A Recognition Method for Sweet Pepper Fruits
Using LED Light Reflections

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Abstract: This paper describes a method for sweet pepper picking robots working in greenhouses to distinguish the pepper fruits from the leaves. The fruits of the sweet pepper plant are recognized by image processing techniques, using a parallel stereovision system installed in the robot. However, as fruits and leaves of the sweet pepper have almost the same color, it is very difficult to recognize fruits using only color information. In this paper, we propose a new method using reflections of LED lights. The fruits of the sweet pepper are more reflective than the leaves; therefore, we can identify fruits by assuming that the more reflective parts are the fruits. We perform experiments using the improved image processing algorithm in a greenhouse, and the algorithm indeed improves the recognition ability of the robots.

Key Words: picking robots, image processing, recognition, visual feedback control, sweet peppers.

1. Introduction

Greenhouse horticulture flourishes in Japan because of its many advantages. Greenhouses are covered with vinyl sheets and protect vegetables from natural risks such as strong winds, bad weather and harmful insects. Greenhouse horticulture thus helps agricultural products to grow more efficiently and maintains their high quality under controlled circumstances. In recent years, the shortage of farming labor has been getting worse because of the falling birthrate and aging farmers. To address this problem, some automatic greenhouse horticulture systems have been proposed. These include, for example, automatic temperature control systems, automatic watering systems, and automatic picking systems. Automatic temperature and automatic watering systems have already been adopted for use in actual greenhouses. It is difficult to build automatic picking systems because of the generally low performance of existing systems for the recognition of fruits, cutting systems, and moving systems. However, picking robots for strawberries and tomatoes have been studied [1],[2]. These studies were implemented under special conditions of planting systems and choosing fruits because it is easy to recognize these fruits by their color.

Our goal is to construct an automatic picking system for sweet pepper fruits to be adopted in usual greenhouses. Although the sweet pepper is a major agricultural product in the greenhouse horticulture industry, no attempt has been made to construct a picking robot for it because the colors of its fruits and that of its leaves are almost the same, and it is difficult to recognize the fruit. We have already developed a prototype of a picking robot for harvesting sweet peppers [3]. However the performance of the robot is unstable because the color of the fruit changes as it grows.

In this paper, we propose a recognition method for sweet pepper fruits using reflections of an LED light. We first introduce a picking robot that has been already built and explain the usual image processing algorithm. We then propose our new supplementary algorithm that uses LED lights and describe some experiments performed using the improved image processing algorithm in a greenhouse. The results show that the new algorithm improves the robot’s recognition ability.

2. Structure of the Picking Robot

A photograph of a Japanese greenhouse in Japan is shown in Fig. 1. In the greenhouse, sweet pepper trees are planted on hills, and sweet peppers grow on the trees, as shown in Fig. 2 (a). Farmers pick sweet peppers that are within the standards shown in Fig. 2 (b). The procedures of picking fruits of sweet pepper are follows. First, farmers use their eyes and hands to look for fruits that meet the size and shape standards. Then, they cut the stems of the selected peppers and put them
To follow the procedures of the farmer, the picking robot for sweet peppers should have the functions shown in Fig. 3. A prototype sweet pepper picking robot has been developed to satisfy the concept in Fig. 3 [3],[4]. The structure of the robot is shown in Fig. 4, and a photograph is shown in Fig. 5. This robot has an image processing system with parallel stereovision, a camera positioning system to approach the recognized sweet pepper fruits by visual feedback control, and a cutting device.

In this image processing system, we use color image processing with images that are transformed to HSI color space, as well as an LED lighting system. H, S, and I denote hue, saturation, and intensity, respectively. HSI color space is employed in color image processing because its color space is more close to human sensibilities, and it is better able to handle the image data in image binarization compared to the RGB color space [5],[6]. In the HSI color space, the color image data are represented by the three components of intensity, saturation, and hue. Sweet pepper components are recognized by the binarizations of these three values. However, the recognition rate of sweet peppers in the existing image processing algorithm is low.

3. Image Processing Algorithm

The image processing system consists of two color CCD cameras (RF SYSTEM SG-55), a capture board (Leutron PicPort), and image processing applications (MVTec HALCON), as shown in Fig. 6. Two cameras are placed in parallel. The distance between the cameras and the recognized fruit can be measured by stereovision using the two cameras. In this image processing system, the light is an important factor in capturing a stable image. We use an LED light device as shown in Fig. 7 [7]. The LED lights are installed around the left CCD camera, as shown in the figure. The LED light device is small, and the area of lighting is limited to a small area because the LED lights have a narrow lighting angle. By limiting the area of lighting, it becomes highly possible that the fruit found as the result of image processing in the left camera corresponds to the fruit found in the right camera [8]–[10].

The previous image processing algorithm is shown in Fig. 8. In this algorithm, we used the image transform from the RGB color space to the HSI color space. The three values of hue, saturation, and intensity are expressed by 256 grades, respectively. The sample data of the captured image from the CCD camera and the HSI color space are shown in Figs. 9 and 10. When the HSI values of fruits and leaves are compared, there is a prominent difference in the hue value. Therefore, it is possible to recognize the fruits of sweet pepper by the binarization of intensity, saturation, and hue in this algorithm. However, the HSI values of sweet peppers are not constant in the greenhouse. The sweet pepper changes color according to its stage of growth. We have to reset the threshold whenever we use the recognition system. This is the reason why we have proposed a new recognition method for sweet pepper fruits using LED
4. Improved Image Processing Algorithm

To improve the method of recognizing the fruits, we propose three techniques. One is to use the reflective parts for finding the fruits. Second, based on the reflective part, the image processing area is reduced. Last, the threshold can be fixed automatically. The last method can also use the results of the first one.

A major difference between the fruits and leaves of the sweet pepper plant is that the fruits are more reflective than the leaves. When a sweet pepper is illuminated, reflections appear on the surface of the fruits and not on the surface of the leaves. Therefore, if a reflective part is observed, it indicates a fruit of the sweet pepper. The reflective part is defined as an area with very high intensity and low saturation. Concretely, we assume that such a part has an intensity range between 250 and 255 and a saturation range between 0 and 50, as shown in Fig. 10 (d). The values of both of these ranges characterize the refraction part. It is possible to recognize the reflective part by the binarization of the intensity and saturation.

Next, the image processing area is reduced to a small area around the reflective part. We set a rectangle of 400 × 200 pixels around the center of the recognized reflective part. By reducing the area, we can increase the recognition rate.

Next, we can automatically fix the threshold for recognizing sweet pepper fruits. As the part around the reflective part can be assumed to be the fruit, the HSI values of this part can be set to the values of the fruit. This method is robust with respect to the color variations of the sweet pepper fruits.

We assume that a range within 12.5 pixels around the reflective part represents a fruit. In this range, we obtain maximum and minimum values of intensity and saturation, and a mean value and a minimum value of hue. These values are adopted as the lower/upper thresholds for recognizing the fruits of the sweet pepper. Fruit of sweet pepper can be recognized by the binarization using the values in the limited small area around the reflective part.

The improved image processing algorithm is shown in Fig. 11. Compared with the procedure in Fig. 8, the procedures to search for the reflective part and obtain the result threshold are added before the algorithm for recognizing the fruits of the sweet pepper. An example of image processing according to this algorithm is shown in Fig. 12.

A grabbed image is shown in Fig. 12 (a). The reflective part in the grabbed image is recognized by binarization of high intensity and low saturation as shown in Fig. 12 (b). Based on the reflective part, the HSI thresholds are obtained from the region around the reflective area, and the image processing area in which to recognize sweet pepper fruits is limited to the small rectangular area shown in Fig. 12 (c). In this limited area, the region is further reduced by repeated binarization of intensity, saturation, and hue, as shown in Fig. 12 (d), (e) and (f). The piecemeal pixels of the reduced regions are connected by the closing operation as shown in Fig. 12 (g) [11]. Furthermore, the connected regions are individuated by the labeling process, and the air holes of the individuated parts are filled by the Fill-up process. Finally, the characteristic individual part is selected by area size and is recognized as the fruit of a sweet pepper, as
5. Experiment and Results

We performed experiments to test the improved image processing algorithm. The images of 24 random frames taken in a greenhouse at night were captured as shown in Fig. 13. It assumed that this robot works at night because the farmers are resting, and the images do not require sunlight.

In this experiment, we defined the criterion for success as follows. Sweet pepper fruits are recognized, and the recognized fruit does not contain stems and leaves.

Some results of the images are shown in Fig. 14. The fruits were recognized successfully in 19 frames. Of these frames, 7 are shown in Fig. 14 from (a) to (g), and 5 frames that the system failed to recognize are shown in Fig. 14 from (h) to (l).

In the image in frame (h), one piece of fruit was recognized as two pieces. This fruit had a large dent, and the area of this dent was darkened by shadow. The HSI value of the dent was beyond the threshold obtained, and the dent separated one piece into two pieces. In (i), the fruit was of an awkward shape, and the appropriate thresholds around the reflective part were not obtained. In (k), the area around the reflective part was darkened, so the appropriate thresholds were not obtained. In (k), the fruit could not be distinguished. There was too great a difference between the HSI value around the reflective part and the value of other area in the fruit because the shape was very rounded.

In (l), the reflective part was on a leaf, and the leaf was recognized as a fruit. This was because the camera was too close...
Consequently, our algorithm was successful in 19 out of 24 frames, so the recognition rate was 79.2%. When using the previous method, the rate was 75% with their image data. In the improved method, the thresholds were obtained automatically, and the performance of the method is comparable to the previous method. This rate may be sufficient to enable the fully automatic picking of sweet peppers. The number of faulty cases may be reduced with better depth perception, which is obtained by the stereoscopic technique. The combination of this information and the small area of the reflective part may improve the recognition rate.

6. Conclusion

In this paper, we proposed a new method of recognition of sweet pepper fruits using reflections of LED lights. This method consists of three techniques: identifying the reflective part, reducing the search area, and setting the HSI binarization range. We performed experiments using the improved image processing algorithm in a greenhouse. The automatic recognition rate was 79.2%, and it is possible to improve the recognition ability. In the future, we hope to examine many more experimental samples in greenhouses. A method to ensure that the fruit identified in the left camera corresponds with that in the right camera using the reflection of LED lights will also be developed in a future research.

References

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