Research on pH Value Control System of Haematococcus Pluvialis Algae Based on Fuzzy PID Algorithm

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Abstract. In recent years, inducing the production of astaxanthin by Haematococcus pluvialis, the application of extracting astaxanthin from it has become more and more widespread. The pH of the algae fluid has an important influence on the rate of accumulation of astaxanthin by Haematococcus pluvialis. However, the pH control system of Haematococcus pluvialis algae fluid has many shortcomings, such as non-linearity, time-varying, severe lag, large inertia and uncertain mathematical model. Therefore, to address these shortcomings, a method of pH control based on fuzzy PID is proposed. In the Matlab simulation software, using traditional PID control system adjust and control the pH value of Haematococcus pluvialis. And then using the fuzzy PID control system adjust and control the Haematococcus pluvialis. Finally, comparing the simulation results of the two systems. According to the Simulink results, we finally get the following conclusion: the fuzzy PID control system has smaller overshoot, no vibration, and the control effect is better.

1. Introduction
Haematococcus pluvialis belongs to single-cell freshwater microalgae, it will produce and accumulate a large amount of astaxanthin in worse living conditions. At present, the biological sources of natural astaxanthin are shrimp, crab and other aquatic product wastes, Phaffia rhodozyma and Haematococcus pluvialis. Among them, the cost of extracting astaxanthin from the wastes of shrimp, crab and other aquatic products is higher than extracting astaxanthin from Haematococcus pluvialis, and the content of astaxanthin is very low. Although natural Phaffia rhodozyma contains astaxanthin, the average content of astaxanthin is only 0.4%. Compared with these methods, Haematococcus pluvialis is recognized as the organism with the highest astaxanthin content in nature. In recent years, artificial cultivation of Haematococcus pluvialis extracting astaxanthin has been a research hotspot and has great application prospect. At present, only a few enterprises have mastered the technology of culturing Haematococcus pluvialis and extracting astaxanthin from it. Most of these companies are located in developed country. There are only a few people in China who know and use astaxanthin, and the development prospect is very broad. Astaxanthin belongs to ketone carotenoids, the chemical name is 3, 3'-dihydroxy - β, β' - carotene-4, 4' dione, relative molecular mass: 596.82. Astaxanthin is an unsaturated chemical, which has the effects of anti-oxidation, strengthening immunity, anti-aging and anti-aging. In addition, astaxanthin has anti-cancer activity. Showing from the experiments, the pH value of the living environment of Haematococcus pluvialis is one of the important environmental factors affecting the astaxanthin accumulation rate of Haematococcus pluvialis.
The pH value of Haematococcus pluvialis algae fluid does not have a fixed mathematical model, it has the characteristic of non-linear and time-varying. Therefore, we adopt fuzzy PID control technology to control the pH value of Haematococcus pluvialis algae fluid. Fuzzy PID control technology is an intelligent control technology. It can avoid the Mathematical model of pH value. Also we can process the worker’s operating experience, summarize the knowledge and extract the control rules from it. To achieve the ability to control the complex system. Contrasted with the traditional PID control technology, it reduces the system’s overshoot. The fuzzy PID control ameliorates the overall stability, robustness, adaptability of the system and the structure of it is simple and easy to realize [1].

2. The Concept of pH, the Development of pH Control Technology and the Selection of pH Values

In 1907, a Danish biochemist named Soren Peter lauritz Sorensen, first put forward the idea of pH. The pH value is the ratio of the total number of hydrogen ions in the solution to the amount of substance in the solution, also named hydrogen ion solubility index. It is a numerical expression of the acidity and alkalinity of the solution. In other words, it is the negative value of the common logarithm of the solubility of hydrogen ions, the expression is shown in equation (1):

\[
pH = -\log[H^+] = \log 10^{\text{solubility of } H^+}\tag{1}
\]

The pH hydrogen ion concentration index is generally between 0-14. When the pH of the solution is equal to 7, it is neutral. It is acidic when the pH is less than 7, the smaller the value, the stronger the acidity. When pH is greater than 7, it is alkaline, and the higher the value is, the more alkaline it is. So far, many practical applications still use traditional PID control method to control the pH value because it is simple and stable in operation. However, when the control process is nonlinear, complex and variable, the control quality is often difficult to achieve the best.

With the continuous development of advanced algorithms, the stable control of the pH value gradually uses fuzzy control, neural network, expert control and other algorithms.

The fuzzy PID algorithm selected in this research both have the strengths of fuzzy algorithm and traditional PID algorithm [2], it has better stability, robustness and adaptability. Studies by Zhang and Xiao pointed out that the pH should be controlled under alkaline conditions (pH = 7.75 ± 0.10) [3]. In this condition, the growth trend of algal cells is better. The inoculation density obtained under this pH environment is conducive to the production and accumulation of astaxanthin during the induction of Haematococcus pluvialis, it is expected to reduce the cost of industrial production of astaxanthin. Therefore, we select pH = 7.75 as the expected pH value of the simulation.

3. Fuzzy PID Control Strategy

3.1. Composition of Fuzzy System

The fuzzy PID control system of pH value is mainly composed of fuzzy controller, sensor, solenoid valve, pH value, etc. [4]. The quality of the fuzzy controller affects the overall function of the system, and it is the most important part of the entire system. It is related to whether the controlled object can obtain the best quality of control. The control ability of fuzzy controller is determined by the quality of control rules and membership function of controller structure variable [5].

3.2. Principle of Fuzzy PID Control

Fuzzy PID controller has the characteristics of both fuzzy controller and PID controller. Because it is combine by fuzzy controller and PID controller, it can adjust the corresponding parameters in time according to system changes. It can improve following ability and reaction time of the system, and is especially suitable for the time-varying and non-linear controlled objects [6].

The fuzzy controller input error \(e\) and error change rate \(\Delta e\) and outputting adjustment value \(\Delta K_p, \Delta K_i, \Delta K_d\) through pre-programmed control rules [7]. The adjustment value is multiplied by a certain scale factor and added to the starting value of the three control factors \(K_p, K_i, K_d\), then will get
new value of $K_p, K_i, K_d$. Continuously calculate $e$ and $\Delta e$ during the calculation process to meet the system control performance requirements. Figure 1 is the working process of the system:

**Figure 1.** Work Process of self-adjusting fuzzy control.

The setting equations of parameters $K_p, K_i, K_d$ are shown in equations (2)-(4):

$$K_p = K'_p + \Delta K_p$$  \hspace{1cm} (2)  

$$K_i = K'_i + \Delta K_i$$  \hspace{1cm} (3)  

$$K_d = K'_D + \Delta K_D$$  \hspace{1cm} (4)  

In the above equation, $K'_p, K'_i, K'_D$ is the preset value, and $\Delta K_p, \Delta K_i, \Delta K_D$ are the adjusted value of the proportional coefficient, the adjusted value of the integral coefficient and the adjusted value of the differential coefficient after being processed by fuzzy inference.

### 3.3. Design of Fuzzy PID Controller

Way of using fuzzy PID to control pH value takes pH value deviation $e$ and deviation change rate $\Delta e$ as two input factors, and $\Delta K_p, \Delta K_i, \Delta K_D$ as three output factors.

According to the requirements of pH value control accuracy, set the fuzzy subsets of input quantities $e, \Delta e$ and output quantities $\Delta K_p, \Delta K_i, \Delta K_D$ to {negative large, negative medium, negative small, zero, positive small, positive medium, positive large}, recording as {NB, NM, NS, ZO, PS, PM, PB} [8]. The domain of $e, \Delta e, \Delta K_p, \Delta K_i, \Delta K_D$ is set to [-1, 1]. The build of fuzzy rules is the most important part to the fuzzy controller, which directly determines the actual effect of the fuzzy controller. Referring to the condition of Haematococcus pluvialis, combined the working rules of pH control system and expert knowledge design control rules.

### 4. System Simulation and Analysis

In this research, a control model is build for the pH control system of Haematococcus pluvialis. Referring to the actual measurement data and work experience, the control model is represented by the first order inertia pure lag system, as shown in equation (5):
\[ G(s) = \frac{1.2e^{-3s}}{10.1s + 1} \]  

To compare the control effect of two control systems on *Haematococcus pluvialis* algae, this article uses Simulink simulation software in Matlab environment to build the simulation model of both, as shown in figure 2:

![Simulation model of traditional PID control and fuzzy PID control](image)

**Figure 2.** Simulation model of traditional PID control and fuzzy PID control.

Firstly, simulate the system, set the simulation time of 50s. Then apply a unit step signal to the system and apply an interference signal to the system at 25s. Figure 3 is the graph of the system after simulation:

![Response curves](image)

(a) Response curve of fuzzy PID pH control system after adding disturbance; (b) Response curve of traditional PID pH control system after adding disturbance.

**Figure 3.** (a) Response curve of fuzzy PID pH control system after adding disturbance; (b) Response curve of traditional PID pH control system after adding disturbance.

From the above two response curves of pH control system after adding disturbance, it can be seen that the fuzzy PID control system’s overshoot is more lower and the adjustment time is also shorter.
And the fuzzy PID control system eliminates shocking phenomenon. When the disturbance signal is added at 45s, the oscillation of fuzzy PID system is more stable.

It can be observed from figure 3 that the pH control system’s delay time is 3s. The target pH value is 7.75. The traditional PID control system’s rise time is 11s. And the adjustment time is 24s. The parameters of the fuzzy PID control system are as follows: it’s rise time is 9s and the adjustment time is 20s. Through simulation comparison, it can be concluded that the control process of the fuzzy PID control system is more steadier and reaches the preset value faster [9].

5. Conclusions

This research aiming at the control of the pH value of algae fluid during the induction of Haematococcus pluvialis, it has the characteristics of strong nonlinearity, large hysteresis, uncertainty and poor robustness. Adopting a fuzzy PID control strategy to control Haematococcus pluvialis’ pH value. Comparing the fuzzy PID control system with the traditional PID control system in the simulink draw the following summary:

In the experiment process, first apply the traditional PID controller to control the pH value process, although it can finally meet the requirements of stability control, a large overshoot will occur, the adjustment time and rise time are relatively long, and the dynamic function of the system is relatively poor. Moreover, when there are external factors affecting the system, it need more longer time to recover, and the effect is not ideal. It shows the traditional PID controller can not control the nonlinear complex system well, and it is hard to obtain the best control quality.

Using fuzzy PID controller to control the pH value of Haematococcus pluvialis algae fluid and experiment simulation with MATLAB simulation software. Comparing with the response curve of traditional PID control, simulation results of fuzzy PID control system have not produce overshoot, and the adjustment time and rise time are relatively short. When interfered by external conditions, the fuzzy PID control system can complete the adjustment in a shorter time.

Through theoretical analysis and simulation experiments. The feasibility of the fuzzy PID control strategy is proved to have a good control effect on the pH value of the algal solution of Haematococcus pluvialis. The control model in this paper is not the most accurate. To simplify the question, there are some assumptions. The control objects used in the simulation cannot fully cover the actual application situation.

Acknowledgments

Write here, near the end of this article. First of all, we want to sincerely thank the research platform provided by the laboratory, and thank the members of the laboratory for their help and suggestions in the process of writing this article. When writing this thesis, we have encountered many difficulties and obstacles. With their help, this article Can be successfully completed.

In the meantime, we sincerely gratitude the scholars’ treatises cited in this article. If we don’t have the afflatus and help of them, we will not be able to complete the final writing of this paper.

Last but not least, thank all those who care, help and support us, and express our gratitude to the experts and professors who use the time to examine this article during their busy schedule!

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