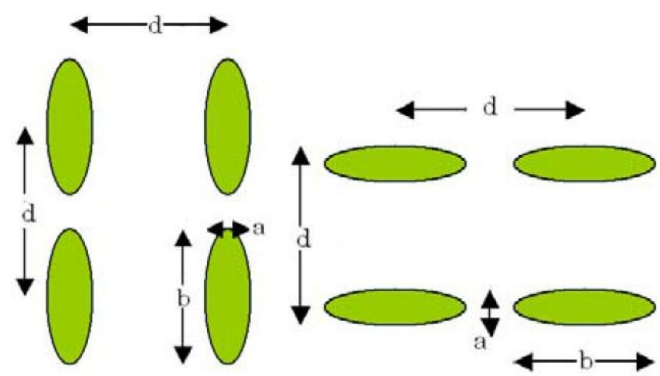


Fig. 5. Prolate and oblate shapes of leaf surface models

These leaves are aligned with d of interval. New borne and young tealeaves are vertically standing leaves while elder tealeaves are horizontally laying leaves. Prolate leaves are assumed to be new borne and relatively young tealeaves while oblate leaves are also assumed to be comparatively well grown elderly tealeaves. The surfaces of the prolate and oblate leaves are modeled with Lambertian surface. The reflectance of the leaves is determined by empirical models. In order to determine the most appropriate harvesting timing for tealeaves, such the discrimination is needed.

III. SIMULATION AND EXPERIMENTAL RESULTS

A. Simulation Results with MCRT

MCRT based simulation is conducted for p and s polarizations individually. The sizes of prolate and oblate shapes of tealeaves are ranged from 5 cm to 20 cm with 5 cm step. 10 million of photons are input to the atmosphere with optical depth of 0.15 for aerosols and 0.3 for atmospheric molecules at the wavelength of 500 nm as well as 0.2 for atmospheric molecules and 0.02 for aerosols at the 730 nm. The reflectance of the tealeaves are set at 0.215 for p polarization and 0.46 for s polarization in the case of oblate shape while 0.22 for p polarization and 0.21 for s polarization in the case of prolate shape), respectively. The reflectance is provided by Grant, L. (Polarized and non-polarized components of leaf reflectance, Doctoral Dissertation, Purdue University, 1985).

Figure 6 shows the number of photons reached at the top of the atmosphere at the wavelength of 730 nm.

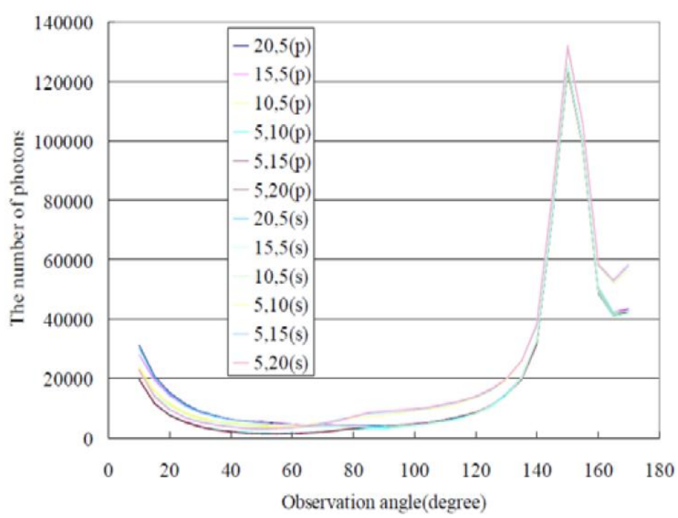


Fig. 6. Example of MCRT simulation results of the number of photons reached at the top of the atmosphere at the wavelength of 730 nm.

Although it is not clear the differences, DP which is shown in Figure 7 shows clear difference between prolate and oblate shapes of tealeaves.

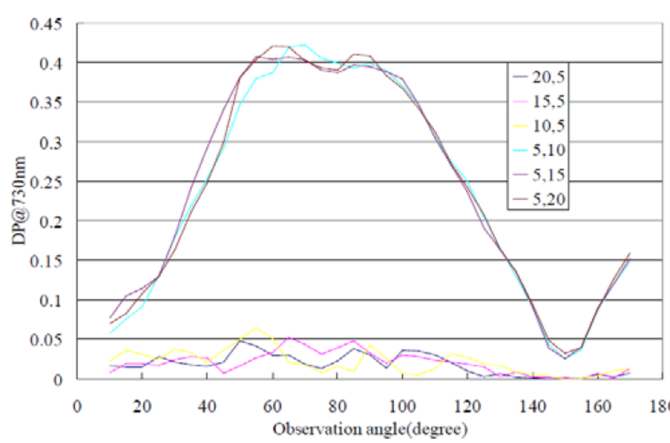


Fig. 7. DP calculated for prolate and oblate shapes of tealeaves at 730 nm

Meanwhile, the reflectance of the tealeaves is 0.1 for p polarization and 0.5 for s polarization for prolate shape while 0.08 for p polarization and 0.21 for s polarization for oblate shape at the wavelength of 550 nm, respectively. MCRT results for 550 nm which is shown in Figure 8 shows almost twice much DP in comparison to those for 730 nm.

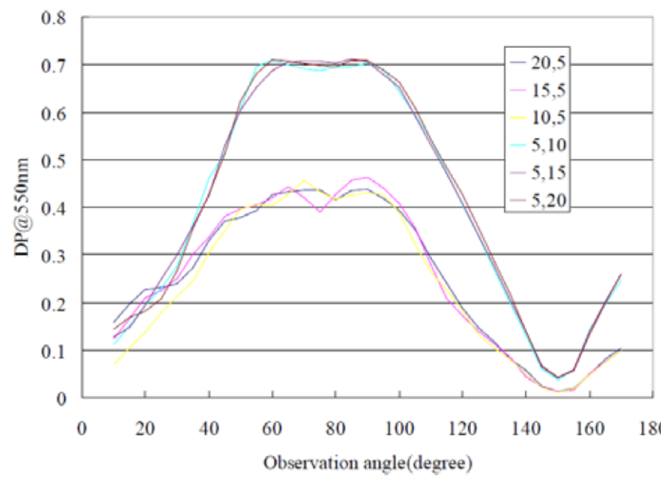


Fig. 8. DP calculated for prolate and oblate shapes of tealeaves at 550 nm

It is clearly found that the calculated DPs for prolate and oblate shapes of tealeaves are quite different. Approximately twice much DP is shown for prolate shape of tealeaves in comparison to the DP for oblate shape of tealeaves. Therefore, it is possible to discriminate between prolate and oblate shapes of tealeaves.

B. Experimental Results at Saga Prefectural Tea Institute

Field experiments are conducted at the Saga Prefectural Tea Institute: SPTI situated at 33:07:03.9 N, 129:59:47.0 E on June 1 2008. The first harvesting is finished in the begging of May. After the harvesting of tealeaves, the top tea trees are used to be cut out. Then new tealeaves appear after that. June 1 is middle moment between the first and the second harvests. There are four tea farm areas which are situated North, East, South, and West sides of the SPTI main building as shown in Figure 9.

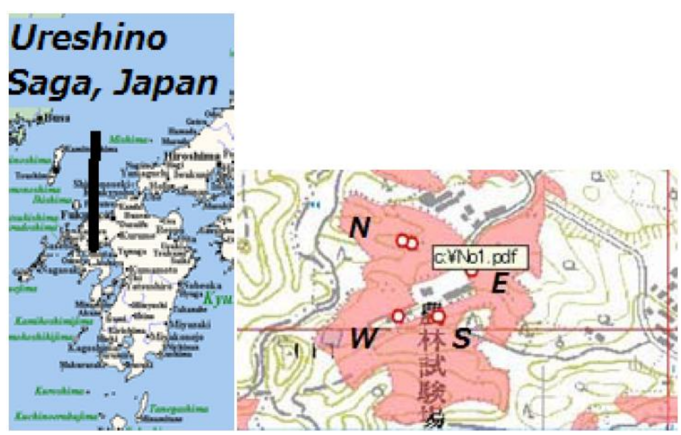
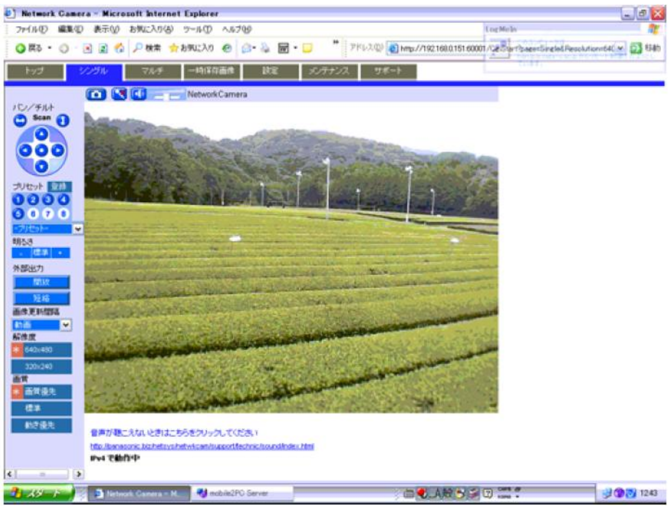


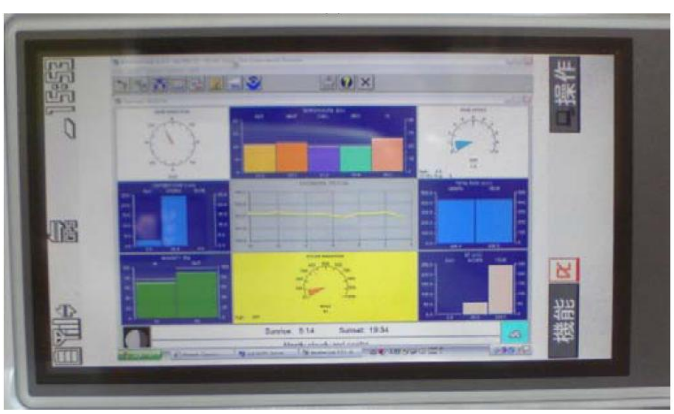
Fig. 9. Tea farm areas in concern situated at SPTI 33:07:03.9 N, 129:59:47.0 E

Figure 10 (a) shows an example of camera monitor images of north tea farm area of SPTI acquired with the proposed tea farm area monitoring system. There are fan mounted poles as shown in Figure 10 (a). The polarization film attached camera is attached to the fan pole. Figure 10 (b) also shows same example image displayed onto mobile phone. Therefore, tea farmers can take a look at their farm area with their mobile phone. Figure 10 (c) shows an example of meteorological data displayed onto mobile phone as well.



(a)

(b)



(c)

Fig. 10. Examples of photos of the tea farm area of SPTI and meteorological data which area situated at just beside the tea farm areas

Figure 11 shows top view of the tealeaves at the four different tea farm areas together with the grass situated at just beside of east tea farm area. Although it is hard to distinguish among these visually, reflectance in near infrared wavelength region of tealeaves is different each other as shown in Figure 12. Figure 12 also shows not only spectral reflectance but also calculated spectral DP. In this case, spectral DP is measured with spectral radiometer of MS-720 manufactured by Eiko Co. Ltd, Japan. Major specification of MS-720 is shown in Table 2.

TABLE II. MAJOR SPECIFICATION OF MS-720

Wavelength_coverage	350 ~ 1,050nm
Wavelength_Interval	3.3nm
Wavelength_Resolution	10nm
Wavelength_accuracy	Less_than_0.3nm
Aperture_angle	180°
Stray_light	Less_than_0.15%
Temperature_dependency	±5%


(a)East(Yabukita) (b)South(Ohiwase)


(c)West(Benifuki) (d)North(Yabukita)

(e)Grass in East Tea Farm Area

Fig. 11. Top views of tealeaves of the tea farm areas of SPTI. Bracket indicates species of the tealeaves

Only the reflectance of the leaves at the wavelength of 550 and 730 nm are given by Grant. Although the reflectance at are similar.

Figure 12 Measured spectral reflectance and DP at tea farm areas which are situated at north, east, south and west tea farm areas of SPTI. Much appropriate wavelengths for discrimination of prolate and oblate shapes of tealeaves are

500 nm, 675 nm and 800 nm as shown in Table 3. As shown in Table 3, DP of the grass is always small in comparison to the others. On the other hand, DP of the tealeaves at north tea farm area and that at east tea farm area shows specific features.

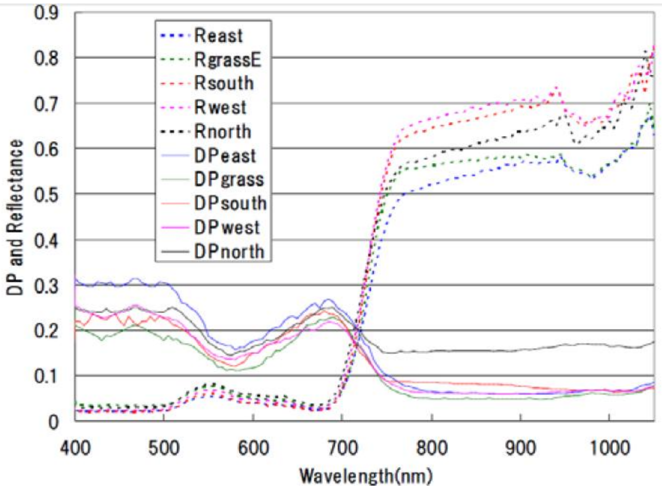


Fig. 12. Measured spectral reflectance and DP at tea farm areas which are situated at north, east, south and west tea farm areas of SPTI

TABLE III. DP CALCULATED WITH MEASURED SPECTRAL P AND S POLARIZED REFLECTANCE AT EAST,WEST, SOUTH AND NORTH TEA FARM AREAS AS WELL ASGGRASS SITUATED JUST BESIDE THE EAST TEA FARM AREA ON JUNE 1 2008

Wavelength(nm)	East	West	South	North	Grass
500	0.3	0.23	0.23	0.24	0.19
675	0.288	0.286	0.218	0.288	0.18
800	0.08	0.09	0.09	0.16	0.05

Namely, DP of the tealeaves at east tea farm area is quite large in comparison to the others while DP of the tealeaves at north tea farm area shows also remarkably large comparing to the others. Sizes and shapes as well as grow up rates of tealeaves are different from each other species, obviously. Both species of east and north tea farm areas are same, Yabukita. In the begging of July, just two weeks later of field experiments, the second tealeaves harvest is conducted. Best harvesting time periods are different by species by species, farm area by farm area. Measured DP would be useful to determine best harvesting time period.

IV. CONCLUSION

Method for discrimination between prolate and oblate shapes of leaves based on polarization characteristics is proposed Method for investigation of polarization characteristics of leaves by means of Monte Carlo Ray Tracing: MCRT is also proposed. Validity of the proposed discrimination method is confirmed with MCRT simulations. Also field experiments are conducted. Through field experiments at the tea estates situated in Saga prefecture, a validity of the proposed method is confirmed. Also discrimination between prolate and oblate shapes of leaves is attempted. The results show that the proposed method is valid and discrimination can be performed. As the results from simulation study and field experiments, it is found that the proposed method is useful for tealeaves harvesting time period. It also can be used validated. The proposed tea farm area monitoring system does works well. Tea farmers may take a look at their farm area with their mobile phone together with meteorological data.

ACKNOWLEDGMENT

The author would like to thank Dr. Hideo Miyazaki and Mr. Masayuki Akaishi of SPTI and Ms. Long Li Li for their effort to conduct field experiments

REFERENCES

[1] Kohei Arai, Y.Iisaka and X.Linag, Aerosol parameter estimation with changing observation angle of hround based polarization radiometer, Advances in Space Research, 39, 1, 28-31, 2007

[2] Ding Ya Liu, Kohei Arai, Forest parameter estimation based on radiative transfer model of Monte Carlo Simulation taking into account crown closer models, Journal of Japan Society of Remote Sensing, 27、2、141-152、2007

[3] Yaliu Ding, Kohei Arai, Forest parameter estimation, by means of Monte- Carlo simulations with experimental consideration of estimation of multiple reflections among trees depending on forest parameters, Advances in Space Research, 43, 3, 438-447, 2009.

[4] Kohei Arai and Yui Nishimura, Polarization model for discrimination of broad and needle shaped leaves and estimation of LAI using polarization measurements, Advances in Space Research, 44, 510-516, 2009.

[5] Kohei Arai, Method for estimation of grow index of tealeaves based on Bi- Directional reflectance function: BRDF measurements with ground based network cameras, International Journal of Applied Science, 2, 2, 52-62, 2011.

[6] Kohei Arai, Method for estimation of total nitrogen and fiber contents in tealeaves with ground based network cameras, International Journal of Applied Science, 2, 2, 21-30, 2011.

[7] K.Arai, Monte Carlo ray tracing simulation for bi-directional reflectance distribution function and grow index of tealeaves estimations, International Journal of Research and Review on Computer Science, 2, 6, 1313-1318, 2012.

[8] K.Arai, Fractal model based tea tree and tealeaves model for estimation of well opened tealeaf ratio which is useful to determine tealeaf harvesting timing, International Journal of Research and Review on Computer Science, 3, 3, 1628-1632, 2012.

[9] K.Arai, Y.Terayama, Monte Carlo ray tracing simulation of polarization characteristics of sea water which contains spherical and non-spherical shapes of suspended solid and phytoplankton, International Journal of Advanced Computer Science and Applications, 3, 6, 85-89, 2012.

[10] Kohei Arai, Hideo Miyazaki, Masayuki Akaishi, Determination method for tealeaves harvesting with visible to near infrared cameras, Journal of Japanese Society for Remote Sensing and Photogrammetry 51, 1, 38-45, 2012

[11] Kohei Arai, Lecture note on Remote Sensing, Morikita Shuppan Publishing Co. Ltd., 2001.

AUTHORS PROFILE

Kohei Arai, He received BS, MS and PhD degrees in 1972, 1974 and 1982, respectively. He was with The Institute for Industrial Science and Technology of the University of Tokyo from April 1974 to December 1978 also was with National Space Development Agency of Japan from January, 1979 to March, 1990. During from 1985 to 1987, he was with Canada Centre for Remote Sensing as a Post Doctoral Fellow of National Science and Engineering Research Council of Canada. He moved to Saga University as a Professor in Department of Information Science on April 1990. He was a councilor for the Aeronautics and Space related to the Technology Committee of the Ministry of Science and Technology during from 1998 to 2000. He was a councilor of Saga University for 2002 and 2003. He also was an executive councilor for the Remote Sensing Society of Japan for 2003 to 2005. He is an Adjunct Professor of University of Arizona, USA since 1998. He also is Vice Chairman of the Commission "A" of ICSU/COSPAR since 2008. He wrote 30 books and published 322 journal papers.