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A Halation Reduction Method for High Quality Images of Tomato Fruits in Greenhouse*

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Abstract

Halation is one of the serious problems for machine vision system which could cause color information lost of image. Images for tomato fruits in greenhouse with different rotational angle of polarizing filter (PL filter) were acquired and combined into one result image to eliminate multiple halation areas from sunlight and reflected light. An image acquisition system composed of a CCD camera and a stepping motor was used to acquire images. The multiple halation areas could be eliminated in the condition with a certain angle of incidence and color representation in result image was improved. The reasonable result shows the feasibility to eliminate multiple halation areas by this method.

[Keywords] halation, machine vision, PL filter, HSI color space, image processing, Brewster's angle, tomato

I Introduction

A machine vision system is one of the important sensing devices for precision agriculture (Kondo *et al*., 2006). Using machine vision as monitoring system farmers can obtain information about plant conditions and health which helps them make decisions for plant cultivation (LEE, 2008). Color information is commonly used to analyze the plant health conditions and the quality. The machine vision technique in the field applications is to overcome the often unpredictable and non-uniform (shadows in the field of view) outdoor illumination because unpredictable and non-uniform illumination in the field of view directly affect the captured image quality (Hong Y *et al*., 2011). In this paper, halation is defined as the high intensity areas in the image caused by specular reflected light on the surface of plants (Nishiwaki *et al*., 2006). To acquire an optimal quality image, halation is one problem that can cause loss of color information. Due to this problem, it is not easy to get correct color information for defect detection and quality classification under natural light condition.

Since halation is a kind of polarized light coming from the specular reflection of sunlight. Polarizing filters (PL filter) are effective to reduce halation when they are set both in front of the light source and of the camera and the PL filters forms an angle of 90°. However, this method is not effective in an outdoor environment because the light source position changes over time and varies from place to place. Nishiwaki *et al*., (2006). tried to reduce halation on leaves of a coffee plant by using two PL filters and one frame box covered by a polarizing film in the field. The first PL filter is a polarizing film covering a frame box in the field. This first PL filter allows only horizontally oriented polarized sunlight to reach the plant surface. The second PL filter is set in front of a camera and only the vertical component of light passes. The camera was installed inside the box. The images were analyzed by an RGB model and a HSV model and the halation areas were extracted using a Saturation threshold of 128. The halation elimination and the color representation results showed that this method is effective to get images without loss of color information. Although their method is promising, two PL filters and the frame box make it not efficient for a real monitoring system. Watanabe *et al*., (2010) proposed a method to minimize the halation area in the field by rotating the PL filter to a specific angle calculated on the basis of solar altitude, solar azimuth and the camera orientation. It is still difficult to use this method in a greenhouse due to multiple halation areas problem. Reflected light from plastic walls or from metallic

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construction elements can cause multiple halation areas on image in greenhouse; it is difficult to remove all of them simultaneously. The objective of this study is to develop a halation reduction method to solve multiple halation areas problem in a greenhouse.

II Materials

1. Fruits provided in experiment

A tomato (*Lycopersicum esculentum* L. cv. Momotaro) purchased at a supermarket was for use in a laboratory simulation experiment. Three tomato clusters of the same cultivar were used in greenhouse experiments. The properties of fruits are shown in Table 1 and images of the materials are shown in Fig. 1.

Table 1 Parameters of the tomato fruit used in the halation reduction experiments

	Number of fruit	Color	Diameter
Material 1	1	Red	70 mm
Cluster 1	3	Red	62 ~ 70 mm
Cluster 2	4	2 Red, 2 Green	60 ~ 75 mm
Cluster 3	6	Red	43 ~ 63 mm

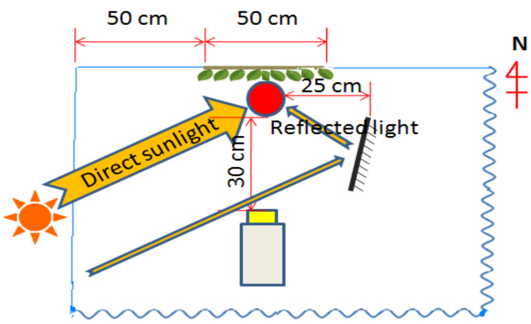
(a) Material 1 for simulation (b) Tomato cluster 1

(c) Tomato cluster 2 (d) Tomato cluster 3

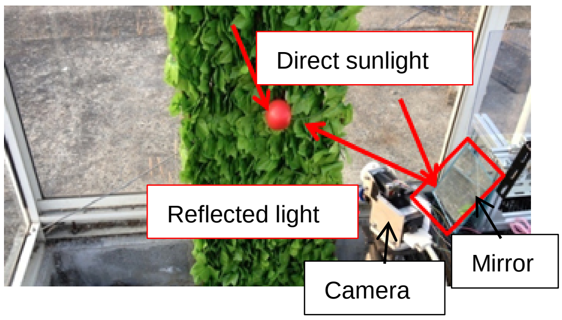
Fig. 1 Images of the experimental fruits

2. Simulation experiment

The simulation was conducted in a laboratory greenhouse located on the roof of a building in Kyoto University (size: 270 cm (Length) × 130 cm (Width) × 250 cm (Height)). The greenhouse was built with glass walls in a metal frame which may cause halation on tomato surfaces. Figure 2 shows the experimental setup for the simulation test. The distance between camera and tomato was 300 mm. A wall constructed from plastic leaves was used as the background. The images were acquired on May 28th, 2012, from 15:00 ~ 16:00. The solar altitude was then from 47.57 ° to 35.30 °. The solar azimuth was from -84.14 ° to -93.05 ° (south is 0 ° and southwest is negative degree). In the simulation, sunlight came from the southwest. One mirror was set on east side of the tomato such that the sunlight itself and the reflected light from the mirror caused two halation areas in the images.



(a) Top view of simulation setup



(b) Simulation experiment

Fig. 2 Simulation experiment setup

3. Greenhouse experiment

The greenhouse experiment was conducted at the National Institute of Vegetable and Tea Science, Aichi Prefecture. The setup of greenhouse experiment for the tomato clusters is shown in Fig. 3. Images were acquired on Dec 8th, 2009. The image acquisition time was (1) 12:00 – 12:12, (2) 14:12 – 14:38 and (3) 15:05 – 15:22 for cluster 1, 2 and 3. The solar altitude was (1) from 32.18 ° to 31.95°, (2) from 22.67 ° to 19.31 ° and (3) from 15.44 ° to 12.83 °. The solar azimuth was (1) from -3.87 ° to -7.12 °, (2) from -36.52 ° to -41.83 ° and (3) from -46.94 ° to -49.96 °. The distance between camera and tomato clusters 1, 2 and 3 were 226 mm, 200 mm and 335 mm, respectively. The arrows in Fig. 3 indicate the optical path for three tomato clusters. Due to sunlight and the light reflected from the plastic wall of the greenhouse, 3 (Fig. 1(b)), 3 (Fig. 1(c)), and 5 (Fig. 1(d)) halation areas could be observed on surface of respectively the tomato cluster 1, 2, and 3, as shown in Fig. 1. The areas marked by green and blue box in Fig.1(b), Fig.1(c), Fig.1(d) correspond to halation caused by direct sunlight and reflected light, respectively.

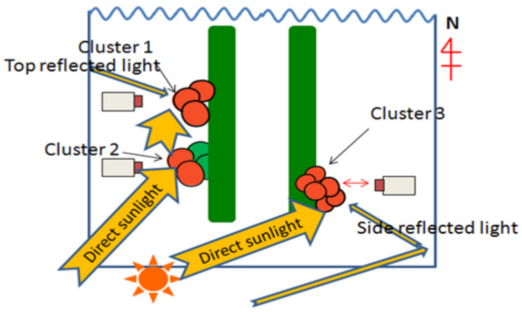


Fig. 3 Greenhouse experiment setup

III Measurement equipment and Methods

1. Image acquisition system

Figure 4 shows the image capturing system for the experiments. A CCD camera (VCC-8350CLTS, CIS CO.,Ltd, RGB signal, resolution: 512(H) × 480(V), frame rate: 60 fps) with 6 mm lens and an image capture board (MTPCI-TL, Micro-Technica) installed in a PC was used to capture tomato images. The camera parameters (shutter speed, gains, white balance) were adjusted by software for the different illumination intensities and color temperatures. A PL filter (with a blue gear diameter: 40 mm, number of teeth: 51, pitch: 2 mm) was set in front of camera lens. A stepping motor (CFK525BP2, ORIENTAL MOTOR CO., Ltd, rotational speed: 60 rpm) (with a white gear diameter: 40 mm, number of teeth: 51, pitch: 2 mm) was mounted on the camera. Pulses generated by PC drive stepping motor with subdivided driving to rotate the PL filter with one degree steps. Tomato images can be acquired with different rotational angles of PL filter. After the adjustment, the parameters of camera were set as: F number is 1.2; shutter speed is 1/2000 s; gain is 150 ~ 180.

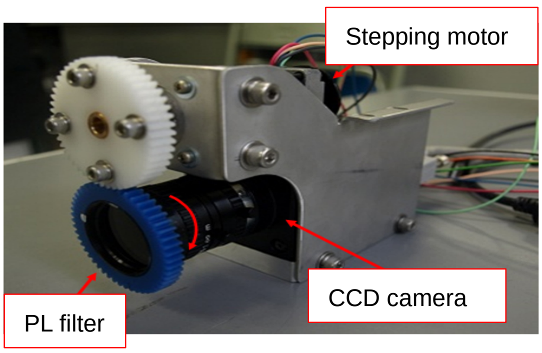
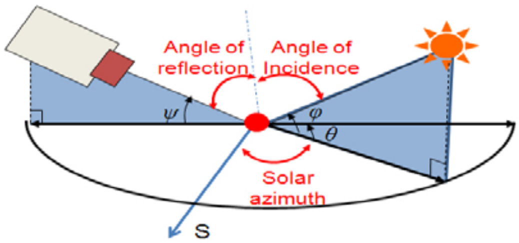


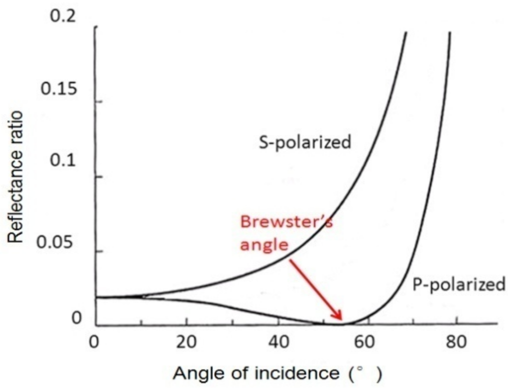
Fig. 4 Image acquisition system

The halation is regarded as light synthesized of *P*-polarized light (the component of the electric field parallel to plane of incidence) and *S*-polarized light (the component perpendicular to plane of incidence). Figure 5(a) shows schematic diagram for angle of incidence and Figure 5(b) shows the relation between angle of incidence and reflectance ratio of polarized light. The angle when the P-polarized light reflectance ratio becomes 0 is called Brewster's angle (around 55°). Since *S*-polarized light increases monotonically and shows higher ratio than *P*-polarized light anytime, reduction of *S*-polarized light makes less halation. Thus if PL filter can block the *S*-polarized light when angle of incidence is Brewster's angle, halation can be eliminated. Based on this principle, Watanabe *et al*., (2010) proposed a method to calculate the rotation angle by solar azimuth: θ; solar altitude: φ; camera orientation: ψ. the rotational angle γ of PL filter which can minimize halation can be calculated by:

$$\gamma = \tan^{-1}\left(\frac{\sin\theta\cos\varphi}{\cos\theta\cos\varphi\sin\psi + \sin\varphi\cos\psi}\right) \qquad (1)$$



(a) Schematic diagram for angle of incidence



(b) Relation between angle of incidence and reflectance ratio

Fig. 5 Halation minimizing method by using Brewster's angle

Since the multiple halation areas in one image cannot be minimized simultaneously with one rotational angle of the

PL filter, images with different rotational angles were acquired. Previous research (Aibara, 2006) found that halation started to appear on tomato surface after rotating PL filter 7 °, which means the rotational step must be less than 7 °. In this study, images were acquired with 5 ° rotational step intervals from 0 ° to 180 ° (for a total of 36 images acquired per cluster) both in the simulation and greenhouse experiments.

2. Image processing method

Thirty six images were captured per each cluster with changing the angle of the PL filter. As the result, the area where the halation is small was different by the angle of the PL filter. Therefore, when the non-halation part in the sequence of 36 is extracted and combined into one picture, then this result should contain the smallest halation area. Figure 6 shows the proposed algorithm to get this high quality resulting image. The approach is to combine the darkest pixels (dark green boxes in Fig. 6) from the different images. As shown in Fig.6, the resultant image was composed of darkest pixels among 36 images. The darkest pixel was selected by the average value of ((R +G +B)/3). Then the values of R, G and B were substituted into the result image.

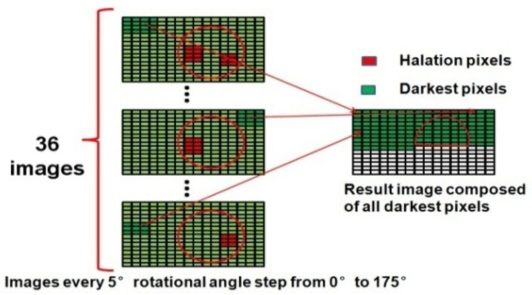


Fig. 6 Pictorial representation of the algorithm to combine 36 images into result image with darkest pixels

In order to analyze the colors of halation parts more accurately, the images were converted from RGB model into HSI model, which is claimed to be the closest approximation to human interpretation of colors. In this experiment, a triangular pyramid model was used and its calculation equations are shown as (2) – (5) (Gonzalez and woods, 1992):

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases} \quad (2)$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{\frac{1}{2}}} \right\}$$

$$s = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)] \quad (3)$$

$$i = \frac{1}{3 \times 255}[R+G+B] \quad (4)$$

$$S = s \times 100;\ I = i \times 100 \quad (5)$$

The R, G and B are normalized value in the range of [0, 1]. To make “Saturation” and “Intensity” easy to interpret, they are multiplied by 100. So the H (Hue), S (Saturation) and I (Intensity) are in the range of [0,360], [0,100] and [0,100], respectively.

3. Halation extraction method

To evaluate the performance of this method, the halation area on the tomato surface in each image must be extracted from the background. In previous research, Nishiwaki *et al.*, (2006) used S value (Saturation) of HSV model to define halation. He defined the halation area in a coffee plant image by a Saturation threshold of 128 (saturation range in his experiment was [0,255]). In the present study, a halation extraction method by using normalized image was proposed: (1) The original image was normalized by:

$$r = R/\sqrt{R^2+G^2+B^2} \times 255 \quad (6)$$

$$g = G/\sqrt{R^2+G^2+B^2} \times 255 \quad (7)$$

$$b = B/\sqrt{R^2+G^2+B^2} \times 255 \quad (8)$$

where r, g and b represents normalized value of red, green and blue components, respectively. (2) The halation areas were extracted with threshold: $r > 140$ AND $105 < g < 170$ AND $80 < b < 170$ AND $R > 80$. (3) The halation areas on tomato surface in original image were marked by blue color.

IV Results and Discussion

1. Captured images with different rotational angle

Figure 7 shows images of four sample types captured using different rotation angles. Each row of images is for one cluster, the columns are for different rotational angle. The number after rotational angle indicates the halation pixels number extracted in each image. The best rotational angle was calculated by the method described in (Watanabe *et al.*, 2010). The first image of four images of each material shows the most halation minimized result by direct sunlight and the PL filter rotational angle. This rotational angle was close to the calculated best rotational angle. The second image of four images of each material shows the most halation maximized result by direct sunlight when PL filter rotational angle was around 90°. The third and fourth images of four images of each material show the most halation minimized and maximized result by reflected light from the structure. Theoretically, the angle change between minimum halation area and maximum halation area should be 90°. However, sun’s position changed during image acquisition procedure, so that an error of about 10°

occurred. However, even when the PL filter was rotated to near the theoretically best angle, halation still cannot be completely reduced. Multiple halation areas caused by sunlight and reflected light appears alternately. The worst situation appeared for cluster 2, where halation areas were not reduced effectively even for the PL filter rotated to the best angle.

75 ° (269) 175 °(1574) 15 °(1203) 95 °(1423)

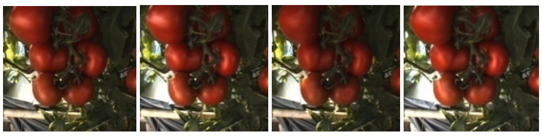
(a) Material 1 (Best angle: 69.78 °)

130 ° (892) 35 ° (3326) 0 ° (2428) 95 ° (3018)

(b) Cluster 1 (Best angle: 140.59 °)

165 ° (959) 75 ° (1128) 120 °(1014) 30 °(1123)

(c) Cluster 2 (Best angle: 159.38 °)



140 °(856) 70 ° (1977) 160 °(1317) 0°(2238)

(d) Cluster 3 (Best angle: 135.97 °)

Fig. 7 Captured images with four different PL filter rotational angles, theoretically the best rotational angle, and the halation area size.

2. Halation elimination result

Figure 8 shows the halation pixel counting result in captured images and in combined result images. The first image of four images of each material shows the result in simulation experiment where the first two images in Fig.8 are the images containing most halation pixels for each cluster. The worst image in simulation counted 1624 pixels as the halation area on the tomato surface (in total the fruit region had 10064 pixels). Compared with the captured image, no halation pixel can be detected in combined image, indicating that both halation areas are successfully eliminated.

Figure 8(b), (c) and (d) show the results in the greenhouse experiments. The halation pixels number in combined image of cluster 1 was significantly reduced. Compared with the worst quality image which contains 3326 halation pixels, result image only contains 734 halation pixels. The remaining halation pixels were mainly caused by reflected light from behind the camera. All the halation pixels caused by direct sunlight and reflected light from the top wall were completely eliminated. However, one failed example of halation elimination was observed from tomato cluster 2. The halation areas were not reduced effectively in combined image especially for the strong halation spot. This halation spot was caused by direct sunlight from behind the camera and it cannot be reduced even with the PL filter changing to a different angle. In the combined image of cluster 3, several halation areas were completely eliminated. This confirms that the proposed method is reasonably feasible for halation elimination in practical applications.

The result of tomato cluster 1 and 2 shows that halation caused by light from behind the camera could not be eliminated by the proposed method. The reason for this problem is that halation is composed of *P*-polarized light and *S*-polarized light. The PL filter was only used to eliminate *S*-polarized light. *P*-polarized is eliminated when angle of incidence is around Brewster's angle. When the light comes from behind the camera, the angle of incidence for the tomato is much lower than the Brewster's angle.

For example, when acquiring images of cluster 2, the original setup is shown as left image in Fig. 9 (solar azimuth was 33.6° and camera faced to east) the angle of incidence was less than 30° so the halation spot could not be reduced in all images. One solution for this problem is changing the orientation of camera as in the right part of Fig. 9, where the angle of incidence was around 55°. A possible optimum position is proposed from the calculation: if the angle between the light source incident vector and the camera viewing vector is around 70°, then the angle of incidence is for the tomato is around 55° regardless of the changing solar altitude. When using this halation reduction method, the camera position should be optimized to make the angle of incidence near Brewster's angle. According to experimental results here, halation can be eliminated when the angle of incidence is in the range: [47°, 57°]. For practical use, because the sun moves from east to west everyday, the camera could be set to face east in the morning and to face west in the afternoon to avoid halation generated by light from behind the camera.

Before (1,624 pixels) After (0 pixels)

(a) Result of Material 1 (angle 130 °)

Before (3,326 pixels) After (734 pixels)

(b) Result of Claster 1 (angle 135°)

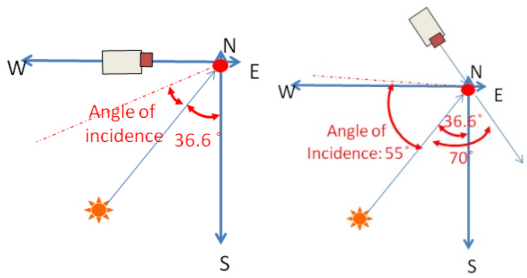
Before (1,209 pixels) After (861 pixels)

(c) Result of Claster 2 (angle 0°)

Before (2,960 pixels) After (0 pixels)

(d) Result of Claster 3 (angle 30°)

Fig. 8 Halation counting result in worst captured image and result image



(Original setup) (Proposed setup)

Fig. 9 Original and proposed setup for acquisition of tomato cluster 2

3. Color representation

Figure 10 shows the hue-saturation distribution found on the single tomato (material 1) in the image taken with the PL filter angle at 130°. At this PL filter angle of 130°, the image contains the most halation pixels number among all the captured images and in combined result image. The Figure 10 also gives the hue-saturation distribution of the combined result image. The captured image had many pixels with saturation value less than 40 when compared with the combined result image. This indicates that the color was not properly represented on these halation pixels. It is seen that all saturation values of tomato pixels in the combined result image are above 40. In addition, the standard derivation (SD) of hue and saturation was smaller in the combined result image. Hence, this method removes halation without losing information of the tomato color.

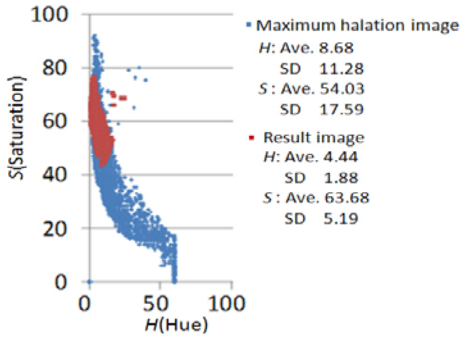


Fig. 10 The hue-saturation distribution of tomato pixels in the laboratory experiment

V Conclusion

A reduction method for multiple halation areas occurring on images taken in a greenhouse was developed by picking the darkest pixels in images taken with different PL filter rotational angles. Multiple halation areas could be eliminated under the condition of a certain angle of incidence. Distribution of hue and saturation values in a combined result image indicated that color representation in this combined result image was much improved. In future studies, usability of Brewster's angle to minimize multiple halation areas in image acquisition in greenhouse needs to be investigated. Two possible solutions are: camera orientation change (location variation) or image acquisition schedule optimization.

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