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Use of Machine Vision to Sort Tomato Seedlings for Grafting Robot

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Abstract

Using a machine vision with backlighting LEDs, a tomato-seedling grading and sorting algorithm was developed for a fully automatic grafting robot. A UXGA camera, a blue color backlighting device and light filtering devices were selected to acquire seedling images. The developed algorithm was used to determine the bending, nodes of leaves and stem diameter of seedlings from their images and then to grade and sort them as the initial task of the grafting robot. Results showed that the sorting success rate was 97% and the rest 3% was failed as the target portions of the images of seedlings were covered by irregular arrangement or bended leaves from all sides.

[Keywords] grafting robot, machine vision, sorting algorithm, tomato seedling

I Introduction

Grafting is a method of asexual plant propagation where the tissues of the plant to be cultivated (*i.e.* scion) are encouraged to fuse or graft onto a strong vital plant (*i.e.* rootstock), so that the scion can grow, blossom and bear fruit using soil based nutrient. Grafting carries out to reduce infection by soil-borne diseases caused by pathogens and to increase the resistance to low temperature as well (Biles et al., 1989). Lee (1994), Ioannou et al. (2002) and Khah et al. (2006) found that grafted plants were taller and more vigorous than self-rooted ones and had a larger central stem diameter. A vital reason of increasing demand of the grafted seedlings is to find an alternative of getting rid of using harmful chemicals like methyl bromide, which are being used as the soil sterilant to control pests and nematodes. The cultivated area of grafted solanaceous plants has increased in recent years (Garcia et al, 2002). To fulfill increasing huge demand, many professional grafting farms have been set up.

Timely grafting is important to reduce the stress of root exposure of the seedlings. Grafting sheds are typically maintained at low temperature and high humidity to further reduce seedling stress. Unfortunately such an environment is not optimal for grafting personnel. On the other hand grafting is a time-consuming and tedious job even for skilled workers. Producing grafted seedlings manually seems insufficient to synchronize with the increasing demand. These factors have stimulated researches into the automation of grafting to fulfill a growing market potential and to replace slower manual grafting.

In Japan YANMAR, ISEKI and MITSUBISHI companies in cooperation with the Bio-oriented technology Research Advancement Institute (BRAIN) of Japan have developed and commercialized semi-automatic grafting robotic systems for cucumber and watermelon, which are about three times faster than manual grafting (Kobayashi et al., 1999). Nishiura et al. (1995a) in Japan, Hwang et al. (1997) in Korea, Lee et al. (2001) and Chen et al. (2009) in Taiwan had been developed automatic grafting robot system. Furthermore, Kobayashi et al. (1996a; 1996b), Kurata (1994) and Lee (1994) have been reported researches on grafting robot system. However all of those grafting robotic systems have employed manual grading and sorting of seedlings. No fully automated grafting robot system yet has been developed, which could save huge human labor as well as production cost. But too much complexity and diversity of seedling features obstruct its development.

For successful grafting, the vascular cambium tissues of the stock and scion plants must be placed properly in contact with each other, which significantly depend on matching the diameter of both stock and scion seedlings. Therefore, prior to the grafting operation, it needs to select the scion and rootstock seedlings of same diameter. For this

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purpose the seedlings need to be graded and sorted, which are costly and labor intensive operations. Graders identify seedlings applying a number of visual grading criteria based on morphological characteristics, which is subjective and susceptible to human error. Further, it is not feasible for graders to inspect every seedling or to grade seedlings into more than two classes (Rigney, et al., 1988).

With the invention of high speed computers, machine vision technology has been widely used in extracting morphological, spectral and temporal information of plants and plant products. Grading seedlings using machine vision has been reported by Regney et al. (1988) and Fly et al. (1992) for loblolly pine seedlings, Nishiura et al. (1995b), Ruzhitsky and Ling (1992) for tomato seedling, Cardensas et al. (1988) for strawberry seedlings, and Sase et al. (1992) for lettuce seedlings. However, they have graded the seedlings as “acceptable” and “cull”. The objective of this study is to develop an algorithm to grade and sort the tomato seedlings into four specific groups using machine vision for grafting robot, so that the seedlings can be grafted more precise, faster and environment friendly.

II Methodology

1. Device selection

Shape of seedlings can be characterized by its phyllotaxis. However, it does not provide any useful quantitative information good enough for pattern recognition, because the shape of seedling varies in great deal even among seedlings in the same variety (Nishiura et al., 1995b). Proper quantitative features that can characterize the shape of seedling have to be identified for the directed pattern recognition of seedlings. The parameters that can identify dimensions of the plant body were inter-nodal length, stem diameter and leaf arrangement, which always differ from one seedling to another. Because of the large variation of dimensional indices, each of seedlings has to be measured separately to quantify its shape and thereby to recognize the required features.

For proper grafting, stem-diameter of both rootstock and scion seedlings should be matched. When human operators graft the seedlings, they use their ‘eye-vision’ to choose the scion and rootstock seedlings of almost same stem-diameter. In an automatic grafting system, a camera can be used to substitute the human eyes for grading and sorting the seedlings.

(1) Camera selection

The main feature of the seedlings to grade and sort them is the stem-diameter. Therefore, each pixel of an image is important to measure the exact seedling diameter. If the number of pixels per unit area of an image is an important issue, then a monochrome camera is always preferable than a color camera. Hence, a UXGA monochrome camera of 1628×1236 pixels resolution was chosen to acquire the images of the seedlings.

(2) Selection of illumination source

In machine vision system, two major categories of artificial lighting sources are generally used to acquire images for visualizing the object: 1) lighting the object from its front side, i.e., from the camera side so that the required features are visualized to the camera (Fig. 1a); 2) lighting the object from its back side so that the shadow of the object is visualized to the camera (Fig. 1b).

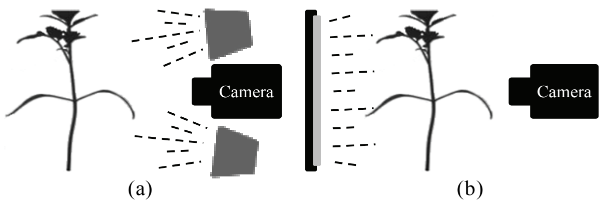

Fig. 1 (a) Front lighting system; (b) Backlighting system

To find the suitable one for this study, both types of the lighting sources were tested. In the first step, four LED lighting sources were placed around the camera facing them towards the seedling. With that arrangement the images of a seedling for 5, 10 15 and 20 cm camera distances were acquired. In the next step, for same seedling and same camera distances, images were acquired placing the lighting source behind the seedling facing it towards the camera, so that the shadow of the seedling can be acquired. Images acquired for both lighting sources were compared, and the source, for which the image found better, was selected for the study.

(3) Backlight color

There are white, blue and red colors LCD panel backlights available in the market to use as the illumination source. To find the suitable one, all three color backlights were separately used with the camera to acquire images of a seedling from same camera positions. The extracted pixel values of the acquired images were compared and the backlight color, for which the image found suitable, was selected for the study.

(4) Light filter

Lighting source produces some reflective or halation effect on the object, which makes certain parts of the object highly bright. To remove this halation effect, polarized light (PL) filters are often used while acquiring images in combination with camera as well as with lighting sources. To find the effectiveness of the PL filters, three different combinations of the devices for 10 cm camera distance were used to acquire the images of a seedling: (i) using no light filtering device, (ii) using PL filter on the camera lens, and (iii) using PL filter on the camera lens as well as on the backlight panel. The acquired images were compared to find the best combination in extracting the required features of the images.

(5) Other tools

The other hardware systems used in this study together with the camera and lighting devices to acquire and process the images of seedlings are an image capture board and a PC with processor of Intel Core2 Quad CPU 2.40 GHz. The programming software used are Visual C++ and Open Source Computer Vision (OpenCV) library under Windows platform.

2. Image acquisition

To conduct test, 200 scion seedlings and 200 rootstock seedlings were collected from a tomato seedlings' grafting farm of Ehime prefecture in Japan. To find the optimal distance between the camera and the seedling, test images of a seedling for 10, 15, 20 and 25 cm camera distances were acquired and then the required features found in the images were compared. The distance for which the number of pixels of the image, that indicate stem-diameter, found maximum per unit area and the desired portions of the seedling were clearly visible inside the field of view (FOV) of the camera, was chosen as the optimal distance. Each seedling was vertically placed in between the camera and the backlight panel to acquire its images. The experimental settings of camera, seedlings and backlight panel are shown in Fig. 2. For the selected optimal camera distance, two images of each seedling were acquired from two different camera directions manually rotating the seedling carrier in 90 degrees.

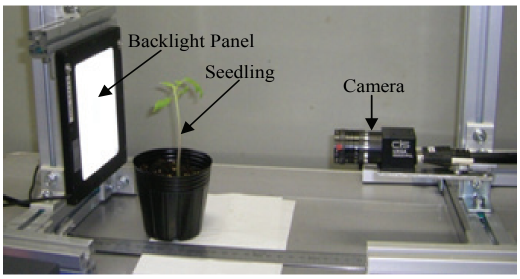

Fig. 2 Experimental setting of image acquisition

3. Image processing

The developed algorithm does not contain complex image processing schemes such as boundary encoding, skeletonizing and so forth in order to facilitate direct high speed image data processing, since the real time processing is essential for the sorting system. To distinguish the seedling image from its background, the gray scale image was converted to binary image. The threshold limit was chosen from the minimum gray value that found among several points of the background images. The number of the pixels having value '1' along each horizontal axis of the image was counted (Fig. 3). The counting process was started from a preselected point of the bottom part of the image so that in the first step the horizontal axis passes through only the stem image of seedling. In each step the horizontal axis was shifted one pixel upward along the vertical axis. When it reached just above the cotyledons, the counted value was almost same to that of the stem. At this point the length of the horizontal axis was reduced to a length nearly double to the width of the main stem so that the stem remains at the center of that axis-length. Then the horizontal axis started to move downward in each step until the counted value reached nearly double to that of the stem diameter. This point was considered as the node of cotyledons. In the same way the node of true leaves was detected moving the shortened horizontal axis upward. The midpoint between the two nodes on the stem is considered as the grafting or cutting point.

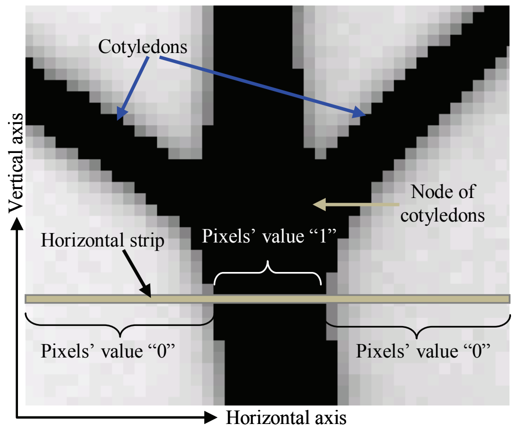

Fig. 3 Values of pixels along the horizontal axis of the binary image of a portion of the seedling

4. Stem diameter determination

The diameter of the stem of seedling at the cutting point was determined from the counted values of the binarized image along the horizontal axis. Average of counted values along five consecutive horizontal axis was considered as the final diameter. If the stem at cutting point is not exactly vertical, the counted value along horizontal axis will not give accurate diameter (Fig. 4). Therefore, before counting the pixels values along the horizontal axis, Eqns. (1) and (2) were used to compensate the inclination of the axis making it perpendicular with the stem:

$$\theta_n = \tan^{-1}\left(\frac{x_n - x_{n-1}}{y_n - y_{n-1}}\right) \qquad (1)$$

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \tag{2}$$

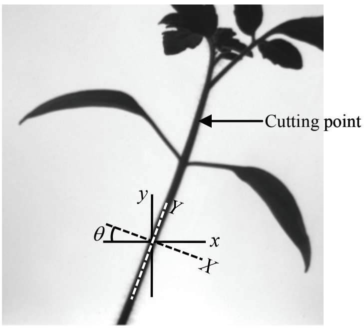

Fig. 4 Compensation of inclination effect on stem diameter

Here *(x,y)* is the coordinate along the horizontal axis, θ is the inclination angle of the stem with the vertical axis, the subscript n is the step number of counting pixels along each horizontal row, (x_0,y_0) is the coordinate at the cross point of the horizontal axis and the midpoint of the stem, and (X,Y) is the coordinate of the new axis which is exactly perpendicular to the stem. The stem diameter indicating pixels were counted along the (X,Y) axis. The (x_n, y_n) and (x_{n-1}, y_{n-1}) are the intersection points of the left most edge of the stem and the horizontal axis at y_n and y_{n-1} respectively.

5. Grading and sorting of seedlings

The initial step of the sorting algorithm was to find the better one from the two images of each seedling acquired from two camera directions, where the angle between the directions was around 90°. A pair of images of a seedling acquired from two camera directions is shown in Fig. 5. The image, in which the inter-nodal length found longer, was considered as the better image, as the orientation of cotyledons in that image was almost perpendicular to the camera axis and thereby the nodes and stem were clearly detectable. If the nodes of leaves in both the images of a seedling were undetectable due to the irregular arrangement of leaves, as shown in Fig. 6, was graded as “D” category or “substandard” and was left for manual grafting.

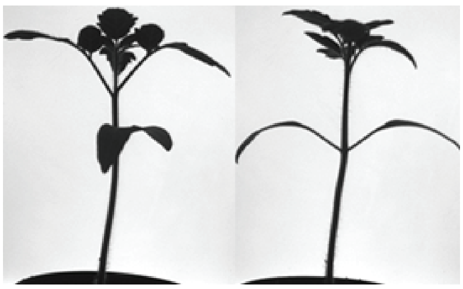

Fig. 5 Two images of one seedling acquired from two camera directions

Before grading the seedlings, number of pixels versus seedling diameter was calibrated for different camera positions. Usually the seedling stem-diameter varies from 1.20 mm to 2.50 mm. Therefore, based on the stem diameter, seedlings were graded as “A”, “B” and “C” categories, which corresponded with “large”, “medium” and “small” stem diameters respectively. Here “large”, “medium” and “small” indicate stem diameter range “more than 2.00 mm”, “in between 1.60 mm to 2.00 mm” and “less than 1.60 mm” respectively and thereby those were sorted according to their grade.

Fig. 6 Image that have undetectable nodes of leaves

III Results and Discussion

1. Device selection

(1) Illumination source

Along a fixed horizontal axis, the gray values of the pixels were extracted from both the images that were acquired for the front lighting as well as for the backlighting systems. The charts drawn using those extracted gray values are shown in Fig. 7. Since the directions of lighting systems were opposite to each other, the line directions of two charts were also opposite to each other. The bottom parts of two trapezoidal curves indicate the seedling width or diameter. Pixels No. 2 through 8 of the image of front lighting system indicate the left edge of the seedling stem, and 17 through 23 indicate its right edge. On the other hand only two pixels (from No. 4 through 6) of the image of backlight system indicate the left edge, and three pixels (from No. 20 through 23) indicate the right edge of the seedling stem. In this figure it is found that in case of the backlighting system, the number of pixels, that indicate the stem diameter, does not change significantly with the change of threshold limit. Therefore, backlighting system was chosen for acquiring images of seedlings.

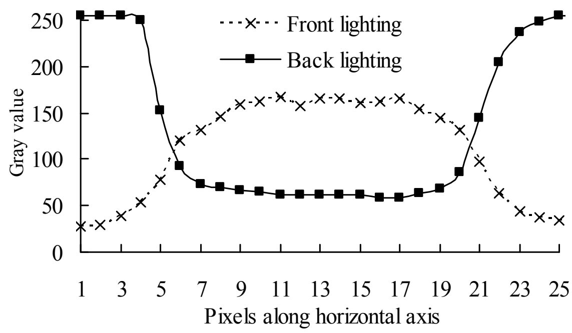

Fig. 7 Front and back lighting effects on the gray values along horizontal axis of a seedling image

(2) Backlight color

Red, white and blue color backlights were independently used with the camera to acquire images of a specific seedling. Figure 8 shows the lines drawn with the gray values of the pixels along horizontal axis at a fixed point of each image of the seedling. The threshold limit is fixed at the gray value 220, for instance. It is clearly perceptible that for the images acquired using white and red color backlights, the number of pixels along horizontal axis will change significantly for any change of threshold limit. However, as the wavelength of blue backlight is short, it can not penetrate the plant tissue. Hence no significant change will take place in case of the blue backlight. Since the number of pixels along horizontal axis indicates the diameter of the seedling, least change of the pixels with the change of threshold limit is expected. Therefore, the blue backlight in this consideration found the best among the three.

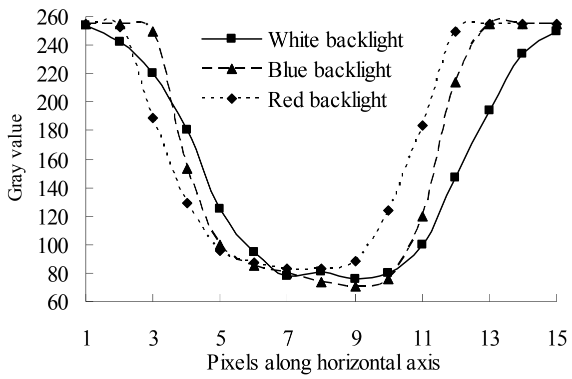

Fig. 8 Effects of the white, red and blue backlights on the gray values along horizontal axis of the seedling images

(3) Light filter

To find the effect of light filtering device on the image quality, three different combinations of camera, backlight and PL filter were used to acquire images of a seedling. The lines drawn with the gray values of the pixels along horizontal axis at a fixed point of each of those images are shown in Fig. 9. It is found that in the image acquired for the combination of camera and backlight but without any PL filter, the number of pixels, that indicates seedling-diameter, was the maximum at the threshold limit 250 compared with other two combinations. It decreases with the position of the pixels from the edge to the inner side of the stem. This indicates that when no PL filter was used with the camera or with backlight, the edge of the seedling stem was brighter due to the halation effect of illumination. On the other hand when images were taken using PL filter, the vertical stiffness of the trapezoidal curves, drawn for those images, were sharp compared to the previous one. This behavior proves that the halation could be successfully reduced using the PL filter. Very insignificant difference is found in using the PL filter only over the camera lens, and over both the camera lens and backlight panel. Finally it was decided to use the PL filter with camera lens as well as with backlight panel.

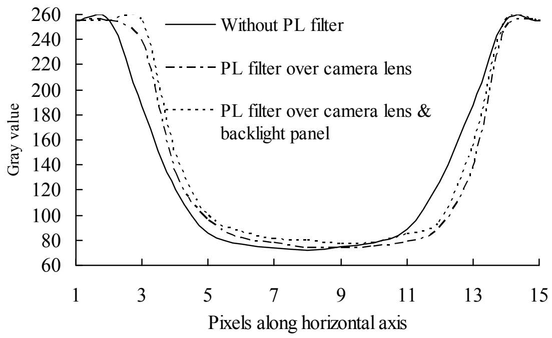

Fig. 9 Effect of PL filter with blue backlight on the sharpness of images

2. Grading and sorting of seedlings

The seedlings were graded and sorted on the basis of their stem diameter at the cutting point. The developed algorithm begins scanning each image along a horizontal axis from some predetermined point at the bottom of the seedling and accumulates the binarized pixel values. Figure 10(a) shows a seedling image in binary scale and Fig. 10(b) shows the counted pixel values of the same image. It is found that up to the pixel number 250 along vertical axis, the accumulated pixel values were almost same indicating it as the stem of the seedling. Above that level along vertical axis, accumulated pixels increased gradually up to the pixel number 360, which indicates the presence of cotyledons. Then the accumulated number of pixels decreased until the vertical pixel number 415 nearly to the one which was found up to the vertical pixel number 250. It indicates again the main stem of the seedling above the cotyledons. The accumulated number indicates the seedling diameter at this point. Moving upward from this point, the node of true leaves was found at the vertical pixel number 550, because the accumulated pixels started to increase again from this point. Using a short horizontal axis and moving downward from the pixel number 415, the node of cotyledons was also detected somewhere in between the vertical pixels 415 and 360. The midpoint of two nodes could be determined easily and the number of pixels that indicates the diameter of the stem at that point also could be determined. Comparing the number pixels with the calibrated data, stem diameter also could be determined using this method and thereby the seedlings could be graded and sorted.

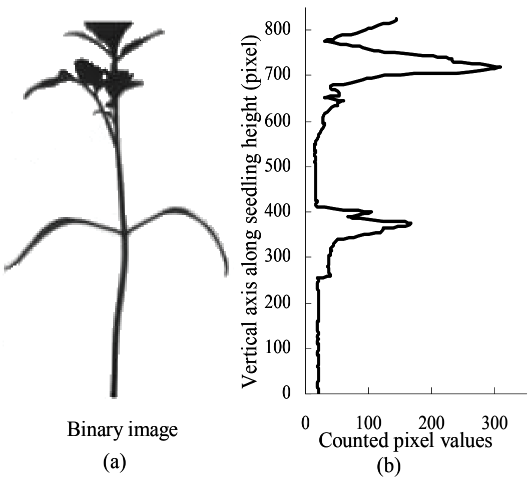

Fig. 10 (a) A seedling image in binary scale; (b) Counted binary values of the pixels along horizontal axis

Figure 11 shows an image of a seedling, where the desired part found covered with the leaves. From the counted binary pixel vales along each horizontal axis (Fig. 11(b)), the stem above the cotyledons could not be detected by the algorithm. Therefore, this seedling will be graded as "D" or "substandard" and will be left for manual grafting.

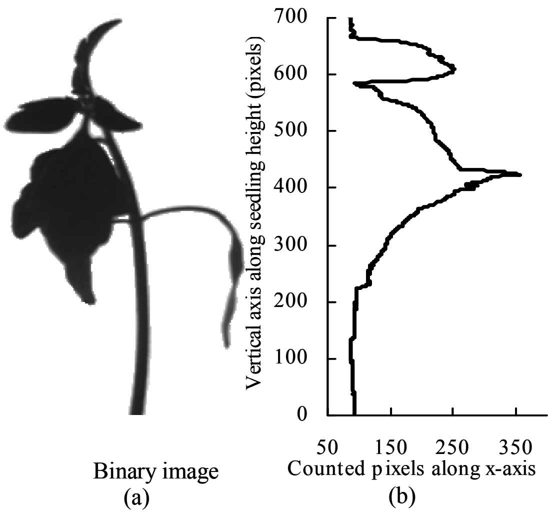

Fig. 11 (a) A substandard seedling image in binary scale; (b) Counted binary values of the pixels along horizontal axis

Table 1 shows that the algorithm could sort 97% of the seedlings successfully. The rest 3% was failed as the target portions of the seedling images were shaded by the abruptly bended or irregular arrangement of leaves, as shown in Fig. 6, which made them undetectable. It is also found that most of the sorted seedlings (69%) had larger stem diameter, which are desirable for proper grafting.

Table 1 Grading and sorting performances of the algorithm

Successfully sorted seedlings (%)	Failure in sorting (%)	Graded seedlings (%)			
		A	B	C	D
97	3	69	22	6	3

IV Summary and Conclusions

An algorithm of grading and sorting tomato seedlings using machine vision is developed for a fully automatic grafting robot system. From the experiment of acquiring images of seedlings, it is observed that backlighting system in combination with PL filter is suitable to recognize the shape of seedlings in the images and UXGA class camera is required for the sorting operation by machine vision. The success rate of the algorithm was 97 %. The rest 3% seedlings was failed to sort as the required portions of the images were covered by irregular arrangement of leaves from all sides and thereby those were kept for manual grafting. The seedlings were graded and sorted into large, medium, and small categories based on their stem diameter at the cutting point. This algorithm is not bound for tomato seedlings only but can also be used for eggplant, pepper and many other seedlings with minor modifications.

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References

Biles, C. L., R. D. Martyn and H. D. Wilson. 1989. Isozymes and general proteins from various watermelon cultivars and tissue types, HortScience 24:810-812.

Chen, S., Y. C. Chiu and Y. C. Chang. 2009. Development of a tubing grafting robot system for fruit-bearing vegetable seedlings. Proceedings of the Bio-Robotics Workshop IV, Illinois, USA, Article No. 507.

Fly, D. E., J. Wilhoit, L. Kutz and D. South. 1992. A low cost machine vision system for seedling morphological measurement, ASAE paper No. 923030, St. Joseph, MI 40985.

Garcia, N. F., V. Martinez, A. Cerda and M. Carvajal. 2002. Water and nutrient uptake of grafted tomato plants grown under saline conditions, J. Plant Physiol. 159:899-905.

Hwang, H., J. H. Chang and S. C. Kim. 1997. Automatic grafting system for fruit bearing vegetables based on inarching graftage. Proceedings of ISAMA 97:75-80, Taipei, Taiwan.

Ioannou, N., M. Ioannou and K. Hadjiparaskevas, 2002. Evaluation of watermelon rootstocks for off-season production in heated greenhouses. *Acta Horticulturae* 579: 501-506.

Khah, E. M., E. Kakava, A. Mavromatis, D. Chachalis and C. Goulas. 2006. Effect of grafting on growth and yield of tomato in greenhouse and open-field. J. of Applied Horticulture 8(1):3-7.

Kobayeshi, K. and M. Suzuki. 1996a. Development of grafting robotic system for cucurbitaceous vegetables (part 3). Journal of Japanese Society of Agricultural Machinery 58(2):83-93.

Kobayashi, K., A. Onada, M. Suzuki and H. Otsuki. 1996b. Development of grafting robotic system for cucurbitaceous vegetables (part 4). Journal of Japanese Society of Agricultural Machinery 58(3):59-68.

Kobayashi, K. and M. Suzuki. 1999. Grafting robot. Journal of Robotics and Mechatronics 11(3):213-219.

Kurata, K. 1994. Cultivation of grafted vegetables II. Developments of grafting robots in Japan. HortScience 29(4): 240-244.

Lee, J. M. 1994. Cultivation of grafted vegetables I. Current status, grafting methods, and benefits, HortScience 29(4):235-239.

Lee, J. J., S. Lin, J. S. Ju, and Y. I. Huang. 2001. Development of an automatic grafting robot for propagating passion fruits. Journal of Agriculture and Forestry 50(1): 1-14.

Ling, P. P., G. A. Giacomelli and T. Russell. 1996. Monitoring of plant development in controlled environment with machine vision, J. of Adv. Space Res. 18(4 & 5):101-112.

Meyer, E. G. and A. D. Davidson. 1987. An electronic image plant growth measurement system, Transactions of the ASAE 30(2):242.

Nishiura, Y., H. Murase, N. Honami and T. Taira. 1995a. Development of plug-in grafting robotic system. Proceedings of the 1995 IEEE International Conference on Robotics and Automation 3:2510-2517.

Nishiura, Y., H. Nishijima and H. Takigawa. 1995b. Shape recognition algorithm for a seedling in vision system of grafting robot system. Acty21 Integrated research report on Technology for artificial intelligence bioinstrumentation machine vision in agriculture 366-373.

Rigney, M. P., and G. A. Kranzler. 1988. Machine vision for grading southern pine seedlings. Transaction of the ASAE 31(2): 642-646.

Ruzhitsky, V. N. and P. P. Ling. 1992. Machine vision for tomato seedling inspection, ASAE paper No. 927020, St. Joseph, MI 40985.

Sase, S., M. Nara, T. Okuya and K. Sueyoshi. 1992. Determining seedling characteristics using computer vision and its application to an expert system for grading seedlings; Acta Horticulturae Number 319, International Symposium on Transplant Production Systems 683-688.

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