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Full Length Article

Quantitative Use of Luminosity-normalized Grayscale Images of Greenness, Redness and Yellowness of a Rice Canopy Derived from Multi-temporally Acquired Digital Photographs

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Abstract

Comparison of spectral profiles of a crop in multi-temporally acquired digital photographs is effective in crop management. However, comparison has been difficult due to temporal changes in brightness of photographs and the absence of correlation among brightness and color components such as blue (B). To circumvent this problem, this study examined luminosity-normalization of the entire area of grayscale images of green (G), red (R), and RGB yellow for a rice canopy in photographs multi-temporally acquired by a surveillance camera. After confirming the linear relationships between luminosity and the above color components using a rooftop invariant, all pixels in the grayscale images of the color components were luminosity 100-normalized. The maturity of rice was described as great intensity values of R, G and RGB yellow, an R/G value of 1.0 and great coefficients of variation of around 17 for the above color components. This was due to light yellowish mature rice grains and incomplete leaf senescence resulting in a color diversity of the canopy. With the luminosity 100-normalization of the entire area of the grayscale images of G, R and RGB yellow, comparison of the continuously and multi-temporarily acquired spectral profiles of the rice canopy was possible. © 2013 Friends Science Publishers

Keywords: Digital photography; RGB color model; Rooftop invariant; Spectral profile; Maturity of rice; Surveillance camera; Temporal variation of brightness

Introduction

Crop spectral profile (colors) is an indicator of plant condition. As a component of the red-green-blue (RGB) color model, green (G) is the color of chlorophyll, which generates energy (Shuvalov, 2007). The loss of the color G is a sign of leaf senescence, nutrient deficiency (Doi, 2012a) or other stresses (Adams *et al.*, 1999). This loss of greenness is also seen when some cereal crops, such as rice, mature. Biochemical changes in apple (Herold *et al.*, 2005) and pear (Tanaka and Kojima, 1996) fruits were related to those of a spectral profile over the period of maturation. These previous findings suggest that continuous monitoring of spectral profiles of crops can be used to identify necessary measures for optimizing crop production.

As such, recent developments in *in situ* digital photographing technologies can provide continuous and precise information on crop spectral profiles over a period of time. However, brightness of the imaging targets varies with image acquisition time. Considering the changes that occur in all color components, adjustment of the entire area of a single digital photograph is difficult (Hadjimitsis *et al.*, 2009). The difficulty in the normalization of brightness in multiple photographs acquired at different time points (Kuchida *et al.*, 2002) is caused by the absence of correlations among bands that may be used for the spectral profiling of crops at different time points (Hayes and Sader, 2001).

To circumvent this difficulty, normalization of the intensity of a single color component from within the entire corpus of grayscale images for the color component acquired at different time points could be a solution if the color component has a significant correlation with brightness. By determining the intensity of G, red (R) and red-green-blue (RGB) yellow, Doi (2012b) demonstrated that these color components have significant correlations with brightness. This suggested that the grayscale images of the above color components, R, G and RGB yellow, can be brightness normalized and provide quantitative and visually perceivable information as normalized grayscale images of the entire photographed scene (Adobe Systems, 2002). Thus, such normalized grayscale images are expected to present temporal changes in spectral profile of the crop, although this normalization has not yet been examined. Therefore, this study was conducted to examine the following hypothesis: the normalization of brightness of the entire

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areas in digital photographs as grayscale images of R, G and RGB yellow enables the comparison of spectral profiles of the rice canopy acquired at different time points.

Materials and Methods

Site Description

Details of the study site are described elsewhere (Arif *et al.*, 2012a). The paddy field was located in the Nagrak District of Sukabumi, Indonesia (6° 50' 42.5" S, 106° 48' 20.2" E). In this study, a rooftop was used as an invariant standard (Fig. 1; Doi, 2012b). The digital photographs, as shown in Fig. 1, enabled visual confirmation of the aforementioned rooftop and the paddy field. The soil texture was silty clay. On 20 Aug 2011, the field was planted with the local variety of rice (*Oryza sativa* L.), Sintanur. We used the following practices: single planting of young seedlings (10 days after sowing), spaced at 30 cm × 30 cm, applying an organic fertilizer at 7 ton/ha, but no chemical fertilizer. The paddy field was watered according to a non-flooded irrigation system (Arif *et al.,* 2012b). The silty clay soil was kept moist but with no standing water. The rice was harvested on 12 Dec 2011.

Digital Photography, Handling Digital Photographs, and Spectral Profiling of Rice Canopy

In this study, digital photographs of the paddy field were used. The photographs were captured by surveillance camera, (UCAM-DLO130, Elecom, Osaka, Japan). The digital photographs were captured daily between 14.00 and 14.30, and stored on a hard disk between 21 Aug 2011 and 15 Dec 2011. Forty-nine digital photographs were acquired. The rooftop and the paddy field were located within a single scene (Fig. 1). When the photograph was captured, the data regarding the values of the red-green-blue (RGB) color intensity were generated. The image datum was then pasted into a new file window of Adobe Photoshop 7.0. In another layer overlapping the paddy image, frames were set on the rooftop and the rice canopy (Fig. 1). The numbers of spectral-profiled pixels were 168 for the rooftop as the invariant standard and 2,516 for the rice canopy in the target canopy frame. For the pixels in the invariant rooftop frame, the intensity values of R and G were read (Doi and Ranamukhaarachchi, 2010). For R or G, a value between 0 (darkest) and 255 (saturated and most colorful) was reported (Doi *et al.,* 2010). As a measure of brightness, luminosity was also read for the pixels of the invariant rooftop and was averaged.

Grayscale images that show the intensity values of R and G were prepared (Doi, 2013). Then the grayscale image of the intensity values of RGB yellow for the pixels was prepared by merging the R and G grayscale layers at the same weights as described in the manufacturer's instructions (Adobe Systems, 2002). Each grayscale image was subjected to adjustment of brightness of the entire image as described later. The luminosity 100-normalization (Doi, 2012b) was applied as the method for normalization of brightness of the entire area of the grayscale image. The intensity values of the above color components were then determined for the target rice canopy framed in Fig. 1.

Analyses of Multi-temporally Acquired Spectral Profiles of the Rooftop Invariant

Yellow is also an important color in crop observation (Adams *et al.,* 1999). Therefore, intensity of RGB yellow was calculated as:

RGB yellow = R + G ………. (1) (Smith, 1999).

As a measure of the relative intensity of R to G, the R/G value was also calculated (Kondo *et al.*, 2000). Using the statistical software SPSS 10.0.1 (SPSS Inc.), linear regression analysis of the luminosity and intensity of the RGB color component was performed to examine if the intensity values of R, G, and RGB yellow, and value of R/G could be luminosity-normalized.

Results

Relationships between Brightness and Intensity of Color Components for the Rooftop Invariant

Fig. 2 presents the linear relationships between luminosity and intensity of the color components of the RGB color model derived from the rooftop profiling. Among the single color components, RGB yellow had the greatest R^2 value (R^2= 0.980) followed by G (R^2 = 0.948), and R (R^2 = 0.836). All the linear relationships were significant at p = 0.001. Because of the aforementioned linear relationships, for each image acquisition time, the raw intensity values of R, G and RGB yellow were luminosity 100-normalized using the following equation:

Luminosity 100-normalized value = Raw value-(luminosity for the rooftop – 100) × slope …….. (2).

Where, slope is the slope coefficient derived from the linear correlation between luminosity and raw intensity of the color component (Fig. 2).

Results of luminosity 100-normalization of the intensity values of R, G, RGB yellow and value of R/G for the rooftop invariant over the period of 121 days are summarized in Table 1. The value of accuracy measure results in a coefficient of variance of 6.74% for R/G (n = 49) or smaller.

Luminosity 100-normalization of all Pixels in the Entire Area of Grayscale Image

The color components had different slope coefficients of linear regression (Fig. 2) Therefore, for each grayscale image indicating the intensity values of the single color component, to obtain a luminosity 100-normalized grayscale image the additional luminosity value was

Table 1: Luminosity 100-normalized intensity values of red, green and RGB yellow and value of red/green for the invariant rooftop in Fig. 1

Statistic	Red (R)	Green (G)	RGB yellow	R/G
Mean*	107	94	201	1.13
Standard deviation*	4.71	2.25	2.92	0.08
Coefficient of variation (%)*	4.41	2.40	1.45	6.74

*Forty nine digital photographs were used for the color components and R/G

Fig. 1: Digital photographs of the paddy field, the invariant standard and the target frame/canopy

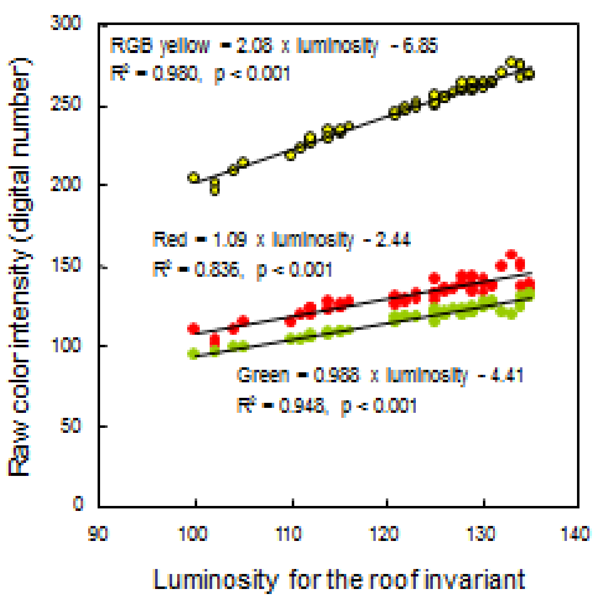

Fig. 2: Relationship between luminosity for the rooftop invariant and the intensity of the red, green and RGB yellow

determined by the following equation:

Additional luminosity value to the entire grayscale image = (Raw luminosity – 100) × slope ……… (3).

From the calculation, the additional intensity value was added to all pixels in the grayscale image (Fig. 3). Fig. 3 demonstrates that comparison of intensity of the color components R, G and RGB yellow is possible among luminosity 100-normalized grayscale images of photographs acquired at different time points.

Temporal Changes in Rice Canopy Spectral Profile

Changes in spectral profile of the canopy are visualized in Fig. 4. On 21 Aug, the bare soil was bright as indicated by the relatively greater values of intensity of the color components. As the rice shoots grew, the color observed in the target frame became darker and the intensity values dropped. Then the canopy became brighter in December. The standard deviations for the pixels in the target frame were large on 21 Aug when the soil surface was not uniform, while the value was small on 16 Oct when the rice shoot was uniform in color. Then on 11 Dec, greater diversity in the canopy spectral profile resulted in the higher values of standard deviation. In the target frame of the grayscale images, it was red-dominant at the time point of transplantation (21 Aug), but later became green-dominant when the target frame was covered by the rice shoot (16 Oct). The intensity values of R and G later became greater and reached the same value of 122 when the colors of the leaves and the rice grain became lighter.

Changes in spectral profile of the target canopy in Fig. 1 are shown in Fig. 5. A large value of intensity (of G, for example) indicates a high degree of saturation, and thus high colorfulness. Soon after the transplantation on 20 Aug, the intensity values of R, G and RGB yellow started to decrease as the rice seedlings grew and the ground was covered. R/G value also decreased during ground cover development, but the decrease in the R/G value started later than those in R, G and RGB yellow. The intensity values of R and G had similar decreasing trends until 30 days after transplantation when the decrease in the intensity value of R became faster than that of G. Around 55 days after transplantation, no soil surface was visually recognizable in the photograph (Fig. 1). At this time point, the intensity values of R, G and RGB yellow, as well as value of R/G were the smallest in the experimental period. Subsequently, from 80 days after transplantation, these values gently increased until the time of harvest.

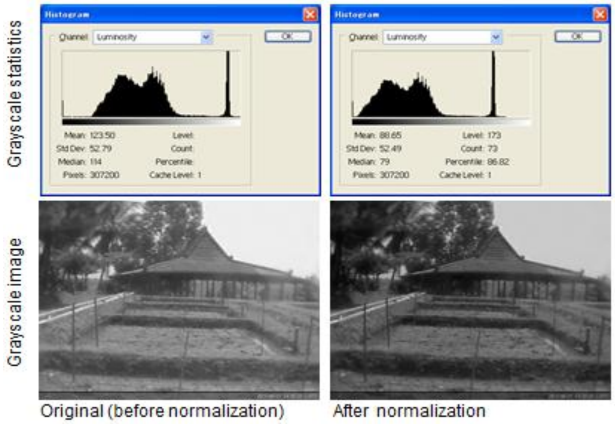

Fig. 3: Luminosity 100-normalization of a gray scale image of the intensity of greenness. The left image was the original acquired on 21 Aug. 2011. The right is the normalized image by changing the brightness value

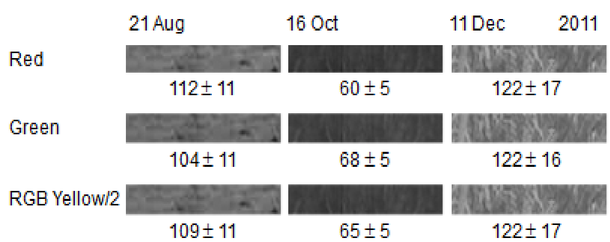

Fig. 4: Changes in visual appearance of the luminosity 100-normalized target canopy. The values indicate the normalized mean intensity for the color component followed by the standard deviation. Half the original values of RGB yellow (R+G) were shown the R and the G gray scale image were merged (adobe systems 2002)

Discussion

The linear relationships shown in Fig. 2 indicate that the rooftop was suitable as the invariant for spectral profiling of the rice canopy by using the digital camera and the acquired digital photographs. The linear relationship between G and luminosity was consistent with the theoretical description by Kirk *et al.* (2009), while the strong linear relationship between luminosity and RGB yellow was previously found by Doi (2012b). The technique in the current study generated grayscale images of single color components of R and G, the grayscale image of RGB yellow was obtained by merging the R and G grayscale images (Smith, 1999). This intermediate property of RGB yellow is indicated as its spectral peak between those of G and R in the RGB color model (Smith, 1999). The intermediate property is evidenced by a vivid greenish color given by only a single RGB color component (R=0, G=255, B=0) described as cyan (C)=161, magenta (M)=0, yellow (Y)=255, and key black (K)=0 in the CMYK model. The greenish color contains a significant yellow component. Likewise, a vivid reddish color (R= 255, G=0, B=0) also has a significant yellow component (C=0, M=252, Y=255, K=0). Hence, among the R, G and RGB yellow, the spectral peak of RGB yellow is thought to be the closest to that of luminosity. Therefore, luminosity 100-normalization of the entire grayscale images of RGB yellow in addition to those of R and G was shown to be relevant.

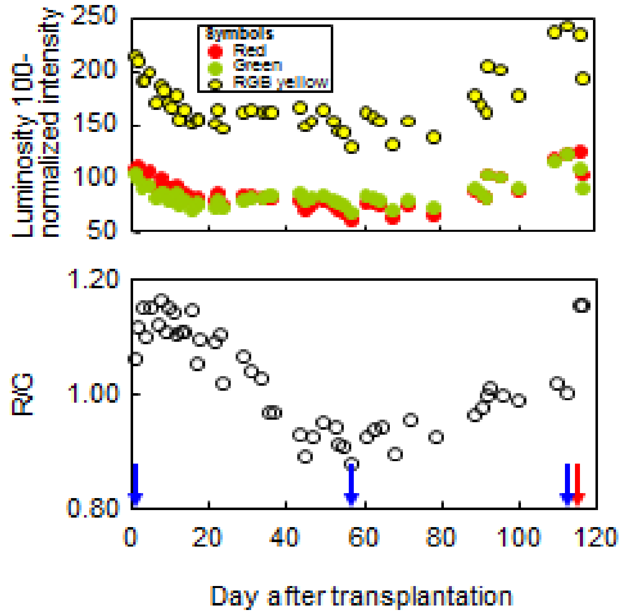

Fig. 5: Changes in luminosity 100-normalized intensity values of the color components and redness/greenness (R/G) for the rice canopy in the target frame set in the digital photographs (Fig. 1). The blue and the red arrows indicate the time points when the photographs in Fig. 1 were acquired and the harvest time, respectively

The luminosity 100-normalized spectral profile of the rooftop (Table 1) was comparable to that of reddish rooftops in Bangkok and Tokyo (Doi, 2012b). Values of coefficients of variation for the color components and R/G show that accuracy was somewhat better than in the previous study on the use of remote sensing images acquired by the satellites, Quickbird and GeoEye (Doi, 2012b). As a measure of accuracy, the range of the coefficient of variance (6.74% for R/G or less, n = 49, Table 1) implies that, at worst, the spectral profiling based on the current normalization technique did not underperform within the *in situ* technique for the measurement of greenness using a chlorophyll meter SPAD-502 (Steele *et al.*, 2008; Coste *et al.*, 2010). In a regional-scale remote sensing study, Yang *et al.* (2008) reported that R/G demonstrated a comparable accuracy to well-investigated indices including the normalized difference vegetation index. Hence, the accuracy of G was demonstrated to be comparable or better than that of well-established indices for the remote sensing of vegetation based on panchromatic information.

Until 30 days after transplantation, the rice leaves were increasing in biomass and thus chlorophylls were also increasing in the space, darkening the spectral profiles of the pixels of the target canopy (Sakamoto *et al.*, 2011), while the original redness of the soil surface had been replaced by another source of redness, carotenoids, in the leaves (Yang *et al.*, 2010) (Figs. 4, 5). Greenish chlorophylls and reddish carotenoids, coexisting in the leaves, should have certain yellow components for the aforementioned properties of G and R (Figs. 4, 5). These changes in spectral profile shown in Figs. 4, 5 also eventually suggested correlations between the changes in spectral profile and in crop coefficient. The changes in crop coefficient indicate a relative loss of soil moisture, transpiration through crop body/evaporation through the soil surface. Based on Arif *et al.* (2012b), during in the period of vegetation growth (from 21 Aug to 16 Oct in this study), crop coefficient should increase. In the period of rice maturity and leaf senescence (from 16 Oct to 11 Dec in this study), crop coefficient dropped. Therefore, the changes in spectral profile may also be an indicator of the physiological activity of rice.

In the 21 Aug image, the target frame was filled with leaves with a large amount of chlorophyll (Sakamoto *et al.*, 2011), while few other things existed in the space. Thus the spectral profiles of the pixels in the target frame were the most uniform in the period of this study (Fig. 4; Doi and Ranamukhaarachchi, 2013). This uniformity was lost in the later stage, as the pixels in the target frame represent yellowish grains and light greenish leaves, which experienced slower senescence than those under conventional flooded rice farming (Mishra and Salokhe, 2010). The maturity of the grains clearly contributed to the increase in yellowness of the spectral profile. In this study site with the cultivation practices, the maturity of the rice grain was described as the luminosity 100-normalized intensity values of 122 (G), 122 (R), and 122 (RGB yellow), thus an R/G value of 1.0.

The results presented above demonstrate the applicability of the current technique in comparison of spectral profiles of crops over a period of time. In actual fields, the colors of crops may vary nonlinearly with time (Fig. 4). Therefore, repeated observations of spatial distribution of greenness, redness, yellowness, and redness/greenness at multiple time points are expected to statistically separate the spatial (Doi and Ranamukhaarachchi, 2009) and the temporal (Summy and Little, 2008) effects on the changes in crop spectral profiles, suggesting effective measures to improve the irregular distributing problems in the area. The normalization technique herein may ensure timely decision making in addition to supporting year-round management strategies. In Aomori prefecture, Japan, it was shown that apple fruit growth and changes in fruit color could be quantitatively measured by continuously acquiring and analyzing digital photographs in a case study conducted by Kishi *et al.* (2010). They found that the best time for the apple harvest in the region could be objectively determined by continuously profiling the fruit spectral profile based on a color model. Thus, experienced farmers could easily transfer their objective knowledge to younger people (Kato *et al.*, 2012). Therefore, the current technique may provide precise, feasible, and timely information in the management of crops and other plant species. It may be used practically in combination with recently developed remote sensing methods, such as balloons with remotely controlled digital cameras (Verhoeven, 2009), in addition to the most advanced remote sensing technologies.

In conclusion, the combination of the rooftop invariant and the surveillance digital camera enabled comparison of continuously and multi-temporarily acquired spectral profiles of the target rice canopy with luminosity 100-normalization of the entire area of the grayscale images of G, R and RGB yellow as well as values of R/G over the period. This reliable luminosity normalization of the entire area of single grayscale images of the color components is well worth further development for optimal crop management.

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