A double image acquisition system with visible and UV LEDs for citrus fruit

Mitsutaka Kurita*, Naoshi Kondo**, Hiroshi Shimizu**, Peter Ling***, Paolo D.Falzea****, Tomoo Shiigi*****, Kazunori Ninomiya*, Takahisa Nishizu******, Kazuya Yamamoto*****

*SI Seiko Co.,Ltd.,
66, Takaoka-cho, Matsuyama, Ehime 791-8036, Japan
E-mail: kurita-m@si-seko.co.jp

**Graduate School of Agricuture, Kyoto University,
Kitashirakawa-Oiwakecho, Sakyo-ku, Kyoto 606-8502, Japan

***Department of Food, Agricultural, and Biological Engineering, The Ohio State University,
1680 Madison Avenue, Wooster, OH 44691, USA

****Faculty of Agricultural Science, Mediterranean University of Reggio Calabria,
Via San Marco 3, Reggio Calabria, Italy

*****Graduate School of Science and Engineering, Ehime University,
3 Bunkyo-cho, Matsuyama, Ehime 790-8577, Japan

******Faculty of Applied Biological Science, Gifu University,
1-1 Yanagito, Gifu 501-1193, Japan

Abstract

There are many types of citrus fruit grading machine with machine vision capability. While most of them sort fruit by size, shape and color, detection of fruit rot remains challenging because their colors are similar with normal parts. Objectives of this research were to investigate if fluorescence would be a good indicator of the fruit rot, and to develop an economical solution to add the rot inspection capability to an existing machine vision fruit inspection station. A machine vision system consisting of a pair of white and UV LED lighting devices and a color CCD camera was proposed for the orange fruit grading task. Since the time lag between the color and fluorescence image captures was short (14ms), it was possible to inspect color, shape, size, and rot of a fruit on the move before it leaves an existing industrial inspection chamber.

Keywords: Fluorescence, Fruit grading, Fruit quality, Machine vision

1. Introduction

Recently, machine vision technology has been applied for commercial grading of agricultural products. The grading system judges agricultural product's color, shape, bruise, and internal qualities automatically. Systems for fruit defect detection using color TV camera[(1)~(4)(6)~(8)], X ray imaging device[(10)~(12)], or near infrared[(9)] have been reported. However, some rotten fruits caused by improper handling could not be detected by vision systems and had to be removed manually. A technology for detecting rotten product automatically is important to reduce labor of grading and to maintain brand reputation.

Uozumi et al.[(13)] reported that the rotten part of citrus fruits includes fluorescence elements. Further, Kondo et al.[(5)] identified flavonoid methyl as one of major fluorescent element in citrus fruits that has an excitation waveband centered at 365nm and emission waveband centered about 530nm and the fluorescent substance detected in the rotten part was not newly created by rotting but was existed originally in the healthy part.

Generally the most type of illumination is used for image processing in the grading facility, is halogen lamp. However the main characteristics of halogen lamp are short lifetime, and high heat. These characteristics are difficult to handle itself in the vision system. Otherwise LED is distributed recently because it has many merits over other lighting sources. For example, it is longer lifetime than halogen lamp and it only needs small electrical power and has high response. Because of its high response, both visible LED and ultra violet LED are used, by flashing another timing momentary each LEDs, same one camera could capture an image for color, bruise, by visible LED and an image for rotten by ultra violet LED, so it does not need to extend the conveyer length in commercial grading facilities.

The instance objective of this research is construction a system which uses white LED and ultra violet LED, which includes one CCD camera that capture both images visible information by white LED and rotten information by ultra violet LED. The energy of fluorescence image is less than the energy of color image. Firstly to investigate wavelength which has maximum sensitivity by minimum ultra violet power, are reported. Secondly to confirm minimum time between visible capturing and rotten information capturing, are described.

2. Material and Methods

2.1 Pre-experiment –Verification for fluorescence reaction by UV LED–

Kondo et al.[(5)] reported that one of the fluorescent substances was flavonoid methyl and it was excited at 365nm wavelength. There are some fluorescent substances are contained in each citrus fruits. Especially, every citrus fruits includes one which the excitation wavelength is about 365 nm, and is one of the strongest reaction in those. As a preliminary evaluation of using a fluorescent imaging system for citrus fruit rot inspection, two model citrus fruits, namely Unshu orange and Iyokan orange were selected and two LED lighting panels were constructed. These two oranges were products of Ehime prefecture in Japan, January 2007. Examples of rotten Unshu orange and rotten Iyokan orange are shown in Fig. 1 and Fig. 2, respectively.

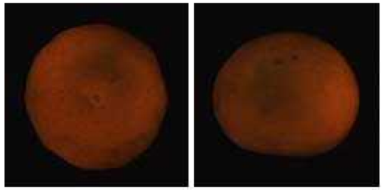


Fig.1 Rotten Unshu oranges

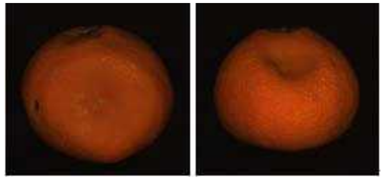


Fig.2 Rotten Iyokan oranges

The constructed lighting panels were shown in Fig.3. Each lighting panel was consisted of 120 LEDs. One was used ultra violet (UV) LED (NSHU550B, Nichia Corporation), which had 365nm of peak wavelength, and the other was white LED (NSPW310BS, Nichia Corporation). The optical characteristics were shown in Tables1 and 2, and the relative emission intensities of the both LEDs were indicated in Fig. 4.

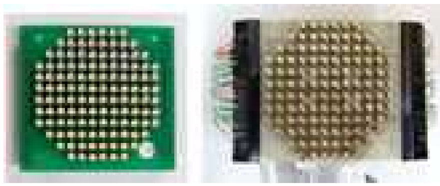


Fig.3 Two lighting devices for the orange fruit image acquisition. A white LED lighting panel (left: Fig. 3a) and an ultra violet (UV) LED lighting panel (right: Fig.3b)

Table 1 Optical Characteristics (White LED: NSPW310BS)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 2 Optical Characteristics (UV LED: NSHU550B)

[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

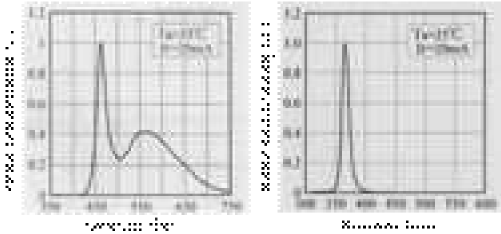


Fig.4 Relative emission intensities of white LED (left) and 365nm UV LED (right).

Fluorescent images of the oranges are shown in Fig.5 (Unshu orange) and Fig.6 (Iyokan orange). In each image, a fluorescent substance on the surface of the rotten part of fruit was excited with 365nm light and caught as whitish pixels. Purple color pixels were halation of LED light reflection because of no PL filter on UV lighting devices. From these images, it was observed that the fluorescent parts had 3-5 times higher grey level than normal parts when they were compared on green component image and that the fluorescent image facilitated rotten part detection. Therefore, it was verified that the method of exciting the florescent substance and capturing the fluorescent image was practicable.

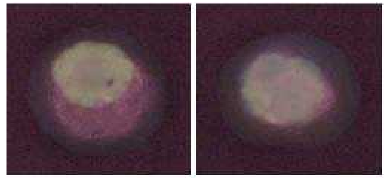


Fig.5 Fluorescent images of two rotten Unshu oranges.

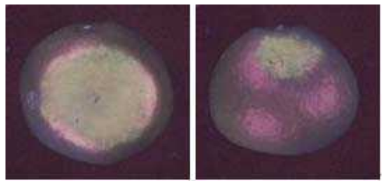
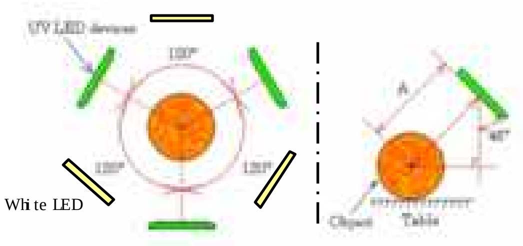


Fig.6 Fluorescent images of two rotten Iyokan oranges.

2.2 Image acquisition system design

Following successful demonstration of detecting fruit rot using the UV LED lighting panel based fluorescent imaging system, effort was continued to design of a double image acquisition system to acquire both color and fluorescent images for the citrus fruit inspection. Design layout of the lighting chamber that consists of the white LED and ultraviolet LED lighting panels (shown in Fig. 3) is depicted in Fig. 7. If this proposed double LED-one TV camera system is installed on actual sorting system, it can keep inspection line length and does not need additional camera but adds only UV LEDs. Many inspection lines are already constructed in fruit grading facilities and it is not easy to make the line length longer. This double imaging system can contribute the construction cost reduction keeping the inspection line length when the fluorescent imaging system is desirable to be added.



(a) Top view (b) Side view

Fig.7 Layout of the lighting chamber with both white light and ultra violet light sources.

The sizes of the lighting devices (Fig. 3) were 59 mm ×59 mm for white panel and 89 mm ×89 mm for UV panel, because LED diameters were 3.4 and 5.4 mm respectively. Since the UV LED's emission intensity is not high enough, the three UV lighting devices were used. Three white LED panels were placed 120° apart. In between every two white LED panels, an ultra violet LED panel was installed. The six light panels form a hexagonal lighting arrangement as shown in Fig.7. The distance between center of a fruit object and the ultra violet LED was about 130mm, while the distance between center of a fruit object and the white LED was about 200mm because of much higher reflectance energy compared to fluorescent energy.

It is well known that halation happens on fruit skin due to cuticular layer of the skin surface even when images are acquired by use of any lamps. To remove halation, polarized light (PL) filters were installed in front of the camera lens and the white LED lighting panels. In this experiment, 67 mm diameter PL filters were used to the white LED lighting devices and to camera lens when the white LED was used. A CCD camera (60 frames /second; VGA) fitted with a C mount lens was used for the image acquisition with a focal length of 6mm, and an F-stop of 1.4. The distance between center of a subject fruit and the lens was 220mm that provides a field of view of 22.5 cm× 21 cm.

The both LEDs were driven by a PIC microcomputer. During the image acquisition, the white lights were pulsed first, followed by pulsing the UV lights. Each pulse had a time duration of 2 msec. Data collected by the camera was sent to a frame buffer via DMA(Direct Memory Access) access using PCI bus housed in a personal computer (CPU: x86 Family6 Model8 Stepping3, OS: Microsoft Windows 2000 SP4). Fig. 8 shows the image acquisition apparatus.

2.3 Fluorescent response of citrus fruits

To examine level of fluorescence can be observed on various citrus fruits more citrus varieties were investigated. Fig. 9 shows sample images of 14 varieties of citrus fruit evaluated in this experiment captured using the color camera under the white LED lighting: Mishokan, Amanatsu, Pummelo, Mandarin, Sampokan, Hassaku, Dekopon, Kiyomi, Grapefruit, Minneola, Navel, Iyokan, Lemon and Kimquat.

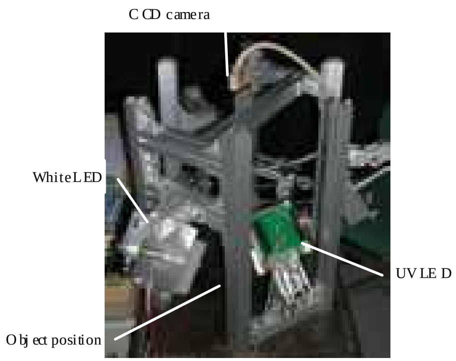


Fig. 8 Appearance of experiment equipment

Due to limited availability of rotten fruits, skin injury typically associated with fruit rot was created by thinly planing with a razor. The treatment releases peel oil stored in certain glands underneath most citrus fruit peel.

2.4 Camera parameters for each light condition

As fluorescence intensity of fruit rot is much lower compared to that of color signals of whole fruits, camera operation parameters (e.g. shutter speed, gain, gamma correction etc.) were adjusted accordingly to obtain good quality images. Camera gain was increased from 0 to 12 db, shutter speed was changed from 1/20000 s to 1/60 s, and γ correction was from 1 to 0.45, when white lighting devices were changed to UV lighting devices. A 6mm or 16mm focal length lens with 1.4 F number was attached to the camera according to the fruit size. Image acquisition was conducted using a function of random trigger by outputting trigger signal through camera link. The trigger signal was also sent to a driver for lighting the LEDs just before image acquisition. Output RGB signals were input to a capture board (MTPCI-TL2, Micro-Technica Co., Ltd.) and image data were transferred to memory of PC. Table 3 lists camera parameters used for imaging under the UV LED lighting and white LED lighting. The camera parameters were dynamically adjusted on the flight through a high speed (9600/19200 bits per second) camera link to acquire color and fluorescent fruit images in sequence.

3. Results and Discussion

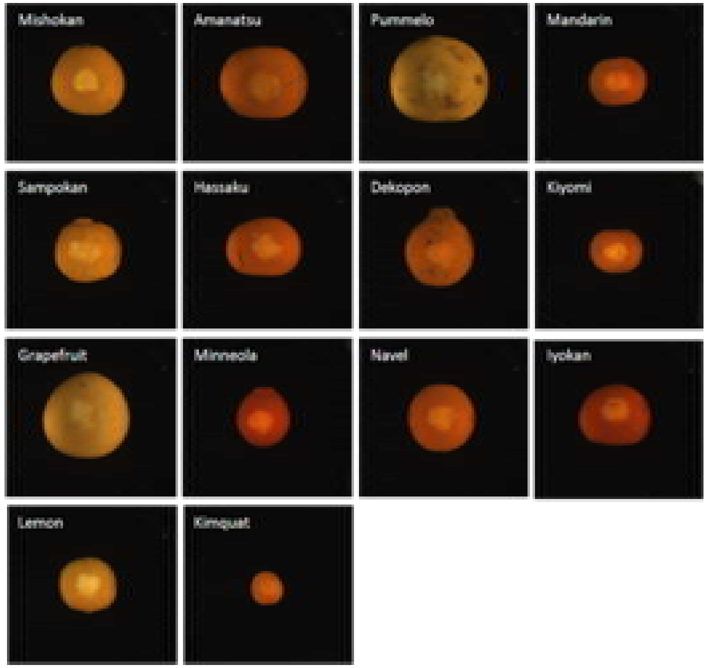


Fig.9 Fourteen citrus varieties were examined for their fluorescent signal strength under the designed fluorescent imaging system.

Table 3 Capturing parameters for each lighting condition

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

The fluorescence images of 14 citrus fruits excited by 365nm were captured with the color camera in the visible region. The captured color images were split into Red, Green and Blue planes. The green plane image had the large difference in gray level between rotten part and the other healthy part, then to recognize the rotten part of citrus fruits, the green plane images were enhanced as shown in Fig.10. The fluorescence part excited by 365 nm looks white in Figure 10. A white part of a central part of fruits was confirmed clearly from Mishokan at the left of uppermost column to Kiyomi from on to the right side of the 2nd column, and it has been understood to be able to detect the material that exists inside the surface where the skin was planed by leather. The part where the skin was planed was not clearly seen as white from Grapefruit at the left of the third column. Fig. 11 shows the result of emphasizing the grey-level difference of a fluorescence part and a healthy part in green plane by manual operation using image-processing software. In Mishokan that had the greatest gray-level difference was 65, while Kumquat was only 4 that was the minimum value. Thus some can be thought as a reason that the grey-level difference between the rotten and healthy parts differs by variety. First, the way to plane the skin by the leather was not the same. Although the important thing is to make a fluorescent material that exists in the skin come to the surface by thinly peeling the skin, a possibility can be considered that a fluorescent substance did not come out on the surface since the thickness of the peel changes with varieties even if it deletes similarly. Since the rotten part was clearly detectable in Iyokan as shown in Fig. 6, it is appropriate to the portion not looking white in Iyokan in Fig.10 to think that it is because a fluorescent substance is not looming in the surface.

Those characteristics of the fluorescence imaging for each rotten fruit indicate that it is applicable to detect rotten part detection after processed by imaging technology. For example, if the detected area is one or more, the fruit should be judged as a rotten fruit.

Time lag between the two image acquisition events was minimized to reduce fruit position shift as fruits are moving continuously on industrial fruit inspection lines. It is also important to keep a moving fruit in the field of view of the inspection camera during the two, fluorescent and color, image acquisition events with the same camera. Fig. 12 shows a timing chart of the image acquisition control. Time required to change the camera operation parameter is labeled ① that is between two image capture. A short time lag between the color and the fluorescent image acquisition was achieved. The shortest time between triggering the white LED and UV LED (②) was 14 msec. The short image

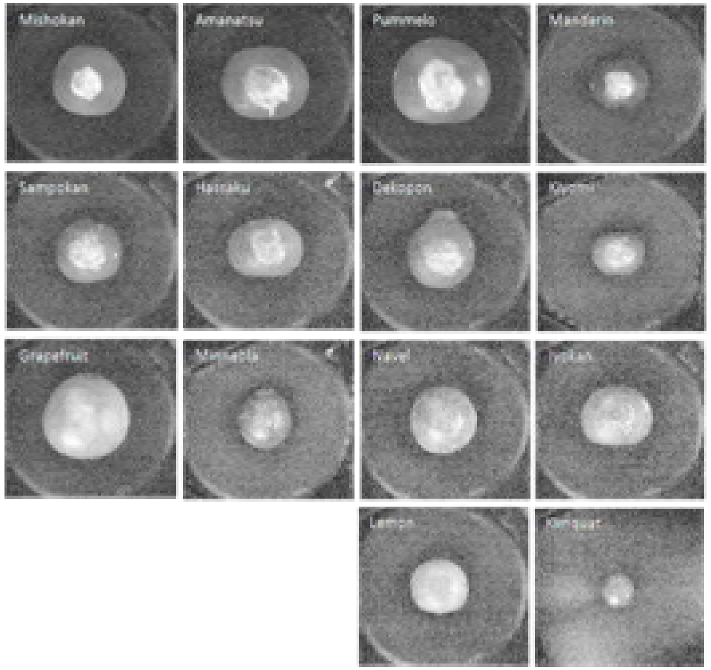


Fig. 10 Fluorescence images

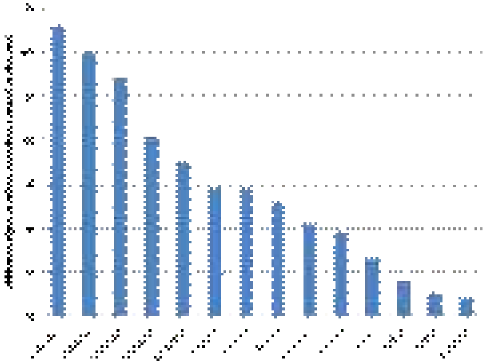


Fig.11 Difference of grey level in green plane between rotten and healthy parts.

acquisition lag time between the color and fluorescent image acquisition make it applicable for existing industrial grading lines. An industrial conveyer line typically moves at a speed of 60 meters per minutes, thus a fruit travels 14mm in between the two image acquisition events described above. As an industrial fruit inspection camera has a typical field of view of 22.5 cm×21 cm, there is no problem to capture a color image than a fluorescent image using the same camera. The time lag duration depends mostly on computer hardware specification, especially usage rate of PCI bus and its bandwidth.

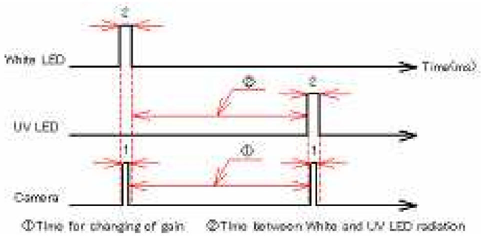


Fig.12 Timing chart of the image acquisition sequence.

4. Conclusions

Peel damage of a wide variety of citrus fruits can be detected using fluorescent imaging. The sensing capability could be valuable for detecting fruit rot, fruit split, and other fruit quality defects related to peel damage. An image acquisition system was designed and evaluated for acquiring fluorescent and color images for on-line citrus fruit inspection. New fruit rot inspection feature was added to complement already proven size, color, shape inspections capability. Fast image acquisition sequence allows implementation of the new fruit rot inspection feature without major changes of existing industrial fruit inspection chambers.

References:

(1) Aleixos, N., Blasco, J., Navarron, F., and Molto, E., Multispectral inspection of citrus in real-time using machine vision and digital signal, *Computers and Electronics in Agriculture* 33(2002), pp.121-137.

(2) Andrew, W., Vision system grades moving food products, *Vision System Design* June (2002), pp.26-29.

(3) Davenel, A., Guizard, C., Labarre, T., and Sevila, F., Automation Detection of Surface Defects on Fruit by Using a Vision System, *J. agric. Engng Res* 41(1998), pp.1-9.

(4) Ishii, T., Toita, H., Kondo, N., Tahara, N., Deciduous Fruit Grading Robot(Part 2) — Development of Image Processing System— (in Japanese), *J. JSAM* 65(6) (2003), pp.173-183.

(5) Kondo, N, Yamamoto, K., Taniwaki, S., Kuramoto M., Kurita, M., and Ninomiya, K., Machine vision system for detecting rotten citrus fruit by use of UV LEDs., *ASABE an International Conference in BIOLOGICAL SENSORICS* (Database) (2007).

(6) Kurita, M., Kondo, N., and Ninomiya, K., Defect Detection for Tomato Granding by use of Six Color CCD Cameras, *Journal of Science and High Technology in Agriculture* 18 (2) (2006), pp.135-144.

(7) Leemans, V., Magein, H. Destain, M. F., On-line Fruit Grading according to their External Quality using Machine Vision, *Biosystems Engineering* 83(4)(2002), pp. 397-404.

(8) Leemans, V., Destain, M. F., A real-time grading method of apples based on features extracted from defects, *Journal of Food Engineering* 61(2004), pp. 83-89.

(9) Lu, R., and Ariana, D., A near-Infrared Sensing Technique for Measureing Internal Quality of Apple Fruit, *Applied Enginееring in Agriculture* 18(5)(2002), pp.585-590.

(10) Njoroge, J. B., Ninomiya, K., Kondo, N., and Toita, H., Automated Fruit Grading System Using Image Processing, *Proc 2002 SICE*, *Osaka* (2002), pp.1290-1295.

(11) Ogawa, Y., Kondo, N. and Shibusawa, S., Internal Quality Evaluation of Fruit with Soft X-ray CT, *Journal of the JSAM* 67(3) (2005a), pp.114-121.

(12) Ogawa, Y., Kondo, N. and Shibusawa, S., Internal Quality Evaluation of Fruit with Soft Transparent Image, *Journal of Science and High Technology in Agriculture* 17(2) (2005b), pp.75-83.

(13) Uozumi, J., Kohno, Iwamoto, and Nishinari., Spectrophotometric System for the Quality Evaluation of Unevenly Colored Food, *Journal of the JSFST* 34(3) (1987), pp.163-170.