SICE Annual Conference in Sapporo, August 4-6, 2004
Hokkaido Institute of Tecnology, Japan

Development of a Real-time Machine Vision System for the Apple Harvesting Robot

Bulanon, D.M. [1], Kataoka, T. [2], Okamoto, H. [2], Hata, S. [2]

[1] JSPS Postdoctoral Fellow, Graduate School of Agriculture, Hokkaido University, Sapporo, JAPAN
duke@bpe.agr.hokudai.ac.jp
[2] Graduate School of Agriculture, Hokkaido University, Sapporo, JAPAN
tkataoka@bpe.agr.hokudai.ac.jp

Abstract: This research describes the development of a real-time machine vision system to guide a harvesting robotic manipulator for the red *Fuji* apples. The machine vision system is composed of a color CCD video camera to acquire *Fuji* apple images at the orchard and a PC to process the acquired images. The machine vision system was able to recognize the fruit under the different lighting conditions and it could locate the fruit in less than one second.
Keywords: apple, harvesting, image processing, machine vision

1. Introduction

The two main tasks of a fruit harvesting robot is to recognize and locate the fruit and to pick the fruit without damaging it and the tree. The first task is the recognition and location of the fruit. This paper describes the development of a real-time machine vision system to guide a harvesting robotic manipulator for the red *Fuji* apples. The machine vision system is composed of a color CCD video camera to acquire *Fuji* apple images at the orchard and a PC to process the acquired images. Although some researchers have demonstrated the feasibility of the machine vision system for robotic guidance[1-4], special difficulties must be considered if the machine vision system would be used in outdoor fields such as the orchard. Most orchard operations, including harvesting, rely on the sunlight as the light source. Changes in lighting condition may result in poor quality images, causing incomplete and improper object segmentation, and affecting subsequent image processing steps[5]. Furthermore, fruits are not receiving the same light according to their position at the same instance of time. These facts should be considered in the development of the recognition algorithm for the machine vision system. In addition, the algorithm should be able to guide the robotic manipulator in real-time. The principal objectives of this research were; (1) to recognize the fruit under different lighting conditions; front lighting, back lighting, fruit in the shade and cloudy, and (2) to estimate the location of the fruit.

2. Methodology

2.1 Image Acquisition

Color images of *Fuji* apples in the orchard were acquired using a digital color CCD camera. The color signals from the camera were transferred as a 24-bit RGB color image data (320 × 240 pixels in each color band) and processed by a PC.

2.2 Lighting Condition

The fruit used for imaging were randomly selected from the apple orchard and images were taken of the fruit hanging on the tree under natural daylight conditions. Four lighting conditions were investigated; a) front lighting, b) back lighting, c) fruit in the shade, and d) cloudy. Conditions a), b) and c) were taken under a sunny weather. In condition a), the direct intensity of the sunlight was at the back of the camera. In condition b), the camera was in front the direct sunlight. A total of 60 images were acquired (15 under each lighting condition). 20 images were used for developing the algorithm and 40 images were used for evaluation.

2.2 Image Analysis and Processing

The recognition part started with analyzing the color models of the images. Three color models were used: RGB model, chromaticity method and luminance and color difference method[6]. In all three models, the fruit, the leaf and the branch had distinct color attribute values. This indicated that the fruit could be separated from the other three portions using these color attributes. However, results showed that the RGB model and the luminance and red color difference method were influenced by the lighting condition while the chromaticity method was hardly influenced by the lighting condition[6]. So in this paper, the chromaticity method was used for fruit detection. The chromaticity method can be represented by the chromaticity diagram. This diagram is made up by two chromaticity coordinates or trichromatic coefficients, r and g. These coordinates are calculated as

$$r = \frac{R}{R+G+B} \quad (1)$$

$$g = \frac{G}{R+G+B} \quad (2)$$

where R, G and B represented the red, green and blue color intensity respectively. A sample chromaticity diagram of the *Fuji* apple tree is shown in Fig.1. The same distribution can be observed in the other lighting conditions.

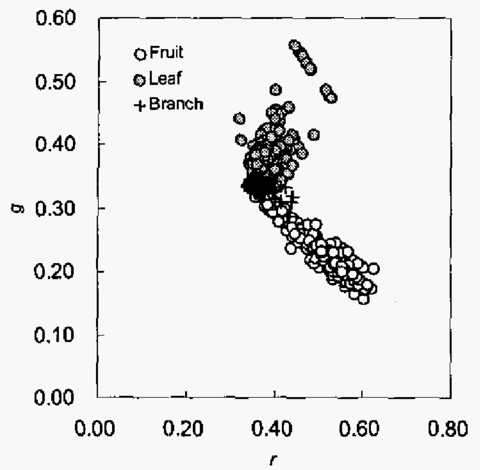

Fig.1. Chromaticity space of apple tree.

2.3 Fruit Detection

Segmentation of the fruit was carried out using the decision theoretic approach[5] and the trichromatic coefficients as patterns. The decision-theoretic approach is a statistical pattern recognition technique, where a discriminant function is defined that will give a certain response with one class and a different response with another. The concept is illustrated in Fig.2. In Fig.2, two object features (properties), M and N, are used and are represented by points (feature vector) to represent Groups 1 and 2 in a two dimensional chart (feature space). A decision surface can be defined that will separate the two feature vector clusters and then can be used to classify the objects.

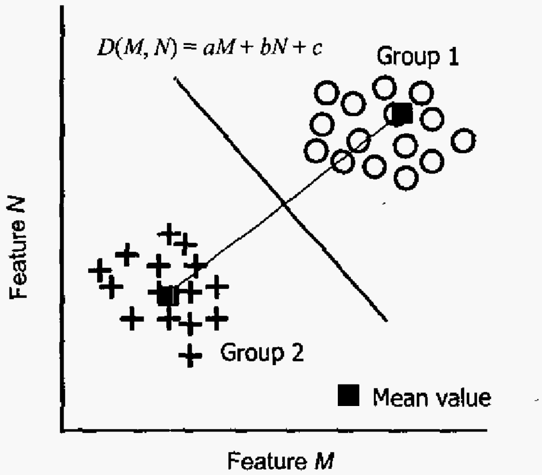

Fig.2. Concept of decision theoretic approach.

A linear decision function can be defined such that:

$$D(M,N) = aM + bN + c \tag{3}$$

All points that lie on this line will satisfy the condition, $D(M, N) = 0$, and any point that lies above the line will satisfy, $D(M, N) > 0$ which is the Group 1 cluster of points while any point that lies below belongs to Group 2 cluster and satisfies the condition, $D(M, N) < 0$.

From the chromaticity space of the *Fuji* apple tree the following decision functions, D_1 and D_2, were derived and these were used in classifying the fruit from the background. D_1 separates the fruit from the leaf and D_2 separates the fruit from the background.

$$\begin{bmatrix} D_1 \\ D_2 \end{bmatrix} = \begin{bmatrix} 0.09 & -0.13 \\ 0.10 & -0.08 \end{bmatrix} \begin{bmatrix} r \\ g \end{bmatrix} \tag{4}$$

Figure 3 shows the fruit detection algorithm. The process starts with determining the decision functions for segmentation. After segmenting the image, standard image processing techniques were made. A low pass filter was conducted on the segmented image to remove noise. The objects were then labeled and the features of the labeled objects such as area, maximum and minimum axes were extracted from the binary image. These features were used to identify and locate the fruit.

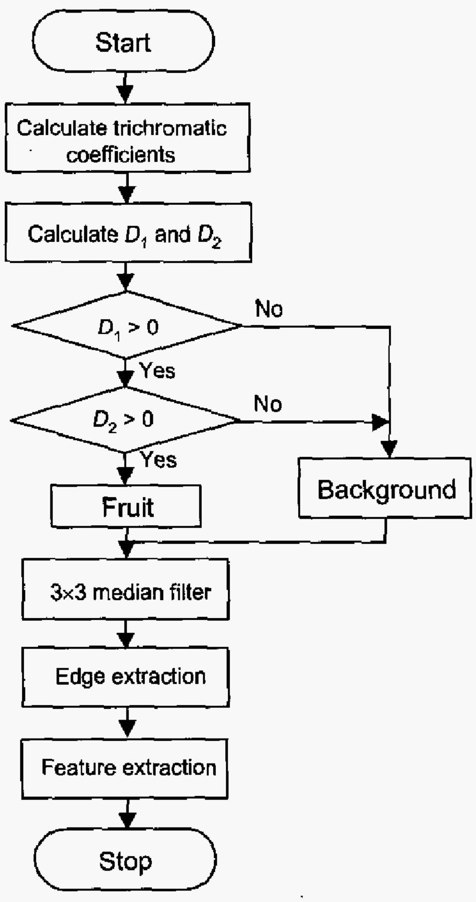

Fig.3. Fruit recognition algorithm.

3. Results and Discussion

3.1 Fruit Recognition

Figure 4 shows the image processing results of the fruit recognition algorithm. The sample image (Fig.4(a)) shows a *Fuji* apple fruit taken under natural lighting and front light condition. The fruit has a yellow color in its upper left portion and a dark shade in its lower left portion. The background is composed of branch, leaf and ground. It can be observed from Fig.4(b), trichromatic *r* gray level image, and Fig.4(c), trichromatic *g* gray level image, that the fruit is enhanced from the background. The fruit was brighter in Fig.4(b) because it had the highest trichromatic *r* while it was darker in Fig.4(c) because it had the lowest trichromatic *g* in the chromaticity space. Using the decision functions, Fig.4(a) was segmented and filtered (Fig.4(d)). The fruit portion was properly segmented from the background (more than 90%). The segmented object was labeled and the edge was extracted (Fig.4(e)). Using the edges, the area, maximum, and minimum axes were determined and these features were used to further identify the fruit portion (Fig.4(f)).

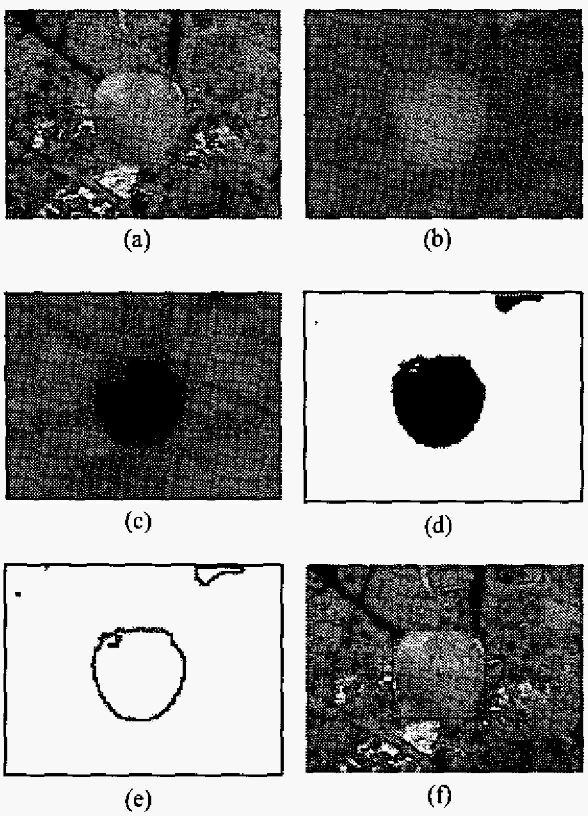

Fig.4. Image processing results of the developed algorithm.

Table 1 shows the performance the decision theoretic approach with the trichromatic coefficients as patterns in segmenting the fruit under different lighting conditions. Segmenting under the front light condition had the highest success rate (over 93 %) while the lowest success rate was with the back light condition (over 79 %). The error rate was below 3 % under all the lighting condition, which shows that this method is effective. Compared with the automatic segmentation algorithm using the luminance and color difference model[7], this method performed better under the back lighting condition. The reason for this is that the trichromatic coefficients were hardly influenced by the lighting condition. This segmentation method could be applied under different lighting condition.

Table 1. Performance of fruit segmentation.

	Success Rate (%)	Noise Rate (%)
Front	93.1	1.3
Back	79.3	2.3
Shade	84.0	1.0
Cloudy	84.5	0.4

3.2 Fruit Location

Since the image is two-dimensional, the distance of the fruit is not known. To estimate this distance, another device will be used. One of these is the laser ranging system. It will work together with the developed machine vision system, the machine vision system detects the fruit and the laser ranging system will estimate the distance of the fruit from the end effector. It will be mounted on the free link of the manipulator together with the camera and the end effector. Figure 5 shows the concept of estimating the distance using this system. After the fruit is detected (Fig. 5(b)), the manipulator will be moved to position the fruit with the largest area (Fruit 2) in the center of the image (Fig. 5(c)). Once the fruit is centered the laser ranging system will measure the fruit's distance.

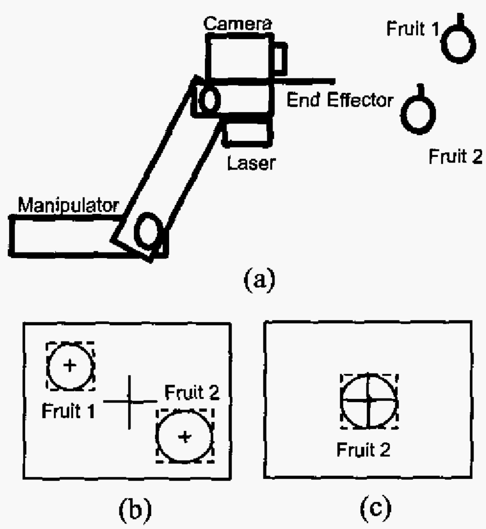

Fig.5. Concept of fruit location.

3.3 Real-time Processing

The fruit recognition algorithm was implemented using both Delphi and Visual Basic. Table 2 shows the time of each image processing step that was taken. Delphi was 14 times faster than Visual Basic. It can also be observed that labeling took most of the time. From these results, it can be concluded that the developed algorithm can be used to guide an end effector as it approaches the fruit in real-time.

Table 2. Image processing time for fruit recognition.

	Delphi Time (ms)	Visual Basic Time (ms)
Segmentation	70	209
Filtering	75	452
Labeling	122	4664
Edge extraction	72	442
Feature extraction	96	195
Total Time (ms)	434	5962

4. Conclusions

A machine vision system to recognize and locate the red *Fuji* apple fruit was developed. The machine vision system is composed of a color CCD video camera and a PC. Based on the results the following conclusions were made.

- The decision theoretic approach using the trichromatic coefficients of red and green was effective in segmenting the fruit from the background. About 80 % of the fruit pixels were correctly classified under all lighting conditions with less than 3 % error rate.
- The developed fruit recognition algorithm could be used to guide a robotic manipulator in real-time. Fruit recognition can be done in less than one second.

5. Acknowledgements

The authors gratefully acknowledge the Japan Society for the Promotion of Science for the fellowship (No.15-3253) and the Japan Ministry of Education, Culture, Sports, Science and Technology for the research grant.

6. References

1. Parrish, E., Goksel, A., Pictorial Pattern Recognition Applied to Fruit Harvesting, Transactions of the ASAE, 20,822-827, 1977
2. Sarig, Y., Robotics of Fruit Harvesting, Journal of Agricultural Engineering Research, 54, 265-280, 1990
3. Slaughter, D., Harrel, R., Discriminating Fruit for Robotic Harvest using Color in Natural Outdoor Scenes, Transactions of the ASAE, 32(2), 757-763, 1989
4. Jimenez, A., Ceres, R., Pons, J., A Survey of Computer Vision Methods for Locating Fruits on Trees, *Trans.* ASAE, 43(6), 1911-1920, 2000
5. Awcock, G., Thomas, R., Applied Image Processing, McGraw-Hill. Inc., 1996
6. Bulanon, D. Kataoka, T., Ota, Y., Hiroma, T., A Color Model for Recognition of Apples by a Robotic Harvesting System. Journal of the JSAM, 64(5), 123-133, 2002
7. Bulanon, D., Kataoka, T., Ota, Y., Hiroma, T., A Segmentation Algorithm for the Automatic Recognition of Fuji Apples at Harvest, Biosystems Engineering Journal, 83(4), 405-412, 2002