Distributed System for Assessment of Water Quality in Shrimp Aquaculture Systems

José Juan Carbajal Hernández[1], Raúl A. Valero Cruz[2]
and Mauricio Suárez López[2]

[1]Department of Real Time Systems and Modeling, Centre of Computer Research – IPN
Av. Juan de Dios Bátiz, Col. Nva. Industrial Vallejo, México D.F., México.
[2]Departamento de Ingenierías, Universidad del Valle de México
Paseo de las Aves No. 1, San Mateo Nopala, C.P. 53220,
Naucalpan de Juárez, Edo de México.
juancarvajal@sagitario.cic.ipn.mx

Abstract. Water quality in aquaculture systems must be under control, a disestablished ecosystem can be harmful for organisms. This work presents a new tool for assessment of the ecosystem status based on a distributed system, whose was developed in three phases: measurement (sensor), data acquisition (conditioning and analog to digital converter), and signal processing (software). A fuzzy inference System processes environmental information using a reasoning process. Potential negative situations and harmful combinations between physical-chemical variables are detected, providing a final water quality index, which describes in a status level of the ecosystem (excellent, good, regular and bad). A user interface was build for an easily water management information of the assessed ponds.

Keywords: Water quality, fuzzy inference, aquaculture, artificial intelligence.

1 Introduction

The water management is an important factor in shrimp aquaculture where the ecosystem must be under control. A disestablished habitat is not conducive for a good farming, also an organism with a weakened immunological system is more likely for getting Sick [1](for example Taura virus, Mancha Blanca, Cabeza Amarilla, Etc.).

The environmental variables have some concentration limits, where low or high concentrations (depending of the variable) can be harmful for the organism [2], [3], [4]. Following this behaviors, it is possible to implement a model in the attention that those limits and changes in the variables can be used for determining when a concentration is good or bad for shrimp, and how the combination of the variables affects the water quality in the artificial shrimp habitat. This strategy will decrease the negative situations; consequently also it will decrease the stress in the organism, and low mortality rates.

This research is based on analyze the water quality of Litopenaeus vanammei

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shrimp, whose is cultivated in farms located in Sonora, Mexico, therefore toxic concentrations for this organism will be analyzed for the construction of the distributed system.

2 Distributed system

The production system and methods for Central America monitors in shrimp aquaculture have different frequencies of environmental variables. Dissolved oxygen, temperature and salinity are monitored daily; pH, ammonia, nitrate, turbidity and algae counts are measured weekly. In this work the pH variable is measured daily in order to control possible ammonia concentrations. Chemical analyses do not come into consideration for water quality management on a routine bases [5]. In attention of those variables with a higher frequency of measuring, the distributed system is implemented using this set.

The monitoring of physical-chemical variables can be classified in three phases: measurement (sensor), data acquisition (conditioning and ADC), and signal processing (software), Fig. 1 shows this process.

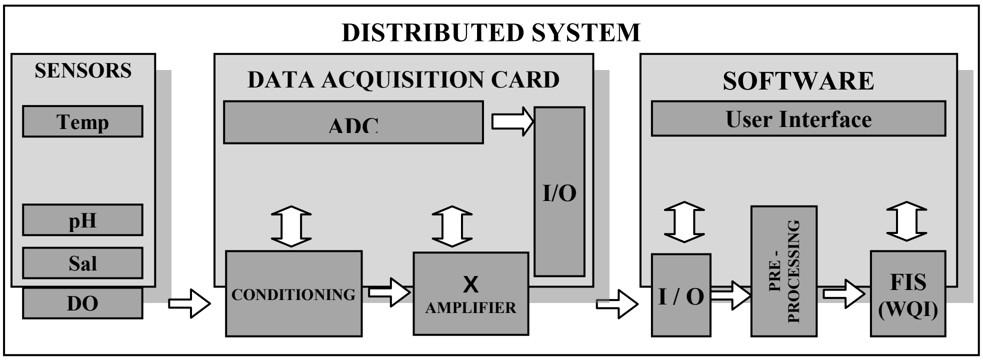

Fig. 1. Architecture of the distributed system for assessment of water quality.

3 Sensors and data acquisition

Different environmental sensors was used for measuring the physical-chemical variables, an explanation of how they were coupled in the distributed system is presented in this section.

pH sensor

The sensor used for measuring the pH was a Signet 2717, which is characterized for having a bulb ORP electrode with bulb protection and a preamplifier [6], whose has a proportionality expressed as follows:

$$pH = (-59)[Lecture(mV)] + 413 \quad (1)$$

The conditioning is a treatment of the original signal for a better lecture of the response. The pH conditioning consist on amplify the mV output in factor of x10 (Fig. 2), where an INA118 low noise instrumentation amplifier was used.

Temperature sensor

For monitoring temperature a LM35 sensor was used, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The measurement range is between -55 – 150 °C, with a linear response of +10.0 mV/°C, as follows:

$$°C = Lecture(mV)\ x\ 100 \quad (2)$$

The temperature conditioning consists on amplifying the *mV* output in factor of x10 (Fig. 2), as the pH an INA118 low noise instrumentation amplifier was used.

Salinity sensor

Salinity was measured using a conductivity sensor Signet 2819, which is characterized for presenting a high resistance in a range between 18.2 MΩ to 10 KΩ for salinity between 0.02 to 50 mg/L [7]. Conductivity sensor conditioning consist on adapt a voltage divisor, measuring indirectly de resistance with a voltage produced by the sensor Fig. 2.

$$°C = (-2.7378x10^{-10})[Lecture(\Omega)] + 5x10^{-3} \quad (3)$$

Dissolved Oxygen sensor

Dissolved oxygen was measured using a TruDO sensor, which is used for the measurement of the amount of dissolved oxygen present in a unit volume of water. DO sensors do not measure the actual amount of oxygen in water, but instead measure the partial pressure of oxygen in water, which is dependent on both salinity and temperature. The sensor output is a current that can be calculated from:

$$i_d = 4\frac{A \times F \times P_{O2} \times P_m(t)}{d} \quad [Amp] \quad (4)$$

where Faraday's constant, *F,* is 9.64 x 104 [C/mol], $P_m(t)$ is the permeability of the membrane (which is a function of temperature), *A* is the surface area of the noble metal electrode, P_{O2} is the partial pressure of oxygen, and *d* is the thickness of the membrane [8]. Dissolved oxygen conditioning consists on convert current to voltage using a LM308 operational amplifier (Fig. 2).

Data acquisition

Data acquisition from sensors must be transmitted to the PC, this process can be implemented using a microcontroller PIC18F2550, and whose has an USB interface that can be programmable using the MPLAB environment (MPLAB, 2009) [9]. The circuit of the USB interface is shown in Fig. 2.

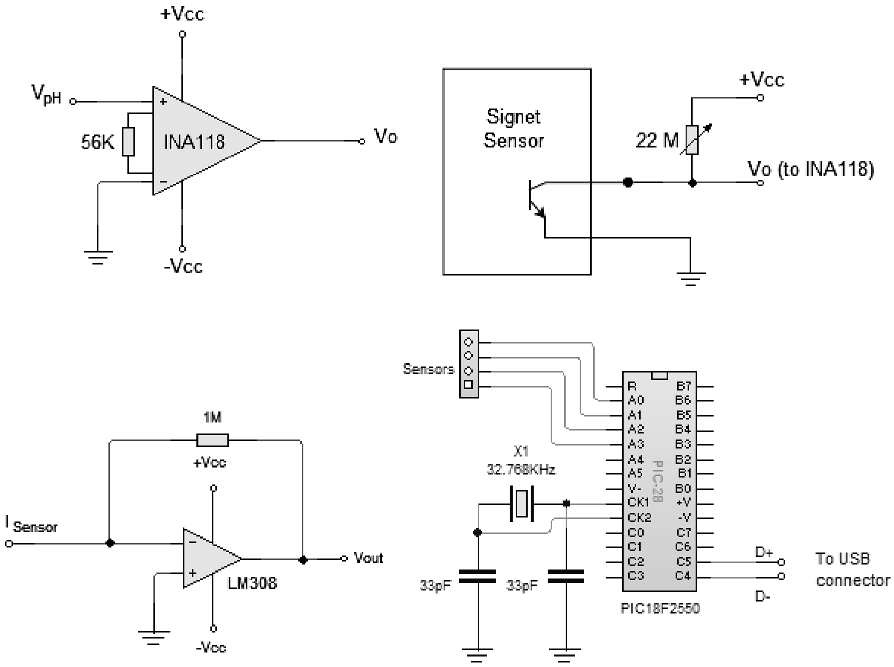

Fig. 2. Conditioning diagrams for sensors; a) low noise instrumentation amplifier (x10); b) Conductivity sensor connection, c) current to voltage amplifier (x1000) for dissolved oxygen, d) a PIC18F2550 is used as interface to ADC conversion and USB communication.

4 Signal Processing

4.1 Physical – chemical classification

In order to classify the behavior of a physical-chemical variable it is needed to define the ranges of optimal or harmful concentrations. The classification levels of the physical-chemical variables (status) are defined in Table 1.

Table 1. Classification levels, tolerances and limits of physical-chemical variables.

Variables	Hypoxia/Acid	Low	Normal	High	Alkaline	Tol	Lím
Temp (℃)	-------	0 – 23	23 - 30	30 - ∞	-------	±1	±1
Sal (mg/L)	-------	0 – 15	15 - 25	25 - ∞	-------	±1	±1
DO (mg/L)	0 - 3	3 – 6	6 - 10	10 - ∞	-------	±0.5	±0.5
PH	0 - 4	4 – 7	7 – 9	9 - 10	10 - 14	±0.5	±0.5

4.2 Fuzzy Inference Systems (FIS)

The Fuzzy inference systems (FIS) theory was applied in this study providing a non-linear relationship between input sets (Physical-chemical variables) and output set (Water Quality Index) [10], [11]. A FIS works in three phases: first it transforms real values in fuzzy outputs for the system using membership functions. Second phase process the fuzzy outputs using a reasoning process based on rules. Finally the output rules are aggregated to create a final output, which is used to determine a [0, 1] index; A Mamdani fuzzy inference system was developed in this work (Fig. 3).

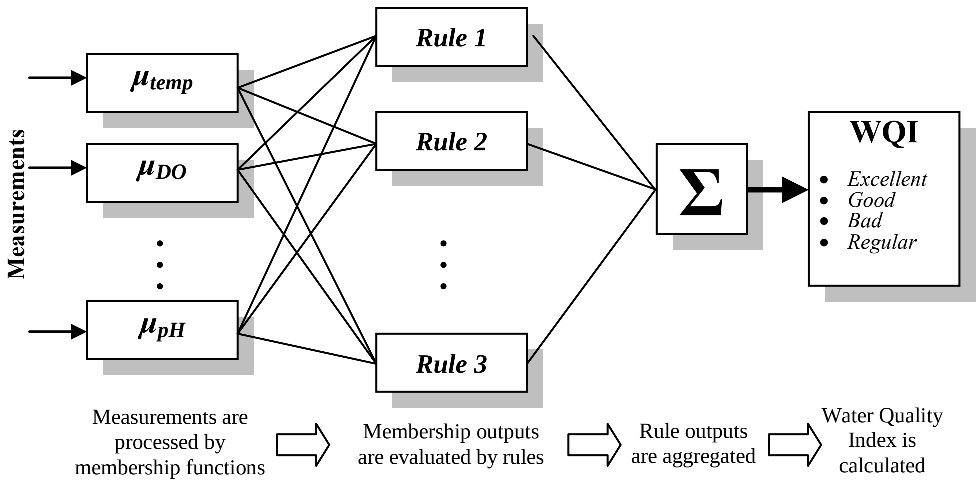

Fig. 3. Architecture of the Fuzzy Inference System applied to the water quality problem in shrimp farms.

Membership functions

Membership functions transform real measurements in [0, 1] indices, those can be implemented in different ways [12]. Expressions of fuzzy memberships are implemented as trapezoidal functions and they can be mathematically expressed as:

$$\mu_{WQI}(x, a, b, c, d) = min\left\{\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right\} \tag{5}$$

where *a, b , c* and *d* are the membership parameters, x is the evaluated variable. Ranges, limits and tolerances in Table 1 are used to build the trapezoidal membership functions, whose are showed in Fig. 4.

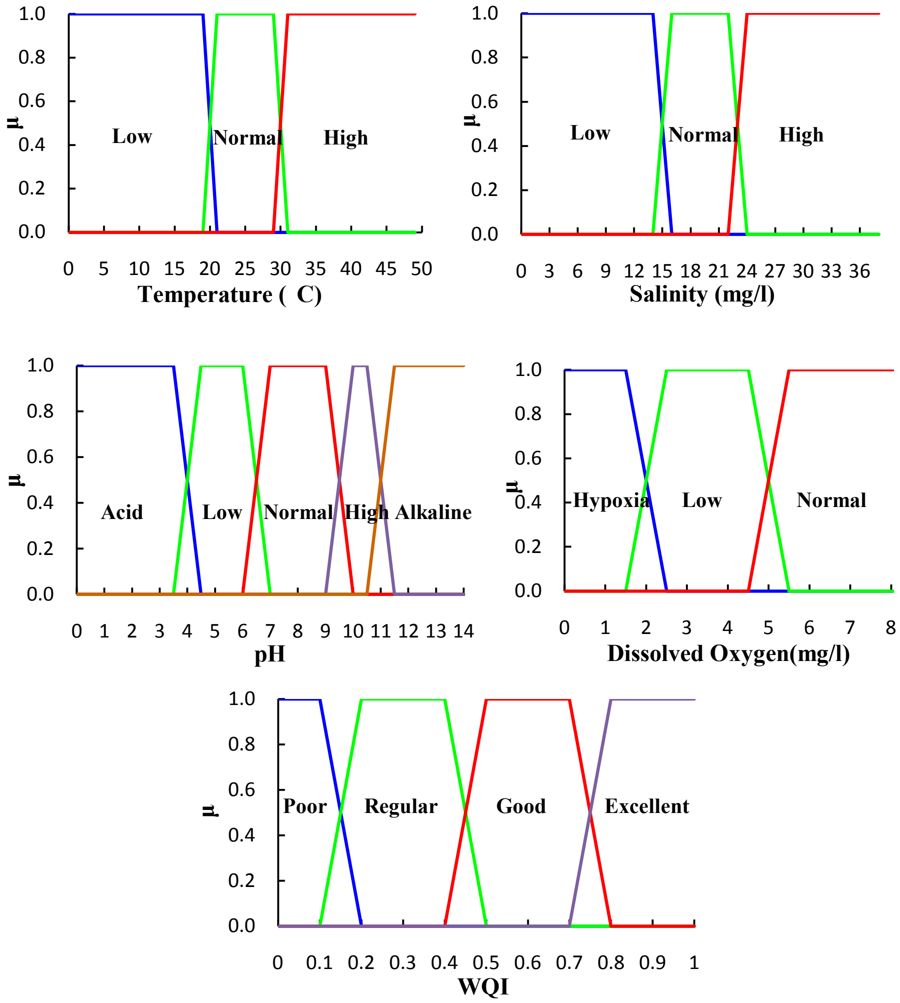

Fig. 4. Membership functions for temperature, salinity, dissolved oxygen, pH and WQI.

Water Quality status

The ecosystem is always changing, and the combination of the variable concentrations defines the status of the water quality. If a high impact variable reports harmful concentrations, therefore the status of the water quality will be deteriorated [1], [2], [3]. The water quality status has been classified in four levels, whose involve all the hypothetical situations in a shrimp pond:

1. *Excellent*: physical-chemical variables report concentrations in the optimal range.
2. *Good*: One variable reports concentrations out of the optimal range; however

this situation do not represents danger in the shrimp.

3. *Regular*: some variables report concentrations out of the optimal range, and the combination between them represents certain stress level in the organism.
4. *Poor*: all the variables concentrations are out of the optimal ranges, or a variable with a high impact level presents concentrations that could generate a potentially danger situation in the pond (p. ej. extremely low oxygen concentrations).

Reasoning process

There are some expressions that are frequently used by experts in water quality, that expressions will be helpful for the construction of the FIS. This kind of expressions implements the fuzzy language of the FIS and they are known as inference rules; they are represented as follows:

Rule 1: If Temp is *normal* and Salt is *normal* and pH is *normal* and DO is *normal* then WQI is *Excellent*
Rule 2: If Temp is *normal* and Salt is *High* and pH is *alkaline* and DO is *low* then WQI is *Poor*

The size of the set rule depends of the number of rules that are involved in the environment; a total of 139 rules have been used in this case. An inference rule process the membership functions values as:

$$\mu_R(\mu_{temp}, \mu_{pH}, \mu_{sal}, \mu_{DO}) = min\{\mu_{temp}^i, \mu_{sal}^j, \mu_{DO}^k, \mu_{pH}^l\} \quad (6)$$

where *i, j, k* and *l* are the ranges of the evaluated variables respectively.

Aggregation

Output rules are matched with the WQI membership functions as follows:

$$\mu_{out} = min\{\mu_R^l, \mu_{WQI}^l\} \quad (7)$$

where *l* defines the assessed status.

Finally all output rules are aggregated in order to create a final membership function, which is evaluated using a gravity center method [11]. It is used for transforming the output membership function in a [0, 1] value, this value represents the Water Quality Index, where 0 means poor and 1 means excellent water quality. Gravity center is calculated using the following equation:

$$WQI = \frac{\int x\mu_{out}(x)dx}{\int \mu_{out}(x)dx} \quad (8)$$

Results using gravity center method never reach the maximum/minimum values, in order to rescale the output; the next expression allows having a [0, 1] index.

$$WQI_n = \frac{WQI - \min(WQI)}{\max(WQI) - \min(WQI)} \quad (9)$$

where WQI_n is the normalized water quality index. The values for *excellent*, *good*, *regular* and *poor* are 1, 6.666, 3.333 and 0 respectively.

5 Software

A graphic user interface was developed in order to assess the artificial habitat in shrimp aquaculture and for an easier handling end-user. Software interface have a set of functions that allows the user assessing water quality, calculate averages, trends, save and restore information as main functions. LabVIEW was used as programming language, which is characterized for having a set of virtual instruments, with a graphic language and a customizable frontal panel as user interface [13].

Fig. 5. User interface designed in LabVIEW environment.

6 Results

In order to prove de functionality of the fuzzy inference model, a data set was extracted from a database of a shrimp farm of Rancho Chapo located in Huatabampo, Sonora, which has a total 24 of measurements with a period of 15 minutes between measurements.

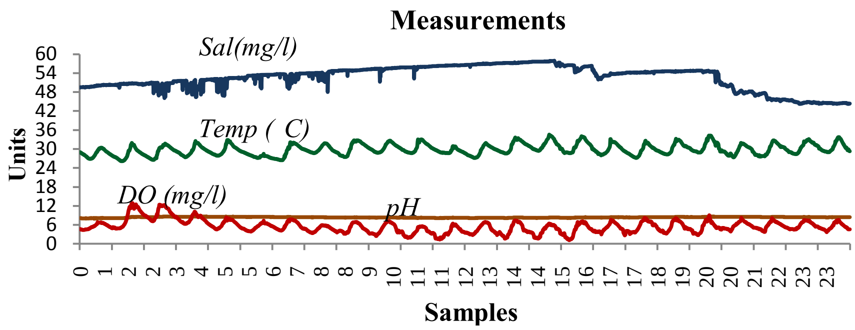

Fig. 6. Physical – chemical signals of the data set measurements registered in June of 2007.

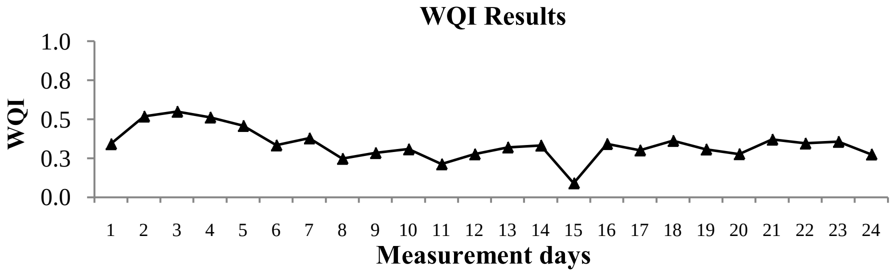

Fig. 7. Water quality assessment using the data set measurements of June of 2007.

Fig 6 and 7 shows a comparison between measurements and results; in Fig. 6 salinity reports values out of its range; Temperature reports values between 25 and 35 °C; DO reports oscillatory concentrations, whose are lightly above of normal range at day and bad range at night the firsts days. PH reports normal concentrations in the month.

In general salinity, temperature and dissolved oxygen report most of the time values out of range; it is clearly seen in Fig. 7, where most of the results are *regular* and *poor*. First days of June pH, temperature and dissolved oxygen concentrations are acceptable and the score is close to *good* water quality.

7 Conclusions

In this paper a distributed system for monitoring the water quality in shrimp farms has been developed. The distributed system is built in three phases; a) Sensor monitoring, b) data acquisition and c) signal processing. A set of four sensors have been conditioned form monitoring the most frequently measured physical-chemical variables. A Data acquisition card was designed receiving data sensors and for transmitting environmental information to a PC software. Assessment software was implemented using fuzzy inference system (FIS) theory for the processing of information. The distributed system results in an excellent tool for water management and treatment of the water quality in shrimp aquaculture.

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