DESIGN AND EXPERIMENT OF ERIOCHEIR SINENSIS BREEDING MONITORING SYSTEM BASED ON VIRTUAL INSTRUMENT TECHNOLOGY
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基于虚拟仪器技术的中华绒螯蟹养殖监控系统设计与试验

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ABSTRACT

The measurement and control system of Eriocheir sinensis, the Chinese mitten crab, could increase its survival rate and quality effectively. Based on the analysis and design of the system, the parameter ranges for major factors of water quality during crab breeding process were determined. Sensors of pH, dissolved oxygen (DO), and temperature were used to detect the value of pH, DO, and temperature. LabVIEW, a virtual instrument technology, was used to monitor water quality parameters during crab breeding process, thereby controlling the relay of inlet valve, water valve and oxygen valve by comparing the actual figures with normal parameter. This technology was used to perform the adjustment of water quality parameters respectively to achieve automatic control. In order to test the performance of the system, the monitoring time, stocking density and planting density were taken as experiment factors, and the error rate of the monitoring index was taken as evaluation index. The verification experiment results show that pH, DO and temperature monitoring errors were less than 10%, under the maximum constraint conditions of experiment factors, which meet the design requirements.

摘要

采用中华绒螯蟹养殖测控系统可有效提高其成活率和品质。本文在研究一种培育中华绒螯蟹苗的实时监控系统的基础上，确定了中华绒螯蟹养殖过程中主要水质因素的参数范围。采用 pH 传感器、溶解氧(DO)传感器、温度传感器对这些水质参数进行检测。利用 LabVIEW 虚拟仪器技术对养殖过程中的水质参数进行监测，将实际数据与正常参数进行对比，控制进水阀、进水阀和氧气阀的继电器。利用该技术分别对水质参数进行调整，实现自动控制。为测试系统工作性能，以监测时间、放养密度和种植密度为试验因素，以监测指标的误差率为评价指标，采用三元二次回归正交旋转组合试验方法进行试验与响应面分析。验证试验得出，监测时间、放养密度、种植密度均保持约束最大条件下， pH、DO、温度监测误差均小于 10%，满足设计要求。

INTRODUCTION

The *Eriocheir sinensis* is the most important breed of river crab in northern China (*Bao et al*., *2022*; *Bashir et al*., *2022*). Outdoor soil pond ecological seedling raising method has replaced the previous indoor artificial seedling raising production technology and has been widely promoted and applied in production. The method is basically to simulate the state of natural reproduction of crab breeding. The crab seedlings cultivated in the outdoor soil pond have better stress resistance and disease resistance, higher survival rate and quality, and the cost greatly reduced simultaneously (*Hu et al*., *2016*).

Aquaculture organisms are closely related to the water environment in which they live. In the process of breeding, there are many parameters that affect water quality and interact with each other, mainly including dissolved oxygen, pH value, ammonia nitrogen, temperature, salinity, electrical conductivity, etc. (*Chen et al., 2022; Hong, 2020; Bao et al., 2018; Huang et al., 2013*). Through the control and adjustment of key parameters by automatic measurement and control system (*Rodríguez-Soto* et *al.*, *2019*), especially the use of virtual instrument technology like LabVIEW (*Zhang et al., 2021; Li et al., 2018; Stoica. et al., 2015*), the accuracy, adaptability and stability of system control are ensured, providing a better growth and living environment for breeding organisms. To some extent, the level of factory aquaculture industry has been improved.

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Europe and other developed countries began factory fish farming early. Countries around the world, like Ireland, Israel and Sweden, have designed the factory fish farming equipment (*Isabel et al., 2021; Naughton et al., 2020*). After years of development, automatic control technology has been rapidly developed in aquaculture industry, and is now in the stage of intelligent development of the monitoring system (*Sneha & Rakesh*, *2017*). The monitoring system adopts interdisciplinary technology to achieve precise control and regulation in the aspects of water disinfection, purification, pond bottom sewage discharge, aeration and temperature control (*Hwang et a*l., *2021*). China's factory agriculture started late and developed slowly, still being in the primary stage of factory farming. At present, manual sampling and chemical analysis are still the main methods for testing various parameters of crab seedling cultivation in China, which takes a long time and costs a lot of labour (*Cai et al.*, *2021*).

Based on the above background, this study developed an automatic control system with simple structure, low cost and real-time operation based on typical water quality parameters of Chinese mitten crab culture and virtual instrument technology. It is of great significance to provide accurate test data for production personnel, reduce breeding cost, improve breeding efficiency, save water resources and improve the level of factory breeding.

MATERIALS AND METHODS

Eriocheir sinensis breeding technical requirements

The breeding process of *Eriocheir sinensis* includes preparation of the crab larvae, detection and adjustment of water quality parameters, and feed preparation for different growth stages. Water quality parameters mainly include pH, dissolved oxygen, light, salinity, ammonia concentration. If the factors above can meet the need of crab metamorphosis requirements, it will be able to successfully complete the growth and development. Otherwise, it cannot normally grow and develop, even long stagnation and death can occur. The main water quality parameters and adjustment method in crab foster normal development process are shown in Table 1.

Table 1

Water quality parameters during *Eriocheir* sinensis breeding

Water Quality Parameter	Parameter Range	Adjustment Method
pH	8.2~8.6	By changing the water
Dissolved Oxygen	≧5mg/L~7mg/L	When the dissolved oxygen is less than the specified level, start the oxygen solenoid valve
Water Temperature	15~25℃	Electronic automatic heating device
Water Level	≧Present Water Level 10%	Start feed solenoid valve

Monitoring system components

The structural arrangement of the *Eriocheir sinensis* breeding monitoring system is shown in Figure 1. When the system runs up, the small crabs are put into the crab cultivation box, and then the inlet solenoid valve is opened. After that, the water drains will connect with the drainage pond through the outlet solenoid valve. After all electrical components are energized, enter the information such as crab growth stage in the monitoring interface of the computer system. Then click the “start” button to begin the work of the monitoring system. In each different period, the corresponding indicator will illuminate, indicating the corresponding period. In the system operation process, various sensors will collect their water quality parameters, such as pH sensor, dissolved oxygen sensor, water temperature sensor, and water level sensors.

After analogy-to-digital conversion through data acquisition card, the data electrical signal is converted into digital signal for the computer to receive and process. The water quality parameter information is displayed in a virtual instrument interface and is prepared for data storage. According to the decision of computer data, the driver makes corresponding actions to the inlet solenoid valve, the outlet solenoid valve and the oxygen pump, in order to realize the operation of drainage output, inlet water input and oxygenation according to the real time needs. The various parameters meet the requirements within the range by controlling the water quality in the crab training stage.

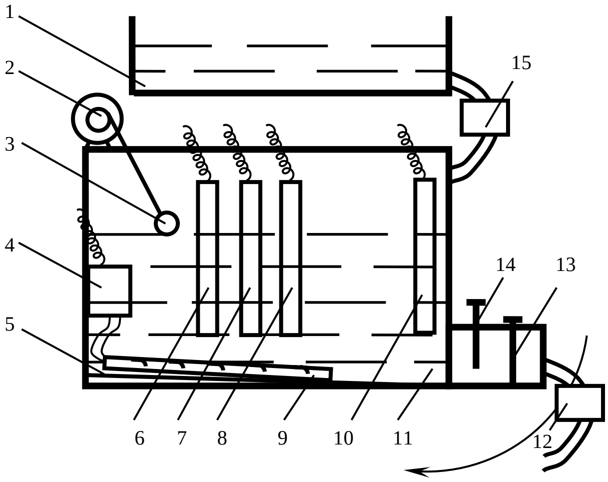
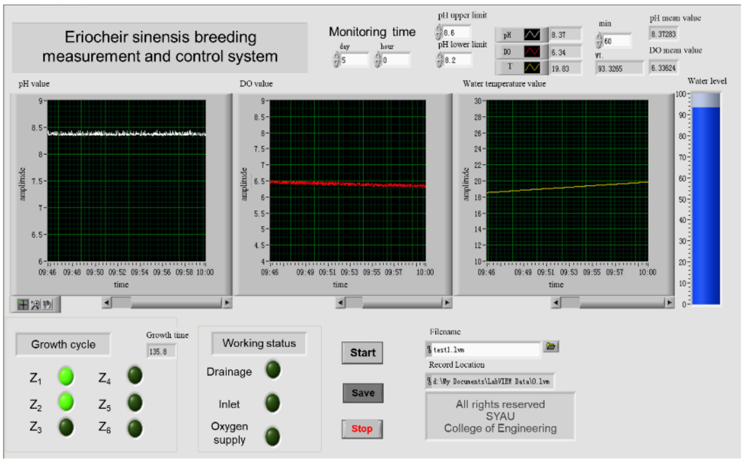


Fig. 1 - *Eriocheir sinensis* breeding monitoring system structural representation

1- Storage Tank; 2- Resistance; 3- Float; 4- Oxygen Pump; 5- Floor; 6-pH Sensor; 7-DO Sensor; 8- Temperature Sensor; 9- Bubble Stone; 10- Temperature Heater; 11- Crab Cultivation Box; 12- Outlet Solenoid Valve; 13- Effluent; 14- Effluent Baffle; 15- Inlet Solenoid Valve

This study uses LabVIEW (Laboratory Virtual Instrument Engineering Workbench) for development of the monitoring system. The system interface is shown in Figure 2. The interface includes crab growth cycle input window, system working status display, and statistical analysis of pH, *DO*, water temperature and other detection data.



Monitoring time day 5 hour 0

pH upper limit 8.6

pH lower limit 8.2

pH 8.37

DO 6.34

T 19.83

min 60

wl 93.3265

pH mean value 8.37283

DO mean value 6.33624

Growth time 135.8

Filename test1.lvm

Record Location d:\My Documents\LabVIEW Data\0.lvm

Fig. 2 - *Eriocheir sinensis* breeding monitoring system interface figure

Design of crab cultivation monitoring system

Hardware configuration of monitoring system

Eriocheir sinensis breeding monitoring system consists of a computer as a master unit, monitor and control data display and output based on the software of LabVIEW version, including data signal input module, data display module and execution module.

The input device includes PHB-300A type pH sensor for detecting water pH value, DOB-300A type dissolved oxygen sensor for detecting water oxygen value, LM35DZ temperature sensor for detecting water temperature, water level value and angular displacement sensor with self-made float for measuring water level. The actuator comprises the strip bubble stone and the SB-748 model 8W double hole oxygenation pump for oxygenation, the normally closed AC220V solenoid valve and S212S02 solid state relay for inlet and drainage, and the 358 100W automatic heating rod for heating. The data acquisition module adopts USB-6009 14-bit multifunctional data acquisition card (NI Company, United States). The data acquisition card performs analogy-to-digital conversion, sampling and retention, multiplexing and amplification of the voltage signals detected and output by each sensor in this system, which are input to the computer and displayed in real time on the virtual instrument interface.

Working principle of monitoring system

Taking pH monitoring as an example, the working principle of *Eriocheir sinensis* breeding monitoring system is shown figure 3. According to the upper and lower pH values in the water quality requirements set by the monitoring system, the output difference of the value ∆p obtained by the pH sensor through analogy-to-digital conversion is compared and displayed on the computer. In the meanwhile, digital-to-analogue conversion is carried out on the collected data to generate high level signal, driving the drainage relay to control the opening of the drainage solenoid valve, and discharge the waste water in the breeding stage. With the waste water discharge, the sensor begins to detect the water level through the water height. When the water level drops below the 10% of the required level, the drain relay will close and input water relay will start to work to introduce fresh water into the crab stage. While the automatic control system has completed its work, in the same time, it can achieve data acquisition, storage, comparison and analysis. Other parameters' (water, dissolved oxygen) working principle is the same as that of the pH monitoring.

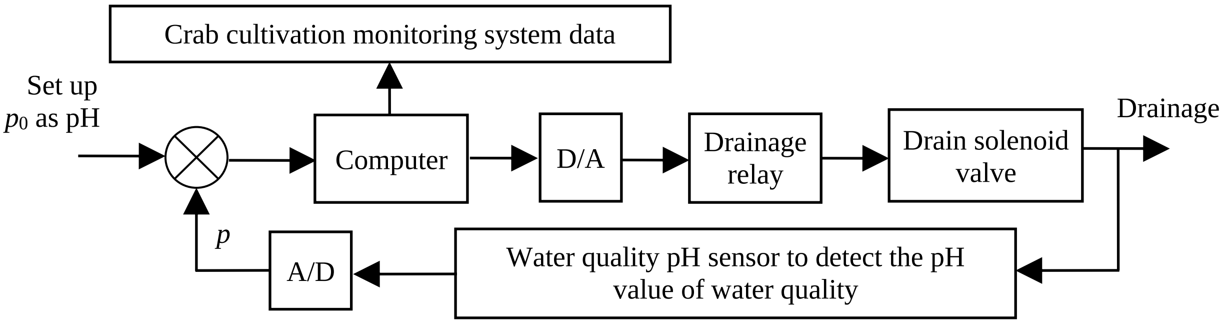


Fig. 3 - Working principle of automatic control system for crab larvae culture

Main program of monitoring system

The main program is a program framework, controls the operational of the monitoring system in a predetermined operation mode, as shown in Figure 4.

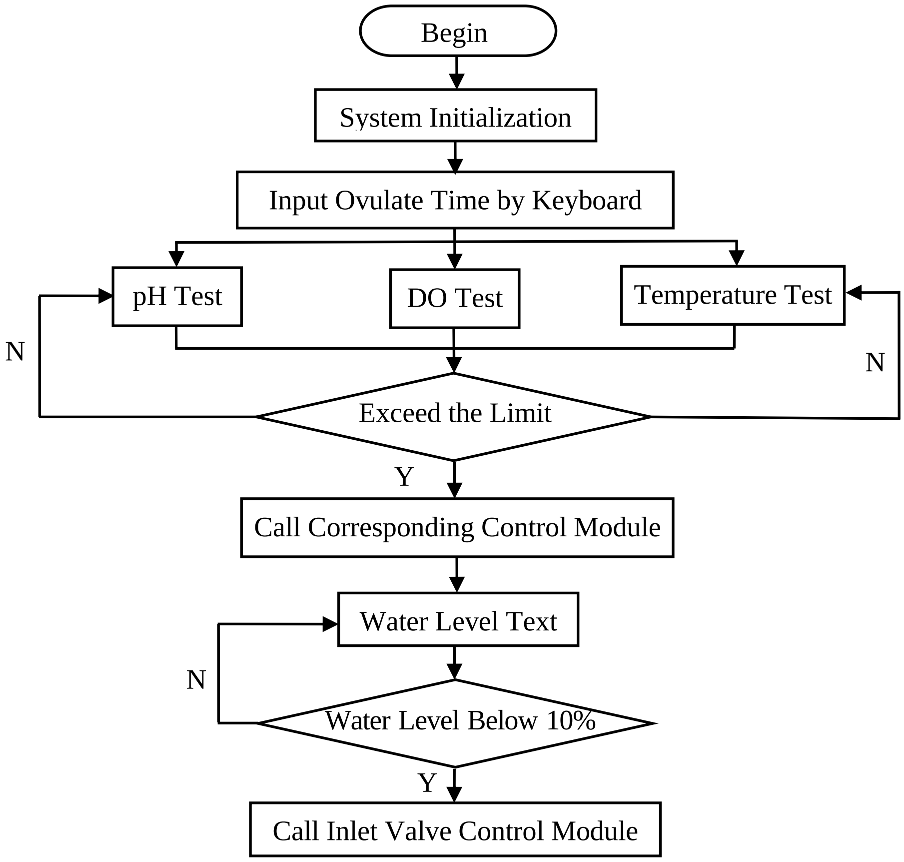


Fig. 4 - Main program

The main program includes the system initial water quality parameter setting and debugging program. After completing the system initialization, the routine will be mobilized in order to achieve to set parameter, data acquisition, data display, relay and solenoid valve control. The system carries out real-time monitoring and comparison of pH, DO and water temperature, controls the work of drainage valve, inlet valve, oxygen pump and heating element. It also monitors, compares and controls the water level in the meantime.

Monitoring system module program

The development of the *Eriocheir sinensis* breeding monitoring system uses modular design, according to the monitoring and controlling system functions. The system is divided into several independent easy-to-solve modules, each module is completed and relatively independent. It can be able to complete the required tasks and achieve specific functions. This design consists of one main program and four blocks. The main models are detection module and display module, which are working for the water quality parameters values (pH, dissolved oxygen, water temperature, and water level). Display module shows the crabs status in each period. The control module mainly controls the operation of inlet valve, drainage output valve, oxygenating pump and heating element.

Experiment design

The experiment was conducted in a rice-crab co-cropping field in *Jinguangzi* Village, *Xinxing* Town, *Dawa* County, *Panjin* City, *Liaoning* Province, China. The rice variety in the experiment was *Yanfeng*-47, and the crab seedlings used in the experiment were cultivated by *Panjin Guanghe* Aquatic Products Co., LTD. The experiment site was shown in Figure 5, and the experiment area in the site was divided into equal parts by using protective facilities.

Fig. 5 - The experiment area

The hardware of the experiment monitoring system includes E-201-C composite electrode for pH sensor, DO-957 electrode for dissolved oxygen sensor and T-818-B-6 electrode for temperature sensor. The manual testing equipment includes PHS-25 digital pH meter (Shanghai Lida Instrument Factory), JPB-607 portable dissolved oxygen tester (Shanghai Weiye Instrument Factory), FLA5016W multi-channel temperature tester (Shenzhen Tuopurai Electronics Co., LTD.), etc. The experiment selects the monitoring error rate of each project as experiment indicators, which was calculated according to equations (1) to (3).

$$Y_{pH}=\left|\frac{X_{pH}-X'_{pH}}{X_{pH}}\right|\times 100\% \tag{1}$$

$$Y_{DO}=\left|\frac{X_{DO}-X'_{DO}}{X_{DO}}\right|\times 100\% \tag{2}$$

$$Y_{T}=\left|\frac{X_{T}-X'_{T}}{X_{T}}\right|\times 100\% \tag{3}$$

where: Y_{pH} is the error rate of pH, %; Y_{DO} is the error rate of dissolved oxygen content, %; Y_T is the error rate of water temperature, %; X is the system detected value; X' is the manually detected value.

The experiment selected the monitoring time, released density and planting density as the experiment factors, which means the days of monitoring, breeding density of *Eriocheir sinensis* per experimental area unit, and transplanting density of rice per experimental area unit, respectively (*Wang et al*., *2022*; *Xu et al*., *2018*). The ternary quadratic regression orthogonal rotation combination experiment was carried out. According to the analysis of relevant literature and the system design, the value range of each factor and the experiment factor levels were shown in Table 2.

Table 2

Factors and levels of combination experiment

Levels	Factors		
	Monitoring time	Released density	Planting density
	[d]	[kg/hm^2]	[cm^2/seedling]
	x_1	x_2	x_3
1.682	13.00	120.00	600.00
1	10.97（11.00）	101.75 (102.00)	539.18（540.00）
0	8.00	75.00	450.00
-1	5.03（5.00）	48.25（48.00）	360.82（360.00）
-1.682	3.00	30.00	300.00
$\triangle j$	2.97（3.00）	26.75（27.00）	89.18（90.00）

Note: The parameters in parentheses were the parameters taken in the experiment. The calculation results were adjusted according to the feasibility of actual operation, and the values in parentheses were taken.

RESULTS

Experiment results and analysis

A total of 23 groups of experiments were considered, and each group was repeated three times. The results were taken as the average value. The experiment scheme design and results were shown in Table 3.

Table 3

Experimental plan and results

No.	Monitoring time	Released density	Planting density	Y_{pH}	Y_{DO}	Y_T
	[d]	[kg/hm^2]	[cm^2/seedling]	[%]	[%]	[%]
1	-1	-1	-1	4.05	3.87	9.55
2	1	-1	-1	5.96	5.19	9.11
3	-1	1	-1	8.63	7.57	11.03
4	1	1	-1	9.60	11.55	8.14
5	-1	-1	1	4.99	7.04	10.01
6	1	-1	1	9.55	6.18	8.47
7	-1	1	1	10.30	10.40	10.34
8	1	1	1	9.86	11.04	2.48
9	-1.682	0	0	8.13	6.08	11.13
10	1.682	0	0	10.62	6.80	4.59
11	0	-1.682	0	5.96	6.23	10.83
12	0	1.682	0	10.65	10.95	5.96
13	0	0	-1.682	7.10	6.77	10.11
14	0	0	1.682	10.98	9.80	6.35
15	0	0	0	7.61	8.02	9.61
16	0	0	0	9.23	8.79	9.64
17	0	0	0	8.06	8.24	7.89
18	0	0	0	8.89	8.04	6.93
19	0	0	0	8.77	8.03	7.72
20	0	0	0	7.91	8.72	8.07
21	0	0	0	9.02	8.26	8.46
22	0	0	0	8.63	9.42	8.85
23	0	0	0	8.07	8.21	7.11

The quadratic polynomial regression models between the monitoring time (x_1), released density (x_2) and planting density (x_3), error rate of pH (Y_{pH}), error rate of dissolved oxygen content (Y_{DO}) and error rate of water temperature (Y_T) were established. Significance test and analysis of variance were performed on the obtained ternary quadratic regression equation, and the results were shown in Table 4.

The correlation coefficient R_{pH}=0.92, R_{DO}=0.94, R_T=0.88, the regression equation significance level F_{RpH}=17.45, F_{RDO}=21.33, F_{RT}=9.44, the lack of fit test F_{LfpH}=1.30, F_{LfDO}=3.03, F_{LfT}=1.15, P_{pH}=0.3529, P_{DO}=0.079, P_T=0.409 were all greater than 0.05 and the difference was not significant, indicating that the regression equations Y_{pH}, Y_{DO} and Y_T had statistically significant. The optimized regression equation after excluding insignificant terms such as x_1x_3 and x_2x_3 of Y_{pH}, x_1x_2, x_1x_3 and x_1x_1 of Y_{DO}, and x_1x_2 and x_2x_3 of Y_T at the significance level of P=0.05 was:

$$Y_{pH}=-19.397+0.681x_1+0.255x_2+0.446x_3-0.018x_1x_3-0.004x_2x_3 \tag{4}$$

$$Y_{DO}=-15.899+2.054x_1+0.005x_2+0.398x_3+0.007x_1x_2-0.026x_1x_3-0.076x_1^2 \tag{5}$$

$$Y_T=-5.856+1.805x_1+0.188x_2+0.262x_3-0.014x_1x_2-0.003x_2x_3 \tag{6}$$

It can be seen from Table 4 that the monitoring time had significant effects on the error rate of pH and the error rate of dissolved oxygen content ($P<0.05$), and had an extremely significant effect on the error rate of water temperature ($P<0.01$); the released density and planting density had extremely significant effects on the error rate of pH, error rate of dissolved oxygen content and error rate of water temperature ($P<0.01$); the interaction of monitoring time and released density had a significant effect on the error rate of dissolved oxygen content ($P<0.05$), and had an extremely significant effect on the error rate of water temperature ($P<0.01$); the interaction of monitoring time and planting density had a significant effect on the error rate of pH ($P<0.05$), and had an extremely significant effect on the error rate of dissolved oxygen content ($P<0.01$); the interaction of released density and planting density had extremely significant impact on the error rate of pH ($P<0.01$), and significant impact on the error rate of water temperature ($P<0.05$) .

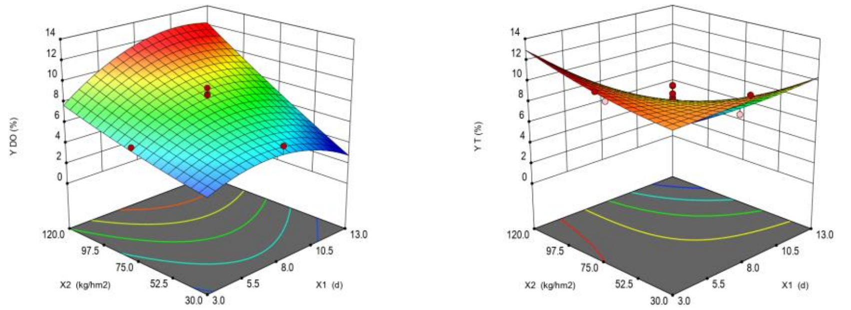
Table 4

Data significance test and analysis of variance

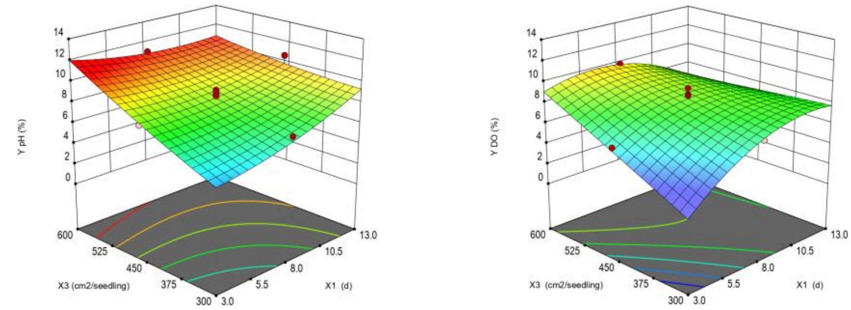
Source of variation	**Error rate of pH Y_{pH}**				**Error rate of dissolved oxygen content Y_{DO}**				**Error rate of water temperature Y_T**			
	SS	**DF**	***F value***	***P value***	**SS**	**DF**	***F value***	***P value***	**SS**	**DF**	***F value***	***P value***
Model	55.77	9	17.45	<0.0001**	76.79	9	21.33	<0.0001**	85.9	9	9.44	0.0002**
x_1	2.81	1	7.92	0.0146*	2.91	1	7.27	0.0183	41.27	1	40.81	<0.0001**
x_2	22.7	1	63.93	<0.0001**	50.36	1	125.9	<0.0001**	13.02	1	12.87	0.0033**
x_3	21.44	1	60.36	<0.0001**	9.81	1	24.52	0.0003**	12.1	1	11.97	0.0042**
x_1x_2	0.1094	1	0.3081	0.5883	2.16	1	5.4	0.0370*	9.61	1	9.51	0.0087**
x_1x_3	1.75	1	4.94	0.0446*	3.81	1	9.52	0.0087**	4.6	1	4.55	0.0526
x_2x_3	5.66	1	15.94	0.0015**	0.4256	1	1.06	0.3211	4.78	1	4.73	0.0487*
x_1x_1	0.6893	1	1.94	0.1869	7.19	1	17.98	0.0010**	0.0236	1	0.0233	0.8810
x_2x_2	0.4695	1	1.32	0.2709	0.1181	1	0.2952	0.5961	0.357	1	0.353	0.5626
x_3x_3	0.1253	1	0.3528	0.5627	0.0063	1	0.0158	0.9017	0.1337	1	0.1322	0.7220
Remaining	4.62	13			5.2	13			13.15	13		
Lack of Fit	2.07	5	1.3	0.3529	3.4	5	3.03	0.0792	5.49	5	1.15	0.4094
Pure Error	2.55	8			1.8	8			7.65	8		
Sum	60.39	22			81.99	22			99.04	22		

Analysis of influencing factors

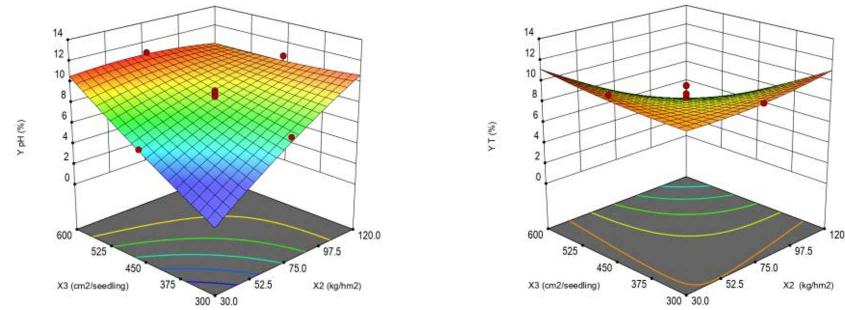
The calculation results of the response surface of each experiment factor and its interaction on the experiment index were shown in Fig 6.



a. The effect of the interaction between the monitoring time and released density on the error rate of dissolved oxygen content (left) and the error rate of water temperature (right)



b. The effect of the interaction between monitoring time and planting density on error rate of pH (left) and error rate of dissolved oxygen content (right)



b. The effect of the interaction between released density and planting density on error rate of pH (left) and error rate of water temperature (right)

Fig. 6 - Response surface analysis of the factors' interaction effect on the index

It can be seen that the primary and secondary order of the influence of each experiment factor on the error rate of pH and dissolved oxygen content was released density> planting density> monitoring time, and the primary and secondary order of the influence of each experiment factor on the error rate of water temperature was monitoring time> released density> planting density.

Figure 6a showed the response surface diagram of the influence of the interaction between the monitoring time and released density on the error rate of DO and water temperature, when the planting density was 0 level. It showed that when the monitoring time was constant and the released density gradually increased within the experiment range, the error rate of DO gradually increased, and the error rate of water temperature increased when the monitoring time was at low level, and decreased when the monitoring time was at high level. When the released density was constant and the monitoring time gradually increased within the experiment range, the error rate of DO first increased and then decreased when close to the boundary value, and the error rate of water temperature gradually decreased. The peaks of the error rate of DO and the error rate of water temperature both appeared at the high level within the experiment range of released density, and at the high level and low level within the experiment range of monitoring time, respectively.

Figure 6b showed the response surface diagram of the influence of the interaction between the monitoring time and planting density on the error rate of pH and DO, when the released density was 0 level. It showed that when the monitoring time was constant and the planting density gradually increased within the experiment range, the error rate of pH gradually increased, and the error rate of DO increased when the monitoring time was at low level, and decreased when the monitoring time was at high level. When the planting density was constant and the monitoring time gradually increased within the experiment range, the error rate of pH increased when the planting density was at low level, and decreased when the planting density was at high level, while the error rate of DO increased when the planting density was at low level and first increased and then decreased when the planting density was at high level. The peaks of the error rate of pH and the error rate of DO both appeared at the high level within the experiment range of planting density, within the experiment range of monitoring time.

Figure 6c showed the response surface diagram of the influence of the interaction between the released density and planting density on the error rate of pH and water temperature, when the monitoring time was 0 level. It showed that when the released density was constant and the planting density gradually increased within the experiment range, the error rate of pH gradually increased, and the error rate of water temperature decreased, which was the same as when the planting density was constant and the released density gradually increased within the experiment range.

The peaks of the error rate of pH appeared at the high level within the experiment range of released density and planting density, respectively. Within the experiment range, the peaks of the error rate of water temperature appeared when the planting density at the high level and the released density at the low level, as well as the planting density at the low level and the released density at the high level.

Parameter optimization and verification test

Set the experiment indicators to the minimize, and the factors parameter to the maximize within the experiment range to obtain the optimal parameter combination of the *Eriocheir sinensis* aquaculture monitoring system: the monitoring time was 13 d, the released density was 69.32 kg/hm^2, and the planting density was 505.23 cm^2/seedling, the overall operation effect being the best. The predicted error rate of pH, DO and water temperature were 10.02%, 6.52% and 4.58%, respectively.

In order to further verify the reliability and applicability of the mathematical model, the optimization results were tested and verified under the same experiment conditions. Considering the operability of the test, two optimization results were adjusted as follows: the released density was 70 kg/hm^2, and the planting density was 510 cm^2/seedling. The average values within three repeated tests for the test values of error rates of pH, DO and water temperature were 9.62%, 6.72% and 5.03% respectively, which were close to the predicted values of the model. The relative error between the actual and predicted values didn't exceed 0.5%, indicating that the established model and analysis results were valid.

CONCLUSIONS

In this paper, the error rates of pH, DO and water temperature were used as the evaluation indicators of the monitoring effect of the virtual instrument technology *Eriocheir sinensis* breeding monitoring system. And the influence of the monitoring time, released density, and planting density under the field experiment condition was studied. A response surface model was established, and the system's monitoring performance was verified through experiments, with the following conclusions:

1) Based on the virtual instrument technology, this study selected appropriate sensors according to the parameters of water quality factors to realize real-time detection, display and storage of monitoring data. Through the data analysis and processing of the *Eriocheir sinensis* breeding monitoring system, the oxygen pump, water flow solenoid valve and heating device were driven to realize timely aeration, water change and temperature control, respectively.

2) Through the ternary quadratic regression orthogonal rotation combination experiment, the monitor performance and verification tests were carried out, and the regression equation between the impression factors and the indexes was established and optimized. The influence of the factors and their interaction on the monitoring performance and laws were analysed too. The best monitoring extent of the system were: the monitoring time 13 d, the released density 70 kg/hm^2, and the planting density 510 cm^2/seedling (30cm×17cm), upon which the error rates of pH, DO and water temperature were the minimum, when the accuracy of measurement was higher than 90%.

This study only conducted related research on the monitoring performance of *Eriocheir Sinensis* under the outside breeding experimental conditions. In the later stage, it is necessary to add different water quality parameters and apply multi-sensor fusion technology to carry out in-depth research to improve the applicability and reliability of the system.

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