Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Position estimation of goldfish using image processing for scooping goldfish robot

Yoshihiko YAMAMOTO
SUN Techno College, University of Yamanashi
Kai, Yamanashi, JAPAN
yoshi@suntech.ac.jp

Hiromi WATANABE
University of Yamanashi
Yamanashi, JAPAN

Tsutomu TANZAWA
University of Yamanashi
Yamanashi, JAPAN

Shinji KOTANI
University of Yamanashi
Kofu, Yamanashi, JAPAN
kotani@yamanashi.ac.jp

***Abstract*—We research and develop it aiming at the realization of a scooping goldfish robot copied from the method that a human being takes. This paper describes estimation method of the 3D position of a goldfish in a water tank. What is important and basic in distinguishing a timing to scoop a goldfish is to estimate the 3D position.**

***Keywords*—scooping goldfish robot, image processing, position estimation, discriminant analysis method, likelihood standard**

I. INTRODUCTION

In Japan, there is a famous place as goldfish's home and scooping goldfish game has been held in August every year. Scooping goldfish is one of the Japanese traditional games. Both children and adults enjoy the game and some people called expert of scooping goldfish. The achievement of the scooping goldfish robot [1] [2] that imitates the method done by the human is aimed and researched and developed. There is a previous work of the scooping goldfish been achieved by the robot [3] [4].

The robot is a method that recognizes the place in which a lot of goldfishes have gathered in the water tank by the video camera set up in the ceiling, and scoops it with the scooping net (net that doesn't tear) fixed to the tip of a large-scale industrial robot arm. The robot of this method is different from the method of the scooping goldfish by the human being.

In this study, it becomes a method to install the robotic arm in the mobile robot, to give "poi" (scooped net that consists of paper and tears) to the robot arm, and to scoop the goldfish.

The recognition of the goldfish and positioning in the water tank are done with the camera installed in the robot.

It takes a picture of the goldfish with one camera, and the image is processed. The center of gravity coordinates of the goldfish and the area of the goldfish are calculated from the image processing. In this paper, the method for presuming the position of the goldfish in the water tank from the information is described.

II. METHOD OF THE POSITION ESTIMATION

The relation between the area of the pixels of the object in the image and the depth is described. One where the object is near from the camera becomes small, and the area of the pixels in the image grows, and far one becomes small. Depth information on the object can be got from the change in this area [5]. Goldfish's position estimation is calculated in the water tank in the present research based on this feature.

A. Relation between Camera coordinate system and Image coordinate system

When taking a picture of the object of 3D space with the camera, 2D image is obtained. It becomes the relation between the camera coordinate system and the image coordinate system in Fig. 1 [6]. Image plane, focus distance *f*, and the focus are called and a vertical straight line to the street image plane is called an optical axis. The intersection of an optical axis and the image plane is decided the image center $c(u_0,v_0)$. The coordinates system with *u*-axis and *v*-axis is called an image coordinate system. The focus is called a starting point and an optical axis are called *Z*-axis and 3D coordinates system with *X*-axis and *Y*-axis in the direction corresponding to *u*-axis and *v*-axis of the image coordinate system is called a camera coordinate system.

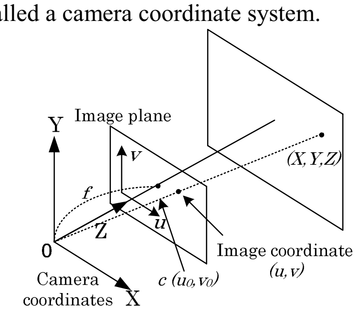

Figure 1. Camera coordinate system

When point $(X, Y, Z)^T$ of the camera coordinate system is projected in the image plane, point $(u, v)^T$ corresponding to this is (1) in the coordinate system of the image plane.

$$\begin{pmatrix} u \\ v \end{pmatrix} = \frac{f}{Z}\begin{pmatrix} X \\ Y \end{pmatrix} \quad (1)$$

B. Calculation Method of Distance estimation

As for the area of the pixels of the object in the image, the change takes place in the size even if the object is the same because of the position of the image inside even if the distance (Z-axis direction) from the camera is the same.

In one with short distance from the camera to the object, the area of the pixels grows. On the other hand, the area becomes small in one with long distance.

It becomes area $S_a \neq S_a'$ at $Z=Z_a$ and it becomes area $S_a > S_b$ at $Z_a < Z_b$ in Fig. 2.

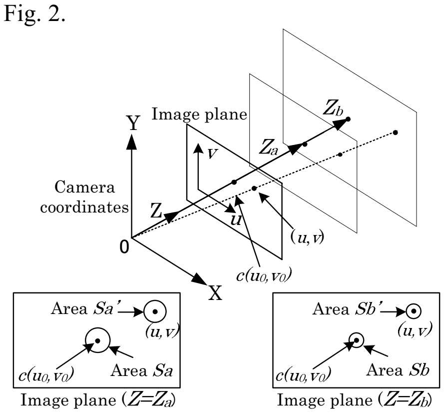

Figure 2. Image plane and Target plane

The relation of area S of center of gravity coordinates $c(u0,v0)$ and S' of center of gravity coordinates (u,v) becomes like (2) and (3) in the image. α and β are constant. k_u and k_v are constant by the pixels count.

$$S' = S + \triangle S = S + \alpha S = S(1+\alpha) \tag{2}$$

$$\alpha = \beta \frac{(u-u_0)^2 + (v-v_0)^2}{k_u{}^2 + k_v{}^2} \tag{3}$$

The area of the object in image center $c(u0,v0)$ is decided S_0 when the object is in distance d_0 from the camera. Distance Z to the camera and the object is (4) in area S of center of gravity coordinates (u,v) case. It is necessary to obtain S from area S' from (2) and (3).

$$Z = \sqrt{\frac{S_0}{S}} d_0 \tag{4}$$

C. Calculation Method of Distance estimation when there is water

Water that the refractive index (1.33) is different from air (refractive index 1) exists for the goldfish in the water tank.

The area of the image inside grows compared with the case without water when there is water even if the distance from the camera to the object is the same and the center of gravity coordinates in the image is same. When the area grows, distance Z becomes small from (4) and the camera becomes near with the distance of the object. It is necessary to consider the refractive index in (4) [7].

In Fig. 3, the incidence angle, the refraction angle and the relation of the refractive index are (5) from Snell's law of refraction.

$$\frac{n2}{n1} = \frac{\sin\theta}{\sin\phi} \tag{5}$$

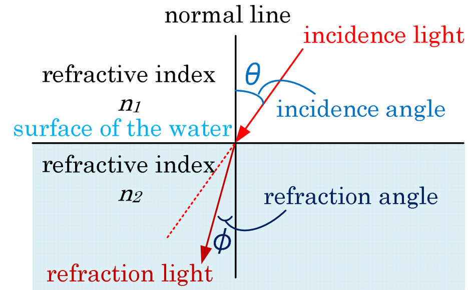

Figure 3. Incidence angle and Refraction angle

In Fig. 4, point P_0 in the image is a projected point in point P_2 when there is no water. When the value of the area on point P_0 is used for (5), Z_2 is calculated. However, when there is water, the projected point in point P_1 on not point P_2 actually but the refraction light is point P_0. d_0 is a distance to the surface of the water.

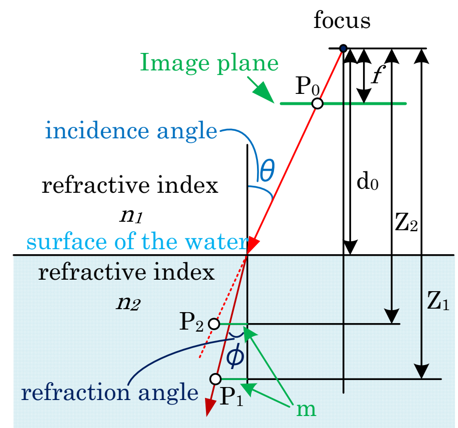

Figure 4. Image plane and Refractive index

The incidence angle θ and the refraction angle φ are (6) and (7) from Z_1, Z_2 and d_0.

$$\tan\theta = \frac{m}{Z_2} \tag{6}$$

$$\tan\phi = \frac{m}{Z_1 - d_0} \tag{7}$$

Z_2 can be calculated from (6) and (7) like (8).

$$Z_2 = \frac{\tan\theta}{\tan\phi} \times Z_1 + d_0 \tag{8}$$

When (8) when there is the refractive index in (4) is applied, it is (9). Moreover, (1) is (10) in similar. Equation (4) and (1) in (9) and (10) in case of the incidence angle θ = the refraction angle φ with the same refractive index.

$$\begin{aligned} Z &= d_0 + \left(\sqrt{\frac{S_0}{S}} - 1\right) \times d_0 \times \frac{\tan\theta_{xy}}{\tan\phi_{xy}} \\ &= d_0 \times \left\{ 1 + \left(\sqrt{\frac{S_0}{S}} - 1\right) \times \frac{\tan\theta_{xy}}{\tan\phi_{xy}} \right\} \end{aligned} \tag{9}$$

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \frac{d_0}{f} \begin{pmatrix} u \\ v \end{pmatrix} + (Z - d_0) \begin{pmatrix} \tan\phi_x \\ \tan\phi_y \end{pmatrix} \tag{10}$$

$$\tan\theta_x = \frac{u}{f}, \tan\theta_y = \frac{v}{f}, \tan\theta_{xy} = \frac{\sqrt{(u-u_0)^2 + (v-v_0)^2}}{f} \quad (11)$$

D. Verification of the Calculation method

Equation (9) and (10) are verified using markers of black circle with the radius of 10[mm] like Fig. 5.

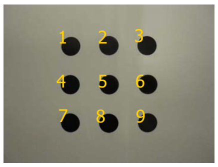

Figure 5. Markers Image

1) Verification environments

- The seal of the markers (black circle with the radius of 10[mm]) are pasted to a white acrylic board.
- The height of the marker board is changed from 0[mm] to 100[mm] in the water tank at 20[mm] intervals.
  0[mm] is surface of the water and 100mm is the bottom of the water.
- The camera is fixed.
  The distance from a camera to the surface of the water is 250[mm].
  The water level is 100[mm].

2) Verification contents

1. When there is no water, we change the height of the marker and verified method of calculation.
2. When there is water, we change the height of the marker and verified method of calculation.

3) Verification results

The change in the area in the image of each marker corresponding to the height change of the marker when there is no water becomes Fig. 6. The area value of Fig. 6 is introduced into (9), and the result of calculating the distance from the camera becomes Fig. 7.

The refractive index 1 of air is used because there is no water. Each marker can obtain the result from the distance from the camera and the distance of each 20[mm] from 250[mm].

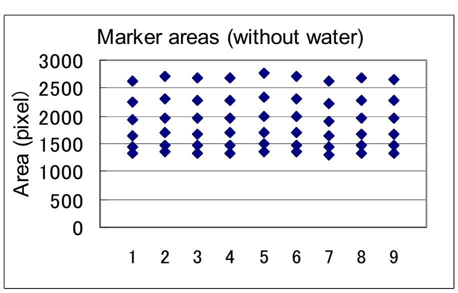

Figure 6. Marker areas (without water)

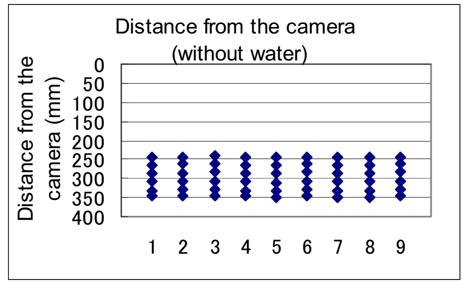

Figure 7. Distance from the camera (without water)

The change in the area in the image of each marker corresponding to the height change of the marker when there is water of 100[mm] becomes Fig. 8. It is understood that the area value is growing compared with the time of Fig. 6. This is due to the influence of the refractive index of water. The area value of Fig. 8 is introduced into (9), and the result of calculating the distance from the camera becomes Fig. 9. The refractive index 1.33 of water and the refractive index 1 of air are used because there is water. Each marker can obtain the result from the distance from the camera and the distance of each 20[mm] from 250[mm]. It can be verified that the formula for computation of (9) is effective even if water exists.

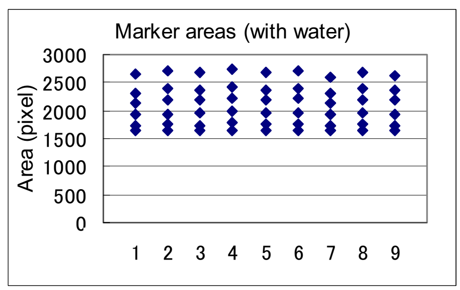

Figure 8. Marker areas (with water)

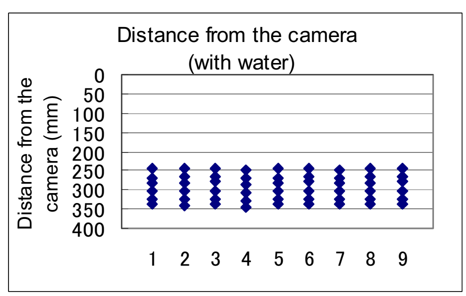

Figure 9. Distance from the camera (with water)

III. EXPERIMENT OF THE POSITION ESTIMATION OF GOLDFISH

The position of the goldfish by image processing is estimated. The position is estimated from the area of the goldfish by taking pictures of the goldfish in the water tank, and processing the image.

A. Experiment environments

The pictures of the goldfish are taken in the environment of Fig. 10. The data is acquired for one minute (1800 frames). Use environment is as follows.

TABLE 1. Experiment conditions

Goldfish	80[mm] in length, black a telescope goldfish
Water tank	260[mm] in length, 400[mm] in width, 280[mm] in height Install acrylic boards in the water tank.
Water level	100[mm]
Camera	Canon iVIS HV2 For taking pictures on water tank.
Source of light	Two Halogen source of light
Image Processor Unit	NVP-Ax135P Renesas Northern Japan Semiconductor Inc.

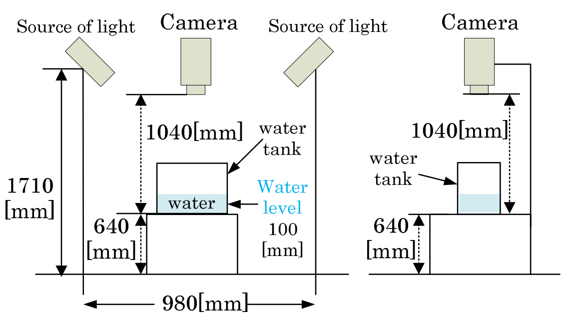

Figure 10. Experiment environments

B. Algorithm

It executes it by using the background difference image and two stage thresholds to request the center of gravity coordinates and the area of the goldfish in the image in the following steps.

Step.0

1. The image for the background difference is used.

Step.1

1. The range of the object of the picture processing is limited and the range is limited in the water tank of 640x480 (pixels).
2. The threshold t1 is calculated by using the threshold calculation algorithm.
3. It makes it to binary by using the threshold t1.
4. The value of center of gravity coordinates and the minimum value and the maximum value of X, Y coordinates are calculated.

Step.2

1. The range of the object of the image processing is limited to rectangle range + α
   (i) The minimum value and the maximum value of X, Y coordinates calculated in step.1 are used.
   (ii) The area of the goldfish: + α is calculated so that rectangle area = 1:3 may come automatically.
2. The threshold t2 is calculated by using the threshold calculation algorithm.
3. It makes it to binary by using the threshold t2.
4. The value of center of gravity coordinates, and the minimum value and the maximum value of X, Y coordinates and the main axis direction angle θ are calculated.

Fig. 11 becomes the original image (0th frame), and Fig. 12 becomes a background difference image to Fig. 11. Fig. 13 becomes an image of making to binary that uses two stage thresholds in step1.

The part of goldfish's caudal fin might cut in step.2 as shown in Fig. 14(left) when the range of the object of the image processing is made the range of the rectangle of a fixed value. It is an area of the goldfish as for the range of the object of the image processing: The range of the rectangle cuts by calculating so that goldfish area: rectangular area = 1:3 may come automatically and the part of the caudal fin doesn't cut as shown in Fig. 14(right).

Fig. 15 becomes an image of making to binary that uses two stage thresholds in step2.

Figure 11. Original image

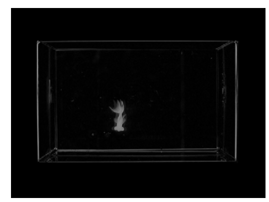

Figure 12. Background differential image

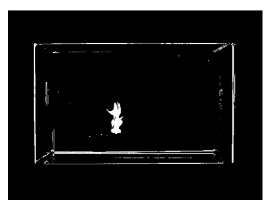

Figure 13. Binary image in step1

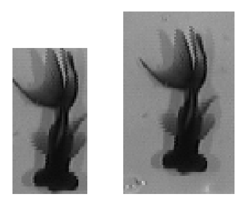

Figure 14. Rectangle Range

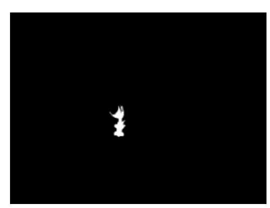

Figure 15. Binary image in step2

In the threshold calculation algorithm of making to binary, discriminant analysis method and likelihood-standard-2 [8] [9][10] and likelihood-standard-4 [11] and the method of Kittler [12] are examined.

TABLE 2. Comparison of the correlation ratio by algorithm

Algorithm	Min.	Max.	Ave.	Standard Deviation
discriminant analysis	0.723	0.776	0.747	0.0098
likelihood standard 2	0.722	0.778	0.749	0.0099
likelihood standard 4	0.714	0.773	0.743	0.0106

TABLE 3. Comparison of the threshold by algorithm

Algorithm	Min.	Max.	Ave.	Standard Deviation
discriminant analysis	55	64	58.43	2.315
likelihood standard 2	54	63	57.40	2.312
likelihood standard 4	58	70	62.52	2.313

TABLE 4. Comparison of the area by algorithm

Algorithm	Min.	Max.	Ave.	Standard Deviation
discriminant analysis	1186	1572	1359.09	66.412
likelihood standard 2	1192	1584	1372.01	66.877
likelihood standard 4	1120	1531	1309.92	67.714

The result of processing the data for 1800 frames in the image is shown in each algorithm and the one that elements of the correlation ratio (ratio of decentralization in the class distributing between classes) and the threshold and the area (pixels value) were compared is shown in TABLE 2, TABLE 3 and TABLE 4. The method of Kittler was not able to calculate the threshold for the goldfish. Three threshold calculation algorithms understand a big difference is not caused at this goldfish. The threshold calculation algorithm of making to binary will use the discriminant analysis method that is a standard function for the image processing used.

C. Position estimation of the goldfish

The one that the simple moving average (16 averages) of the area of the goldfish of the image processing result was taken becomes Fig. 16. The moving average is used to consider between frames and the error margin whose displacement between one frame in X-Y coordinates (0.33 milliseconds) is larger than the center of gravity coordinates and the area of the goldfish. Fig. 17 having calculated the distance from the camera by using the area value results.

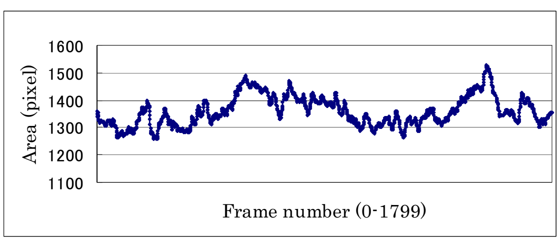

Figure 16. Goldfish areas

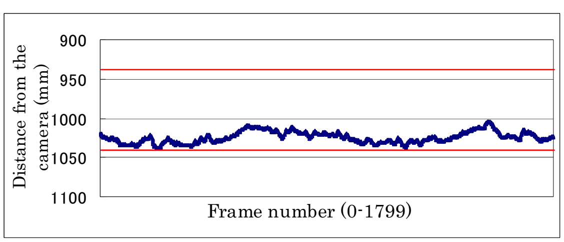

Figure 17. Calculated the distance from Goldfish areas

Fig. 18 shows the one that goldfish's position was plotted in X-Y coordinates and Fig. 19 shows the one that goldfish's position was plotted in X-Z coordinates.

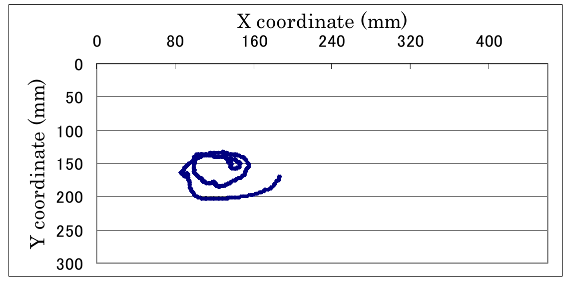

Figure 18. X-Y coordinates of the goldfish

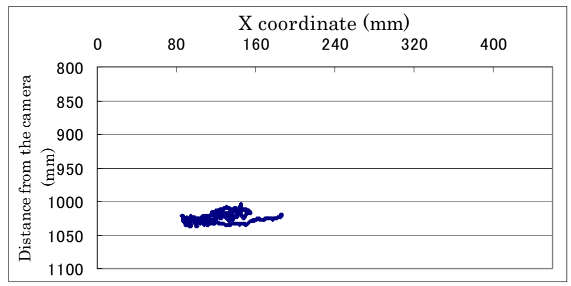

Figure 19. X-Z coordinates of the goldfish

The result of the position estimation of an effective goldfish by the method for proposing it was obtained.

IV. CONCLUSIONS

It proposed the method for the position estimation of the goldfish based on information from the camera of the water tank on to discern timing in which the goldfish was scooped and it verified it.

In the future, we experiment on the base of a further goldfish for behavior the action study and the calculation and goldfish's behavior pattern will be made a database. We do the calculation processing of the goldfish. Moreover, it is necessary to think about the influence of the ripple caused in turbulence and the surface of the water that sounds, the person approaches, and “poi” approaches.

REFERENCES

[1] K. Kobori, T. Hori, N. Nakamura and K. Nishio: "POSTER: Development of Virtual Goldfish Scooping Using Haptic Device", WSCG'2007

[2] C. C. Ho, C. L. Shih: "Real-Time Tracking and Stereo Vision-Based Control of a Goldfish-Catching System", Proceedings of the 35th International MATADOR Conference, pp.319-322, 18-20, 2007.

[3] N. Ukita, T. Kitajima and M. Kidode: "Estimating the Positions and Postures of Non-rigid Objects lacking Sufficient Features based on the Stick and Ellipse Model", Proc. of IEEE Workshop on Articlated and Nonrigid Motion, in conjunction with CVPR2004, Jun., 2004.

[4] N. Ukita, T. Kitajima, and M. Kidode: "Temporal Posture Estimation of Nonrigid Objects Lacking Sufficient Features Based on the Automatically Generated Stick and Ellipse Model", Systems and

Computers in Japan, Vol. 37, No. 6, 2006
[5] R. Niwa, M. Iwamura, K, Kise, S. Uchida, S. Omachi: "Rectifying Perspective Distortion into Affine Distortion Using Variants and Invariants", Meeting on Image Recognition and Understanding 2007 (MIRU2007), 2007 (in Japanese).
[6] David A. Forsyth, Jean Ponce: "Computer Vision: A Modern Approach" Prentice Hall; 2002.
[7] A. Yamashita, H. Higuchi and T. Kaneko: "3-D Measurement of Objects in Water Using the Light Stripe Projection Method", Journal of the Japan Society for Precision Engineering, Vol.73, No.2, pp.265-269, February 2007 (in Japanese).
[8] N. Otsu: "Discriminant and Least Squares Threshold Selection," 4IJCPR, pp.592--596 (1978-11).
[9] N. Otsu: "A Threshold Selection Method from Gray-Level Histograms," IEEE Trans. Syst. Man & Cybern., Vol. SMC-9, No. 1, pp. 62--66, January 1979.
[10] N. Otsu: "An Automatic Threshold Selection Method Based on Discriminant and Least Squares Criteria", Trans. of IECE, Vol. 63-D, No. 4, pp. 349--356, April 1980 (in Japanese).
[11] T. Kurita, N. Otsu and N. Abdelmalek: "Maximum likelihood thresholding based on population mixture models", Pattern Recognition, Vol. 25, No. 10, pp. 1231--1240 (1992-10).
[12] J. Kittler and J. Illingworth: "Minimum Error Thresholding", Pattern Recognition, Vol. 19, No. 1, pp. 41--47 (1986).