RESEARCH ON IMAGE-BASED FUZZY VISUAL SERVO FOR PICKING ROBOT

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Abstract: An open eggplant picking robot experiment system is developed successfully which includes a arthral manipulator with 4 DOF, a motion controller, a color image processing card, a camera and a PC. The fixed bilateral threshold based histogram is adopted to segment the G-B gray images of eggplant in the growth environment.. To meet the vision requirement of the eggplant picking robot, the object's characters, such as outline, area, center of gravity, enclosing rectangle and the point to cut off, are extracted. We applied fuzzy control to the visual servo of picking robot and selected the fruit image's centre of gravity coordinate as variable for the fuzzy control system to create a fuzzy controller. The output control was modified by the self-adjustment factor and thus a fuzzy control diagram for the precise output control was obtained. The results show that the image-based picking robot fuzzy visual servo control overcomes time variation, nonlinearity and strong coupling of the robot visual servo control and has high response speed and good robustness.

Keywords: picking robot, image processing, visual servo, fuzzy control

1. INTRODUCTION

Harvest and picking takes much time and effort in the course of fruit and vegetable cultivation. Statistics shows that harvest and picking accounts for 50 to 70 percent of the total workload (Liang, 2005；Song, 2006). From the

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1980s, the Western developed countries such as Japan have been working at the picking robot and have developed artificial intelligence robot to pick vegetables and fruit (Kondo, 1996; Sario, 1993; Shigehiko, 2002). However, these vegetable and fruit picking robots can't adapt to the external environmental changes due to limited sensitivity, which affect their promotion (Hollingum, 1999). With the development of computer vision, the visual servo system that combines robot control and robot vision provides conditions for improving robots' sensitivity and intelligence (Wang, 2005).

Since Hill and Park put forward the concept of visual servo in 1979(Weiss, 1987), scholars at home and abroad have done numerous studies on robot visual servo and acquired some achievements in these years. But because of its complexities, there exit such difficulties as low speed in processing visual information and narrow appliance ranges. Visual servo control algorithm is still a challenge to be solved (Sun, 2006).

The present study is to develop a opening eggplant picking robot. The main objectives of the study go as follows:

(1) To develop open picking robot experiment system based PC for eggplant.

(2) To study the object's recognition and orientation in the growth environment.

(3) To design the fuzzy controller of picking robot.

2. OPEN PICKING ROBOT EXPERIMENT SYSTEM FOR EGGPLANT

In order for vegetable and fruit picking robot to have favorable extensibility, commonality and flexibility, open architecture is used for the eggplant picking robot experiment system. The system is composed of a PC, a DMC2280 motion controller, Y-E DATA AC servomotor, DH-CG320 color image processing card, Panasonic WV-CP470 camera, a arthral manipulator with 4 degree of freedom, as shown in fig.1.

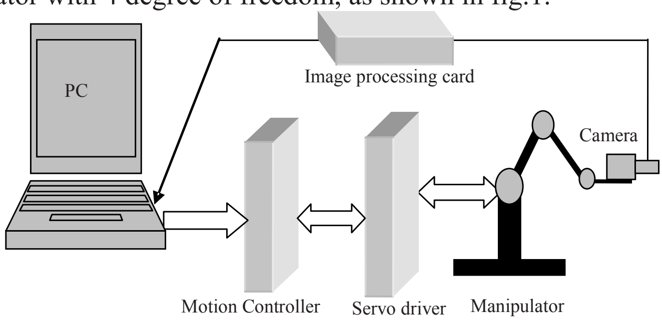

Fig.1: Schematic diagram of picking robot system

The picking robot control system is a master-slaved structure. The PC, as the master controller, runs the main robot control program, provides the user interface, and completes the Motion Planning. The DMC2280 motion controller, as the workshop controller, accomplishes the motion control for joint electric motor via the motor driving system.

3. IMAGE PROCESSING ALGORITHM

It is the task for machine vision system to distinguish the ripening fruits from the complex background based on the colors, sizes and shapes of the target fruits, and to extract their characteristics to determine their spatial location, in order to provide corresponding kinematical parameter for the robotic arm.

3.1 Image segmentation

Image segmentation in picking robot visual system is to extract and mark the eggplant fruits from the image, i.e., to segment the image into two parts: the eggplant fruits and the background. The fixed bilateral threshold based histogram is adopted to segment G-B gray image according to the analysis of the color characters of the eggplant fruits and surrounding.

In specific operation, as for input image pixels whose gray value is between 20 and 192, the corresponding output image pixels is given white (pixel value is 255), others black (pixel value is 0), as shown below:

$$g(x,y)=\begin{cases}1 & f(x,y)\prec 20\\ 0 & 20\le f(x,y)\le 192\\ 1 & f(x,y)\ge 192\end{cases} \tag{1}$$

Where: $f(x, y)$ is the pixels gray values at (x, y) before being processed, $g(x, y)$ is the pixels gray values at (x, y) after being processed, and t is the threshold value. The result of image segmentation is shown in Fig.2.

Fig.2: Result of image segmentation

3.2 Feature extraction of the target fruit

Picking robot needs machine vision system to provide characteristic parameters of the picking target, such as outline, area, center of gravity, enclosing rectangle and the point to cut off, etc. The contour has been labeled in two-dimensional array through edge extracting and contour tracing from binary image. In this way, it is convenient to extract the character desired for the target fruit. The result of feature extraction is shown in Fig.3.

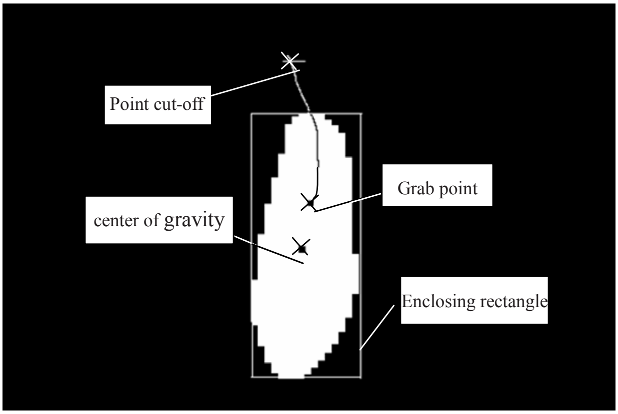

Fig.3: Result of feature extraction

4. IMAGE-BASED FUZZY VISUAL SERVO

4.1 Description of fuzzy visual servo control

The eye-in-hand configuration is applied to the visual servo system of picking robot. Target image information from the camera in the end effector of picking robot is used as input variable of the visual servo system. The fuzzy controller makes use of the input variable to determine the relative position between the end effector and the target and sends commands to complete the process of “perception- route choice -position adjustment- reaching target location”.

4.2 Design of fuzzy visual servo control

4.2.1 Selecting input variables for fuzzy control system

The image-based visual servo control needs to select proper image character to indicate the position relationship between the target and the robot because its task is to adjust the pose and position of the manipulator according to the picking robot job requirement. Thus the gravity center coordinates of the target fruit $G(\overline{x}, \overline{y})$ is selected to reflect the relative posture between the target fruit and the manipulator. The difference value between the ideal value and current value acts as the input variable for the fuzzy controller. The wrist rotational motion $\overline{R}$ and vertical up-and-down motion $\overline{V}$ around the waist are selected as the output variable for the fuzzy controller. The block diagram of picking robot's fuzzy controller is shown in Fig.4.

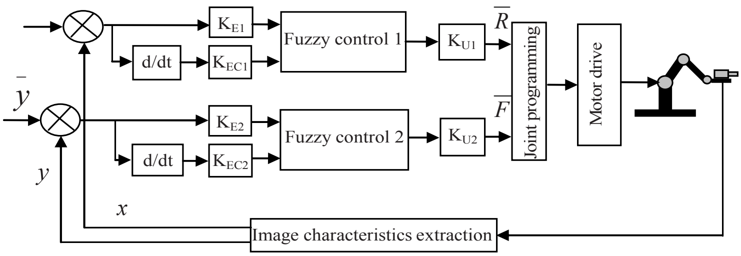

Fig.4: Block diagram of picking robot's fuzzy controller

4.2.2 Fuzzification process of the fuzzy controller

The actual range of the input and output signals of the fuzzy controller is called the basic universe of the variable, which is the exact value. Before fuzzy reasoning, it needs to fuzzificate the exact value in the first place. The grades of the basic universe are to be classified because it needs to fuzzificate the exact value before fuzzy reasoning. There are certain requests for control precision and real-timing in accordance with the particular case of the vegetable and fruit picking robot. Therefore, the quantification grades for both the input variable and the output are classified as 12, namely:

$$\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$$

The corresponding word set of fuzzy Language is chosen as:

$$\{NB, NM, NS, O, PS, PM, PB\}$$

Both the input variable and the output variable adopt Triangle-shape grade of membership function. The curve of membership function is shown in Fig.5.

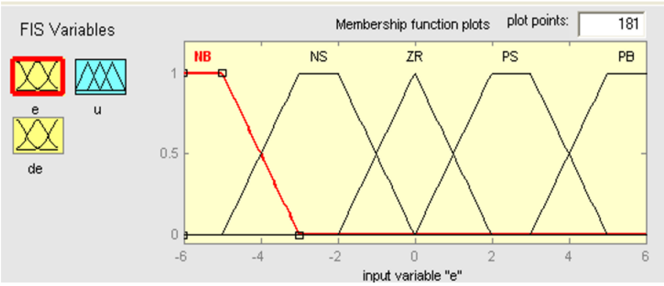

Fig.5: Curve of membership function

4.2.3 Fuzzy reasoning

It is through fuzzy reasoning rule to realize the mapping relationship between input fuzzy data and output fuzzy data. For the fuzzy controller in this research, the input is error E and error change rate Ec, and the output is U. There are the conditional statements of the fuzzy reasoning rules as shown by the following:

$$if \quad E = E_i \quad Ec = Ec_j \quad then \quad U = U_{ij} \tag{2}$$

Where: $i = 1,2,\cdots,7 \qquad j = 1,2,\cdots,7$

The membership function of the fuzzy relation can be expressed as:

$$\mu_R(x,y,z) = \bigvee_{i=1,j=1}^{i=7,j=7} [\mu_{Ei}(x) \wedge \mu_{Ecj}(y)] \wedge \mu_{Uij}(z) \tag{3}$$

Where: $\forall x \in E, \forall y \in Ec, \forall z \in U$

From the analysis of robot control, 49 reasoning rules can be established as shown in Table.1.

*Table 1.*Fuzzy control rule table

Ec	E						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PB	PM	PS	Z	NM	NM
Z	PB	PB	PM	Z	NM	NB	NB
PS	PM	PM	Z	NS	NM	NB	NB
PM	Z	Z	NS	NM	NM	NB	NB
PB	Z	Z	NS	NM	NM	NB	NB

Therefore, the corresponding fuzzy relation for the main system control rule is:

$$R\bigcup_{i=1}^{49} R_i \quad (4)$$

The formula for seeking the control decision is $U = (E \times Ec)R$, namely：

$$\mu_U(z) = \vee_{x\in E, y\in Ec} \mu_R(x, y, z) \wedge [\mu_E(x) \wedge \mu_{Ec}(y)] \quad (5)$$

4.2.4 Defuzzication and the creation of fuzzy control table

The result from fuzzy reasoning is only a fuzzy quantity, which cannot be used directly for the controlled object. It needs to be converted in a precision quantity which can be run by an the executing agency through defuzzication process. The median method is selected to complete defuzzication process according to engineering application practice. The fuzzy control table corrected by the self-adjusting factors is set up, as is shown in Table 2.

*Table2.*Fuzzy control table

Ec	E												
	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	6	6	6	5	4	4	4	4	3	1	0	0	0
-5	6	6	6	5	4	4	4	4	3	1	0	0	0
-4	6	6	6	5	4	4	4	4	3	1	0	0	0
-3	6	6	6	5	4	3	3	3	2	0	-3	-3	-4
-2	6	6	6	5	3	2	2	2	1	-2	-4	-4	-5
-1	6	6	6	5	3	1	1	1	0	-4	-5	-5	-6
0	6	6	6	5	2	0	0	0	-3	-5	-6	-6	-6
1	5	5	5	3	0	-1	-1	-1	-3	-5	-6	-6	-6
2	4	4	4	2	-1	-2	-2	-2	-3	-5	-6	-6	-6
3	3	3	3	0	-2	-3	-3	-3	-4	-5	-6	-6	-6
4	0	0	0	-1	-3	-4	-4	-4	-4	-5	-6	-6	-6
5	0	0	0	-1	-3	-4	-4	-4	-4	-5	-6	-6	-6
6	0	0	0	-1	-3	-4	-4	-4	-4	-5	-6	-6	-6

5. TEST RESULT AND ANALYSIS

Experiments have been carried out in the laboratory in order to verify the validity of image-based fuzzy visual servo control. The single background is set for the convenience of the test. During the test, a Panasonic WV-CP470 camera is installed on the fourth degree of freedom (the wrist) of the four-degree-of-freedom manipulator, whose resolution is set as 320×240, video speed is 10 frames/sec, and the sampling period is 100ms.

The objectives in the test are some eggplant fruits with a variety of shapes and sizes. The control task is to lay the center of gravity of the objective fruit in the center of the image plane. In the beginning, the eggplant fruit is lain in the filed of the camera vision, then the robot automatically adjusts its the position and pose until the objective image meet the requirements. Test curve of fuzzy control is shown in Fig.6.

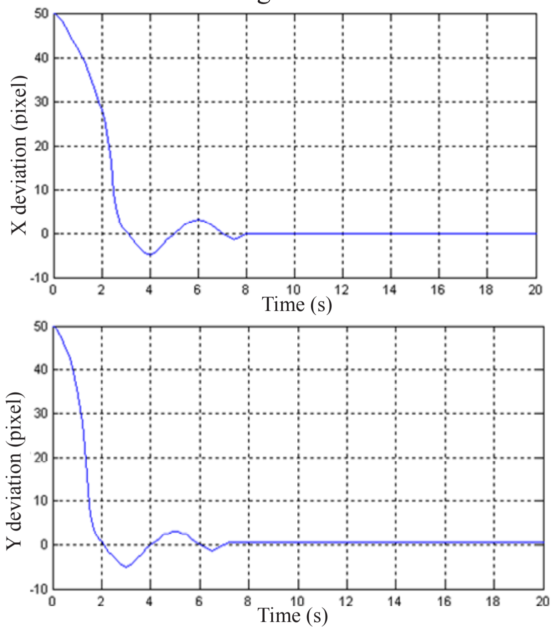

Fig.6 Test curve of fuzzy control

Step signals are inputted to 50 pixels for Ex and Ey respectively in the test. As can be seen from the figure, the control system responds fairly fast, and its steady state error is relatively small. Although there is certain steady state error, overshoot and oscillation, it can meet the demands of picking robot for the visual servo control.

6. CONCLUSION

1) The open f eggplant picking robot experiment system is established successfully which consists a arthral manipulator with 4 DOF, a motion controller, a color image grabbing card, a camera and a PC.

The application of fuzzy control to the visual servo control of the vegetable and fruit picking robot, not relying on precise objective models, can overcome the influences of such factors as nonlinearity, close coupling and time-variation on the robot visual servo.

2) Histogram-based dual threshold method is adopted to segment G-B gray image and the contour has been labeled through edge extracting and contour tracing from binary image. This Image processing algorithm has some distinct characters, including simple and compact structure, high efficiency, and good real-time.

3) The coordinates of the center of gravity of the objective fruit is selected as the input variable for the fuzzy control system. The self-adjusting factors are used to revise output controlled quantity, thus creates the fuzzy control table for outputting precisely.

4）The application of fuzzy control to the visual servo control of the vegetable and fruit picking robot, not relying on precise objective models, can overcome the influences of such factors as nonlinearity, close coupling and time-variation. The test results show that image-based fuzzy visual servo control for the eggplant picking robot has fairly high response speed, good robustness

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