DESIGN OF NEURONAL NETWORK TO CONTROL SPIRULINA AQUACULTURE

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Keywords: Neural Network, Spirulina, Control, Aquaculture, Signal Processing System.

Abstract: A neural network that was designed to control a Spirulina aquaculture process in a pilot plant in the north of Chile, is presented in this work. Spirulina is a super food, but is a delicate alga and its culture may be suddenly lost by rapid changes in the weather that can affect its temperature, salinity or pH. The neural network control system presented is complex and non linear, and has several variables. The previous automatic control system for the plant proved unable to cope with large climatic variations. The advantage of this new method is the improvement in efficiency of the process, and a reliable control system that is able to adapt to climatic changes. The future application of this work is related to the industrial production of food and fuel from micro algae culture, for the growing world population.

1 INTRODUCTION

Spirulina Platensis is a single cell micro alga that belongs to the cianobacteria group. It has a blue-green colour and spiral shape and reproduces by intracellular rupture. Its length varies between 20 and 50 microns. Spirulina can survive at temperatures between 13° and $33^{\circ}C$ and at a pH between 8.5 and 10.5. This micro alga is 60% all-vegetable protein, rich in beta carotene, iron, vitamin B-12 and the rare essential fatty acid, GLA. It is considered the super food of the future (Henrikson, 1994), (Spirulina.com, 2004), (Jourdan, 2002).

In 2002 a sudden weather change destroyed the Spirulina culture in a pilot plant (raceway system) in Azapa Valley, Arica, Chile, by causing variations in density, salinity, pH and temperature. The classic automatic control in place could not manage the changes and the culture was lost. It was therefore necessary to design an intelligent control system able to adapt to adverse weather changes.

In Chilean modern water farms a complete system that controls Spirulina alga cultivation does not exist. The control system designed and presented here was based on a neuronal network. The variables are pH, temperature, salinity (electrical conductivity, directly related to the density of the solution) and population density. The independent variables of the system were entered. The exit of the network was forced with the evolution state of the culture in time. This procedure was repeated several times having changed the input variables (Hagan et al., 2002). Once the control system was in place, the neural network continued to learn and evolve.

2 THEORY

2.1 Neuronal Networks

Neural networks, inspired by biological nervous systems, are composed of simple elements that operate in parallel (Figure 1). As in nature, the network function is determined by the connections between elements. A neural network can be ”trained” to perform a particular function by adjusting the values of the connections between elements (Hunt et al., 2002). Thus neural networks can be trained to solve problems that are difficult for conventional computers or human beings. Moreover, they can incorporate the best techniques for pattern recognition and tendency analysis.

Ponce E., Ponce C. and Barraza B. (2008).
DESIGN OF NEURONAL NETWORK TO CONTROL SPIRULINA AQUACULTURE.
In *Proceedings of the Fifth International Conference on Informatics in Control, Automation and Robotics - ICSO*, pages 289-292
DOI: 10.5220/0001482002890292

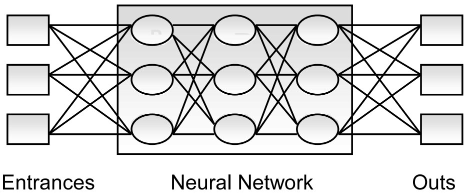

Figure 1: Basic model of a neuronal network.

For applications that demand networks with fewer than 100 neurons and little training, the software implementations are sufficient. When the problem requires over 100 neurons and 10000 synapses, is necessary to use hardware.

3 DEVELOPMENT

- Design of neuronal network
- Method
- Network training
- Operation

3.1 Design of the Neuronal Network

The variables of the system are:

- pH: This variable is very important because the alga survives within a range of pH between 8.5 and 10.5. pH can be measured with a pH meter. If the pH is low, then a valve connected with a little tank, is open to give a bicarbonate sodium solution. If it is high, another valve gives CO2 to a dome on the surface aquaculture.
- Temperature: Spirulina Platensis can tolerate temperatures between 13° to 33°C. If the temperature rises over the top limit a fan is connected and the windows open. If the temperature is low, the windows are closed (the aquaculture is in a greenhouse).
- Flow density: The density of the flow is directly related to salinity and conductivity. Thus, it can be controlled by the regulation of the doses of clean water, marine salt, nitrate and sodium bicarbonate supplied to the culture. The maximum and minimal density values are 1.05 and 1.20 g/cm^3
- Population density: When the Spirulina population reaches a maximum density, this may result in sudden death. The optimum time for collection (harvest) is therefore before maximum density is reached, at a density of 900 mg/l. Density was measured with a laser device (Ponce, 2001). At 800 mg/l a pump is connected and the harvest begins.

In order to train the neural network, the independent variables were measured and the dependent variable was forced to a desired value. During the training, time was used as an additional variable to distribute the learning into discrete cycles (Hagan and Demuth, 1999).

Independent variables:

- pH
- Temperature
- Flow density (salinity and electrical conductivity)

Dependent variable:

- Population density

After training, the system controlled 4 variables:

- pH
- Temperature
- Flow density (salinity and electrical conductivity).
- Population density

3.2 Method

It has 4 inputs (measured variables), and 4 outputs - 3 of which variables that must be controlled; the remaining output is for training the neural network. The best way to train a neuronal network is by means of variable forced learning (Gutiérrez et al., 2004). Training consists of producing successive cultures, each one under different constant conditions, maximum and minimum values. Training is completed when the learning margin error approaches zero. For a different condition the system will compute between the 2 extreme data. Offside these maximum and minimal data the control does not work.

The extreme conditions are: pH min= 8.5 ; pH max = 10.5
Temperature: min = 13°C; max = 33°C
Population density mg/l: min = 100; max = 800
Flow density g/cm^3 : min = 1.05 ; max = 1.20

The best control scheme for this problem is a NARMA2 network (Norvig and Russell, 2003), a neuronal controller that transforms nonlinear system dynamics into linear dynamics by canceling the nonlinearities during training. This optimizes the performance of the hardware. A linear system enables faster training and control in real time for microprocessors.

The control input is computed to force the plant output to follow a reference signal. The neural network plant model is trained with static back propagation and is reasonably fast. It requires minimal online computation (Rio and Molina, 2002).

The hardware has a 4*x*4 parallel pic processor array, with 4 inputs and 4 outputs. This array emulates 20 layers with 4 files, (80 neurons). This hardware is an experimental prototype.

In a NARMA2 structure, each neuron is simulated as:

$$u(k+1) = \frac{yr(k+d) - f[y(k),\dots,y(k-n+1),u(k),\dots,u(k-n+1)]}{g[y(k),\dots,y(k-n+1),u(k),\dots,u(k-n+1)]} \quad (1)$$

Where $y(n)$ is the system input, and $u(n)$ is the system output. The system function is a linear combination of $f(y(n-1),u(m-1))$ and $g(y(n-1),u(m-1))$. Each neuron can be simulated as shown in Figure 2:

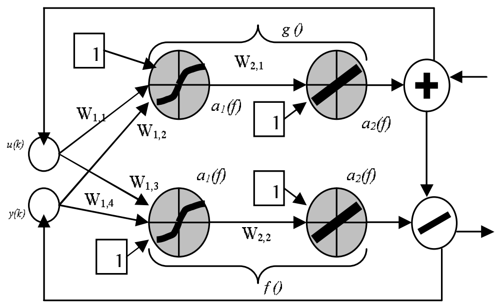

Figure 2: Neurons of NARMA2 model.

3.3 Network Training

The neural network was connected to the culture as shown in Figure 3. The training error is e_c. The inputs are y_r, and the exit variables are u.

Each line is equal to 7 lines. The controller with 80 neurons emulates the system as a linear combination of g and f (generated in the train).

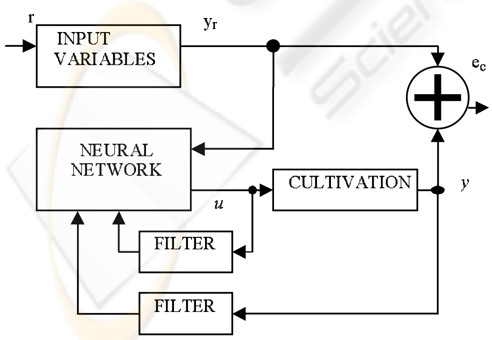

Figure 3: Connection of the Neural Network to the cultivation.

The training of the neural network is online, supervised and forced. It takes at least 6 weeks (6 cultivations in different conditions).

Employing 2x3 maximum and minimal values (2 by each parameter) a simulation with 3 set of variables was made in MATLAB.

Based on the variation of each input, the neural network built a linear model system. This enables each output to be related to the variation of all inputs. The training simulation is carried out with a forced reference. The dependent variable automatically adjusts the inputs and tries to follow the reference (Figure 4).

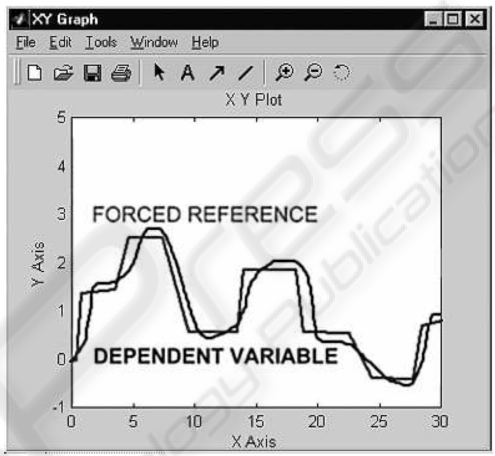

Figure 4: Simulation in MATLAB during the training stage.

Figure 5 shows the output 1 ($u1$) due to input 1 ($y1$), when the system is in operation.

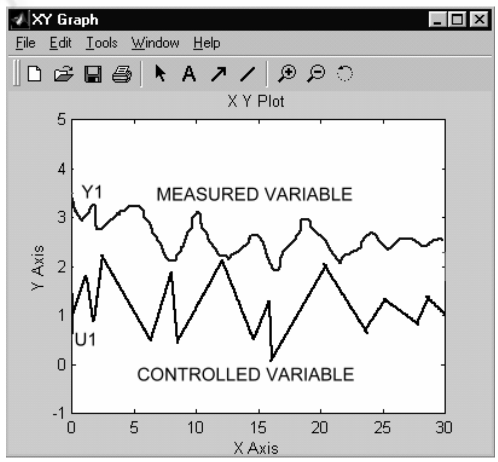

Figure 5: Simulation in MATLAB using 1 variable after training with 3 variable.

3.3.1 Operation

After training, the neural network has 3 inputs and 3 outputs. During the operation, the neural network learns new rules, it works as an expert controller.

4 CONCLUSIONS

When used to control a Spirulina alga aquaculture process, a classic automatic control system was unable to respond adequately to sudden climatic variations.

This neural network design presented here provides a good control alternative, one that is able to adapt to climatic changes and seasons, between maximum and minimal operation parameters (previously known) .

The neural network bestows a reliable, robust control system which can give a correct response to unknown situations. If part of the hardware is damaged, the information can be saved.

Furthermore, implementation is not expensive. The cost of building the prototype control system was approximately US $ 500 for a pilot plant race way system (Area= $3m^2$, volume = $0.5m^3$).

In the future it will be necessary to obtain more and more foods and fuels. The aquaculture is not an expensive solution and neither is the intelligent control proposed. A similar control system could be applied, with some changes, to another aquaculture focused to obtain fuel from glycerol (Dunaliella Salina) or petroleum (Botryococcus).

ACKNOWLEDGEMENTS

With acknowledgements to the Spirulina Control Process Project: DIPOG 8741-00, Tarapaca University (Chile) and Associate Professor Claus Brieba of the Arthur Prat University, without all of whom, this work would have been impossible.

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