MEKATRONIKA
e-ISSN: 2637-0883
VOL. 3, ISSUE 2, 42 – 48
DOI: https://doi.org/10.15282/mekatronika.v3i2.7352

UNIVERSITI MALAYSIA PAHANG

ORIGINAL ARTICLE

Design of a Fuzzy Logic Controller for Optimal African Catfish Water Production

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ABSTRACT – Fish, unlike other animals, feed and defecate inside the same water where they live. When water quality depreciates, consumed feed is not properly converted into body flesh, poor growth is recorded, fish survival is affected and ultimately massive fish deaths may occur. In fish production, key water quality parameters which need to be continually monitored and controlled are temperature, dissolved oxygen (DO), pH, and ammonia. These parameters are highly non-linear, and thus difficult and expensive to use conventional controllers. Fuzzy logic controllers can suitably adapt to non-linearity because it uses sentences for control actions rather than equations. FisPro (Fuzzy Inference System Professional) is used to create fuzzy inference system (FIS)/ fuzzy logic controller (FLC) for simulating physical or biological systems. The selected water quality parameter are temperature, 14 to 45°C, potency of hydrogen (pH), 0 to 14, and turbidity, 1 to 5. At a pH of 3.5 and 39°C, the aerator speed is 6982 rpm. Similarly, at a pH of 3.5 and turbidity of 1.5, the valve position is 47°. The results obtained shows the completeness, consistency and continuity of the designed rule system. Nine rules were designed for each control action giving a total of eighteen rules. The control actions are; water discharge/refill in form of valve actuation and aeration in form of air pump activation.

ARTICLE HISTORY
Received: 14th April 2021
Revised: 2nd July 2021
Accepted: 30th July 2021

KEYWORDS
African catfish
Aquaculture
Fuzzy logic controller
Fish water quality

INTRODUCTION

With a growing population, reducing natural stocks and improving level of education, there is an increase in the awareness that fish is the best source of protein further affirming the importance of aquaculture. Thus, the number of entrepreneurs in culture fishery is increasing, and this is expected to continue in the future. Fish, unlike other animals, feed and defecate inside the same water where they live. The quality of the water which they live in directly affects their feeding efficiency, rate of growth, survival and their state of health. When water quality depreciates, consumed food is not properly converted into body flesh, poor growth is recorded, fish survival is affected and ultimately massive fish deaths may occur [1].

In fish production, key water quality parameters which need to be continually monitored and controlled are temperature, dissolved oxygen (DO), pH, and ammonia. These parameters are highly non-linear, and thus difficult and expensive to use conventional controllers. Fuzzy logic controllers can suitably adapt to non-linearity because it uses sentences for control actions rather than equations [2]. Catfish grown in ponds and tanks, is the most farmed fish species in Nigeria, constituting over half of the total aquaculture production by volume [3]. Commonly grown species are the African catfish (Clarias gariepinus and C. nigrodigitatus), as well as the clariid catfish known as Heterobranchus bidorsalis, all of which thrive in freshwater habitats.

A survey revealed that almost 81% of small scale fish farmers in Jos are growing and rearing the Clarius gariepinus species [4]. Therefore this study is aimed at using the water parameters of African catfish to develop a fuzzy inferencing system. The parameters are pH, temperature and turbidity because their variation affect or is affected by other factors. High pH is influenced by NH_3 and low pH indicated the possible presence of high CO_2, and hence a depletion of DO which is also caused by high temperature.

According to the National Bureau of Statistics unemployment rate accordingly, increased from 18.8% in September 2017 to 23.1% in September 2018. Youth, especially those with a degree tend to shy away from labour intensive jobs in search for "white collar" jobs which are not easy to come by. Reducing human labour intelligently is one of the goals of this work, thereby reducing unemployment and increasing the number of youth engaging in fish farming. The more the fishes produced, there will be a proportional increase in food security in the country. Small scale fish farmers will be able to focus on other sources of income and personal development as this system will save time spent by fish farmers in monitoring their pond. Large scale fish farmers will also find the outcome of this study extremely helpful for real-time monitoring and automation.

Human understanding of most physical processes is based largely on imprecise reasoning. Requiring precision in engineering models and products translates to requiring high cost and long lead times in production and development [5]. The Fuzzy Logic tool was introduced by Lotfi Zadeh in 1965 and is a mathematical tool for dealing with uncertainty. It is an important concept of computing with words and provides a technique to deal with imprecision. The fuzzy logic controller (FLC) provides a means of converting a linguistic control strategy based on expert knowledge into an automatic

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control strategy [6]. This research therefore aims to build a Three-Inputs-Two-Outputs (TRITO) Fuzzy Logic Controller (FLC) for a recirculating aquaculture system with Short Message Service (SMS) monitoring.

RELATED WORK

Table 1. Review of related past works.

S/No.	Author & Year	Research Focus	Findings
1	Umam & Budiarto, (2018) [7]	Water Quality Control for Shrimp Pond Using Adaptive Neuro Fuzzy Inferencing System (ANFIS)	Developed an adaptive control system using ANFIS method to control pH balance (7.5-8.5), temperature (25-31), water
2	Chavan *et al.*, (2018) [8]	Design and Implementation of IoT Based Real Time Monitoring System for Aquaculture Using Raspberry Pi.	The system continuously monitors water quality and send data to farmers' mobile phone through cloud so they could take preventive measures. The system sends alert to mobile phone with feasible solution.
3	Nocheski S. & Naumoski A., (2018) [9]	Water Monitoring IoT System for Fish Farming Ponds.	Used wivity modem connected to Arduino Mega 2560 which takes monitored data and sends SMS messages for the most vital events that can jeopardize fish health. It also gives audio signal when such events occur.
4	Yuliana (2017) [10]	Microcontroller Applications Based Fuzzy Logic Controller for Temperature on Breeding Fish Pond (Carp).	Developed a fuzzy logic temperature controller using a pmw solid state relay.
5	Yalcuk & Postalcioglu, (2015) [11]	Evaluation of pool water quality of trout farms by fuzzy logic: monitoring of pool water quality for trout farms.	This study is designed to bridge the gap in environmental monitoring and evaluate the water quality of trout farm. Large data of pH, COD, NH4-N and EC from four trout farms were collected. Fuzzy logic was developed using Matlab/ Simulink to evaluate these data and provide a GUI for easy monitoring.
6	Singhala et al., (2014) [12]	Temperature Control using Fuzzy Logic	A unique FLC using a small number of rules and simple implementation is demonstrated to solve a temperature control problem with unknown dynamics commonly found in industry

METHODOLOGY

Selection of FIS Design Parameters

1) Temperature: Water temperature is among the most important physical variables affecting vital functions in fish [13]. Functions such as growth rate, food intake, food conversion efficiency (FCE), and other metabolic activities are significantly influenced by temperature [14]. Rates of chemical and biological reactions double for every 10ºC rise in temperature [8]. This means that aquatic organisms will use twice as much DO at 30ºC than at 20ºC. Chemical reactions will also progress twice as fast at 30ºC than at 20ºC. The average decennary monthly minimum and maximum temperature of Zaria for a period of 30 years (1986-2015) was surveyed and it was found that in April there can be temperature as high as 36.54ºC, while December the temperature can be as low as 14.67ºC [15]. This inform the choice of temperature universe of discourse to be 14ºC to 45ºC.

2) Potency of Hydrogen (pH): [16] investigated the effect of pH on growth performance and survival rate of catfish (Clarias gariepinus) at an average temperature of 26.5ºC and found 100% mortality after 24hrs at pH of 2, 3, 10, 11 and 12. While pH of 4 recorded complete mortality after 192hrs. The percentage survival in the other pH varied between 99.7% (in pH of 7 and 8) and 51.67% (in PH of 5). This suggests the need for constant monitoring and control of pH changes in water especially in fish farming operations. Hence, a recommended range for fish production is shown in figure 1. Therefore, universe of discourse for pH is chosen to be from 0 to 14.

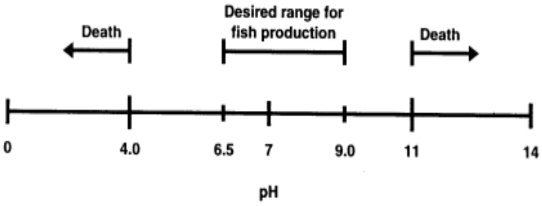


Figure 1. pH scale showing recommended ph range.

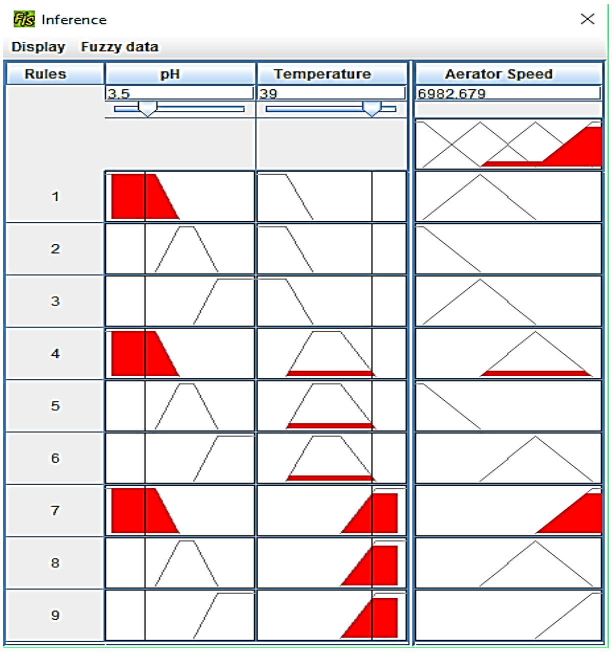
3) Turbidity: It was discovered in an experiment by [17] with African catfish that increased turbidity decreases their visual sense leading to territorial fight causing external injuries. High mineral turbidity (clay, silt, uneaten food) affects fish directly by injuring their gills, reducing their growth rate or preventing their reproduction. It can also harm the minute animals called cladoceres and copepods (zooplankton), which are important food for young fishes [18].

Working Principle of the Proposed FLC

It The system starts by reading pH, temperature and turbidity from the sensors and store these parameters in the SD card. If all the parameters are within the set limit, a green LED turns `ON'. The system delays for a minimum of 60 minutes and read the parameters again, going through a loop. If any or all of the parameters are outside the desired limits, a red LED turns `ON' and these values are sent to the FLC as inputs to the controller. The FLC uses the designed inference system and decides the appropriate control action(s) to take based on the values of these parameters. The control actions are in form of aerator speed and valves control (for discharge and refill) which can occur separately or simultaneously.

EXPERIMENTAL RESULTS

Figure 2 shows the inference system for the aerator speed with the nine (9) rules. At 3.5pH and 39ºC it will be observed that two rules fired. Minimum of the two is taken and center of area (COA) defuzzification method was used to obtain the aerator speed of 6982rpm. This is the speed at which the aerator speed will pump air into the fish pond to increase amount of dissolved oxygen.



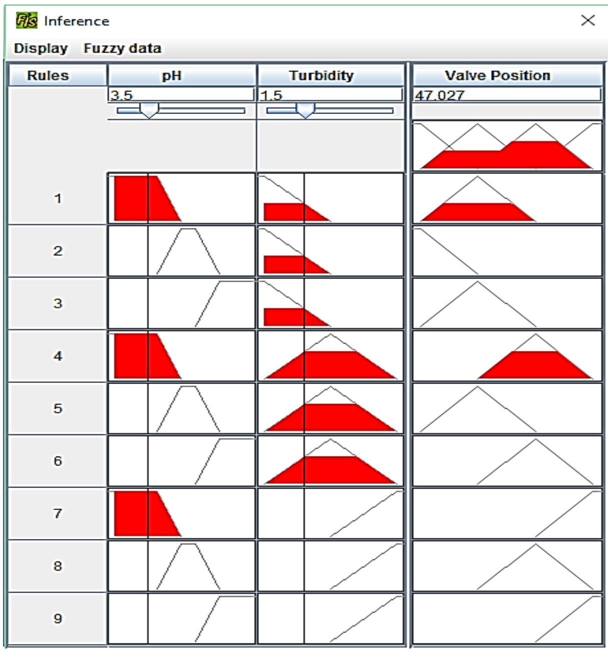
pH 3.5

Temperature 39

Aerator Speed 6982.679

Figure 2. Inference System for Aerator Speed (rpm).

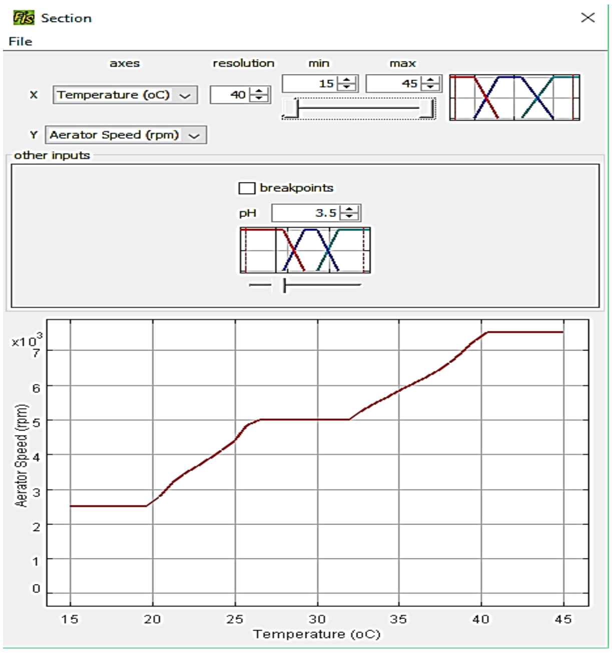
Figure 3 is a sampled inference at 3.5pH and turbidity of 1.5, with rule 1 and 4 fired to produce the output of 47º opened valve. The valve opening controls the discharge (volume flow rate) of polluted water and refill with fresh water.



pH 3.5
Turbidity 1.5
Valve Position 47.027

Figure 3. Inference System for valve position.

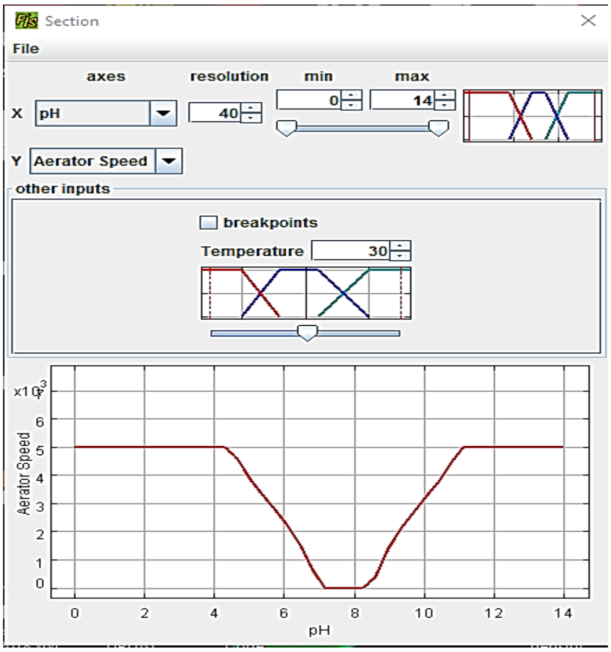
Figure 4 shows the variation of aerator speed at 3.5pH. At temperature between 26°C and 32°C aerator speed is kept constant as this is the suitable temperature range for African catfish production. The aerator speed drops as temperature drops and increases as temperature increases.



X Temperature (oC) resolution 40 min 15 max 45
Y Aerator Speed (rpm)
☐ breakpoints
pH 3.5

Figure 4. Variation of Aerator Speed with temperature at 3.5pH.

At extreme pH below 4.5 and above 11 the aerator speed is maximum, but drops to minimum at 7 to 8.5pH values. At desirable temperature between 26 and 32°C and at desirable pH range, the aerator will be off as shown on figure 5.



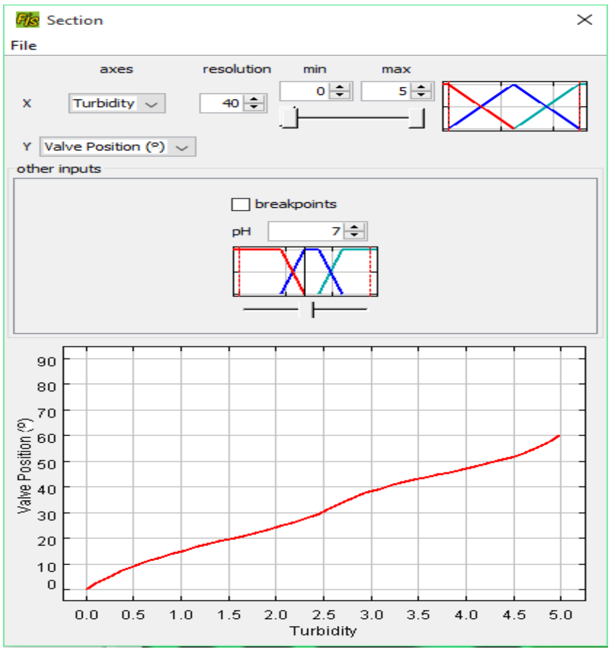
X: pH, resolution 40, min 0, max 14

Y: Aerator Speed

Temperature 30

Figure 5. Variation of Aerator Speed with pH at 39ºC.

Figure 6 is the variation of valve positions at 7pH. At zero turbidity (clear water) the valve will be shot at desirable pH (7 – 8.5). When turbidity increases, valve position also increases allowing more water exchange.



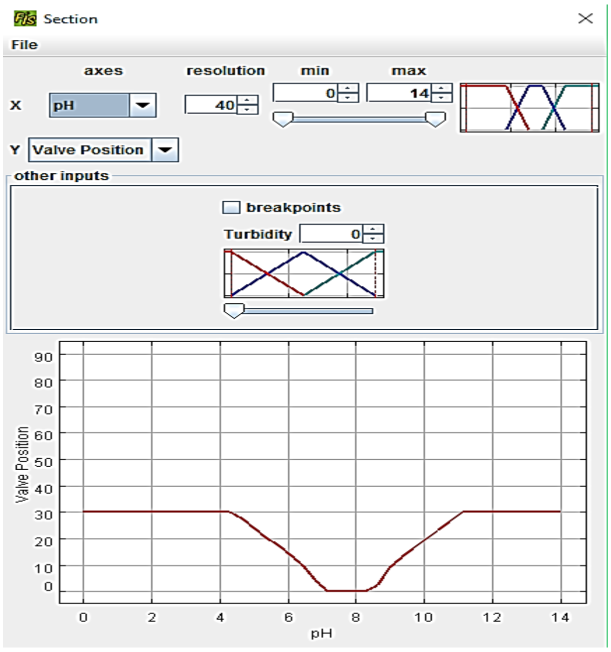
X: Turbidity, resolution 40, min 0, max 5

Y: Valve Position (º)

pH 7

Figure 6. Variation of valve position with turbidity at 7pH.

At extreme pH values below 4.5 and 11 the fish will be stressed and possibly death. Therefore, the valves open to 30º to initiate water change and at pH of 7 to 8.5 the valves remain closed because the turbidity is also low as seen in figure 7. But as turbidity increase the v-curve rises to 900 when pH and turbidity are at extreme.



axes: X pH
resolution 40
min 0
max 14
Y Valve Position
other inputs
☐ breakpoints
Turbidity 0

Figure 7. Variation of Valve Position with pH at Low Turbidity (Clear water).

CONCLUSION

The results obtained shows the completeness, consistency and continuity of the designed rule system. Nine rules were designed for each control action giving a total of eighteen rules. The control actions are; water discharge/refill in form of valve actuation and aeration in form of air pump activation. At pH between 7 – 8.5, turbidity of 0 (clear water), and temperature between 26 to 32oC, the controller will take no action because these are the desirable water parameter. Any small change in any of these parameters will trigger the controller to action until desired water parameters are attained.

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