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Study on Grade Judgment of Fruit Vegetables Using Machine Vision

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Abstract

Grade judgment is an essential component of a vegetable and fruit sorting system. Judgment of capability should be integrated with the collection of raw data from an object, and classification of algorithm of processed data. Machine vision is a useful tool for collecting raw data and for classification. Recently, machine vision applications for sorting and inspecting some fruit vegetables have been studied by many scientists [4-7, 10, 12-16]), However, the traditional image recognition and image understanding methods cannot evaluate satisfactorily irregularly shaped fruit vegetables. Thus, in this article a new feature extraction procedure and neural network were applied to the machine vision system to precisely evaluate fruit vegetables. As the newly developed machine vision system has a learning capability, it can evaluate more than one variety of fruit vegetables. The results obtained for 4 kinds of strawberry varieties and 1 variety of green pepper showed a high accuracy, confirming that the system has a great potential for grade judgment [3, 9]),

Discipline: Agricultural machinery
Additional key words: image processing, feature extraction, strawberry, green pepper,

Introduction

In Japan, to upgrade the commodity value, fruit vegetables are generally sorted into grades based on shape, damage and color and into grades based on size or weight before marketing. For most of the fruit vegetables, grade sorting according to size or weight has already been mechanized. However, grade sorting based on shape, internal quality, etc., such as in the case of orange, apple, and cucumber, is still in the initial stage and in most cases performed manually. Along with the unprecedented severe shortage of farm labor, the rapid ageing of Japan's experienced growers and producers with few potential successors pose a difficult problem to the industry. Therefore, to eliminate the errors of judgment of producer and inspector, to meet the consumers' demand for strict standardization and to be able to market fruit vegetables uniformly, it is essential to improve the sorting methods.

At present, because of the advances in electronic technology, machine vision can be applied to research on the development of an automatic sorter. Machine vision enables to handle a large amount of raw data and perform remote judgment. It is used extensively in fruit vegetables sorters. On the other hand, there are conventional image recognition methods such as matching, statistical method and logical method of computation. However, they are not suitable for determining the shape of fruit vegetables because of the complexity and ambiguity involved.

This paper describes a general-purpose grade judgment system with high performance rate and capability of evaluating more than one kind of fruit vegetables using image processing technology and multiple-valued neural network theory[1,2,8,11]. One of the unique characteristics of this system is that it enables to evaluate fruit vegetables according to their standard patterns, which are learned by the software before the actual judging operation is performed. The system also enables to evaluate different kinds of fruit vegetables by learning their corresponding extracted shape characteristics.

Concept of sorting fruit vegetables

1) Shape features of fruit vegetables and representation

The fruit vegetables are biological products. Although vegetables or fruits may be cultivated in the same way, their shape, size, color and other characteristics are different. Moreover, one vegetable or fruit may consist of many varieties, which requires that sorting standardization for each kind be performed. Using machine vision to evaluate the shape of fruit vegetables, expression and extraction of shape features become an important element because compared with an industrial product, the shape standard of vegetables or fruits does not follow quantitative rules. In this article a set of shape features, which are expressed as thickness, length and curve is proposed, and a method of extraction of characteristic patterns from an object of standard shape is described.

2) Sorting of fruit vegetables

After harvest, sorting of many fruit vegetables is still carried out manually. Inspection standard table classified those that have a good shape and color into grade A, while those with inferior characteristics were graded B. The strawberry inspection standard was set up by the Agricultural Cooperative Association in Miyazaki Prefecture, Japan. Accordingly, there are 3 grades based on shape, namely: A, B and C, and 5 grades based on the size: 3L, 2L, L, M, and S as shown in Fig. 1.

It is important that a machine vision judging system has learning and fuzzy process functions. Such a system enables to overcome the weakness of traditional type systems. Therefore, the researchers have developed an advanced judging system using machine vision, involving image processing, shape feature extraction, neural network and computer technologies. The system can grade various fruit vegetables according to their shape using the learned standard pattern.

Materials and methods

1) Strawberry and green pepper

Four kinds of strawberry varieties, namely 'Reiko', 'Toyonoka', 'Nyoho' and 'Akihime', and one green pepper variety 'Sadowarahikari super' were used in the experiment.

The characteristics of each variety are as follows: Reiko variety has a large fruit with a circular conical shape and a strong pericarp. The flesh has an excellent taste. It is fragrant and has high sugar and acid contents. Generally, the fruits with deformed shape account for about 4 to 5%, while those with a good shape account for 80%.

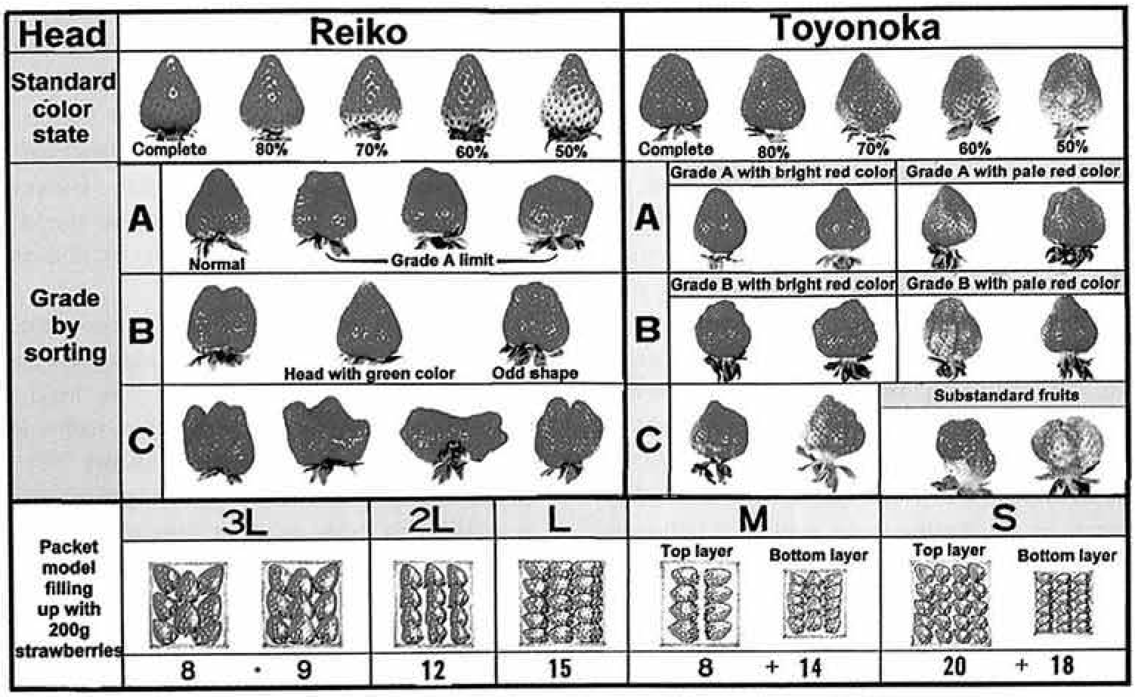


Fig. 1. Standard table for strawberry sorting in Miyazaki Prefecture

Toyonoka variety has a large fruit with a short circular conical shape. The color of the pericarp, which develops more slowly when shaded by other plant parts from sunlight, is cherry-like. The pulp density is high. As the flesh is not porous, the juice content is high.

Nyoho variety shows a circular conical shape and the top is not sharp. The occurrence of an odd shape is low. Its shape resembles that of Reiko because it was produced by cross-fertilization with the Reiko variety. The size of the fruit is medium. Pericarp and pulp are cherry-like in color and hard, and the flesh is not porous. The sugar and acid contents are high and the taste is good.

Akihime fruit is large with a long circular conical shape. The occurrence of an odd shape is very low. The pericarp is lustrous and cherry-like in color.

Sadowarahikari super is well suited to greenhouse cultivation. This variety of pepper has a medium size with a dark green color. Under low temperature and daylight conditions, the flesh is thick and of high quality which makes it highly marketable.

2) Proposed method for shape feature extraction

Reading and writing of image dot data require a long processing time. By decreasing the frequency of readings, length of processing can be reduced. This paper describes a new shape feature extraction method for easy calculation and faster operation.

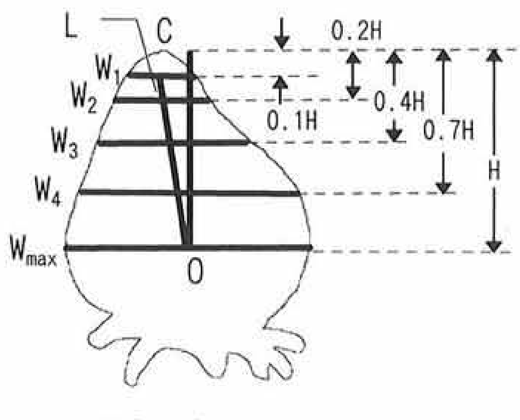
The 3 parameters, i.e. thickness, length and bend are illustrated in Fig. 2. After preprocessing of the fruit image into a binary form using the image processing technique, 5 horizontal widths, W_1, W_2, W_3, W_4, and W_{max}; one vertical height H and a length L of a line which connects the midpoints of W_1 and W_{max} were extracted. H is the perpendicular distance of the topmost point of the image from the maximum horizontal width, W_{max}, while W_1, W_2, W_3, W_4 are 0.1H, 0.2H, 0.4H, and 0.7H, respectively, from the topmost point of the fruit's binary image. From these measured parameters, K_1, K_2, K_3, K_4, K_5, and K_6, were calculated as follows:

$$K_1 = W_1/W_{max}$$
$$K_2 = W_2/W_{max}$$
$$K_3 = W_3/W_{max}$$
$$K_4 = W_4/W_{max}$$
$$K_5 = H/W_{max}$$
$$K_6 = L/H \quad \cdots\cdots (1)$$

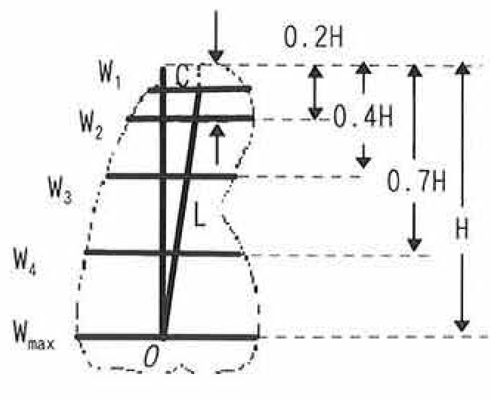
3) Neural network and algorithm

The machine vision system must be able to recognize a vegetable or fruit when it "sees" one and must decide to what grade or class the fruit should belong based on its shape and size. This is essentially the function which the judging component has to accomplish by employing appropriate software.

In this study, the multiple-valued neural network (MVNN) theory, generally accepted as a useful tool for the recognition of various patterns, and image processing technique were used for the development of the desired software. For example, Fig. 3 shows a 3-layer neural network model consisting of an input, a hidden and an output layer. Six input units, K_1, K_2, K_3, K_4, K_5, and K_6, representing a set of features, are fed into the network through the input layer. Each unit is connected to all the nodes of the hidden layer which is in turn connected to the 2 nodes of the output layer. Computation of the value of each unit in the hidden and output layers is then carried out using a piecewise linear operation expressed as:



(a) Strawberry



(b) Green pepper

Fig. 2. Feature extraction of fruit vegetables

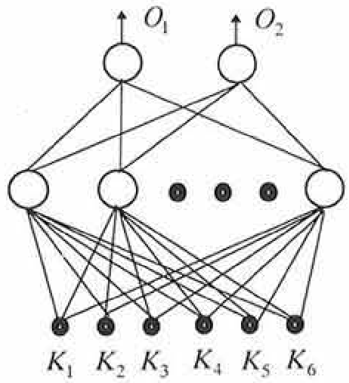
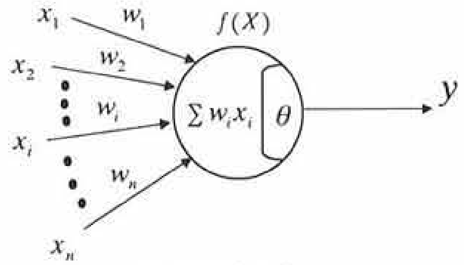
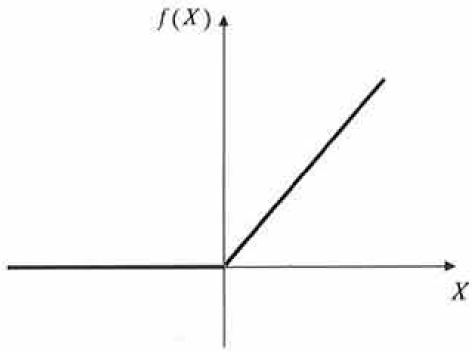


Fig. 3. Model of multiple-layer neural network



(a) Model of a unit



(b) Piecewise linear activation function

Fig. 4. Basic unit for multiple-valued neural network

$$Y = f(X) \quad \text{......................................} \quad (2)$$

where f is the arithmetic function and X is the weighted sum of the units in the previous layer, as shown in Fig. 4.

$$f(X) = \begin{cases} X & X > 0 \\ 0 & X \leq 0 \end{cases} \quad \text{............................} \quad (3)$$

An algorithm using the back-propagation method was applied to the neural network model to calculate the weight (synapse) values. That is, K_1, K_2, K_3, K_4, K_5, and K_6 were fed to the MVNN as inputs for learning, the weight values were then adjusted until the output value became very close to that of the teaching signal.

4) Machine vision judging system and its software

The machine vision system for grade judgment of fruit vegetables is illustrated in Fig. 5. The turntable moves automatically and draws the position of strawberry exactly under a CCD camera (ELMO EC-202 II lens: 16 mm, f = 1.5 – 1.0). The frozen image of fruit could be viewed in the monitor (SONY PVM 9221) through the image digitizer board FDM-4-256. The developed software, loaded into NEC PC 9801 RA analyzes the image of fruit to ascertain its shape and size. Soon after the shape of strawberry is ascertained, the 5-joint robot picks up and transports the fruit to predefined locations. As shown in Fig. 5 (b), the robot arm distributes the fruits subjected to evaluation.

The flowchart of the judging system software is shown in Fig. 6. This software displays learning and judging components as follows:

(1) Learning program

① The name of the fruit vegetables to be handled and the kind are inputted.

② Input the standard shape of an object from a CCD camera in order to develop a pattern for learning. (Shape features K_1, K_2, K_3, K_4, K_5, and K_6 are generated from this.)

③ The teaching signal is inputted from the computer keyboard.

④ The numbers of layers in the middle, number of units in each layer, learning coefficients are adjusted to a specific MVNN model.

⑤ According to the teaching signal, the MVNN model learns a set of standard patterns.

⑥ If learning succeeds, data are saved then go to end, if not, go to ④, until the learning operation is completed.

(2) Judging program

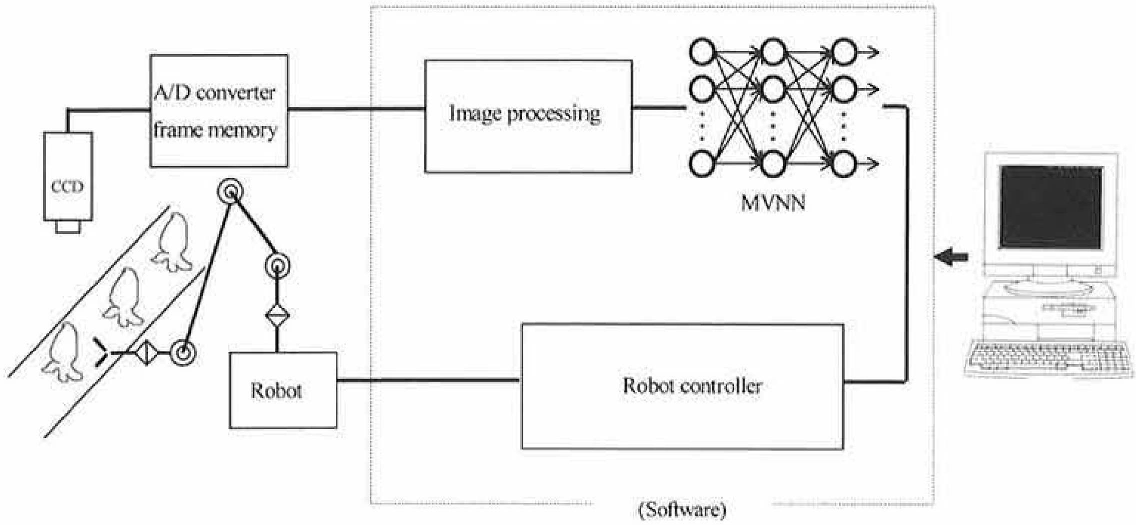
① Determine, in interactive style, whether the learning operation for the kinds of fruit vegetables has already been completed for evaluation, if not, the learning program is called upon.

② Load synapse or weight data to MVNN.

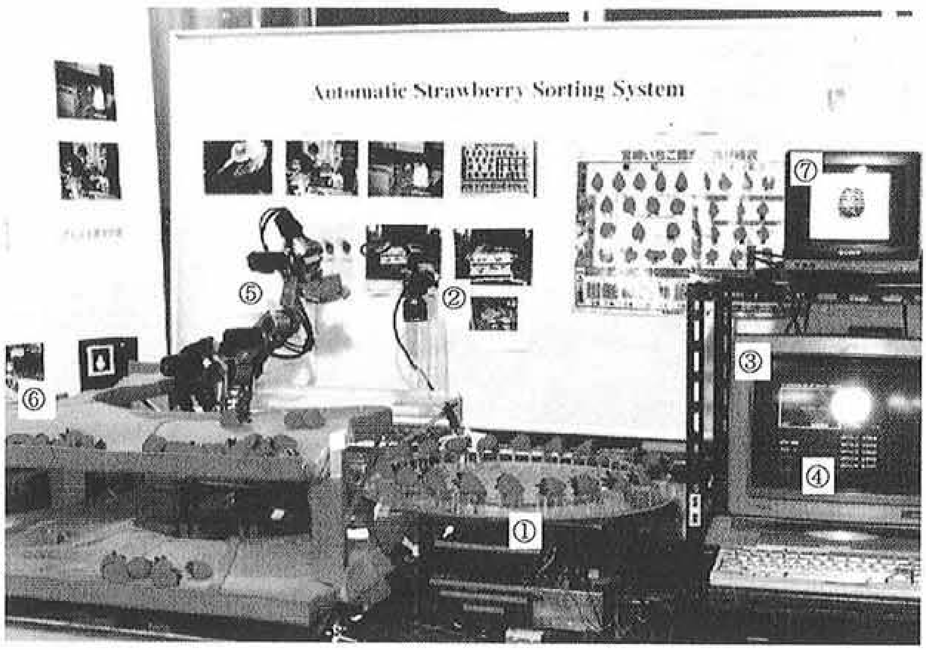
③ Rotate turntable, and the specimen is brought to a location under the CCD camera.

④ Image processing and feature extractions are performed.

⑤ The MVNN evaluates shape features, and sends



(a) Configuration of judging system



① Turntable, ② CCD Camera, ③ Computer,
④ Model of MVNN, ⑤ Robot, ⑥ Ranking area,
⑦ Monitor.

(b) Judging system set-up

Fig. 5. Machine vision judging system

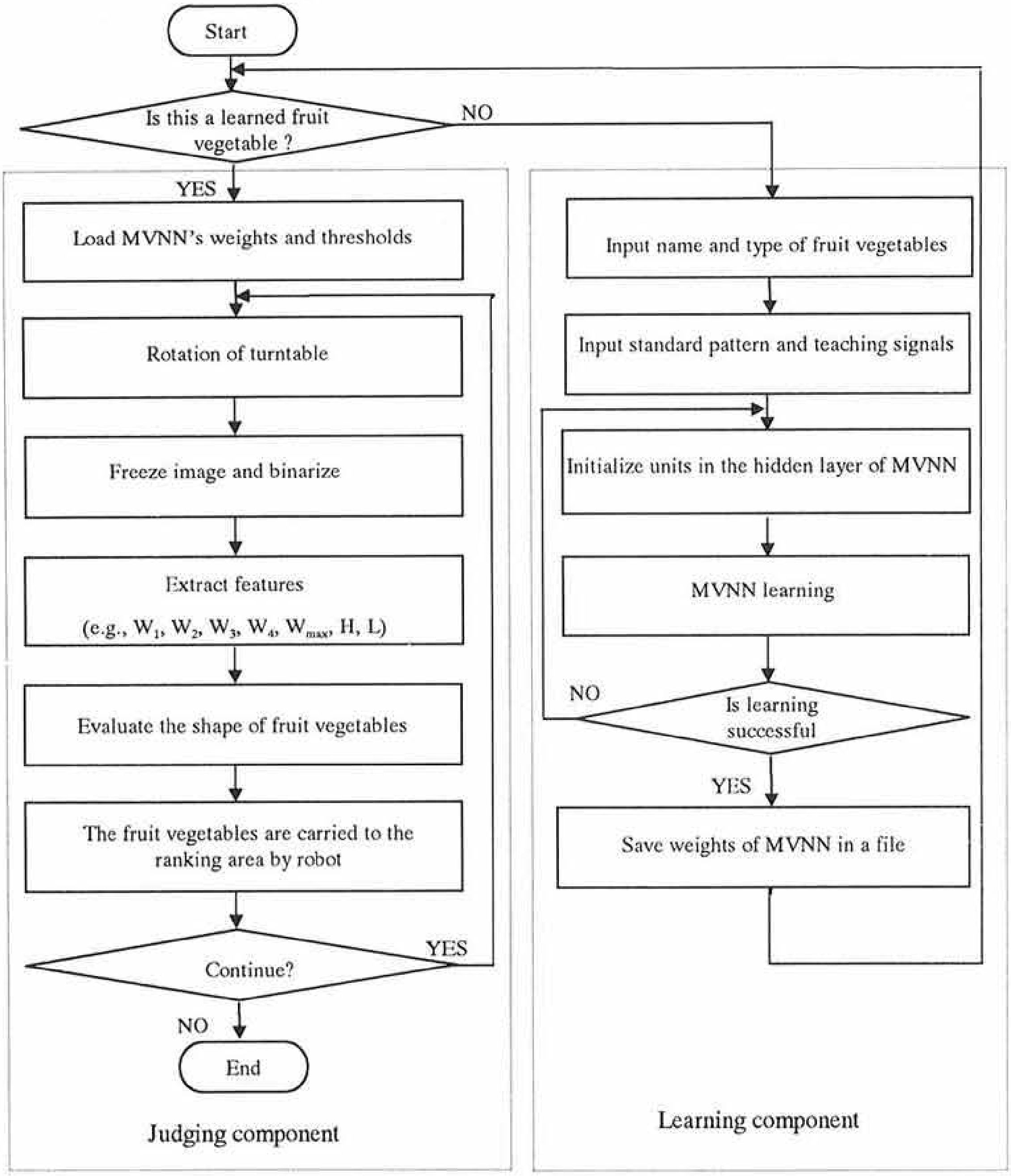


Fig. 6. Flowchart of machine vision judging system software

control signals to the robot.

⑥ The robot carries the object evaluated to the correct area in the collection unit.

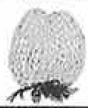
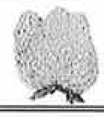
Results and discussion

1) Shape judging standards and learning patterns

Shape judging standards of fruit vegetables are determined in every producing district. This time, the shape judging standards of Fukuoka, Miyazaki and Tochigi Prefectures were used. The shape grade of 4 varieties of strawberry and 1 variety of green pepper is shown in Table 1. Based on Table 1, learning patterns of fruit vegetables used in the experiment were generated and are shown in Fig. 7.

2) Input and acquisition of learning patterns

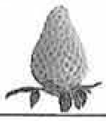
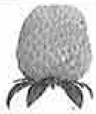
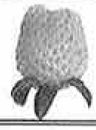
According to the learning patterns (Fig. 7), one by one, the standard pattern is put under a CCD camera and the teaching signal ($A=0, 0$; $B=1, 0$; $C=0, 1$) is inputted accordingly from the computer keyboard in every set of learning patterns.

Shape class	Standard pattern	Teaching signal	
	$K_1, K_2, \dots K_6$	T_1	T_2
A		0	0
B		1	0
C		0	1

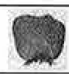
(a) Reiko

Shape Class	Standard pattern	Teaching signal	
	$K_1, K_2, \dots K_6$	T_1	T_2
A		0	0
B		1	0
C		0	1

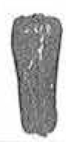
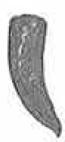
(b) Toyonoka

Shape class	Standard pattern	Teaching signal	
	$K_1, K_2, \dots K_6$	T_1	T_2
Super fine		0	0
LA		1	0
2A		0	1
3A		1	1

(c) Nyoho

Shape class	Standard pattern	Teaching signal	
	$K_1, K_2, \dots K_6$	T_1	T_2
			
A			
		0	0
			
B			
		1	0

(d) Akihime

Shape class	Standard pattern			Teaching signal	
	$K_1, K_2, \dots, K_6$			T_1	T_2
A	① 	② 	③ 	1	0
B	④ 	⑤ 	⑥ 	0	1

(e) Sadowarahikari super

Fig. 7. Learning patterns of 4 strawberry varieties and 1 variety of green pepper

Table 1. Standard shape ranks of 4 varieties of strawberry and 1 variety of pepper

Variety	Shape class				
Reiko	A	B	C		
Toyonoka	A	B	C		
Nyoho	Superfine	LA	2A	3A	B
Akihime	A	B			
Sadowarahikari super	A	B			

Here, the error limit is defined as 0.01, 5 kinds of learning patterns were acquired, and the learned results all succeeded. Therefore, after learning, the machine vision judging system could evaluate more than 1 variety of vegetables.

3) Judgment and appraisal

Judging system requires attention because the fruit should be placed on the turntable vertically (see Fig. 8) in order to extract features correctly. Experimental judging results were compared with those of manual judging to assess the accuracy rate. Since the judging standard of fruit vegetables is fuzzy, it is likely that different results will be obtained from different persons for the same object. Thus, manual judging results as defined above should be agreed upon by 3 persons aside from an instructor and student, i.e. a total of 5 persons in the laboratory. For example, when 5 persons determined that the strawberry shape is A, A, B, A, B, respectively, the human judging results are taken as A.

In this judging experiment, fresh fruit vegetables were used, including Reiko (122 fruits), Toyonoka (187 fruits), Nyoho (170 fruits), Akihime (167 fruits), and Sadowarahikari super (100 fruits). The agreement rate of human judging results and the machine vision judging system are shown in Table 2.

The test results of the machine vision sorting system displayed a high degree of precision. Table 2 shows that robotic sorting and manual sorting exhibited only a marginal difference in terms of accuracy. Percentage accuracy ranged from 89 to 98% and the percentage of error in shape judgment for different varieties ranged from 2 to 11%.

4) Future problems

It is important for MVNN to produce learning patterns in the machine vision judging system. Since a given set of precise learning pattern is acquired by MVNN, the accuracy of the machine vision judging system increases. Moreover, it is necessary to increase the number of features and to improve the components of the extracting method, because there is still a difference in the judgment from human. In order to evaluate fruit vegetables such as green pepper that have a complex shape, it is necessary to develop a judging method that combines fuzzy and MVNN theories to improve the judgment accuracy.

Table 2. Agreement rates of shape judgment

Variety	Accuracy	Error
Reiko	95%	5%
Toyonoka	97%	3%
Nyoho	98%	2%
Akihime	94%	6%
Sadowarahikari super	89%	11%

Conclusion

In order to evaluate more than one kind of fruit vegetables, according to the shape, the machine vision system was studied. The shape judgment of fruit vegetables is difficult compared to industrial products of fixed form because of the naturally unique outline. In this study image processing and MVNN technologies were used for the advanced machine vision judging system, which enabled to alleviate the fuzzy judging problem of shape. Due to its learning capability, the system was able to evaluate different kinds of fruit vegetables according to their learned standard pattern. In the judging experiments, 4 varieties of strawberry, Reiko, Toyonoka, Nyoho, Akihime and 1 variety of green pepper Sadowarahikari super were used. The results showed that the judging accuracy for strawberry ranged from 94 to 98% while 89% for green pepper. Therefore, the system has a high potential in grade judging of fruit vegetables which is still in the developmental stage.

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