Feasibility of using Polarizing Filters to reduce Halation Effects during Image Acquisition in the Field

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Abstract. Machine vision is widely applied in automated inspection and monitoring systems. One of the most important components of machine vision systems is illumination. To remove and avoid halation on images, indirect lighting devices such as diffusers or domes with several lamps have been studied for post-harvest operations. However, it is difficult to control natural illumination in the field, because sunlight constitutes a point source, which causes shiny and shady parts on objects, and its intensity fluctuates with time. In addition, most parts of plants have a cuticular layer, causing halation effects, which reduce image quality.

In this study, a tractor-mounted imaging system was developed to acquire high quality crop images. The system consisted of a frame box (1m X 1m X 1m), covered by a polarizing film (1m X 1m), 2 identical cameras in the box, and a PC with two image capture boards. All 4 sides of the frame box were covered with black curtains so that only polarized sunlight could enter. Polarizing filters were also fitted to the lens of one camera to compare 2 images from the cameras at a time. In experiments, images of coffee plants were acquired under varying sunlight conditions. From the results, it was observed that the polarizing filtering technique was capable not only reduce by 97% of halation on the surfaces of leaves but also of achieving high accuracy color representation of the leaves.

Keywords. polarizing filter, sunlight, machine vision, illumination, halation, image
1 Introduction

The outdoor environment poses unique challenges for the image capturing devices essential to agricultural automation. Due to limited energy availability, it is often impractical to bring artificial lighting to the field, which leaves natural sunlight as the only alternative light source. The use of natural sunlight limits the control over lighting conditions and as a result, halation areas of excessive light intensity as well as shadow areas, both of which impede capturing the original leaf color, were often observed in field images of leaves. Additionally, sometimes those areas overlap on areas of interest that makes the algorithm complex and limits the application realm.

It is well known that polarizing filters both in front of the light source and the camera are useful to reduce halation effects. This was used in earlier research in indoor environments for the purpose of fruit grading (Aleixos et al., 2002, Nakano et al., 1992, Nakano et al., 1997, Njoroge et al., 2002), but hasn't yet applied in an outdoor environment.

2 Halation reduction on plant leaves using polarization filters

![Diagram](image.png)

Figure 1. Principle of reducing halation by applying two perpendicularly oriented polarization filters.

Specular reflected light on the surface of plants is responsible for high intensity areas in the image, which is commonly referred to as halation. Figure 1 shows how using a pair of polarizing filters can reduce the halation. The first polarizing filter, allows only horizontally oriented light to reach the plant surface. This light reflects on the plants in two ways. One part reflects specularly on the surface of plant called the cuticular layer. This light does not contain plant color, and causes halation. The other part of light penetrates into the plant body, and is partially absorbed by molecules such as chlorophyll in parenchyma cells, which cause the reflected light to be colorized. This light leaves the plant in a diffused form.
The second polarizing filter, which passes only the vertical component of light, is set in front of a camera. Since specularly reflected light doesn't have vertical component, this light cannot pass the second filter. The diffuse reflected light has a vertical component and reaches the camera.

3 Materials and methods

For experiments, a tractor-mounted aluminum-frame box (1 m x 1 m x 1 m) was built (Figure 2). A polarizing film (Edmund Optics, Linear Polarizing Film, 1m x 1m) was used to cover the top face of the box, and the side faces were covered with black curtains such that only polarized light could enter. Two cameras (CIS, VCC-8350CL) with lenses (Optart, OM6NC) were installed inside the box. One of the cameras was fitted with a polarizing filter so that two images with and without polarizing filter could be taken simultaneously. The object distance of the identical cameras was set to 300 mm, the focal lengths were 6 mm and size of the CCDs was 1/2 inch, so object of approximately 320 mm x 240 mm size could be captured. The number of pixels output from the cameras was 648 x 492, hence one pixel corresponded to an approximate area of 0.5 x 0.5 mm. Image capture boards (Micro-Technica, MTPCI-TL) were installed in a PC. The cameras and imaging board communicated through a digital link (CameraLink, Automated Imaging Association), which prevented deterioration of data. Image capturing software controlling shutter speed, gain, and white balance of the cameras was provided by SI-Seiko.

![Figure 2. Image capturing box with polarized cover and curtains at the sides (one side shown).](image)

To remove the halation from the plant leave images, the first and second polarizing filters need to be set to proper angles depending on the scene. Images of a shiny ball were taken inside the imaging box, while adapting the second filter angle to minimize the halation.

To equalize the characteristics of the two cameras with and without polarizing filters, a color reference (Macbeth, P37-756) was used. The reference was placed on a platform in the box and apertures of both cameras were adjusted using a color patch (#22 neutral 5, this correspond to N 5/- in Munsell color system) so that the average Green level of the patch would be captured as an identical value. Subsequently, the white balance of each camera was adjusted so that levels of Red and Blue color resulted in the same value as Green.
A coffee plant was used in the experiment since they have very glossy leaves as a worst-case scenario. Images were acquired at August 12, 2005, in the time interval from 10 AM to 2 PM to maximize the amount of solar radiation entering the box. The illuminance at clear sky and pallid sky conditions were around 100kLux and 50kLux respectively. Three conditions were applied to the imaging process, 1) the side faces of the box were completely covered, 2) only the upper half of the side faces were covered and 3) all of the side faces were completely opened.

The coffee plant leaves were cropped manually from the background from images with and without the polarization filters. The points, whose values of any color were less than 25 or more than 250, were extracted as under- and over-exposed areas. The color model of the images was changed from RGB (Red [0:255], Green [0:255], Blue [0:255]) model to the HSV (Hue [0:360], Saturation [0:255], Value [0:255]) model using MATLAB®, (MathWorks, Inc). The halation areas were extracted using a Saturation threshold of 128.

The same leaf areas were imaged according to the following methods: (A) with polarizing filter, (B) without polarizing filter, (C) without polarizing filter and masked halation areas. The average values and the Standard Deviations (SD) of extracted three leaf images in both the RGB model and the HSV model were calculated and the values were compared.

4 Results and discussion

4.1 Halation elimination

Figure 3 shows captured coffee plant images with the side faces of the box completely closed. As is clear from the left images in figure 3, there are many halation areas when the second polarizing filter was not used. The right side images show that, with the second polarization filter in place, few halation areas remain. Figure 4 and figure 5 show the distribution of detected irregular areas; background, under-exposed areas, over-exposed areas and the area where Saturation <128 and shown as blue, light blue, pink and red areas respectively.

Firstly, the ratios of under-exposed areas (shown as light-blue) to the whole coffee plant areas were near identical (0.6% with the filter, 1.2% without the filter), implying that the characteristics of the two cameras were very similar.

Secondly, the ratios of over-exposed (pink) areas to the whole coffee plant areas were 0% with the filter and 3.5% without the filter, it was assumed that some parts of the halation areas reflected the sunlight strongly and the brightness of those pixel value exceeded 250.

Thirdly, the ratios of Saturation<128 area to the whole coffee plant were 1% with the filter and 12% without the filter.

Three areas of interest were distinguished:

A. Areas near over-exposed areas, which were assumed to cause halation.

B. Areas at the leaf edges where Saturation reduced to less than 128 since the value of the pixels appeared to be a mixture of lights from one leaf and other leaves, one leaf and background, or a leaf in a sunny and in a shadow place. These areas do not exhibit halation, but they were too noisy and subsequently removed from the analysis.

C. Areas in the shadow of upper leaves, which do not look like halation areas. However those areas are dark enough to be affected by indirect lights from the sky or buildings which causes halation in shadow areas.
Image without second polarization filter  Image with second polarization filter

**Figure 3.** Captured image (at 100kLux, side faces of the box completely covered)

**Figure 4.** Cropped leaves from the images, (Background: Blue, Under-exposed areas: Sky-blue, Over-exposed area: Pink, Halation area: Red)

**Figure 5.** Detected ineffective areas
As a result, ineffective areas were 1.6% and 16.7% with and without the polarizing filter respectively, therefore the image capturing system with 2 polarizing filters was effective in both sunny and shadow areas. In addition, Saturation was regarded as a good measure to remove halation areas from captured images.

4.2 Effect of lightproof curtains

![Figure 6. Relationship between light shielding levels and halation areas](chart)

Figure 6 shows the relationship between light shielding levels of side face of the box and halation areas. The polarizing filters reduced halation areas effectively, however when all side faces of the box were completely opened and the illuminance was 50kLux, the ratio of halation areas to the whole coffee plant areas was nearly 15%. The cause was concluded as overcast skies, which increased the influence of light entering the box through the side faces compared to light entering through the polarized top face. With all sides opened at an illuminance of 100kLux, the ratio was almost 5%, which corroborates this conclusion since now the sunlight entering the box through the polarized top dominates the illumination.

When the side faces were completely and half closed, the ratios of halation areas to the whole coffee plant area were less than 1.5% and 3% respectively. The latter number represents a good compromise between halation reduction effectiveness and handling during field measurements.

4.3 Color representation

Figure 7 shows the distribution of pixel values in both RGB and HSV models within a single leaf, extracted from the images shown in Figure 3. The three columns represent (A) image using a polarization filter, (B) image without a polarization filter and (C) image without a polarization filter where halation areas were manually removed. Since halation areas were removed, the cropped area of the image was smaller (79%) than for the other two images.

In the RGB model (middle row) for the image without polarization filter (B) the average values of each color were consistently higher than for the image with polarization filter (A). The reason was that the image without polarization filter contains the specular reflected light from the leaf, which also led to an increased SD of the image without polarization filter. By manually
removing the halation areas (C), as expected, the average color values reduced to values close to the image with polarization filter (A), however the SD was larger due to the specular reflected light still being contained on the image with halation areas removed (C).

In the HSV model (bottom row) the Hue represents color. The Hue values among the three images were similar (indicating a consistent average color) but the SD was markedly different. This means that a comprehensive color of a leaf obtained without polarization filter (B)
can be obtained, but local colors from the same region may be erroneous. On the other hand, the SD of the image with polarization filter (A) was small, implying that a local color can be obtained from this area. The SD of the image with halation areas removed (C) was slightly larger than that of (A), which was caused by the specular reflected light, which was contained in the image.

5 Conclusions

A tractor-mounted imaging system with 2 polarizing filter was developed to acquire high quality crop leaf images.

1) Saturation of the HSV color model as a threshold allowed for extract halation areas. Thus, saturation was regarded as a good measure to remove halation areas from captured images.

2) Coffee images with and without polarizing filters were taken using the system to investigate the effect of the polarizing filters to remove halation areas. Ineffective areas, which were cropped by the intensity of RGB and Saturation, were 1.6% and 16.7% with and without the polarizing filter respectively. Additionally, the filter could remove the halation area in both sunny and shadow areas. Therefore, polarizing filters were shown to be good tools to remove halation in outdoor leaf images.

3) Even if lower half part of the side face of the image capturing box was opened, it was possible to get images with virtually no halation. This represents a good compromise between halation reduction effectiveness and handling during field measurements.

4) When 2 polarizing filters were used at optimally adjusted angles, the SD of Hue became substantially small, thus the polarizing filter approach provided a good representation of coffee leaf color.

6 References


