Reduction of Variable Illumination Effect on Pixel Gray-levels of Machine Vision

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Abstract: This study was carried out to develop methods of reducing the effect of solar illumination on pixel gray-levels of machine vision for agricultural field use. Two kinds of monochrome CCD cameras with manual and auto-iris lenses were used to take pictures within a range of 15 to 120 klux of solar illumination. A camera having more precise automatic control functions gave much better result. Four kinds of indices using pixel gray-level of the 99% white DRS (diffuse reflectance standard) as a reference were tried to compensate pixel gray-levels of an image for variable illumination. Coefficients of variation of the indices within a range of illumination were used as a criterion for comparison. The study concluded that an index of (A+B)/A, where A is gray-level of the 99% DRS and B is gray-level of the tested material, gave the best consistency in the range of solar illumination.
Keywords: Variable Illumination, Index for Compensation, Pixel Gray-level, Machine Vision

Introduction

Machine vision is a useful sensor for various agricultural operations and is expected to be used for agricultural field operations. An image of an object captured by a machine vision system is not only a function of the optical properties of the object surface but also a function of the spectral intensity of the illumination and optical response of the imaging sensor used. In order to extract optical property of an object surface using machine vision, the major property of illumination kept constant or, if it can not be kept constant, the effect of illumination should be eliminated as much as possible. Under sunlight where the property of illumination is continuously varying, it is necessary in most of case to reduce the effect of solar illumination. Researchers have developed various techniques to accomplish this. Several indices of chromatic coordinates using color machine vision under variable lighting conditions were designed by Woebbecke et al. (1995) to identify weeds in field. They tested the indices under outdoor solar radiation to select well performing indices. Thai et al. (1998) tried a small Teflon reference target and a black and white Spectralon (reflectance standard) to control the reference white gray value for a spectral imaging system of dynamic scenes in outdoor conditions. An environmentally adaptive segmentation algorithm (EASA) for outdoor·field plant detection was developed by Tian and Slaughter (1998), especially to adapt a machine vision to varying solar lighting conditions. The study was continued by Steward et al. (1999). They tried to characterize solar lighting variability and detect and track the variability for real-time operation of the EASA in order to adapt to lighting change. They measured illuminance and chromaticity of daylight to determine how light varies as a function of time and time of day. Kim et al. (2001) developed an algorithm to compensate for non-linear responses in reflectance measurement of a known object under solar illumination using a spectral imaging system with a sensor for measuring ambient illumination. The algorithm took solar zenith angle as a key variable for the compensation. Spectral intensity of solar illumination varies mainly due to variation of overcast clouds and the sun's position in the sky (Steward et al., 1999). In order to eliminate the effect of solar illumination on machine vision, those parameters should be precisely quantified. However, the job is very complicated. Pixel resolution of a frequently used machine vision system is 8 bit, and if the resolution is considered, it would be more practical to use a simple indirect method to reduce the effect of solar illumination by applying the technique experienced by Thai et al. (1998). On the other hand, recent hardware and software of CCD cameras have developed to a highly sophisticated level to adapt to a wide range of lighting. Details of this develop-

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ment are not open to the public, but known that the automatic control functions of the cameras were upgraded. Therefore, performance of newly developed cameras needs to be tested from a viewpoint of reducing the effect of outdoor solar illumination.

The objective of this study was to develop methods for reducing the effect of solar illumination on pixel gray-levels of machine vision for agricultural field use and to evaluate their performance. To this end, different camera models were tested and compared with each other. Several indices using gray-levels of the 99% white diffuse reflectance standard (DRS) as a reference were also tried to compensate pixel gray-levels for variable illumination.

Materials and Methods

This study consisted of two parts. The first part compared the consistency of pixel gray-levels of images taken by the selected hardware at variable outdoor lighting conditions. The second part involved the development of a method to modify pixel gray-levels of an image to compensate pixel gray-levels for variable outdoor illumination.

1. Equipment

Two monochrome CCD cameras, model BCE-142F and BCE-341IA (Unimo Technology, Korea), were used. Clear differences in the performance of the cameras were not evident according to their specifications but the manufacturer of the cameras claimed that the BCE-341IA camera was relatively new, having more precise automatic control functions than the BCE-142F. Both cameras could install manual or automatic iris control (manual or auto-iris) lenses. The BCE-142F camera was tested with a manual lens (Avenir, Japan) of F1.3 (f=8 mm) and an auto-iris lens (Avenir, Japan) of F1.2 (f=8 mm). The BCE-341IA camera was only tested with the auto-iris lens. The cameras and the lenses were selected as they proved to have good consistency of gray-level of pixels in laboratory experiments. A frame grabber, Meteor-II/MC (Matrox, Canada) having a resolution of 640×480 pixels, was used to capture, digitize, store and process the image data transmitted from the cameras. A lux meter (DX-100, Takemura Elec., Japan) was used to measure outdoor solar illumination.

2. Methods

In order to compare the consistency of pixel gray-levels of images taken by the selected hardware at variable outdoor lighting conditions, pictures were taken using the cameras mounted at a height of about 60 cm with the angle between the axis of the camera lens and the horizontal set at 90° under outdoor solar illumination in a range of 15 to 120 klux. A diffuse reflectance standard (Labsphere Co. U.S.A.) of 20% reflectance, color papers, a wood plate and a lump of dried soil were used as test materials. Images of the test materials were taken together. The experiment was replicated twice.

Normally machine vision is designed to have the maximum and 0 of gray-levels for white and black surfaces respectively and vary proportionally to reflectance of surface. However, real pixel gray-levels for white and black surfaces vary according to intensity of illumination and the rate of variation is a function of illumination as a consequence. Moreover the rate is not exactly the same over the entire range of the gray-level even at a certain illumination.

The study to reduce the effect of variable illumination on pixel gray-levels was performed with assumptions that pixel gray-levels for white and black surfaces do not change under the same illumination condition and the rate of variation of the gray-levels to reflectance of surface keep constant also. With the assumptions, a diffuse reflectance standard of 99% reflectance (standard white) was chosen as a reference of reflectance in order to describe pixel gray-levels in a relative form through normalization. Index 1, B/A where A is pixel gray-level of the standard white and B is pixel gray-level of an image of test material, is the simplest form of normalization. If the rate of variation is exactly the same over the entire range of the gray-level, the other index is not necessary. In order to considerate the nonlinearity while the relative form of index be kept, variables of (A+B) and (A−B) were chosen. With the variables, 3 other indices were designed as shown in Table 1.

The compensated pixel gray-levels of images of the test materials were obtained using the equations for each index. Coefficients of variation (CV) of the modified pixel gray-levels were determined and used as a criterion of the consistency (i.e., CV for the indices were compared with each other to select an index which resulted in the smallest value).

Table 1 Four indices to compensate variable illumination effect on pixel gray-levels of an image using a 99% diffuse reflectance standard where A is pixel gray-level of the 99% DRS and B is pixel gray-level of an image

Index 1 = B/A	Index 3 = (A+B)/A
Index 2 = (A-B)/(A+B)	Index 4 = (A+B)/B

Results and Discussion

1. Performance of a BCE-142F Camera with a Manual Lens

Average pixel gray-levels of images of the test materials from the pictures taken by the BCE-142F camera equipped with a manual lens were determined and plotted with respect to the intensity of solar illumination. As shown in Fig. 1, the original pixel gray-levels were affected considerably by the intensity of solar illumination.

The four indices of pixel gray-levels for each test material were obtained to compensate for variable solar illumination. Fig. 2 shows variation of the four indices obtained from images of DRS of 20% reflectance as an

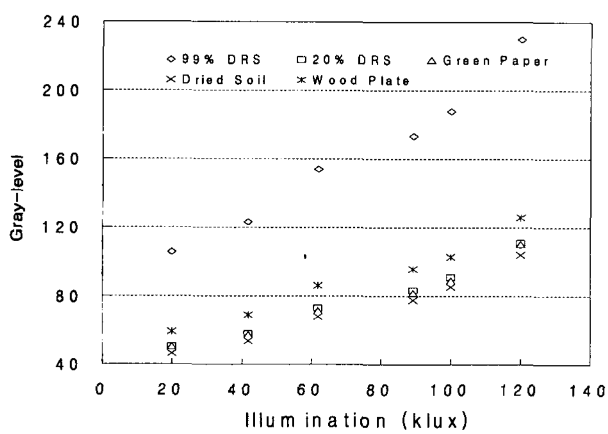

Fig. 1 Variation of pixel gray-levels of image of the tested materials at variable illumination conditions- from pictures taken with a BCE-142F monochrome CCD camera with a manual lens.

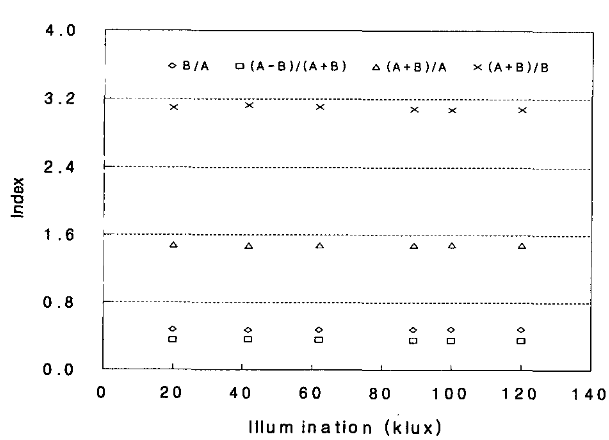

Fig. 2 Variation of the four indices obtained from the pixel gray-levels of 20% DRS at variable illumination- from pictures taken with a BCE-142F monochrome CCD camera with a manual lens.

Table 2 Coefficients of variation of the modified data by the 4 indices to reduce illumination effect using the 99% DRS as a reference-images taken with a BCE-142F camera with a manual iris lens

Repli.	Materials Tested	Index 1	Index 2	Index 3	Index 4
1st	20% DRS	6.09	8.46	**2.05**	4.32
	Color Paper	3.90	5.51	**1.33**	2.53
	Dried Soil	6.13	9.37	**2.14**	4.15
	Wood Plate	3.97	5.69	**1.36**	2.71
2nd	20% DRS	3.95	7.43	**1.48**	2.44
	Color Paper	5.66	11.08	**2.15**	3.45
	Dried Soil	6.45	8.84	**2.18**	4.19
	Wood Plate	3.89	8.24	**1.15**	2.35

example. The indices show almost constant values with very little variation in the range of solar illumination tested.

CV of the modified pixel gray-levels for each index of the test materials were determined and shown in Table 2. Among the 4 indices to modify pixel gray-level, index 3 resulted in the smallest variation at the variable solar illumination for most of test materials and the same result was obtained from two replications of the experiment as shown.

2. Performance of a BCE-142F Camera with an Auto-iris Lens

Average pixel gray-levels of images of the test materials taken with the BCE-142F camera equipped with an auto lens were determined and analyzed using the previous method. The pixel gray-levels of the test materials varied as the intensity of solar illumination changed similar to the way shown in Fig 1. The magnitude of the variation was a little less than that of pixel gray-levels of images taken using the camera equipped with a manual lens. However, the magnitude of the variation was still considerable.

The four indices of the pixel gray-levels for each test material were obtained to compensate for variable solar illumination. The indices showed almost constant values with very small variation in the experimented range of solar illumination as shown before.

CV of the modified pixel gray-levels for each index of the test materials were determined and shown in Table 3. Among the 4 indices to modify pixel gray-level, index 3 resulted in the smallest variation in the two replications of the experiment, similar to the experiment using a BCE-142F camera equipped with a manual lens.

Table 3 Coefficients of variation of the modified data by the 4 indices to reduce illumination effect using the 99% DRS as a reference-images taken with a BCE-142F camera with an auto iris lens Coefficients of variation of the modified data by the 4 indices to reduce illumination effect using the 99% DRS as a reference-images taken with a BCE-142F camera with an auto iris lens

Repli.	Materials Tested	Index 1	Index 2	Index 3	Index 4
1st	20% DRS	3.19	4.15	**1.05**	2.17
	Color Paper	8.24	18.54	**3.24**	5.17
	Dried Soil	4.77	7.46	**1.69**	3.14
	Wood Plate	10.37	20.69	**3.95**	6.68
2nd	20% DRS	1.04	2.69	**0.42**	0.62
	Color Paper	6.69	14.28	**2.38**	5.37
	Dried Soil	4.24	5.94	**2.85**	3.50
	Wood Plate	2.98	10.02	**1.97**	3.03

Performance of the manual and auto control modes of the camera lens in reducing the effect of solar illumination on pixel gray-levels were compared by investigating CV values of index 3 obtained from the image of the test materials. The comparison did not revealed any vivid difference between the two lens control modes, however, the auto iris lens showed better performance than the manual lens with the test material of the DRS of 20% reflectance.

3. Performance of a BCE-341IA Camera with an Auto-iris Lens

Average pixel gray-levels of images of the test materials taken using the BCE-341IA camera equipped with an auto lens were determined and analyzed using the previous method. As shown in Fig. 3, the pixel gray-levels were fairly constant without varying as much as the results obtained with the BCE-142F camera. The results imply that selection of camera is important in reducing the effect of illumination on machine vision.

The four indices of the pixel gray-levels were obtained to compensate for variable solar illumination. Fig. 4 shows variation of the four indices obtained from images of DRS of 20% reflectance. As expected from the Fig. 3, the indices show much better consistency than the results from pictures taken with the BCE-142F camera. CV of the indices for color papers #1 and #2 and DRSs of 20% and 99% #1 and #2 reflectance were 2.2%, 2.8%, 3.4% and 2.9%, respectively, which are about the same as the CV of index 3 of pixel gray-level obtained from pictures taken with the BCE-142F camera.

CV of the modified pixel gray-levels for each index of the test materials were determined and shown in Table 4. Among the 4 indices to modify pixel gray-level, index 3 resulted in the smallest variation in the two replications of the experiment, identical to the experiments using a BCE-142F camera. As a consequence, it is clear that index 3 is the most effective among the 4 indices in reducing the effect of variable illumination for application of machine vision under outdoor field conditions.

CVs of the index 3 for DRS of 20% reflectance and color paper could be reduced to 0.99% and 0.21% by using the BCE-341IA camera. These are considered to be ranges acceptable for outdoor field measurement.

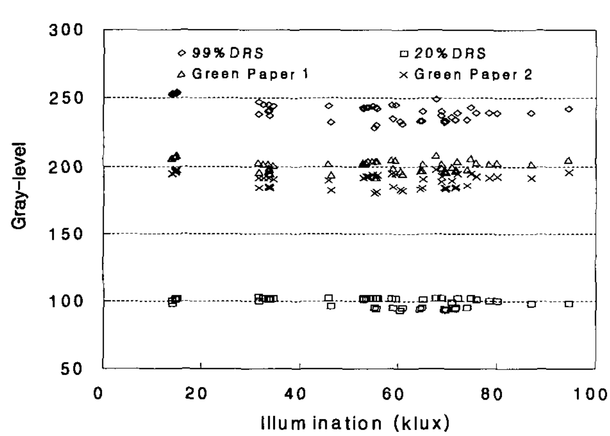

Fig. 3 Variation of pixel gray-levels of image of the tested materials at variable illumination conditions-from pictures taken with a BCE-341IA monochrome CCD camera with an auto iris lens.

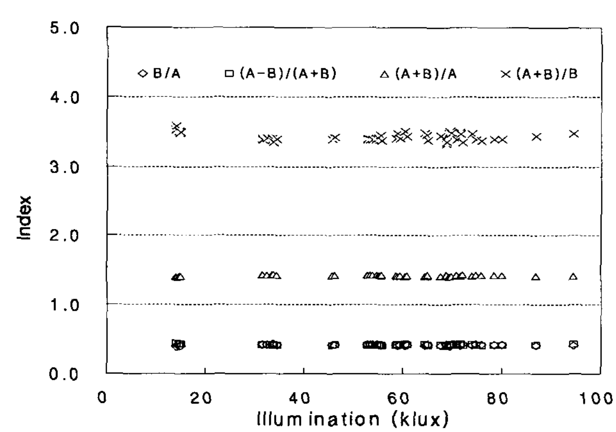

Fig. 4 Variation of the four indices obtained from the pixel gray-levels of 20% DRS at variable illumination-from pictures taken with a BCE-341IA monochrome CCD camera with an auto iris lens.

Table 4 Coefficients of variation of the modified data by the 4 indices to reduce illumination effect using the 99% DRS as a reference-images taken with a BCE-341Ia camera with an auto iris lens

Repli.	Materials Tested	Index 1	Index 2	Index 3	Index 4
1st	20% DRS	4.24	4.18	**0.99**	0.72
	Color Paper #1	0.67	11.74	**0.21**	0.25
	Color Paper #2	2.39	7.92	**0.68**	0.81
2nd	20% DRS	1.61	1.80	**0.27**	0.40
	Color Paper #1	0.68	13.53	**0.21**	0.24
	Color Paper #2	0.60	7.00	**0.18**	0.20

Conclusions

This study was carried out to develop methods of reducing the effect of solar illumination on pixel gray-levels of machine vision for agricultural field use. Two kinds of monochrome CCD cameras with manual and auto-iris lenses were used to take pictures within a range of 15 to 120 klux of solar illumination. A camera having more a precise automatic control function showed much better results. Four kinds of indices using pixel gray-levels of the 99% white DRS as a reference to compensate pixel gray-level of an image for variable illumination were tried. Coefficients of variation of the indices were used as a criterion for comparison. The study concluded that an index of (A + B)/A, where A is gray-level of the 99% DRS and B is gray-level of tested material, gives the best consistency in the range of solar illumination

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