Method for Estimation of Grow Index of Tealeaves Based on Bi-Directional Reflectance Distribution Function: BRDF Measurements With Ground Based Network Cameras

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Abstract

Methods for estimation of grow index of tealeaves based on Bi-directional Reflectance Distribution Function: BRDF measurements with ground based network cameras is proposed. Due to a fact that Near Infrared: NIR camera data is proportional to total nitrogen while that shows negative correlation to fiber contents, it is possible to estimate nitrogen and fiber contents in tealeaves with ground based NIR camera data and remote sensing satellite data. Through regressive analysis between measured total nitrogen and fiber contents and NIR reflectance of tealeaves in tea estates, it is found that there is a good correlation between both then regressive equations are created. Also it is found that monitoring of a grow index of tealeaves with BRDF measured with networks cameras is valid. Thus it is concluded that a monitoring of tea estates with network cameras of visible and NIR is appropriate.

Keywords: Minneart, BRDF, Network Camera, Grow Index, Tealeaf.

1. INTRODUCTION

Vitality monitoring of vegetation is attempted with photographic cameras [1]. Grow rate monitoring is also attempted with spectral reflectance measurements [2]. Total nitrogen content corresponds to amid acid which is highly correlated to Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid so that total nitrogen can be used for a measure of the quality of tealeaves. Also fiber content in tealeaves is highly correlated to the grow rate of tealeaves. Both total nitrogen and fiber content in tealeaves are highly correlated to the reflectance in the visible and near infrared wavelength regions and vegetation index derived from visible and near infrared data so that it is possible to determine most appropriate tealeaf harvest date using the total nitrogen and fiber content in the tealeaves which are monitored with ground based visible and near infrared cameras and with visible and near infrared radiometers onboard remote sensing satellites. Namely the most appropriate time for harvesting tealeaves is whenever total nitrogen shows the maximum and fiber content shows the minimum. It, however, is not so easy because no one knows the minimum and maximum and because grow rate cannot be estimates with fiber content which is monitored with just cameras and radiometers perfectly. Therefore, it is required to monitor grow rate with the other method with a much precise manner.

BRDF is the "Bidirectional Reflectance Distribution Function" [3]-[12]. It gives the reflectance of a target as a function of illumination geometry and viewing geometry. The BRDF depends on wavelength and is determined by the structural and optical properties of the surface, such as shadow-casting, multiple scattering, mutual shadowing, transmission, reflection, absorption and emission by surface elements, facet orientation distribution and facet density. BRDF of tealeaves has a good correlation to grow index of tealeaves so that it is possible to monitor an expected harvest amount of tealeaves. It can be done with network cameras. BRDF monitoring is well known as a method for vegetation growth [13], [14]. On the other hand, degree of polarization of vegetation is attempted to use for vegetation monitoring [15] together with new tealeaves growth monitoring with BRDF measurements [16].Tea estate monitoring system with network cameras together with remote sensing satellite data is proposed in the following section followed by proposed estimation methods for BRDF and total nitrogen and fiber contents with network camera data together with some experimental results. Finally, concluding remarks is followed with some discussions.

2. PROPOSED METHOD

2.1 BRDF Measurements With Network Cameras

The proposed method for BRDF measurements is illustrated in Figure 1. Visible and NIR network cameras are equipped on the pole in order to look down with -5-95 degrees of incident angle which depends on the location as is shown in Figure 1. The pole is used for avoidance of frosty damage to tealeaves using fan mounted on the pole (approximately 5 m above the ground). With these network cameras, reflectance in the wavelength region of 550nm (red color) and 870nm (NIR) at the several elevation angles are measured results in BRDF measurements assuming that vegetated areas are homogeneous and flat. From the acquired image, four portions of small pieces are extracted for elevation angles of Spectralon(almost 0 degree), 22.5, 45 and 67.5 degrees. From the first portion of image, reflected radiance from the Spectralon is estimated. Meanwhile, almost flat tealeaf is extracted from the other second to fourth portion of images for estimation of BRDF. There are many tealeaf angles and also tealeaf angle is changed depending on wind direction and speed. Through visual perception, it is possible to extract such tealeaf which looks almost flat situation. Taking a ratio between Spectralon of radiance and tealeaf radiance, the reflectance at the tealeaves at the location which corresponds to 22.5, 45 and 67.5 degrees of elevation angles is estimated then BRDF can be calculated.

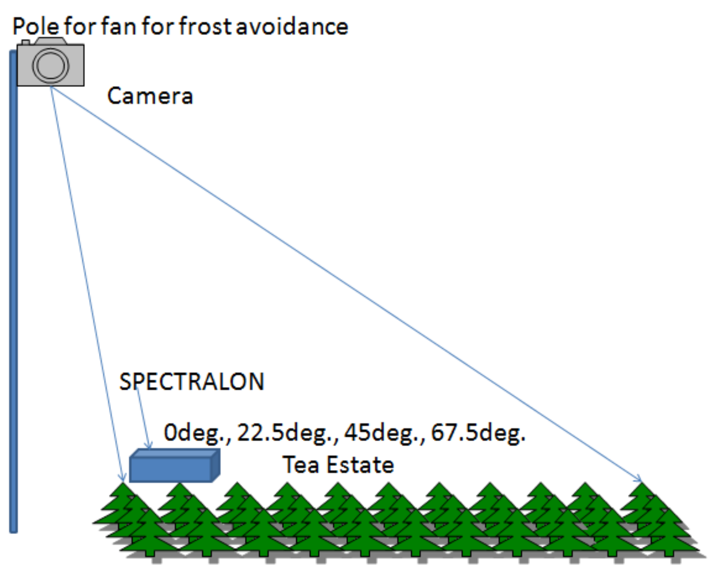

FIGURE 1: Illustrative view of the proposed vegetation monitoring system with two network cameras, visible and NIR.

Look angle of the cameras with wide viewing angle (100 degree for both horizontal and vertical directions) of lens are fixed at 45 degree of elevation angle so that the camera acquire the field from -5 to 95 degree of elevation angle (Angle is measured with a digital angle meter with 0.1 degree accuracy). The geometric relation between camera and tealeaves is known so that we can calculate BRDF. The cameras acquire the image every 30 minutes (shutter speed of 0.5 ms). For BRDF measurement, MS-720 of spectral radiometer is used for the reference. In order to check the measured reflectance and BRDF with visible and near infrared filter film attached cameras, those with MS-720 is used as a reference.

Table 1 shows the specification of MS-720. Meanwhile Panasonic BB8-HCM371 of Pan-Tilt-Zoom camera is used for monitoring BRDF in visible and near infrared wavelength (Band pass filters, 550nm film and 840nm film) are attached to the optics entrance of the camera). The specification of camera is shown in Table 2.

Wavelength coverage	350～1,050nm
Number of channels/Wavelength interval	256ch/3.3nm(interpolated with 1nm)
Wavelength accuracy	<0.3nm
Wavelength resolution (Half power width)	10nm
Temperature Dependency	±5%（- 10～ + 40℃)
Unit of the measurements	$W/m^2 \cdot \mu m$
Full aperture(deg.)	10

TABLE 1: Specification of spectral radiometer of MS-720 manufactured by Eiko Co.Ltd.,

Detector elements	1/4inch、0.32 million of CCD elements
Focal length	Fixed (ranges　0.5m～∞)
F No.	F3.5
Sensitivity Aperture	3Lux～100,000Lux 53 deg. in horizontal direction (extensible to 173 deg.), 40 deg. In vertical direction (extensible to 105 deg.). Aperture for both horizontal and vertical directions is set at 100 deg.

TABLE 2: Specification of visible to near infrared camera mounted on the “Fan pole” for frost damage avoidance

2.2. Relation between BRDF and Grow Index (GI) of new tealeaves

In order to express un-isotropic characteristics of angle dependency of reflectance of tealeaves with one parameter, Minneart coefficient[1] is calculated with the measured BRDF characteristics at 0, 22.5, 45 and 67.5 degrees of elevation angles through regression analysis. Minneart coefficient is used for estimation of Grow Index (GI). Minneart coefficient is assumed to be increased with growing new tealeaves. Old tealeaves used to be shown Lambertian surface

[1] The Minneart formula is presented as follow :
$I = (N \text{ dot } L)^k \quad (1 - N \text{ dot } E)^{1-k}$
where :
N = normalized normal vertex
L = normalized vertex to light
E = normalized vertex to eye
k = Minneart coefficient
“dot” denotes inner product. Minneart function of k=1 is totally equal to the well known Lambertian which is isotropic reflectance function. Un-isotropic characteristics become remarkable in accordance with Minneart coefficient.

(Menneart coefficient=1). From the surface of the old tealeaves, new tealeaves is grown results in increasing of Menneart coefficient. It is obvious that reflectance of new tealeaves is greater than that of old tealeaves, in particular, in the near infrared wavelength region. Cross section of new tealeaves in the field of view at each viewing angle, in particular, for the large off-nadir angle is increased so that Minneart coefficient is increased with growing of new tealeaves.

In the proposed method, visible and near infrared cameras are used for reflectance and BRDF measurements. The cameras are mounted on the pole which is used for fan which is mainly used for frost damage avoidance. Also cameras are connected each other with wireless LAN (Local Area Network) and make measurements automatically. Also we put the Spectralon[2] on the tealeaves manually once a day just before measurements for calibration purpose. In order to avoid influences of pixel-to-pixel sensitivity difference, spectral response difference, out-of-band response, vignetting, a limited portion of camera images are used. Also only the pixels data situated in the center of the optics viewing angle are used for reflectance and BRDF measurements (only a tealeaf which assumed to be directed to the normal and zenith direction is selected). Sensitivity stability is key issue. Because Spectralon is measured only once a day so that spectrometer sensitivity has to stable enough for one hour (reflectance and BRDF measurements takes about one hour). It is also obvious that meteorological conditions have to be monitored. Meteorological conditions are fundamental characteristics of the tealeaves grow. Therefore meteorological stations are equipped at the tea estates.

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3. EXPERIMENTS

3.1. Experimental Conditions

The monitor systems are equipped at four test sites of tea estates of the Saga Prefectural Institute of Tea: SPIT which is situated at 1870-5 Shimojuku Ureshino city in Saga prefecture Japan. There are four tea estates at the institute, East, South, West and North tea fields. Species and ages are different each other among the four tea fields. Yabukita is situated at the eastern tea field, Ohiwase for southern tea field, Benifuki for western tea field and Yabukita and Okumidori for northern tea field, respectively, as are shown in Figure 2.

[2]Spectralon is well qualified standard plaque (Reflectance panel). I used to calibrate spectral-radiometer or spectrometer with Spectralon (manufactured by Labsphere Co. Ltd., U.S.A.) for reflectance measurements. I used to keep a master of Spectralon with care in a desiccate box for many years which is NIST traceable. I used to make reflectance measurements with a working master of Spectralon. Then working master is used to be calibrated with the master after the field campaigns. The most important thing is stability of spectrometer (or radiometer) during the time required for reflectance measurement because reflectance can be calculated with the ratio of measured readings with spectrometer of the surface and Spectralon.

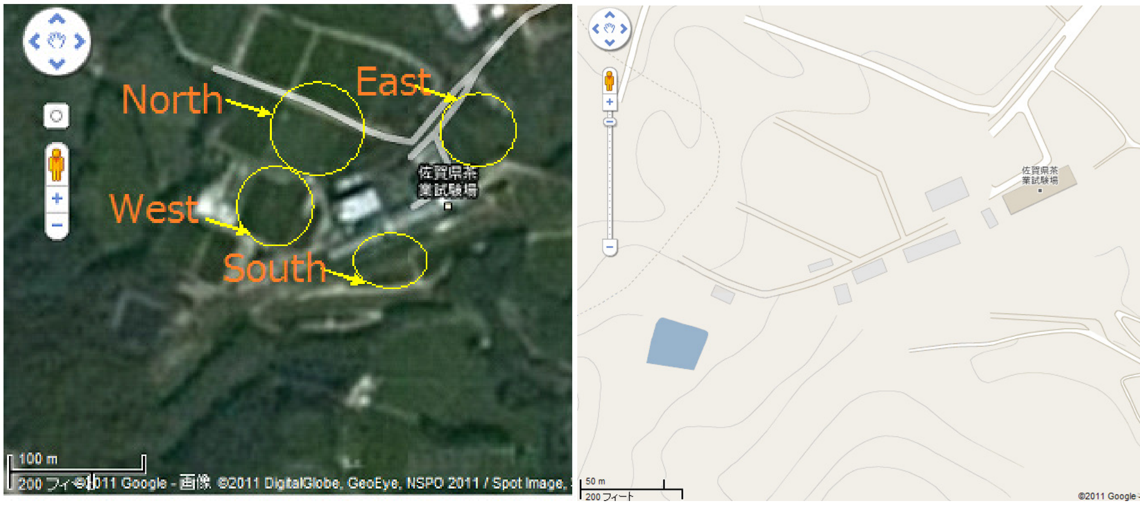


FIGURE 2: Test sites of four tea estates (East, South, West, and North) situated at Saga Prefectural Institute for tea (E129°59′22.3″N33°05′50.7″) (c) Google.

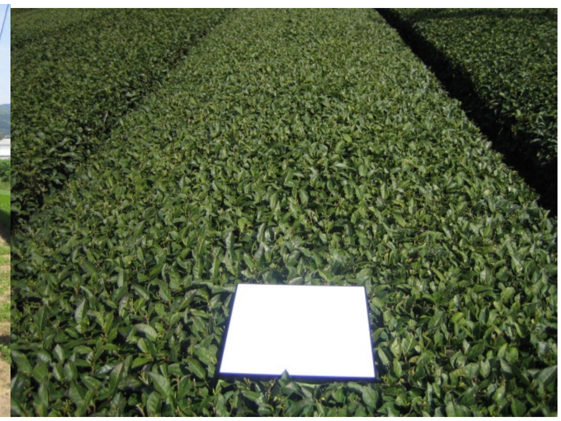
Look angle of the cameras with wide viewing angle (90 degree) of lens are fixed 45 degree of elevation angle so that the camera acquire the field from 0 to 90 degree of elevation angle. Sky condition is monitored pyrometer (hemispherical radiometer). If the sky condition is not good enough, then I omit such unreliable data. I used to measure spectral optical depth. Also I used to estimate absorption due to water vapor, ozone and Rayleigh scattering and aerosol scattering. If the atmospheric condition is varied too much, then I also omit such unreliable data.

Figure 3 shows one of the examples of the photos which show how does tea estate look like (a) and also show Spectralon on the tealeaves (b). It also shows outlook of the meteorological station (Vantage Pro-II manufactured by U.S.A.) equipped at the test site of tea estates (c) together with the cameras in the box on the frost damage avoidance pole (d).

3.2. Experimental Results

Examples of the acquired camera images of off-nadir angles of 22.5, 45 and 67.5 degrees (portion of images) are shown in Figure 4(a), (b) and (c), respectively. Through visual perception, one piece of tealeaf which is situated in the horizontal and zenith directions is extracted from the image as is shown in Figure 4(d), (e) and (f) for 22.5, 45 and 67.5 degrees of off-nadir angles. Figure 4 (g), (h) and (i) also shows histogram of the piece of tealeaf of the green colored image for Figure 4 (d), (e) and (f), respectively. Through a histogram analysis, reflectance[3] can be calculated with mean of pixels of the one piece of tealeaf and pixel value of the Spectralon. Histogram in the Figure 4 shows green color (550nm) of wavelength channel of histogram measured at north tea estate (Yabukita) on April 4 2010. The value in the bracket of Figure 4 shows the calculated reflectance. Thus BRDF can be calculated with the acquired camera data. Then Minneart coefficients are estimated through regression analysis with Minneart function and the calculated reflectance as a function of off-nadir angles.

[3] Reflectance can be defined as a ratio of the mean of pixel value and pixel value of the Spectralon.

(a)

(b) Out look of the tea estate (North tea estate of SPIT) (b) Spectralon on the tealeaves


(c)Meteorological data collecting robot (d)Network cameras in the box mounted on the frost damage avoidance pole

FIGURE 3: Example of the photos which show how does tea estate look like and also show Spectralon which is set-up on the tealeaves. Meteorological station equipped at the test site of tea estates together with network cameras attached on the frost damage avoidance pole.

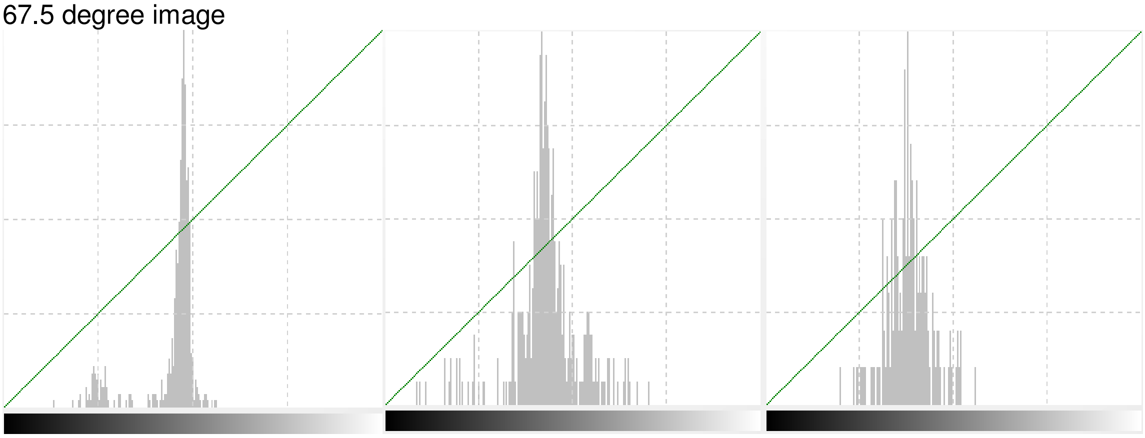
Examples of the Minneart function and the calculated reflectance of east, south, west and north tea estates which are measured on January 8 2008 are shown in Figure 5. Usually, new tealeaves start to grow in the begging of April and grow-up rapidly. Theanine in new tealeaves increases in accordance with grow-up. Then Theanine changes to Catechin due to sun light so that Theanine decreases for the time being. Tea taste good if the tealeaves contain a lot of Theanine while it tastes bad for the tealeaves containing a lot of Catechin. It used to harvest before Theanine changes to Catechin, approximately in the late of April or the begging of May. After the harvesting the first new tealeaves, next new tealeaves grow-up again. Then second new tealeaves harvesting is done in the begging of July. Third harvesting is used to be scheduled in the September usually. After the third harvest, old tealeaves are cut for maintaining vitality of tea trees for a long winter time, during from October to March. These are annual events for tealeaves. Taste of firstly harvested tealeaves is the best followed by the secondly and thirdly harvested tealeaves. The difference between the firstly harvested tealeaves and the other two harvested tealeaves is pretty large. In other word, most of tea farmers concentrate the firstly harvested tealeaves rather than the other two harvested tealeaves. Therefore this paper focuses BRDF monitoring results for the firstly harvested tealeaves only. Figure 6 shows the BRDF changes

(Minneart coefficient trend) for eastern tea estate of Yabukita tealeaves during from March 29 to April 30 2008.

May 19 2009

(a) 22.5degree (b) 45 degree (c) 67.5 degree

(d) Extracted tealeaf from 22.5 degree of image (e) That from 45 degree image (f) That from 67.5 degree image



(g) 22.5 degree (0.97) (h) 45 degree (0.8) (i) 67.5 degree (0.75)

FIGURE 4: Histogram of green color of a tealeaf extracted from the acquired image and reflectance at the off-nadir angle of 22.5, 45 and 67.5 degrees measured at north tea estate (Yabukita) on April 4 2010. The value in the bracket shows reflectance.

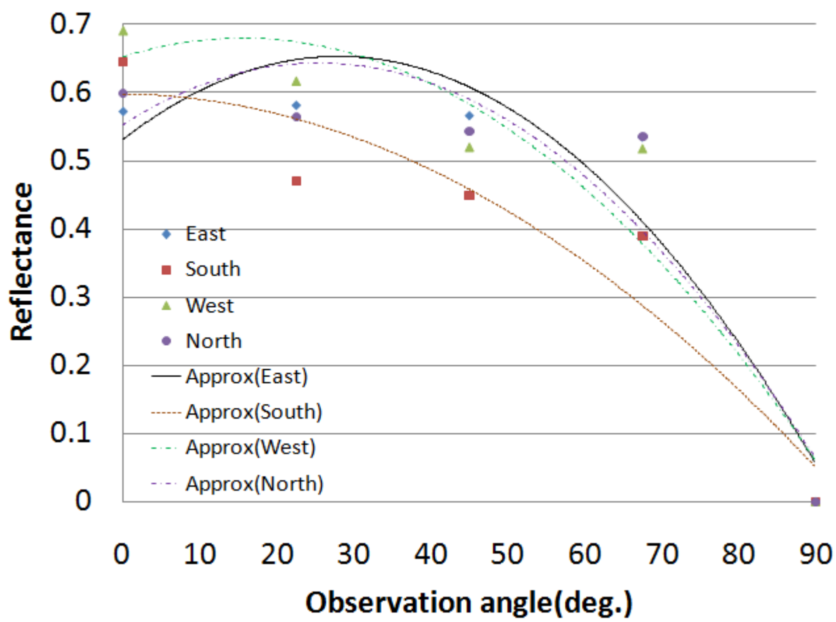
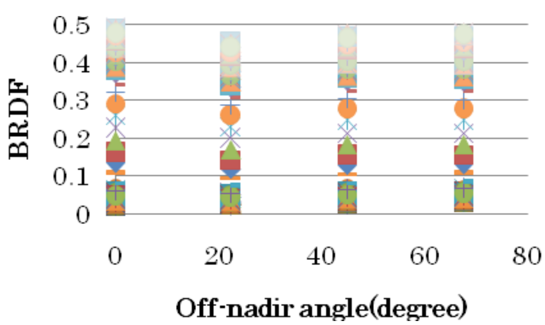
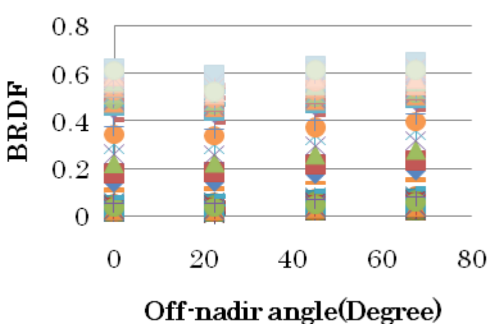
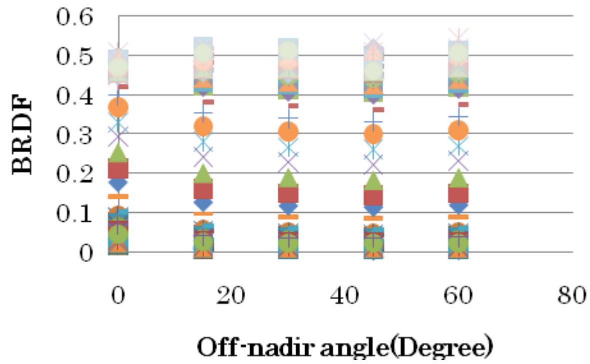


FIGURE 5: Approximated Minneart reflectance function derived from regression analysis with the measured reflectance at the four off-nadir angles with the acquired camera data situated in the east, south, west and northern tea estates on January 8 2008 (tea estates are covered with just old tealeaves).





(a) March 29 2008 (1.4) (b) April 8 2008 (1.9)



(c)April 30 2008 (1.2)

FIGURE 6: BRDF changes for each wavelength starting from 400nm to 1050nm with 10nm steps.

Minneart coefficient (the number in the bracket shows Minneart coefficient) for the Figure 6(a) is not small because new tealeaves appeared on that day of March 29 2008. Then Minneart coefficient increases for the time being as is shown in Figure 6(b) of BRDF characteristics of April 8 2008. Finally, Minneart coefficient decreases after the harvest of new tealeaves as is shown in Figure 6(c).

3.3. Verification of the Proposed Method

Truth data of firstly harvest amount of new tealeaves is shown in the Table 3 together with age of the tea trees and area of tea estates. Firstly harvested new tealeaf amount depends on the age of the tea trees and also on the year as is shown in Figure 7. As is aforementioned, Minneart coefficient becomes the index for harvesting amount of new tealeaves.

		Harvest amount/10a			
Name	Age	2008	2009	2010	Area(a)
E:Yabukita	20	474.9	430.2	335.7	7.8
S:Oiwase	8	115.9	351.8	395.5	4.7
W:Benifuki	7	121.2	400.0	326.1	3.4
N:Okumidori	25	333.1	400.0	554.7	9.7
N:Yabukita	36	549.0	553.3	606.2	10.1

TABLE 3: Age of the tea trees and area of tea estates of the tea estates and firstly harvest amount of new tealeaves per 10 a.

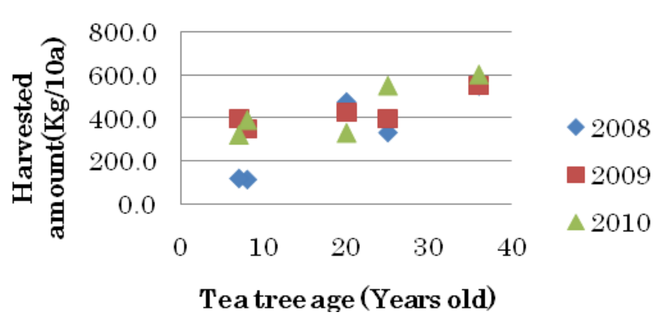


FIGURE 7: Relation between tea trees age and firstly harvested amount of new tealeaves.

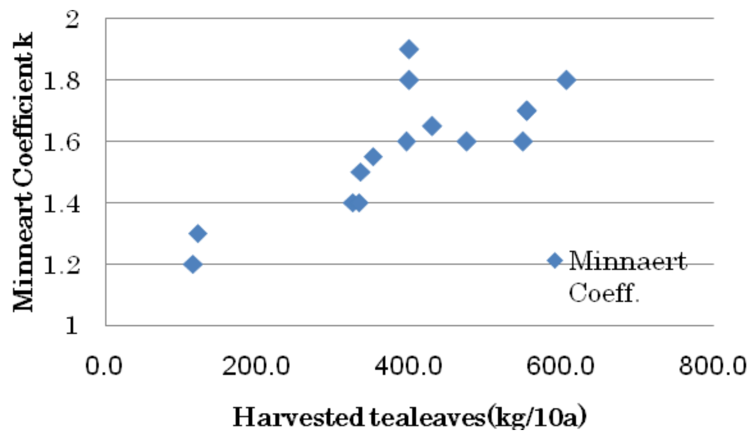


FIGURE 8: Relation between harvested tealeaves and estimated Minnerart coefficient.

Figure 8 shows a relation between harvested amount of new tealeaves in unit of Kg/10a and the measured Minneart coefficient on just before harvest. The amount of new tealeaves is measured for firstly harvested new tealeaves for three year starting from 2008 and 2010. Figure 8 shows a good relation between harvested amount and Minneart coefficient so that the proposed method for estimation of possible amount of harvesting amount of new tealeaves is validated. Furthermore, it would help to determine the date for harvest of new tealeaves together with monitored total nitrogen contains which is highly related to the Theanine.

4. CONCLUSIONS

It is found that the proposed new tealeaf monitoring system with network cameras is useful through field experiments of BRDF measurement with the matching BRDF derived from MCRT as well as Minneart model. Acquired images with visible and near infrared web cameras mounted on the pole that is used to avoid frosty damage with fan for convection of the boundary atmospheric layer are also useful to monitor the mass and quality of new grow tealeaf because observation angle ranges from zero (Nadir) to 75degree which is very sensitive to the size (length) of new tealeaves in the sense on BRDF changes. Thus the most appropriate time for harvesting new tealeaves is determined. Also it is possible to estimate mass and quality of new tealeaves based on monitored camera imagery data and satellite imagery data derived total nitrogen and fiber contents in the new tealeaves. It is obvious that nitrogen rich tealeaves tastes good while fiber rich tealeaves tastes bad. Theanine: 2-Amino-4-(ethylcarbamoyl) butyric acid that is highly correlated to nitrogen contents in new tealeaves are changed to Catechin [17],[18],[19] due to sun light. In accordance with sun light, new tealeaves grow up so that there is a most appropriate time for harvest in order to maximize amount and taste of new tealeaves simultaneously.

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5. REFERENCES

[1] J.T.Compton, Red and photographic infrared linear combinations for monitoring vegetation, Journal of Remote Sensing of Environment, 8, 127-150, 1979.

[2] C.Wiegand, M.Shibayama, and Y.Yamagata, Spectral observation for estimating the growth and yield of rice, Journal of Crop Science, 58, 4, 673-683, 1989.

[3] Nicodemus, Fred (1965). "Directional reflectance and emissivity of an opaque surface" (abstract). *Applied Optics* **4** (7): 767–775. doi:10.1364/AO.4.000767. http://ao.osa.org/abstract.cfm?id=13818, 1965.

[4]Rusinkiewicz, S., "A Survey of BRDF Representation for Computer Graphics". http://www.cs.princeton.edu/~smr/cs348c-97/surveypaper.html. Retrieved 2007-09-05, 2007.

[5] Wojciech Matusik, Hanspeter Pfister, Matt Brand, and Leonard McMillan. A Data-Driven Reflectance Model. ACM Transactions on Graphics. 22(3) 2002.

[6] B. T. Phong, Illumination for computer generated pictures, Communications of ACM 18, no. 6, 311–317, 1975.

[7] James F. Blinn (1977). "Models of light reflection for computer synthesized pictures". *Proc. 4th annual conference on computer graphics and interactive techniques*: 192. doi:10.1145/563858.563893. http://portal.acm.org/citation.cfm?doid=563858.563893., 1977.

[8] K. Torrance and E. Sparrow. Theory for Off-Specular Reflection from Roughened Surfaces. J. Optical Soc. America, vol. 57. pp. 1105–1114, 1976.

[9] Lubin, Dan; Robert Massom (2006-02-10). *Polar Remote Sensing: Volume I: Atmosphere and Oceans* (1 ed.). Springer. p.756. ISBN3540430970, 2006.

[11] Matt, Pharr; Greg Humphreys (2004). *Physically Based Rendering* (1 ed.). Morgan Kauffmann. p.1019. ISBN012553180X, 2004.

[12] Schaepman-Strub, G.; M.E. Schaepman, T.H. Painter, S. Dangel, J.V. Martonchik (2006-07-15). "Reflectance quantities in optical remote sensing--definitions and case studies". *Remote Sensing of Environment* **103** (1): 27–42. doi:10.1016/j.rse.2006.03.002. http://www.sciencedirect.com/science/article/B6V6V-4K427VX-1/2/d8f9855bc59ae8233e2ee9b111252701. Retrieved 2007-10-18., 2006.

[13] S.Tsuchida, I.Sato, and S.Okada, BRDF measurement system for spatially unstable land surface-The measurement using spectro-radiometer and digital camera- Journal of Remote Sensing, 19, 4, 49-59, 1999.

[14] K.Arai, Lecture Note on Remote Sensing, Morikita-shuppan Co., Ltd., 2000.

[15] K.Arai and Y.Nishimura, Degree of polarization model for leaves and discrimination between pea and rice types of leaves for estimation of leaf area index, Abstract, COSPAR 2008, A3.10010-08#991, 2008.

[16] K.Arai and Long Lili, BRDF model for new tealeaves and new tealeaves monitoring through BRDF monitoring with web cameras, Abstract, COSPAR 2008, A3.10008-08#992, 2008.

[17] Greivenkamp, John E., *Field Guide to Geometrical Optics*. SPIE Field Guides vol. **FG01**. SPIE. ISBN 0-8194-5294-7, 2004.

[18] Seto R, H. Nakamura, F. Nanjo, Y. Hara, *Bioscience, Biotechnology, and Biochemistry,*Vol.61, issue 9, 1434-1439, 1997.

[19] Sano M, Suzuki M ,Miyase T, Yoshino K, Maeda-Yamamoto, M.,J.Agric.Food Chem., 47 (5), 1906-1910 1999.