A Micro-Computer Control and Monitoring Strategy Applied to Aquaculture, K. A. Rusch, and R. F. Malone, Techniques for Modern Aquaculture, pp. 53-60 In Proceedings of an Aquacultural Engineering Conference, Spokane, Washington, June 21-23, 1993.

A MICRO-COMPUTER CONTROL AND MONITORING STRATEGY APPLIED TO AQUACULTURE

K. A. Rusch and R. F. Malone[1]

ABSTRACT

With the aquaculture industry moving in the direction of intensive culture, management practices will become crucial. To address this issue, a micro-computer control and monitoring algorithm was developed as a management tool for aquaculture systems. The algorithm, incorporated into the Turbo Pascal 4.0 software program, "Supervisor", contains three core elements: (1) a "stack" or chronologically ordered array of commands and associated execution times, (2) a "stack sorter" that positions the commands within the "stack" according to execution time and (3) a "supervisor" that continuously polls the time of the top command and the internal clock. The integration of these elements creates a control environment that circumvents temporal conflicts from simultaneous or nearly simultaneous processes within a system. This control and monitoring approach has been incorporated in several research projects within the Civil Engineering Aquatic Systems Laboratories (CEASL). Extensive use of this management approach by the authors has lead to increased operational efficiency and reduced costs through a dramatic decrease in labor and the complimentary control and monitoring capabilities. "Supervisor" is presently most suited for research activities and smaller, customized facilities where frequent programming adjustments are desired or needed. Presented in this paper is a brief description of the control and monitoring algorithm, the hardware components used to implement this program, a discussion of the capabilities and reliabilities of the control system and an indication of relative cost of this technology.

Keywords: computer control, aquaculture, monitoring, automation

INTRODUCTION

As system complexity and demands increase with system expansion and sophistication, automated systems based on timers may not accommodate the level of control required. Development of cost-effective, high production aquaculture systems may require the utilization of computer based control and monitoring systems to reduce labor and accommodate all routine processes. Generally speaking, scientifically based management of aquaculture systems will require precise control of a variety of parameters affecting operational success including temperature, pH, lighting conditions, dissolved oxygen, production levels, harvest rates, etc. Additionally, inexpensive monitoring data will be required to provide a database for decision making processes.

---

[1]K. A. Rusch, Assistant Professor - Research and R. F. Malone, Associate Professor, Department of Civil Engineering, Louisiana State University, Baton Rouge, Louisiana 70803-6405

The move from an industry based largely on extensive culture to one utilizing computerized, intensive systems has been inhibited by the slow development of aquaculturally oriented software. Yet, both the electronics and programming required for implementing a basic control and monitoring program are basic compared to state-of-the-art in parallel industries including wastewater treatment and chemical operations (Briggs, 1990; Berg, 1991; Hughson, 1991; Stover and Campana, 1991). One of the key features of a control system is flexibility. Aquaculture systems are computerized to: (1) execute routine operational processes, (2) optimize production levels, (3) monitor and maintain water quality, (4) control cost of operations, (5) warn operators of oncoming system failure and (6) modify operational procedures based on feedback information. Although interest is often focused on a specific area, the complex interactions that occur in most aquaculture systems normally dictate management of all these objective areas simultaneously. Subsequently, control systems must be carefully designed and loosely configured to permit the use of data from a variety of inputs and to provide control through a series of devices.

This paper presents a programming approach that has been developed and implemented with success in the authors' laboratories. The ease of programming and low cost of support hardware has enhanced the testing and documentation of various aquaculture systems. The programming approach provides researchers and small scale commercial adventures, with customized needs, a long term cost-effective means of system management.

CONTROL AND MONITORING SYSTEM

Software

Of the few automated systems reported in literature, the majority employ a series of timers that activate valves and pumps to effectuate various processes (Munson, 1970; Sorgeloos et al., 1976; James et al., 1988). Although this technique may suffice for simple, straightforward applications, complex systems containing processes that must be executed simultaneously or rely on any level of feedback will fail. Subsequently, the development of a micro-computer control and monitoring system must: (1) address and circumvent temporal conflicts caused by simultaneous processes, (2) provide for information between the software and sensors, with automatic adjustments in routine processes, (3) reduce long term operational costs over present methods through the minimization of labor and (4) provide for the rapid collection and storage of information obtained from the system.

Temporal requirements for many aquaculture systems are not particularly demanding; not many operations require timing resolution less than one second. Thus, control programs based on simple serial execution of operations are intuitively apparent (Fig. 1). Programs written in this format execute commands one after the other; however, they do not facilitate the overlapping temporal demands of several simultaneously occurring operations. This inherent structural weakness in serially based programs becomes increasingly difficult to deal with as the complexity of system operations increases. Simultaneous or nearly simultaneous operations not executable by serial algorithms may be addressed by a software program containing a central supervisor that manages the potentially conflicting demands of a multitude of operations (Fig. 2). The control and monitoring algorithm developed by the CEASL group contains three core elements used to sort and execute all processes required for the daily operation of any aquaculture system. Central to the three core elements is a chronologically ordered array of commands and execution times, the "stack". The "stack" is loaded by the "stack sorter" which employs a variation of a bubble sort routine (Miller, 1981; Zaks, 1986) to position commands chronologically within the "stack", to add delayed commands and to reload the just executed command for the next cycle. The "supervisor" procedure continuously polls the execution time of the top

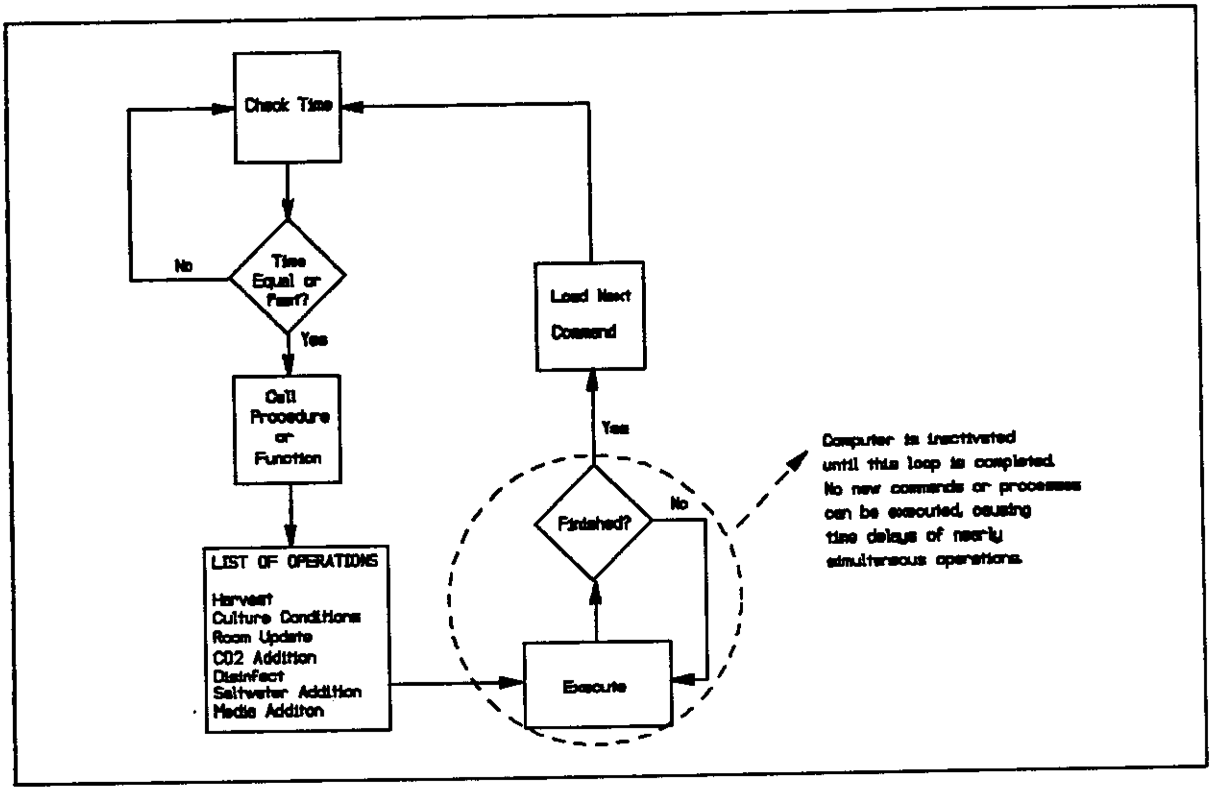

Figure 1. Control and Monitoring Algorithms Employing Serial Execution of Operations may Lead to Temporal Conflicts.

command against the current time and calls the procedures associated with the command at the appropriate time.

The control system is actually driven be the commands themselves, since the "supervisor" procedure can only execute commands loaded to the "stack". Each command is configured to: (1) execute instantaneous operations, (2) load delayed commands to the "stack" and/or (3) reload itself for the next cycle. Thus, the "supervisor's" control is relinquished only momentarily as a command is executed. The timing resolution of the "supervisor" is limited to a few hundredths of a second by the analog/digital conversion process required for control or monitoring of external sensors. Therefore, commands are executed at almost the same precise time everyday. Furthermore, future commands can be loaded by the user at the initiation of the program and executed at the appropriate time. Temporal conflicts are avoided by splitting processes into a command and a delayed command, with the latter being loaded by the former. Thus, in the case of simultaneous requests, the execution error is limited to the execution time of one command, and not the entire operational process.

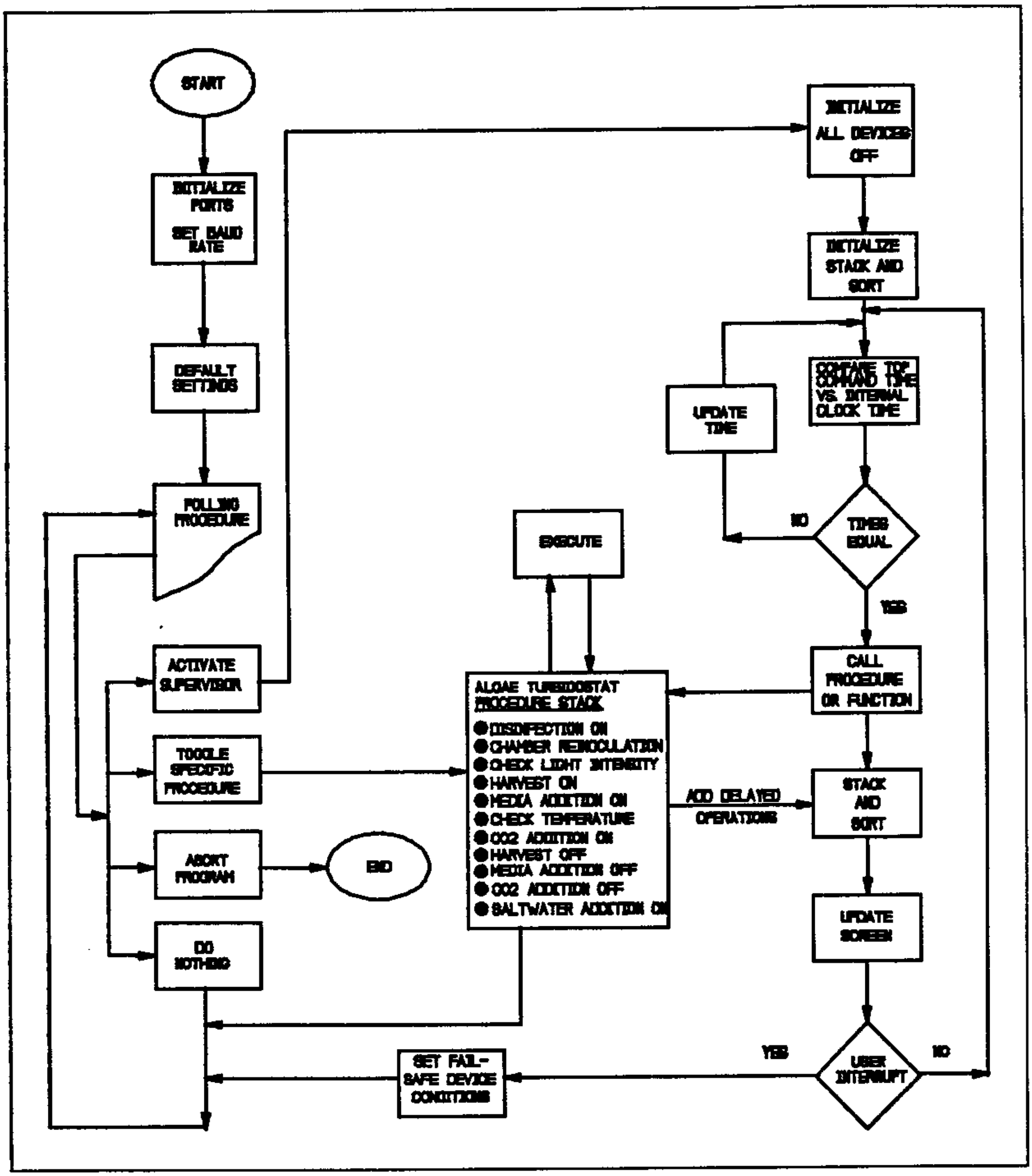

Figure 2. Control and Monitoring Algorithms Employing a Centralized Chronological Array of Operations Mitigates Temporal Conflicts. Illustrated is the Flow Chart Diagram of "Supervisor" for the Control of the Algal Turbidostat.

Operations are related to one another only through the "stack" or through checks of system conditions and programming flags. This creates an extremely friendly programming environment, facilitating the addition of new operational algorithms without increasing the complexity of the program. The core of the program is generic, permitting the application of this control strategy to a variety of projects including: (1) the complete control of an algal turbidostat for feed production (Rusch, 1992), (2) the continuous monitoring of crawfish activity within an automated soft-shell separation system (Robin, 1992; Rondelle, 1992; Chen et al., in press), (3) the execution of temperature controlled ablation studies performed on crawfish and (4) the control and evaluation of recirculating systems (Malone et al., 1986).

The core control and monitoring elements have been integrated into the menu-driven, Turbo Pascal 4.0 (Borland International, 1987) software program, "Supervisor", providing an interactive environment for the operator. The computer program, in addition to providing a level of system management not easily achievable under manual operation, allows for high frequency data collection and storage and furnishes warning messages pertaining to ensuing system anomalies.

Hardware

The computer control system used in the authors' laboratories consists of a micro-computer, an interface device and input and output devices (Fig. 3). The control point for all system components is a Zenith Supersport laptop micro-computer (Zenith Data Systems, Inc.). Irrespective of type, computers only understand digital information (binary code). Therefore, central to the control system is the analog/digital (A/D) converter, ADC-1-B+12 (Remote Measurement Systems, Inc.), facilitating communication between the computer and the input and output devices through the computer's serial port. The A/D converter provides for the conversion of analog signals (continuous voltage) produced by the input devices to digital code. Conversely, the converter also functions as a control device, facilitating the conversion of digital signals from the computer into electronic pulses that implement control actions. Control of output devices is accomplished by an intermediate electronic relay that uses low voltage output signals from the converter to activate the desired output device.

The A/D converter contains 16 analog input channels, 4 digital input channels and 12 controlled output channels. The converter provides for an analog channel sampling frequency of 10-20 readings per second, allowing nearly simultaneous execution of commands. The analog channels have an input voltage of ±0.4095 volts. Most sensors and probes work within this range; however, for those which do not, voltage dividers made from two resistors may be connected to the input channels in question or signal conditioning components may be installed between the sensor and the converter to modify the electronic signal produced by the input device to fall within the range of the interface unit. If the majority of the probes have outputs outside the standard voltage range, an internal circuitry modification may be made.

While the input channels receive information that is converted and transmitted to the computer for decision making processes, the controlled outputs activate external 'on/off' devices either in response to incoming information or as a part of a predetermined routine command contained within the "stack". Output devices are actuated by an intermediate switch, a 10 amp solid state electronic relay.

If the number of input and output devices exceeds the capacity of one A/D converter, a multiport controller (Bay Technical Associates, Inc.) can be used as an interface between the computer and up to four A/D converters. Communication between the computer and a particular A/D unit is easily performed automatically through the software. With this type of technology, multiple systems within an aquaculture facility can be simultaneously controlled by one central computer unit.

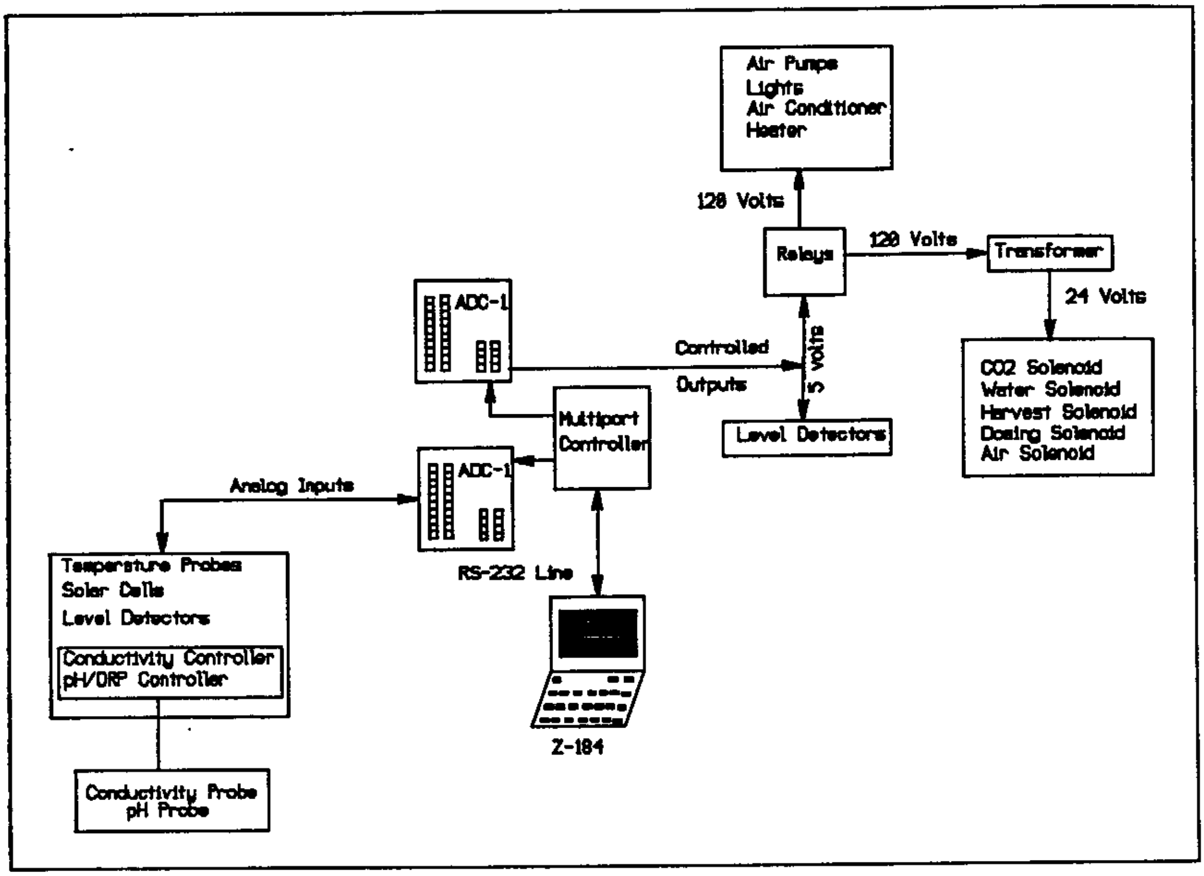

Figure 3. The Control and Monitoring System Consists of a Micro-Computer Interfaced to Inout and Output Devices through a Analog/Digital Converter.

ISSUES

The control and monitoring algorithm and associated program was developed as a generic software tool to aid in the advancement of aquaculture (both research and industry), and has proven to be a reliable and stable management device for the experimental systems contained within the authors' laboratories. The main advantage of "Supervisor" is the integration of the three core elements that results in a flexible programming environment adaptable to a broad spectrum of applications. While the control and monitoring system described in this paper is a powerful management tool, operators must understand the needs of their systems. This tool is not meant to completely replace manual supervision, but to increase operational efficiency and reduce costs through complimentary control and monitoring techniques. "Supervisor" is most suited for research activities and customized smaller facilities where frequent programming adjustments are desired. The authors do agree, at this time, that larger commercial facilities that do not require frequent program modifications may find "CANNED" programs to be more cost-effective.

The overall reliability of this technology depends to a large extent on: (1) the stability of the supporting control system and (2) the accuracy and precision of the data obtained from the input devices. The cost of implementing this basic control and monitoring system (Table 1) depends, to a large extent, on the selection of the supporting technology, mainly the input and output devices which will vary from system to system. Table 2 provides a capital cost breakdown of the authors' algal turbidostat, showing the relative cost of the control components to the overall system. The core control system for the algal turbidostat, excluding input and output devices, can be implemented for 20% of the total system cost. As will be true with any aquaculture system, as the economy of scale increases, the cost of the control system will become negligible. Additionally, this 20% cost expenditure may be reclaimed over the long run by reduced manual labor requirements.

Table 1. Major Hardware Elements Required for a Basic Micro-Computer Control and Monitoring System.

Component	Cost	Manufacturer	Function
Computer	\$900-\$1900	Variable	Provides logical control of all system components
Analog/Digital Converter ADC-1-B+12	\$613	Remote Measurement Systems, Inc.	Provides primary interface between the computer and input/output devices
Input Devices	System Specific	Item Specific	Probes/sensors providing monitoring data
Signal Modifier	Input Device Specific	Item Specific	Electronic components frequently required to assure sensor signal compatibility with analog/digital converter
Output Devices	System Specific	Item Specific	Pumps, heaters, valves, and other units which are physically activated by the system
Multiport Controller 524	\$299	Remote Measurement Systems, Inc.	Permits up to four peripheral devices to be interfaced to the computer's RS-232 port
Transformers (optional)	\$10 - \$40 (each)	Local Electronics Store	Facilitates voltage decreases from 110 volts to 24 volts
Solid State Relays 110 volts, 10 amps	\$10/each	Local Electronics Store	Switching devices that use low voltage output from the A/D converter to provide 'on'/'off' control of output devices

Table 2. Capital Cost Estimate for the Computer Automated Algal Turbidostat.

Component	Cost
Control System	
Computer	$ 1,400.00
ADC-1-B+12 (2)	$ 1,200.00
Multiport Controller 524	$ 299.00
Relay Boxes (2)	$ 300.00
Transformers (7-optional)	$ 70.00
	$ 3,269.00
Input Devices	
pH Transmitter/Probe	$ 390.00
Conductivity Transmitter/Probe	$ 390.00
Temperature Sensor (3)	$ 24.00
Solar Cells (6)	$ 66.00
Level Detectors(4)	$ <5.00
	$ 875.00
Output Devices	
Solenoid Valves (5)	$ 650.00
(2)	$ 60.00
Actuated Ball Valves (4)	$ 600.00
Metal Halide Lamps (2)	$ 340.00
Air/Vacuum Pump	$ 320.00
Air Conditioner	$ 400.00
Heater	$ 30.00
UV Lights (2)	$ 240.00
Pumps	$ 200.00
Centrifuge	$ 7,500.00
	$10,340.00
Miscellaneous Components	
Culture Chamber (2)	$ 800.00
Harvest Chamber	$ 100.00
Activated Carbon Column	$ 100.00
Exhaust Fan	$ 75.00
Gauges (Vacuum, Pressure) (3)	$ 65.00
Pressure Reducer/Relief Valve	$ 50.00
Check Valves (6)	$ 50.00
PVC Pipe, Acrylic, Fittings	$ 500.00
Electronic Supplies	$ 100.00
	$ 1,800.00
	$16,324.00

With the aquaculture industry moving in the direction of intensive culture systems, management practices will become crucial. The control and monitoring approach presented in this paper has proved reliable for the complete control of the various experimental systems in the authors' laboratories, with a substantial reduction in labor. Regardless of the degree of support given by the control system, the end result will be a reduction in the operational costs over manually operated systems.

ACKNOWLEDGEMENTS

This research was supported by the Louisiana Sea Grant College Program, an element of the National Sea Grant College Program, under the auspices of the National Oceanic and Atmospheric Administration, U. S. Department of Commerce. The authors would like to thank Mr. Minh Troung for his computer assistance and Ms. Pamela Rupert for her clerical support.

REFERENCES CITED

1. Berg, H.J. 1991. Process control system DPC 400 for decentralized structures in the basis of personal computers, Water Supply, 9(2):177-189.

2. Borland International. 1987. Turbo Pascal, Owner's Manual, Scotts Valley 640 pp.

3. Briggs, R. 1990. Recent developments in new sensors for environmental engineering, Environ. Monit., 29:1-8.

4. Chen, S., K.A. Rusch and R.F. Malone. (in press). Design of an electrical inhibition gate for application in an automated soft-shell crawfish separation system, Journal of Applied Aquaculture.

5. Hughson, R.V. 1991. Programs to help keep you in control, Chemical Eng. Prog., 87(11):68-71.

6. James, C.H., Abdul Mohsen Al-Khars and P. Chorbani. 1988. pH dependent growth of Chlorella in a continuous culture system, World Aquaculture Society, 19(2):27-35.

7. Malone, R.F., D.G. Burden and D.P. Manthe. 1986. Automatic determination of filter efficiency in recirculating systems, *In*: J.G. Balchen and A. Tysso (Eds.), Symposium on the International Federation of Automation Control, Aquaculture '86, Trondheim, Norway, pp. 143-146.

8. Miller, A.R. 1981. Pascal Programs for Scientists and Engineers, Sybex, San Francisco, 374 pp.

9. Munson, R.J. 1970. Turbidostats, Chapter XV, *In*: J.R. Norris and D.W. Robbins (Eds.), Methods in Microbiology, Volume 2, Academic Press, New York, pp. 349-376.

10. Remote Measurement Systems, Inc. 1990. Owner's Manual, Seattle, 146 pp + appendix.

11. Robin, J.E. 1992. Water Quality and Performance of a Commercial Scale Automated Soft-Shell Crawfish Production Facility, Master's Thesis, Louisiana State University, Baton Rouge, Louisiana.

12. Rondelle, R.F. 1992. Vertical Distribution on an Automated Soft-Shell Crawfish Separator, Master's Thesis, Louisiana State University, Baton Rouge, Louisiana.

13. Rusch, K.A. 1992. Demonstration of a control strategy for sustained algal growth at a full-scale level under computer automated, continuous culture conditions, Ph.D. Dissertation, Louisiana State University, Baton Rouge, Louisiana.

14. Sorgelass, P., E. Van Outryue, G., Persoone, and A. Cattoir-Regnaerts. 1976. New Type of Turbidostat with Intermittent Determination of Cell Density Outside the Culture Vessel, Appl. Environ. Microbiol., Vol. 31, pp. 327-331.

15. Stover, E.L. and C.K. Campana. 1991. Computerized Biological Treatment Operational Process Control, Water Sci. Technol., (G.B.), 24(6):323-330.

16. Zaks, R. 1986. Introduction to Pascal, Including Turbo Pascal, Sybex, San Francisco, 464 pp.