Design and Implementation of Gimbal on Remotely Operated Vehicle with Fuzzy Logic Controller

Ilham Dwi Kurniawan
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
ilham.d.k@mail.ugm.ac.id

Indra Budi Setyawan
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
indra.b.s@mail.ugm.ac.id

Fakhruddin Hanif Nashrullah
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
fakhruddin.h@mail.ugm.ac.id

Sartono Indo Frans
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
sartono.indo.f@mail.ugm.ac.id

Andri Khoirul Huda
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
andri.khoirul.h@mail.ugm.ac.id

Jans Hendry*
Dept. of Electrical Engineering and Informatics
Vocational College
Universitas Gadjah Mada
Yogyakarta, Indonesia
jans.hendry@ugm.ac.id

2022 8th International Conference on Science and Technology (ICST) | 978-1-6654-5622-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICST56971.2022.10136294

***Abstract*—The Tsukamoto and Mamdani fuzzy logic is compared to find the most appropriate fuzzy logic controller for underwater remotely operated vehicle (ROV) gimbal. The comparison is made by observing the closest estimation from both toward the manual calculation. The Mamdani fuzzy logic is the most appropriate because the error is smaller. This fuzzy logic is implemented on Raspberry Pi with an Ov5647 camera in the real-time experiment. Based on the experiment, the boundaries for fuzzy are set to 220 and 280, and 170 and 200 for vertical and horizontal movement. When dealing with diagonal direction, it always starts with horizontal (X) followed by vertical (Y). The results show that whenever the object's centroid is successfully found, the gimbal automatically converts it to angle and moves the two servo motors accordingly.**

Keywords*—*ROV, gimbal, servo, Mamdani, Tsukamoto

I. INTRODUCTION

A Remotely Operated Vehicle (ROV) is one of the underwater machines that can help us to monitor shallow waters. But this machine should be equipped with additional sensors to benefit from it. One of the sensors is a camera. A camera can help to bring visual information being observed by the ROV. An ROV with a camera can track specific or predetermined objects under the water. But the camera should be able to move its body to follow the object's movement (tracking problem). For this, at least 2-axis motors should control the camera's direction. The motor configuration that enables this movement is called pan and tilt motors or gimbal.

Some research has been conducted to provide a better prototype of a gimbal for object tracking. Research to develop a prototype of a gimbal with a 2-axis motor with brushless motors has been conducted. It used PID (Proportional, Integral, and Differential) control programmed to microcontroller ATMega2560. They used data from the accelerometer and gyroscope as feedback input. Using the Ziegler Nichols tuning method, they found a specific coefficient for P, I, and D in which response time is less than 1 second for roll and pitch [1].

Research from [2] that designed gimbal prototype for quadrotors combined PID and Fuzzy logic to control the motors. They used brushless dc motors as the actuator and inertial measurement unit (IMU) as feedback input. The designed gimbal can rotate clockwise and counterclockwise. The response time for roll and pitch is 0.12 s and 1.07 s, consecutively.

Both types of research used an IMU sensor as feedback input. It means that the control solely depends on the position of the main body frame. Research that discussed object tracking based on the image was conducted by [3]. It used a convolutional neural network (CNN) to track human faces. In addition to the gimbal, IMU and low-level controller were also attached. YOLOv3 (You Only Look Once) model was also utilized for gimbal prototyping by [4]. They used a Remotely Piloted Aircraft System (RPAS) as the media where the gimbal was attached. The motor can rotate the camera on 3-axis: yaw, roll, and pitch. The designed prototype looks promising in the Gazebo simulator.

Previously mentioned research has exhibited promising results regarding gimbal design. Differs from those, our system needs a method that can bridge pixel coordinate system and angle that clearly have different units. One of the feasible methods is fuzzy logic. In our study, a gimbal prototype for underwater ROV is developed for 2-axis translation movement, called pan and tilt. The controller is designed according to fuzzy logic to make the center of the camera always match the center of the object (centroid). The parameters needed in this method are based on our experiment that makes it differs to other studies. Before selecting Mamdani as the fuzzy logic controller, we compared it with Tsukamoto to get the most suitable controller for our gimbal. The comparison is based on calculation. Thus, Mamdani is selected as the most appropriate controller for our design.

This paper is arranged as follows: The background is discussed in I. Then, the theory of fuzzy logic and suitable fuzzy logic controller selection is introduced in II. The

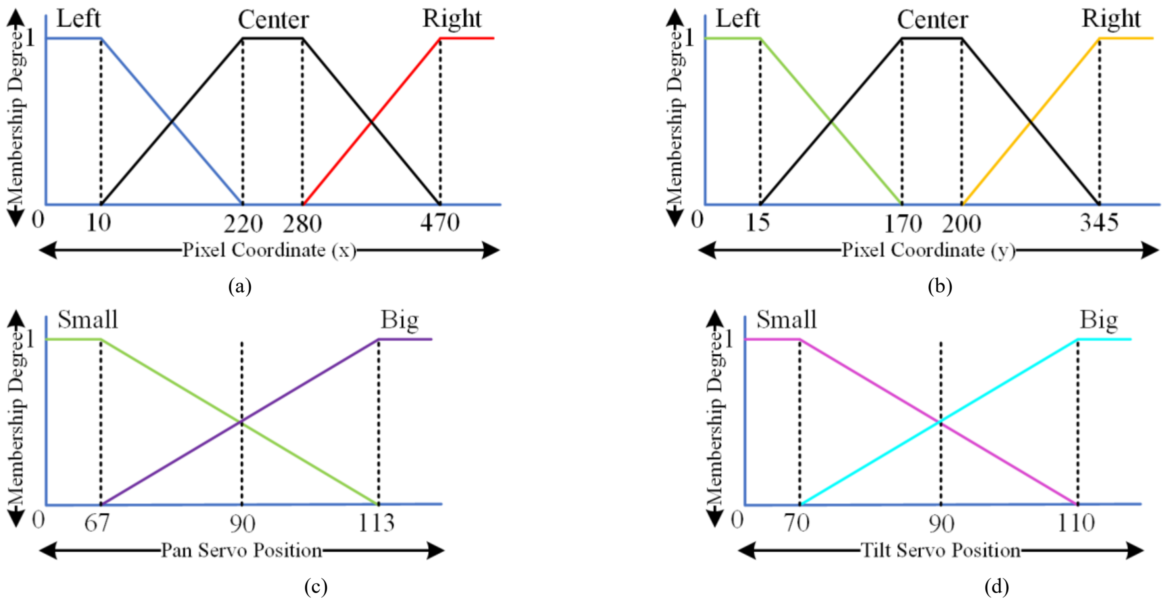


Fig. 2. Membership degree for input and output

experimental setup is reported in III. Finally, the result after gimbal implementation in ROV is reported in IV.

II. Fuzzy Logic Controller Design

We design a Fuzzy Logic Controller (FLC) for two types of fuzzy logic, Tsukamoto and Mamdani. In the end, we provide a simple analytic calculation to select the most appropriate FLC for our gimbal.

A. *The Centroid of Object*

Images captured by the camera installed in ROV have a dimension of 480-pixel wide x 360-pixel height. Then, the

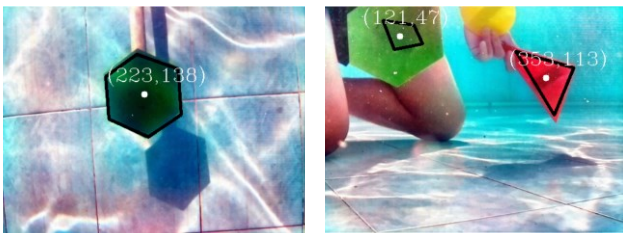


Fig. 1. Illustration of object's centroid as input to the controller

visibility of the image is enhanced using [5]. The objects used in this research are regular 2D shapes: circles, triangles, rectangles, and hexagons. They are made from white acrylic and painted in different colors consecutively, i.e., yellow, red, blue, and green. All the objects that appear in the enhanced image are detected using [6]. Then, the centroid of each object is found. This centroid, a white-color circle, is the input to the controller to control the gimbal movements, as illustrated in Fig. 1.

In this research, two servo motors are used. The servo's position can be regarded as an angle in a circle. The mapping between image dimension and servo should be established as membership degree, as shown in Fig. 2. The input for FLC is the centroid of the object in the form of pixel coordinates. At the same time, the output is an angel, which describes the servo's position. The input pixel for the pan and tilt (gimbal) motor can range from 0 – 480 and 0 – 360, respectively. At the same time, the angle output ranges from 0 – 180 for both.

B. *Tsukamoto Fuzzy Logic*

1) Input and output fuzzification for x-direction: there are 3 linguistic variables for input: right, center, and left. Based on Fig. 2(a), the membership degree is formulated as in (1) – (3), where μ is the membership value, and x is the coordinate pixel.

$$\mu_{right} = \begin{cases} 1 & x < 10 \\ \frac{220-x}{220-10} & 10 < x < 220 \\ 0 & x > 220 \end{cases} \tag{1}$$

$$\mu_{left} = \begin{cases} 0 & x < 280 \\ \frac{x-280}{470-280} & 280 < x < 470 \\ 1 & x > 470 \end{cases} \tag{2}$$

$$\mu_{center} = \begin{cases} \frac{x-10}{220-10} & 10 < x < 220 \\ 1 & 220 < x < 280 \\ \frac{470-x}{470-280} & 280 < x < 470 \end{cases} \tag{3}$$

The membership degree for output is depicted in Fig. 2(c). Based on our observation, the boundaries for small and big linguistic variables are 67° and 113°, so the camera's center will always match the center of the object (centroid). The starting position of both servos is always at 90°. Thus, the formula to calculate the membership function for output is expressed in (4) and (5).

$$\mu_{small} = \begin{cases} 1 & \theta < 67 \\ \frac{113-\theta}{113-67} & 67 < \theta < 113 \\ 0 & \theta > 113 \end{cases} \tag{4}$$

$$\mu_{big} = \begin{cases} 0 & \theta < 67 \\ \frac{\theta-67}{113-67} & 67 < \theta < 113 \\ 1 & \theta > 113 \end{cases} \tag{5}$$

2) Inference: the inference in linguistic variable is expressed in (6) and (7). It comprises of 1 antecedent and 1 consequent.

$$\textbf{\textit{IF}}\ pixel\ left\ \textbf{\textit{THEN}}\ angel\ small \tag{6}$$

$$\textbf{\textit{IF}}\ pixel\ right\ \textbf{\textit{THEN}}\ angel\ big \tag{7}$$

3) Defuzzification: angle output as the input to pan servo, φ_{pan}, is expressed in (8) using weighted average [7].

$$\varphi_{pan} = \frac{[\mu_{right}*(113-46\mu_{left})]+(90*\mu_{center})+[\mu_{left}*(46*\mu_{right}+67)]}{\mu_{right}+\mu_{center}+\mu_{left}} \tag{8}$$

4) Input and output fuzzification for y-direction: meanwhile, the membership degree in the y-direction is expressed in (9) – (11). The linguistic variables are up, down, and center, as shown in Fig. 2(b).

$$\mu_{up} = \begin{cases} 1 & y < 15 \\ \frac{170-y}{170-15} & 15 < y < 170 \\ 0 & y > 170 \end{cases} \tag{9}$$

$$\mu_{down} = \begin{cases} 0 & y < 200 \\ \frac{y-200}{345-200} & 200 < y < 345 \\ 1 & y > 345 \end{cases} \tag{10}$$

$$\mu_{center} = \begin{cases} \frac{y-15}{170-15} & 15 < y < 170 \\ 1 & 170 < y < 200 \\ \frac{345-y}{345-200} & 200 < y < 345 \end{cases} \tag{11}$$

The membership degree for output is depicted in Fig. 2(d). According to our observation, the boundaries for small and big servo angles are 70° and 110°, respectively. The equations to calculate the membership function for output in the y-direction are shown in (12) and (13).

$$\mu_{small} = \begin{cases} 1 & \theta < 70 \\ \frac{110-\theta}{110-70} & 70 < \theta < 110 \\ 0 & \theta > 110 \end{cases} \tag{12}$$

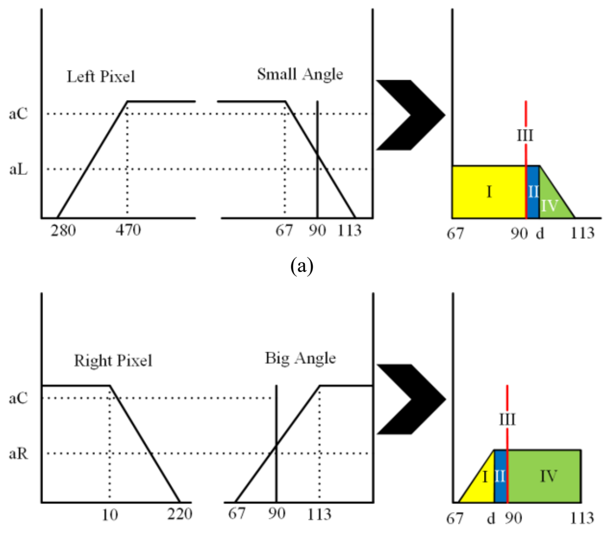
$$\mu_{big} = \begin{cases} 0 & \theta < 67 \\ \frac{\theta-70}{110-70} & 70 < \theta < 110 \\ 1 & \theta > 110 \end{cases} \tag{13}$$

5) Inference: the inference in the linguistic variable is expressed in (14) and (15). It comprises of 1 antecedent and 1 consequent.

$$\textbf{\textit{IF}}\ pixel\ up\ \textbf{\textit{THEN}}\ angel\ small \tag{14}$$

$$\textbf{\textit{IF}}\ pixel\ down\ \textbf{\textit{THEN}}\ angel\ big \tag{15}$$

6) Defuzzification: angle output as the input to tilt servo, φ_{tilt}, is expressed in (16).



(a)

(b)

Fig. 3. Area and center point (a) left pixel, (b) right pixel

$$\varphi_{tilt} = \frac{[\mu_{up}*(50*\mu_{down}+70)]+90*\mu_{center}+[\mu_{down}*(110-50*\mu_{up})]}{\mu_{up}+\mu_{center}+\mu_{down}} \tag{16}$$

C. Mamdani Fuzzy Logic

1) Inference: Different from Tsukamoto, the defuzzification in Mamdani is calculated using the center of gravity (CoG) [7]. The inference calculation follows (17) and (18).

$$\textbf{\textit{IF}}\ pixel\ left\ \textbf{\textit{THEN}}\ angel\ small \tag{17}$$

$$\textbf{\textit{IF}}\ pixel\ right\ \textbf{\textit{THEN}}\ angel\ big \tag{18}$$

The membership degree follows (1)-(3), (9)-(11), that subject to Fig. 1(a)-(b). Based on Fig. 3, we can formulate the equations to calculate the area and center as in Table I and Table II.

TABLE I. AREA AND CENTER CALCULATION FOR LEFT PIXEL

No.	Area	Center Point
I	$(90-67)*aL$	$(90+67)/2$
II	$(d-90)*aL$	$(d+90)/2$
III	$aC*1$	90
IV	$\frac{(113-d)*aL}{2}$	$\frac{113+2*d}{3}$

TABLE II. AREA AND CENTER CALCULATION FOR RIGHT PIXEL

No.	Area	Center Point
I	$((67-d)*aR)/2$	$d-(\frac{67-d}{3})$
II	$(90-d)*aR$	$(90+d)/2$
III	$aC*1$	90
IV	$(113-90)*aR$	$(113+90)/2$

2) Defuzzification: the defuzzification of Mamdani can be calculated with (19).

Fig. 4. The ROV we made for experiment

$$\varphi = \frac{\sum_{i=1}^{K} center\_point\ x\ area}{\sum_{i=1}^{K} area} \tag{19}$$

with K is the number of the area in Fig. 3.

III. THE EXPERIMENTAL SETUP

Our team builds an ROV equipped with 6 thrusts: 4 thrusts for horizontal translation and 2 thrusts for vertical translation [8], as shown in Fig. 4.

A. Gimbal Realisation

The gimbal consists of 2 MG90 servo motors with specifications as in Table III and a camera with specifications shown in Table IV. The camera is chosen because it is compatible with Raspberry pi. The frame rate used in the real-time process is 30 fps. It means that the resolution of the captured frame is 1080p. Then, the resolution is resized into 480 x 360 pixels to speed up the object centroid coordinates finding.

The implementation is done in Python language. The designed gimbal is placed inside the tube of ROV, as shown in Fig. 5, marked with red-color circles.

TABLE III. SERVO SPECIFICATION

No.	Type	Specification
1	Strain Torque	1.8kg/cm (4.8V) 2.2kg/cm (6V)
2	Speed	0.1sec/60degree (4.8V) 0.08sec/60degree (6V)
3	Rotational Angle	180^{O}

TABLE IV. CAMERA SPECIFICATION

No.	Type	Specification
1	Sensor	Ov5647
2	Resolusi	5 MP
3	Video	Maximum 1080P
4	Frame Rate	30 fps di 1080P, 60fps di 720P

B. Camera to Image Projection

The camera's center and its lens dimension are projected into the image. Our observation shows that the radius of the camera lens can be projected onto *m-wide* x *n-height* pixels in the image, as shown in Fig. 6. Then, these values are used as boundaries to the fuzzy logic input.

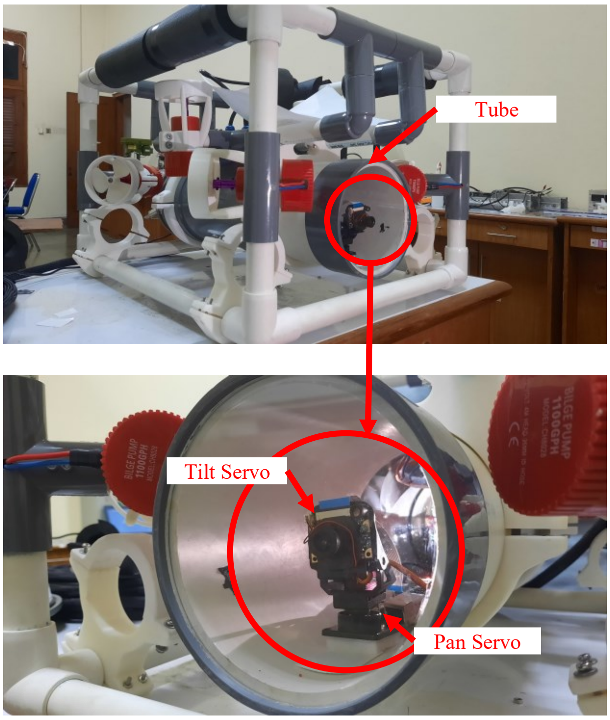


Fig. 5. The installation of gimbal in the ROV

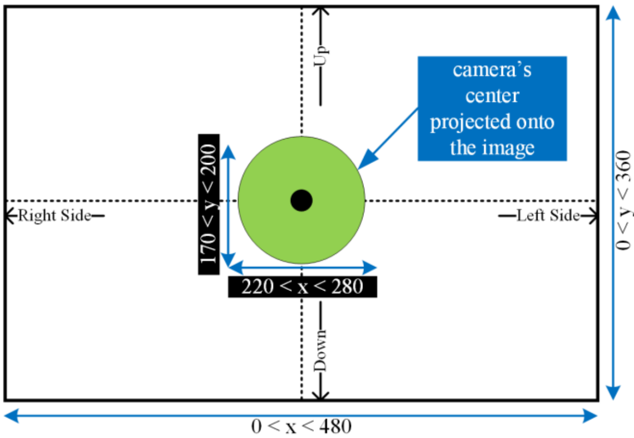


Fig. 6. Camera's center projection onto the image

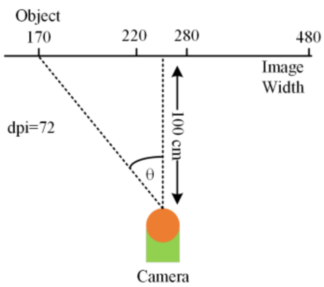


Fig. 7. Fuzzy logic selection

C. X-Y Movement Strategy

The strategy for the gimbal to move when the center of the object is in a diagonal position toward the center of the camera is to move the gimbal horizontally then vertically.

IV. Result and Discussion

Two fuzzy logic methods have been introduced, Tsukamoto and Mamdani. However, only one method is used in this research. Hence, the selection of appropriate fuzzy logic is conducted prior to the implementation in ROV.

A. *Fuzzy Logic Controller Selection*

The selection is conducted by calculating manually the angles between the camera and the pixels coordinate on the image. Assume that we know the distance between camera and object, L = 100 cm, dot per inch of the captured image, dpi = 72. Take (x, y) = (170, 0) as the centroid of the object in the image, as shown in Fig. 7. Using a simple calculation, we can estimate the angle θ.

$$d = (220 - 170) * \left(\frac{2.54}{72}\right) = 1.7635\ cm$$

$$\theta = \tan^{-1}\left(\frac{1.7635\ cm}{100\ cm}\right) = 1.01^o$$

Hence,

$$\theta = 90^o + 1.01^o = 91.01^o$$

We add more x-coordinates and calculate their angles with the same steps as shown in Table V.

TABLE V. Angles Manual Calculation

No.	The x-coordinate (pixel)	Estimated Angle (°)
1	170	91.01
2	100	96.04
3	320	89.4
4	10	97
5	460	86
6	50	97
7	370	88
8	400	87

Then, these angles are plotted versus angles calculation using Tsukamoto and Mamdani as shown in Fig. 8. It can be seen that the angles with manual analysis, marked with red-color circles, where the distance between camera and object is assumed known, are close to Mamdani fuzzy logic than Tsukamoto. Furthermore, the angle resulting from conversion from centroid pixels to angle in Mamdani is declivous. At the same time, the Tsukamoto forms piecewise linear curve, which is steeper. Based on this experiment, the Mamdani is chosen to be implemented in ROV.

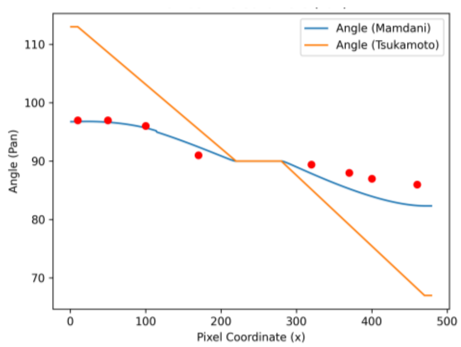


Fig. 8. Comparison between manual calculation and fuzzy methods

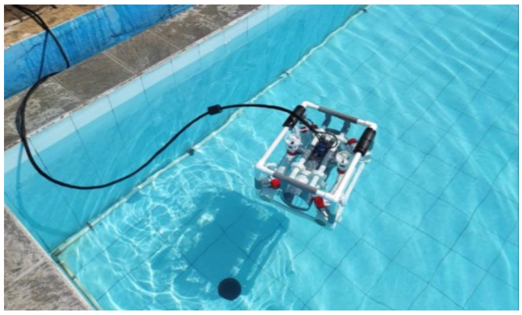


Fig. 9. Real-time testing in a pool

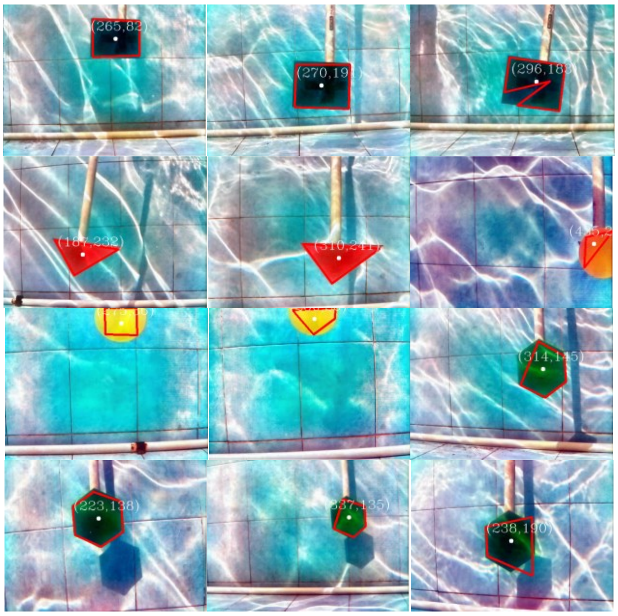
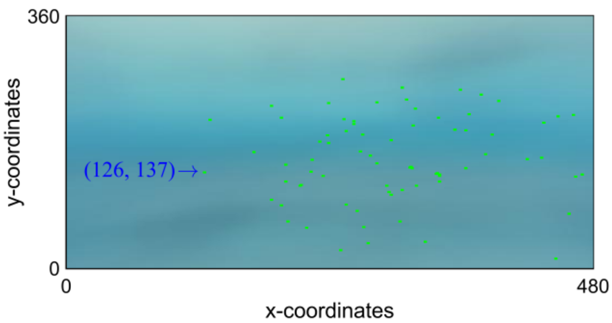
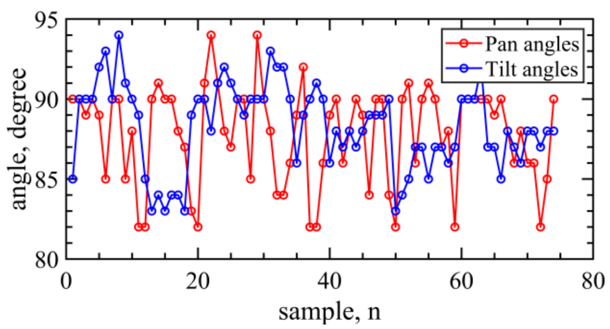


Fig. 10. 12 out of 74 centroid images from real-time processing used for angle calculation



(a)



(b)

Fig. 11. Real-time testing in a pool

B. Pan and Tilt Angle in Real-Time Process

The designed Mamdani fuzzy logic is programmed in a single board computer (SBC) Raspberry Pi 4 using Python. The Ov5647 camera is connected to this SBC. They are put inside the tube of the ROV as shown in Fig. 9. Actually, all ROV's PCBs are placed inside this tube. Then the ROV is sunk in a pool. The ROV is controlled from the surface using a remote control to move around the pool.

The camera start taking data afterward. Some preprocessing is running before the gimbal tracks the object. The raspberry stores the centroid of the object and servo's angle estimated by Mamdani in a CSV file. Around 92 images are captured for the preliminary test, and only 74 images have valid centroids. The 12 images out of 74 images as examples of centroid object converted to angles are shown in Fig. 10. All 74 angles as the result of conversion are shown in Fig. 11. The centroids are shown as green-colored dots over an image. Based on Fig. 11(b), angles vary depending on centroids of objects in the underwater images captured by the camera.

V. Conclusion

The result shows that Mamdani's fuzzy logic succesfully convert the centroids of objects in underwater images captured by the camera into angles. These angles are used to move the camera using two servo motors. In the future, we will use these angles to move the ROV to track the objects automatically.

Acknowledgment

We thank the Directorate of Research of Universitas Gadjah Mada, Indonesia which has fully supported this research through the RTA program with contract number 3550/UN1.P.III/Dit-Lit/PT.01.05/2022.

References

[1] T. K. Priyambodo, "Implementasi Sistem Kendali PID pada gimbal kamera 2-sumbu dengan Aktuator Motor Brushless," *Indonesian Journal of Electronics and Instrumentations Systems*, 7, 2, pp. 111-126.

[2] M. S. Haris, A. Dharmawan, and C. Atmaji, "Sistem Kendali Gimbal 2-sumbu Sebagai Tempat Kamera Pada Quadrotor Menggunakan PID Fuzzy," *Indonesian Journal of Electronics and Instrumentations Systems*, 7, 2, pp. 185-196.

[3] R. Cunha, M. Malaca, V. Sampaio, and B. Guerreiro, "Gimbal Control for Vision-based Target Tracking," in *Proceedings of the EURASIP European Signal Processing Conference (EUSIPCO)*, Satellite Workshop: Signal Processing, Computer Vision and Deep Learning for Autonomous Systems, 2019.

[4] D.J Regner, J. D. Salazar, P. V. Buschinelli, M. Machado, D. Oliveira, J. M. Santos, C. A. Marinho, and T. C. Pinto, "Object Tracking Control Using a Gimbal Mechanism," in *Proceeding of The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2021.

[5] F. H. Nashrullah, "Peningkatan Visibilitas Citra Bawah Air dengan Metode CLAHE dan Frankle-McCann Retinex Diimplementasikan Pada Remotely Operated Vehicle," *Bachelor Thesis*, Vocational College, Universitas Gadjah Mada, unpublished, 2022.

[6] S. I. Frans, "Deteksi Objek Sederhana Citra Bawah Air Berdasarkan Warna dan Morfologi Pada Remotely Operated Vehicle," *Bachelor Thesis*, Vocational College, Universitas Gadjah Mada, unpublished, 2022.

[7] S. N. Sivanandam, S. Sumathi, and S. N. Deepa, "Introduction to Fuzzy Logic using Matlab," Springer, 2007.

[8] I. B. Setyawan, "Perancangan dan Implementasi Sistem Kendali Semi Otomatis pada Remotely Operated Vehicle Berbasis Kendali PID dan Exponential Moving Average Filter," *Bachelor Thesis*, Vocational College, Universitas Gadjah Mada, unpublished, 2022.