TRANSACTION ON CONTROL AND MECHANICAL SYSTEMS, VOL. 2, NO. 1, PP. 20-25, JAN., 2013.

Transaction Series on Engineering Sciences and Technologies

Approaching Fuzzy Logic in Fish Robot for Obstacle and Collision Avoidance Problem

Nguyen Truong Thinh [1], and Trinh Duc Cuong [2, ✉]

Abstract: **This paper is focused on fuzzy algorithm and show how it works in decision making process to change on trajectory direction of robot's path. In general, the problem consists of achieving sensors based motion control of a fish robot among obstacles in structured and/or unstructured environments with collision-free motion as the priority. While robotic fish is swimming in the environment with a high potential of hurdles, it is possible for them to meet with collisions because there are many kinds of obstructions in water. Therefore, approaching natural and smooth movements for robotic fish is related to the detecting and recognizing obstacles as well as trying to avoid any kind of collision. The fundamental data is the measuring of distance from sensors to obstacles and the possible existence of obstacles. Because the data is nonlinear, they can be solved with the fuzzy trajectory direction. The changing direction of trajectory of a robot should be made so that the robot can move in the direction with no hurdles. The experimental results indicate that robotic fish changes the trajectory planed following the proposed fuzzy decision results within the higher obstacles density without collision.**

Keywords: Fish robot, Robotic fish, Fuzzy, Obstacle Recognition, Collision Avoidance
1

1. INTRODUCTION

At present, biologically inspired artificial systems mimicking real fish mostly concentrate on fishlike motion mechanism. There are two major classes of underwater robots. The first involves attempts to make submarines and related vehicles autonomous and it is suitable to military. The second class of underwater vehicles is inspired by biology and attempts to create robots that move like fish, and other water-based animals.

Biomimetics, a new research area involving in both biology and robotics, has been receiving more and more attention. Bio-mimicking systems provide important insights into the theories and applications of robotics. In the category of swimming robots, biomimetic robot fish is modeled after real fish in nature having the virtue of high speed, tremendous propulsive efficiency and excellent maneuverability [1-4]. These advantages are of great benefit to practical applications in marine and military fields such as undersea operation, military reconnaissance, leakage detection, aquatic life-form observation and so on [4]. Underwater robots are widely used in the fields of ocean development, ocean investigation and marine environmental protection [1]. As the request that the underwater robots are widely used in the fields of ocean development, ocean investigation and marine environmental protection. Autonomous underwater robots are planned, and several robots have been already developed. They need higher efficiency of propulsive performance and good dynamics performance. On the other hand, it is well known that several kinds of fish have a good ability of turning and acceleration. If the underwater robot that can simulate a fishlike locomotion is developed, it is considered that the robot has dynamics performance similar to fish [5].

Biomimetic systems provide valuable information of algorithms and practical applications for underwater robots. In the category of propulsor, the fish like propulsor is designed as the real fish in the nature having the good characteristic of high speed, efficient using power, propulsive efficiency and excellent maneuverability. There are many benefits to practical applications in marine and military such as underwater operation, aquatic life-form observation and so on. On the other hand, several kinds of fish have a good ability of turning and acceleration. If the bio-mimicking robot can simulate a fish's locomotion is developed, it is considered that the robot has dynamics performance similar to fish. As the required that the underwater robot should be carried out more efficiently, becomes strong, several robotics fish have been already designed. They need higher efficient of propulsive performance and good dynamics performance. Fishlike swimming mechanism is expected as a new propulsive device for underwater robots, because it has a possibility to get high-speed swimming and efficient propulsion, therefore the combination of robotic fish and the simultaneous mapping system is the good selection. Obstacle sensing and collision avoidance is one of the fundamental problems that need to be solved before achieving truly autonomous robots. For this reason, in recent years it has been receiving more and more attention [5]. Multiple techniques have shown promising good results in a variety of practical applications: indoor, outdoor, on land and even airborne. However, the underwater environment is one of the most challenges for mapping because of the reduced sensorial possibilities. Acoustic devices are the most common choice, while infrared sensors are employed in the robot that is very near to the floor. Another important issue is the size of infrared sensor, It is suitable for attach to the robotic fish.

In the aquatic environment, the various kinds of water

This work was supported by the Ho Chi Minh City University of Technical Education.
[1]*Nguyen Truong Thinh Department of Mechatronics, Ho Chi Minh City University of Technical Education, VietNam* (thinhnt@hcmute.edu.vn)
[2]*Trinh Duc Cuong*(✉) *Department of Mechatronics, Ho Chi Minh City University of Technical Education, Viet Nam* (cuongtdc@hotmail.com)

RECEIVED: 22, NOV., 2012; **REVISED:** 17, JAN., 2013; **ACCEPTED:** 19, JAN., 2013; **PUBLISHED:** 20, JAN., 2013. ISSN: 2345-234X
01020100200025201300010 5

plants and trashes slow down the robot's smooth and natural movements. Generally, the distance sensory systems which provide robotic fish with data about location or objects at a distance without a need for the fish to directly touch them. Such distance sensing systems are important, because they allow providing information about the location of food and predators, and about avoiding obstacles or maintaining position. Therefore, taking advantage of this feature will make robot detect the obstacles in advance in order to move without collision. The solution is to employ sonar sensor or camera possibly. They analyze the acquired data of the target areas to recognize the possible obstacle.

However, neither sonar sensor nor camera is used to simplify and neaten the robot structure. As a result, the use of simpler IR distance sensors is proposed for robotic fish's eyes. Robotic fish makes appropriate propulsion direction movements to avoid collision based on the analyzing IR distance sensors data. All circuits, sensors, and RF transmission module are contained in a chassis.

An illustration of applications of robotic fish, a new method of mapping and tracking systems is introduced by using ubiquitous sensors networks [1]. In the water pool imitating the similar situation such as the high density of obstacles, the robot swims to the plain area. The changes in the direction of trajectory direction of monitoring robots based on fuzzy decision are proposed. It employs two fundamental data of the measured distance from sensor to obstacles and the possible existence of obstacles. The experimental results show that robotic fish, which employs changing direction following fuzzy decision results, increases movement ability in the region of high obstacles density without collision.

2. ROBOTIC FISH

Nowadays, the robotic fish is a research involving in biomimetics. The robot which has various structures and shapes of real fish imitate the real fish swim. The biologically inspired artificial system, mimicking real fish mostly concentrates on fishlike motion mechanism. Combining morphological character with swimming character, both morphological and kinematic parameters can be abstracted qualitatively. Based on the above characteristics, a feasible mathematical model is finally established, which provides parameters to design, implementation, control and optimization of the robot fish. The structure of the body depends on the payload layout and the functionality of the robot. In this case, the robotic fish can work in several tasks as monitor and acquirement data of environment from underwater. For this reason, robot can carry some sensors and camera. A framework of robotic fish can be divided into two parts: anterior portion and posterior portion like as shown **Fig. 1.** In order to have a simple structure, the robotic fish has three joints and four-links with connected with 3 servo motors to produce the propulsion through the and to get good stability and increase the flexibility, which is a top requirement in this application. As structure of robotic fish, the links of 1, 2, 3 and link 4 have connected by 3 joints and 3 servo motors. For acquiring smooth motion like fish, it is better to have as many joints as possible. As a result, the tail peduncle and tail fin are moved independently and optionally.

In the obstacle detection module, redundant IR sensors are used to increase detection resolution and sensor data reliability. Since infrared distance sensors have a width dihedral detection angle, the resolution of detected obstacles is very low. The implemented approach uses always two infrared distance sensors for one half of the same angle and one sensor located in front of the head of robot. Hence, though the triple amount of sensors is needed, the redundancy and resolution is also tripled. The noise level becomes higher as the distance gets longer. An RF transmission module is integrated to transmit user command and sensor data between the robotic fish and a host PC. **Figures 1** and **2** indicate the configuration of the sensors on the fish robot's body and the IR distance sensor ranges in air and water environments. **Table. 1.** shows the robot's specification.

The robotic fish is employed two turning algorithms which are the turning using kinetic energy and the turning using moment of rotation. In the first mode, the robot swims straight and gets kinetic energy. Next, it turns its tail to one side, and keeps the posture to the side. Afterwards, the robotic fish turn by hydrodynamics force. In the second mode, robot swings its tail to one side rapidly from stationary state. In this turning mode, inertia force and friction force of the moving tail and a body are changed to the moment of rotation [6].

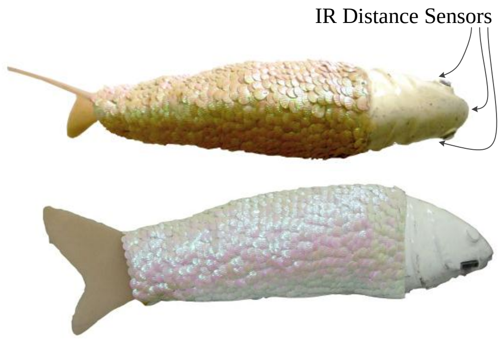


Fig. 1. Configuration of the sensors on the Robotic Fish (a) Top view (b) Side view.

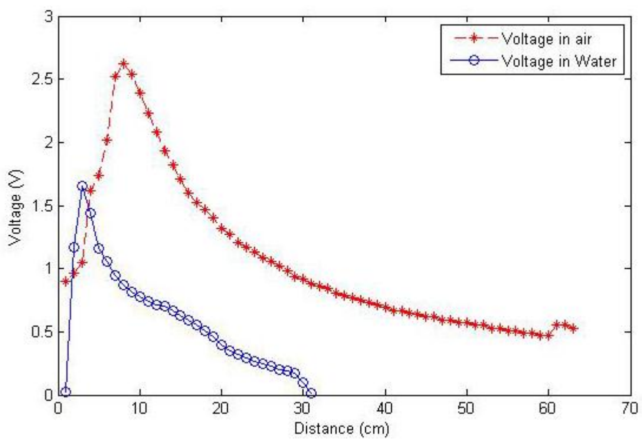


Fig. 2. IR distance sensor ranges.

TABLE 1.
SPECIFICATIONS OF A ROBOTIC FISH

Item	Specification
Length	580 mm
Width	80 mm
Height	125 mm
Weight	1200 g
Length of tail fin	150 mm
Maximum angle of tail fin	90^o
Minimum rotation radio	6 mm
Maximum speed	200 mm/s
Maximum torque of motors	9 KgCm

3. TAKAGI-SUGENO FUZZY CONTROLLER

Fuzzy logic, which is the logic on which fuzzy control is based, is much closer in spirit to human thinking and natural language than the traditional logic systems. The essential part of the fuzzy of the fuzzy logic controller (FLC) is a set of linguistic control rules related by dual concepts of fuzzy implication and the compositional rule of inference. This controller provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzy logic system is a name for the system which have a direct relationship with fuzzy concepts and fuzzy logic. Takagi and Sugeno's fuzzy system is a type of most popular fuzzy logic systems.

Takagi-Sugeno(T-S) system has recently become a powerful practical engineering tool for controlling complex systems. Fuzzy making decision is an interpolation method partitioning the membership functions into fuzzy area. Each area is estimated by the simple local model which is often a linear model. The global area is obtained by interpolating all of areas. As a result, the fuzzy making decision can observe the strongly nonlinear function through a simple structure and the limited rules [2].

A T-S fuzzy rule is described by a set of fuzzy "IF …THEN" rules. A generic T-S rule can be written as follows:

R_i: If x_i is A_{i1} AND x_2 is A_{i2} … AND x_r is A_{ir}, THEN

$$y_i = f_i\left(x_1, x_2, ..., x_r\right), i = 1, 2, ..., n_R \quad (1)$$

Where A_{i1}, A_{i2}, …, A_{ir} are fuzzy sets in the antecedent, while y_i is a crisp function in the consequent. y_i is usually a polynomial function of input variables. However, it can be any function as long as it can appropriately describe the output of the model within the fuzzy region specified by the antecedent of the rule. When y_i is a first-order polynomial, as in this paper, the resulting fuzzy inference system is called a first-order Sugeno fuzzy model [3].

$$y_i = a_{i1}x_1 + a_{i2}x_2 + ... + a_{ir}x_r + b_i, i = 1, 2, ..., n_R \quad (2)$$

When a_{i1}, a_{i2}, …, a_{ir} and b_i are the parameters which should be identified. The results of T-S fuzzy rule are hyperplanes (r-dimensional linear subspaces) in R^{r+1} whereas the if - part of the rule partitions the input space and determines the validity of the n_R locally linear model for different regions of the antecedent space. Since each rule has a crisp output, the overall output of the T-S system could be obtained via weighted average formula (3).

$$y = \frac{\sum_{i=1}^{n_R} y_i w_i}{\sum_{i=1}^{n_R} w_i}; w_i = \prod_{i=1}^{r} \mu_{A_i}\left(x_i\right) \quad (3)$$

where n_R is equal to the number of rules.

The remains of the T-S controller is a method to estimate parameters a_{i1}, a_{i2}, …, a_{ir} and b_i of the model shown in **Eq. 2**.

4. DISTANCE ESTIMATION

The movement of a caudal fin produces oscillations of robotic fish's body. Therefore, the outputs of the infrared sensor change in a swing pattern, but the real distance is maintained. **Fig. 3.** shows the real distance and various measured distance. **Eq. 4.** shows general swim function [5].

$$A_i\left(t\right) = K_i Am_i \sin\left(2\pi f t - \theta_i\right) + \Delta_i\left(t\right) \quad (4)$$

A_i is the angle of i^{th} tail motor, K_i is amplitude factor, A_{mi} is amplitude, f is frequency of caudal fin, θ_i is phase delay of i^{th} motors, and Δ_i is deflection angle for slow and quick turn. We use 10 degree maximum amplitudes of angle and 35 degree phase delays for general swim. Swim frequency is 0.5 Hz.

When the approaching angle of the robotic fish is θ and the swing angle of head is A_i, the fish robot reads real distance as d_{real} and long distance as d_{long}. Therefore, it is necessary to estimate the exact real distance from the robot to the obstacle. A fuzzy distance estimation method is used to find the exact distance regardless of the swing of its head. The mean value of distance data of one period from the previous half to the next half period is defined as a real distance. However, it is impossible to use future distance data in a real time system. Thus, the previous distance of one swing period is used get distance estimation. This data is mean distance of half period ago. Therefore, a moved distance in the past half period should be added to get a current distance. The sampling time is 20 ms, and the swing period is 2 seconds are applied for the fish robot.

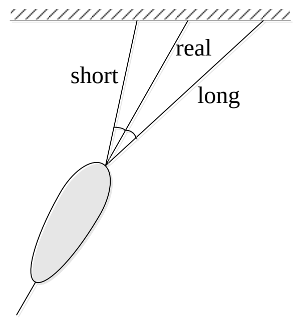
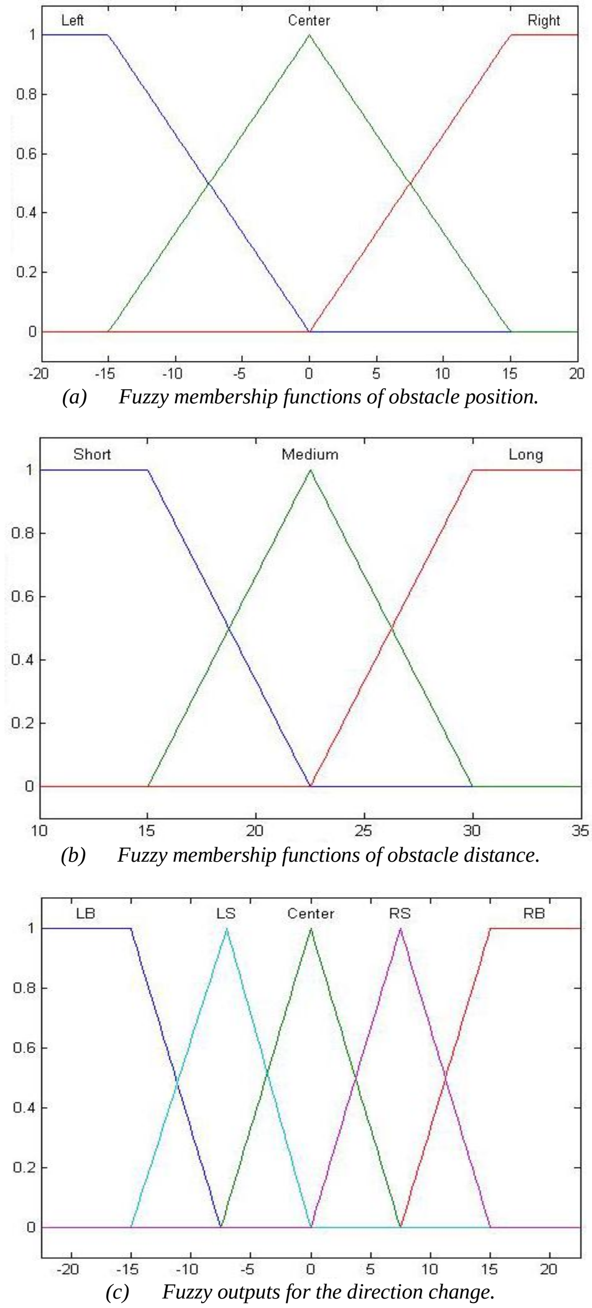


Fig. 3. Real distance and measured distances.

The flowing procedures are proposed to get a fuzzy distance estimation:

- Calculate the mean value of distance data (D_m) for past one swing period.
- Calculate the mean value of past ten samples at current (D_c) and past (D_p) one swing period ago.
- Calculate the distance change for half swim period (O_p) with $O_p = (D_c - D_p)/2$.
- Calculate a compensation factor O_c which is calculated by a fuzzy logic system.

The inputs of fuzzy system are distance data D_m, distance change for half swim period O_p and the direction information D. The ANFIS inference is employed to train the distance estimation.



(a) Fuzzy membership functions of obstacle position.

(b) Fuzzy membership functions of obstacle distance.

(c) Fuzzy outputs for the direction change.

Fig. 4. Fuzzy membership functions inputs- and control output variables

5. PROPOSED METHOD FOR FUZZY DECISION MAKING ON DIRECTION CHANGES

Robotic fish probably encounters serious difficulties avoiding obstacle collision due to various kinds of obstacles in the water. In order to approach natural and smooth movement for robotic fish concerns the detecting and recognizing obstacles as well as the avoiding collision, we propose a fuzzy decision making on trajectory direction changes. In the experiment, the measured distance from sensor to obstacles and the possible existence of obstacles are two essential input data for the fuzzy algorithm.

A. Establish the upper and lower margins for the inputs

The assignment process to define the upper and lower margins can base on some algorithms or local operation as well as intuition. It also derived through understanding and prior knowledge about the systems [4]. For example, the upper and lower margins of the Center range are 15^o and -15^o, respectively. The upper and lower margins of the Long range are 20^o and 0^o, respectively.

B. Defining fuzzy membership functions

The choice of membership function will help define the output surface that is based on the combination of the multiple surfaces. Because of insuring smooth transition among these surfaces, membership functions must be even, same type and input domain must be equally divided. The range of obstacle position (O.P.) is divided into three membership functions of Left, Center, and Right which are mean that the intensities of obstacles in left, center, and right side are higher than any other ranges, respectively. The range of obstacle distance (O.D.) is also separated into three membership functions of Short, Medium, and Long express distances from a sensor to the obstacle. The output for the direction change is divided into five membership functions of LB: Turn Left Big, LS: Turn Left Small, Center, RS: Turn Right Small, RB: Turn Right Big. **Fig. 4**. demonstrates the two fuzzifications of inputs for the obstacle distance and obstacle position and an output for the direction change.

C. Training data

The most important factor for T-S systems is the sufficient set of input-output data. This data should explain the behavior of unknown systems. In the experiment, the main goal of the proposed method is designing a suitable response for swimming propulsion which uses the least number of training data.

The total number of required data is computed by **Eq. 5** and n indicates the number of inputs.

$$\text{Total number of data} = 3^n . \quad (5)$$

The required number of data in this method is the same as a three-level factorial design [7]. Each input has three levels (low, medium and high). Because robotic fish has two inputs, so the total number of data is nine. As a result, the corresponding fuzzy variables are represented in **Fig. 5**.

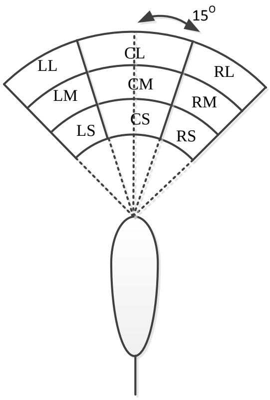


Fig. 5. Fuzzy variables of direction and distance for obstacles.

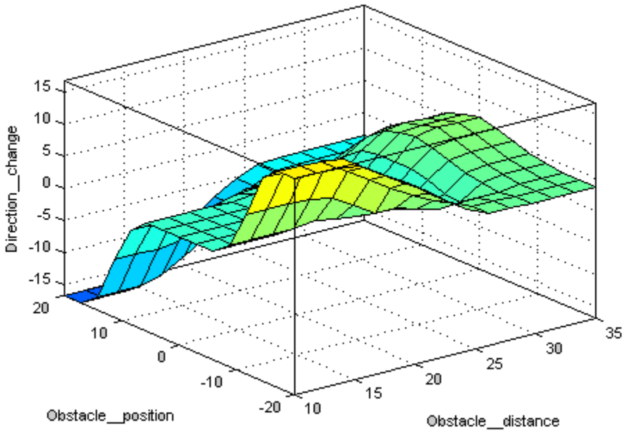
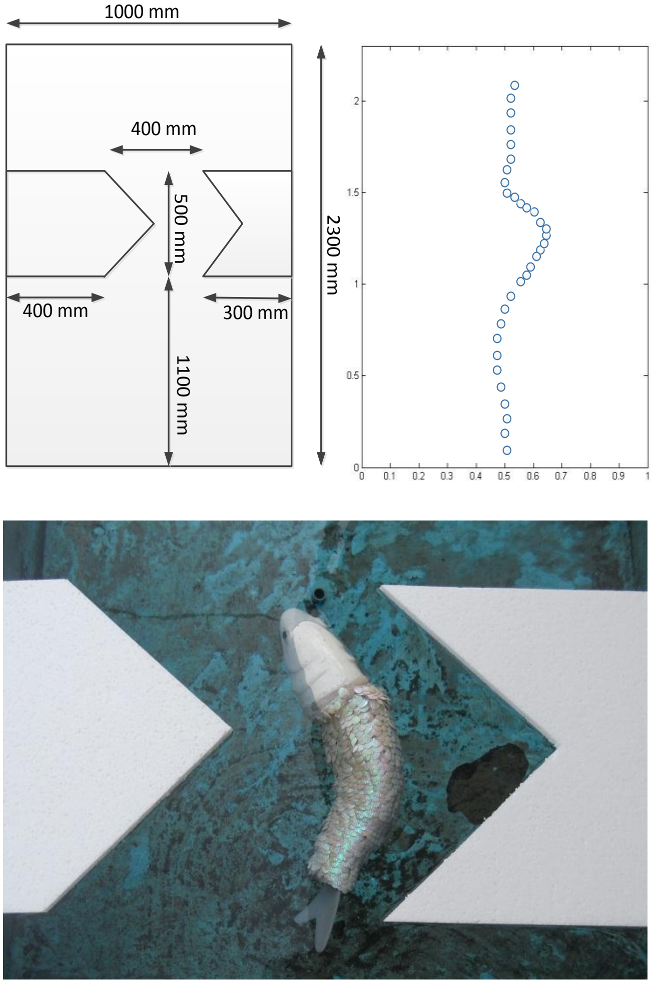


Fig. 7. Control surface

TABLE 2.
FUZZY RULES FOR DIRECTION CHANGES

O.D. \ O.P.		Left	Center	Right
Left	**Short**	RB/LB	RB/CT	RB/RB
	Medium	RS/LB	RS/CT	RS/RB
	Long	X/LB	RS/CT	RS/RB
Center	**Short**	LB/LB	RB/CT	RB/RB
	Medium	LB/LB	RS/CT	RB/RB
	Long	LS/LB	RS/CT	RB/RB
Right	**Short**	LB/LB	LB/CT	LB/RB
	Medium	LS/LB	LS/CT	LS/RB
	Long	LS/LB	LS/CT	X/RB



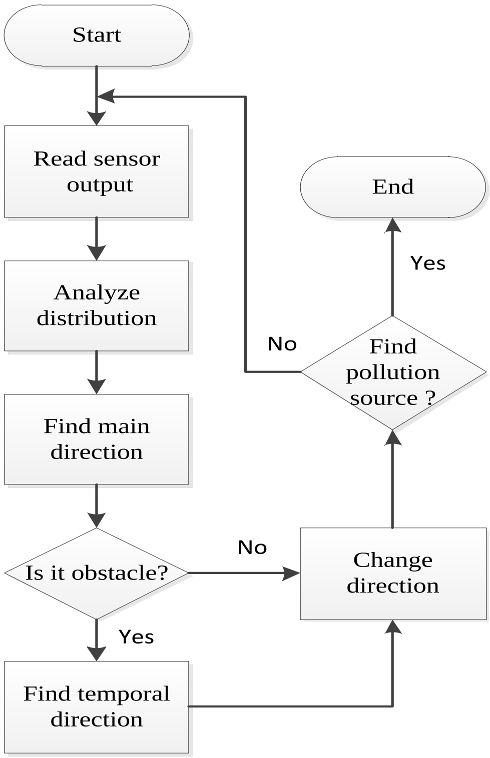


Fig. 6. Flow chart for direction changes

Fig. 8. Experiments of direction fuzzy control

D. Fuzzy rules and deffuzification

The direction control of the tail fin considering obstacles is carried out using fuzzy inference. Assuming two membership functions for each input, the fuzzy rules are summarized in **Table. 2**. In the table, X represents 'don't care'. Every output in **Table. 2.** has two directions: Temporal Direction and Main Direction. Main Direction is

the output variable when there are no obstacles while Temporal Direction is the one when an obstacle is detected. The autonomous making decision for the direction changes is based on the **Fig. 6**. The control surface of the system is shown in **Fig. 7.** Finally, the weighted average method is employed to defuzzify the output variable **Eq. 3.**
Examples of fuzzy rules are as follows:
* R1: If O.P. is Left and O.D. is LS, then Temporal Direction is RB and Main Direction is LB.
* R2: If O.P. is Left and O.D. is LM, then Temporal Direction is RS and Main Direction is LB.
* R3: If O.P. is Left and O.D. is LL, then Temporal Direction is X and Main Direction is LB.
The scanned positions of head swing are denoted by a circle in server during the real time. Appropriate changing direction for path changes is obtained through Takagi-Sugeno fuzzy controller. Typical experimental results of trajectories for directional fuzzy control are denoted in dots in **Fig. 8.** It shows successful collision avoidance while swimming in high obstacles density areas.

6. CONCLUSION

This paper mainly indicates the implementation of a robotic fish, including the robotic hardware and the movement control algorithm. There are several easy improvements that could be made to future iterations of this paper in order to improve the robot's performance. The robot consists of three IR distance sensors placing at the left, right and front. Using this sensor system instead of cameras or sonars propose the effective in changing the direction for avoiding collision. The movement control algorithm is using Takagi-Sugeno fuzzy controller. The fuzzy controller was tested to perform collision-free navigation toward any given goal and corridor following. The experimental results have shown that the proposed architecture provides an efficient and flexible solution for the light autonomous differential fish robots. Two fundamental data of the measure distance from sensor to obstacles and the possible existence of obstacles are employed for fuzzy system. The fuzzy system's output decides the change of direction. The experimental results indicate that the robotic fish successfully makes their movement without collision to the area of high obstacles density. The intelligent movement of robotic fish is improving to tracking accurately, avoiding obstacle abilities and communication as well as agile swimming. As a result, it can be applied in military and ocean surveying research.

REFERENCES

[1] Daejung Shin, Seung Y. Na, Jin Y. Kim and Seong-Joon Baek, "Water Pollution Monitoring system by Autonomous Fish Robots," WSEAS Trans. on SYSTEM and CONTROL, Issue 1, Vol. 2, pp. 32-37, 2007.

[2] Y. Farzaneh, A. Tootoonchi, "A Systematic and Simple Approach for Designing Takagi-Sugeno Fuzzy Controller with Reduced Data," IEEE Conference on Cybermetics and Intelligent Systems, pp.521-526, 2008.

[3] T. Takagi, M. Sugeno, "Fuzzy identification of systems and its applications to modeling and control," IEEE Transactions on Systems, Man and Cybernetics, vol. 15, pp. 116-132, 1985.

[4] Seung Y. Na, Daejung Shin, "Fuzzy Decision Making on Direction Changes of Water Pollution Monitoring Underwater Robots," Proceedings of the IASME / WSEAS, pp. 3-5,2007.

[5] M. J. Lighthill, "Novel on the swimming of slender fish, Journal of fluid Mechanics," vol. 9, pp. 305-317, 1996.

[6] Hirata K, Takimoto K, "Study on turning performance of fish robot," In Proceeding of First International Symposium on Aqua Bio-mechanisms, USA, pp. 287-292, 2000.

[7] D. C. Montgomery, "Design and Analysis of Experiments," 6th ed, Wiley,2005.

Nguyen Truong-Thinh received his Ph.D. in Mechanical Engineering from Chonnam National University – Korea in 2009. His M.S. and B.S in Mechanical Engineering from Ho Chi Minh city University of Technology - Viet Nam in 1997 and 2000, respectively. Since 1998, he has been working with Ho Chi Minh city University of Technical Education – Viet Nam as Associate Professor. His research interests include service robotics systems, industrial robotics, intelligent control and design.

Trinh Duc Cuong received his B.S. degree in Mechatronics from Ho Chi Minh city University of Technical Education, Viet Nam in 2012. His research interests include parallel robots, industrial robotics and automation. He has published a number of papers in these areas. He is now a researcher in Ho Chi Minh city University of Technical Education. He is also a student member of IEEE.

Available online at:
http://tsest.org/index.php/TCMS/article/view/105
Download full text article at:
http://tsest.org/index.php/TCMS/article/download/105/66
Cite this work as:
Nguyen Truong Thinh, and Trinh Duc Cuong, "Approaching Fuzzy Logic in Fish Robot for Obstacle and Collision Avoidance Problem," *TSEST Transaction on Control and Mechanical Systems*, Vol. 2, No. 1, Pp. 20-25, Jan., 2013.