Linking R&D Activities with Teaching

Water Quality Monitoring in Aquaculture as a Remote Laboratory Proxy for Environmental Studies

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***Abstract*—This work presents a system for on-line study purposes and for demonstrative operation of water quality monitoring based on previous full-scale trials in a commercial aquaculture facility under the scope of a R&D project. This system is still under development, and was designed for sharing resources in R&D activities and later in distance learning blended courses. An application developed in LabVIEW is responsible for receiving information from physical and chemical data (water level, flow, oxygen, temperature, pH, ORP and CO2) through a hardware interface. The acquired data are recorded in a Microsoft Access database that can be locally queried as desired. An IP camera allows students to observe the system in real-time. Students can log into the system and follow the real-time variations of a specific water quality parameter and the synergetic effects of these changes on the levels of other constituents. The water tanks contain no living beings in order to allow free adjustments of the parameters under study. The system description, data and remote access link is integrated in a basic course available in a Moodle® server. The goal of this course is to provide a stimulating interdisciplinary environment to a diverse group of undergraduate students, where critical research questions related to water are addressed. This system, unique in the area concerning with our knowledge, intends to contribute also to students' training on data monitoring and analysis; and to nourish analytical skills and creativity of future scientists by encouraging potential graduate students to go further. Finally, this system allows the students to be familiar with the use of some new information technologies.**

***Index Terms*—Distance learning, remote laboratories, water quality monitoring, aquaculture application.**

I. INTRODUCTION

The use of remote laboratories in natural and fundamental sciences is not as popular as in engineering areas, probably due to the lack of technological expertise necessary to setup and maintain a computer based remote system. However, there is a growing interest in this approach because of the increasing pressure to save resources, as well as to introduce new and more effective teaching tools. Examples of broad subject areas of application include Environment, Ecology, Water Quality Monitoring and Management, and more specifically Aquatic Biological Resources (including Aquaculture), Environmental Biotechnology, Wastewater Treatment and Environmental Chemistry. Remote systems, like the one reported here, may improve students' knowledge and skills in a blended learning approach, by confronting them with new technologies in an interdisciplinary environment. This kind of experience presents a different challenge and definitely contributes to open students' minds increasing their ability to deal with new situations. Examples of remote systems are available from engineering schools worldwide [1-6] and can be used to help to develop systems suitable for science teaching applications.

One of the most transversal themes that are highly amenable to remote laboratory development is water quality monitoring. Remote systems can be used to study diverse water bodies (rivers, estuaries, lakes, reactors for waste water treatment, culture tanks for fish production, etc.) and the respective obtained data can be analyzed using various tools (statistical, graphical, etc.) as well as for modeling and validation. Other potential advantages of such a type of system include independence of sampling campaigns (costly, time consuming, prone to logistic drawbacks, etc.), contact with different types of sensors (some of them too expensive for individual training purposes), and the possibility of real-time data collection and analysis (avoiding sample storage and post-treatment). Furthermore the possibility of a continuous monitoring of physical and chemical parameters gives a better understanding of the overall dynamics of the system under study and is useful for an early alert of possible occurrence of catastrophic events. An emphasis can be put on parameter interaction (as in a real environmental situation), assessment of the prediction capacity of the database created, immediate explanation of certain events (like point-source pollution, aeration failures, etc.), and also evaluation of the effect of sampling aliasing [7] in the gathered data.

In this context, aquaculture can provide a profitable demonstrative activity as it is well-known that water quality is of outmost importance for aquatic life. Fish metabolism is dependent on good water quality but it also affects negatively the environment (e.g., through breathing and excretion).

So, to produce fish in a cost-effective manner, aquaculture production systems must be capable of maintaining appropriate levels of water quality (WQ) parameters like temperature, dissolved oxygen, pH, un-ionized ammonia, nitrite and carbon dioxide [8-10]. To meet this goal, monitoring and control are crucial operations. The objective of this work is to present the results of a joint collaboration between teachers and researchers from the Faculties of Sciences and Engineering of University of Porto, working in different research Centres (CIIMAR, CIQ and UISPA-IDMEC-Pólo FEUP), in the form of a prototype of a dedicated computer-based monitoring system for critical WQ parameters with data logging, data analysis and alarming capabilities, for R&D achievements but also to be used for improving teaching/learning tools, in a base of a blended learning approach in a laboratory model of an aquaculture facility.

II. EXPERIMENTAL SETUP

A. *Configuration of the sensors array*

In the present case the instrumentation available in the market for WQ monitoring was not suitable for a small scale laboratory aquaculture system prototype. Moreover the challenge involved small water depth tanks (shallow raceways), a new technology object of an R&D European Union funded project. Solutions found are of multiparameter transducers type which were either too big for using in small volume tanks (enabling only one point measurement) or were not customizable. The adopted alternative was focused in the development of a sensing array based on commercially available individual transducers for each parameter to be monitored. Thus the acquired instrumentation includes: RS331-017 level detectors, ORP/Redox transducer HI2930B/5 and several transmitters, one OXY 1100 unit ranged 2-50 mL for oxygen, one pH type HI2910B/5, three temperature Oxyguard 420T, one CO2 Oxyguard and one flowmeter Parker DFT.990.RS.

The hardware interface is composed by a signal concentrator unit built for this purpose and a data acquisition board (NI PCI-6221, from National Instruments). In the signal concentrator unit there is a connector board (NI CB-68LP), two power supplies (RS: 32012B and 32024B), eight differential analogue inputs (3x T, ORP, pH, O2, CO2, Q), ten digital inputs (level detectors) and two digital displays associated with ORP/Redox BL932700-0 and pH BL931700-0 controllers. All the transducers are of transmitter type (4-20 mA output) in order to have a universal signal with convenient noise immunity level. A relay unit (NI USB-9481, 4 Channel General Purpose SPST Relay Module) is used to switch on/off the water recirculation pump.

The water dissolved gas levels can be changed by injecting O_2 or CO_2 from high pressure gas bottles. Presently, injecting the gas has to be done manually, but it is expected in the future to be able to control remotely these actions too, through electric valves.

B. *Aquaculture model system*

Based on a literature survey and known field data from a commercial fish facility, a laboratory prototype of three fish production tanks with low water depth (7 cm) and water reuse possibilities (including biofitration) was built (Fig. 1, right). The tanks are equipped with two level detectors and temperature transmitters; dissolved oxygen, pH and ORP transmitters are located in the water collection tank (Fig. 1, bottom) and one flow meter is at the water distribution system outlet (Fig. 1, top right, not shown).

C. *Software Application developed*

An application named Waterscan v1.0 was developed in LabVIEW 8.5 to monitor, present and record the data of tanks transmitters/detectors: water level (10) and temperature (3), water flow (in the water delivery system), dissolved oxygen, pH, ORP and Carbon Dioxide. The respective user interface (Figure 2) offers monitoring and configuration capabilities. It is also possible to interact with the system by switching on and off the water recirculation pump or by defining limit values for the different parameters to trigger critical situation alarm messages, which configuration is password protected.

In the future it is expected that actions required to solve triggering alarms caused by abnormal problems could be remotely performed.

The data is recorded in a Microsoft Access database, being easily exported for further data processing. The software application has five Tabs (Scheme, Nitrogen, Graphics, Definitions and Report) which are shortly described in the Table 1. The application implements a user friendly interface that graphically reproduces the real system, making its operation very intuitive for users. The values from all sensors are acquired at pre-defined intervals and the respective maximum and minimum values are displayed in the report Tab. With the information from existing transducers and data from colorimetric analysis, it is possible to calculate the fraction of unionized ammonia (NH3-N), extremely toxic to fish, using a built-in analytical equilibrium evaluation method (Nitrogen Tab). The graphs with the evolution of the different parameters (Graphics of Temperature, O2, CO2, pH, flow, Redox) are plotted on the Graphics Tabs.

Figure 1. Interface hardware and laboratory aquaculture system prototype

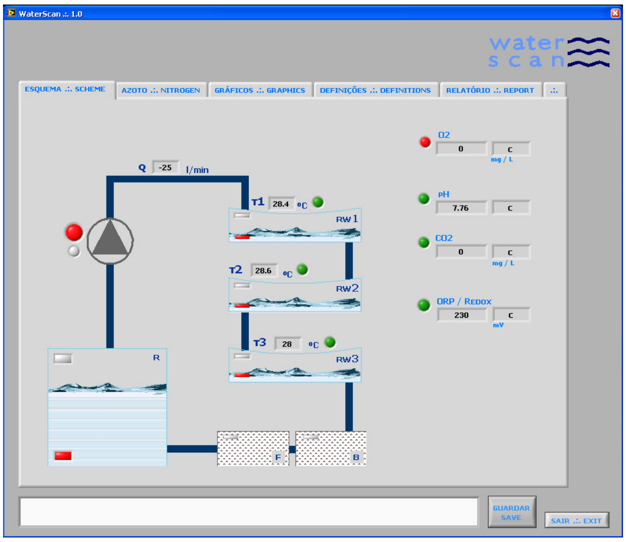

Figure 2. Waterscan user interface (Scheme Tab)

The Definitions Tab enables the user to set the alarm levels for each parameter, the email address for reporting and the data acquisition sampling rate. Finally, Report Tab enables the user to report the saved comment notes, desired data from the transducers/transmitters (between defined dates) and alarms logged/trigger values.

D. System Architecture

Number LabVIEW implements its own web server that enables the publication of the front panel of the application either for monitoring or for control purposes (Figure 3). In the first case, multiple users can simultaneously access the interface, while in the second case the access is given to only one user in an exclusive way. A Windows Server 2003 platform acts as the main server for all remote lab experiences (http://elabs.fe.up.pt). To improve the liability, the computer is running another virtual system as well, that can be used for validation and test. The experiment is integrated in a Moodle course (running in the main server) as to give to the user complementary information on the subject of the experiment. The connection between the Moodle and the LabVIEW servers is based html link. Time differences between linked computers can be a troublesome, thus the time is kept synchronous with the server using an external windows time server.

Although the installed version of Moodle does not support the experiment scheduling, the present version includes an agenda that will simplify the access process.

TABLE I.
APPLICATION SOFTWARE INTERFACE TABS

Tab	Function
Scheme	Setup overview and input/output signals
Nitrogen	Calculation of un-ionized ammonia (NH_3-N) and other N species
Graphics	Graphics: Temperature, O_2, CO_2, pH, flow, Redox; several functionalities
Definitions	Alarm trigger values, sampling rate and email address for sending report
Report	Report generation interface, start/stop time, variables to be reported

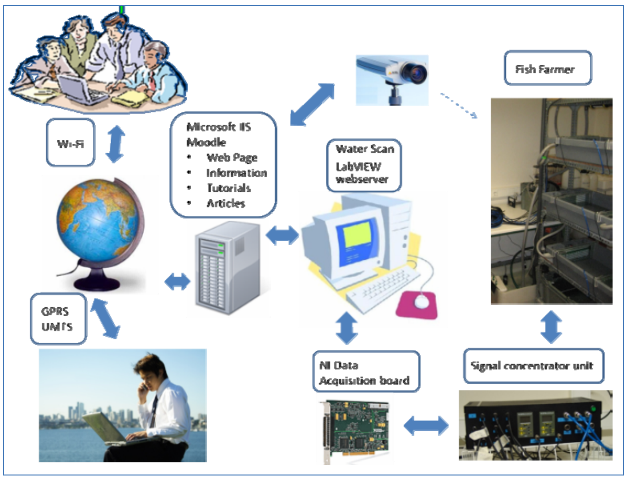

Figure 3. System architecture

E. Real-time Video

By adding to the application software real-time video image from an IP internet camera, it is possible the live broadcasting of events in the remote laboratory, (Fig. 4).

III. RESULTS

A. Monitoring System Performance

Preliminary tests with this system were done without fish to comply with ethical issues. Short term (hours) and long-term (week) periods of continuous operation were run to test system stability, response time, noise, logging and exporting capabilities.

An example of a Report generated after injecting O2 in a tank (a common procedure in aquaculture to safely cultivate high fish loads) can be found in Figure 5.

A bilingual text was produced to facilitate the use in Portuguese fish farms.

The Figure 6 shows the graphic evolution of the O_2 in water during the experiment referred in Figure 5.

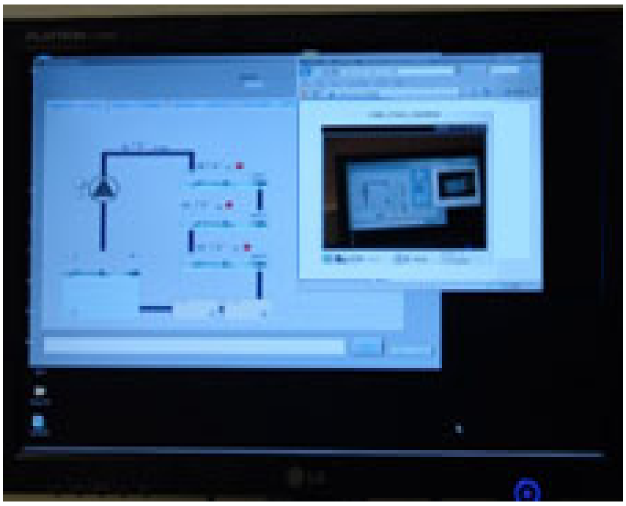

Figure 4. Application Software and IP camera webserver window

utilizador .:. user	Teresa Borges				
início .:. Start	02-12-2009	11:30:37			
Fim .:. End	02-12-2009	17:40:48			
		Temp	O2	pH	ORP/Redox
Minimo .:. Minimum		12,80136	2,170241	6,312871	169,4075782
Máximo .:. Maximum		14,1018	32,43982	8,586964	244,3465889
Média .:. Average		13,39565	23,66042	8,02474	184,0044397
Desvio padrão .:. Standard Deviation		0,383841	11,45569	0,729942	23,32470397
Data .:. Date	**Hora .:. Time**	**T RW3**	**O2**	**pH**	**ORP/Redox**
02-12-2009	11:31:15	12,80948	8,981199	7,909343	195,7418823
02-12-2009	11:32:15	12,80542	9,0275	7,905929	196,2295547
02-12-2009	11:33:15	12,80745	9,023844	7,912757	193,7911927
02-12-2009	11:34:15	12,80542	9,038465	7,925843	192,2468968
02-12-2009	11:35:15	12,81558	9,064052	7,917308	192,2468968
02-12-2009	11:36:15	12,81761	9,068926	7,914464	191,4341094
02-12-2009	11:37:15	12,80136	9,05796	7,910481	192,4907329
02-12-2009	11:38:15	12,80745	9,060397	7,919015	191,1089945
02-12-2009	11:39:15	12,82371	9,088421	7,919584	190,7838796
02-12-2009	11:40:15	12,82167	9,046994	7,92186	189,8898136
02-12-2009	11:41:15	12,8359	9,046994	7,913895	190,1336498

Figure 5. Example of the type of reports generated by the system for four water quality parameters

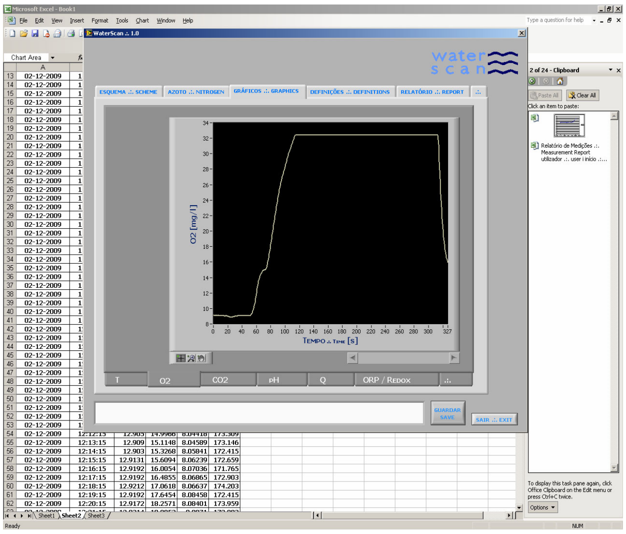

Figure 6. Graphical output generated by Waterscan interface for a dissolved oxygen experiment. Background dataset is from the Report of Figure 5

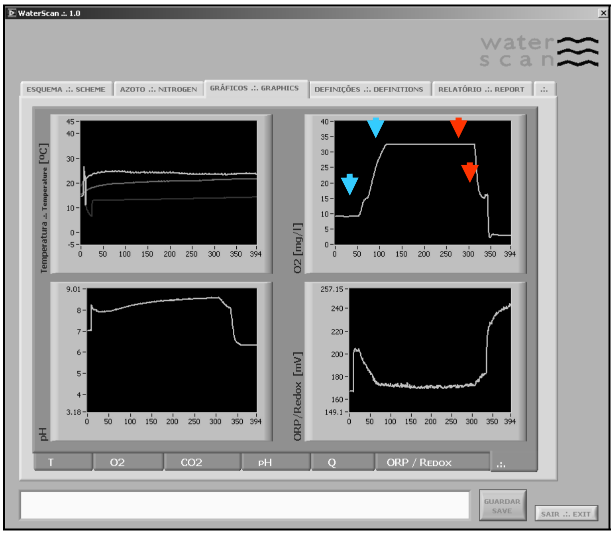

Figure 7. Example of the effect of continuous O2 (blue arrows) and CO2 (red arrows) injection on pH, dissolved oxygen and ORP readings

B. *Developed system for education*

The Waterscan software package and the prototype aquaculture system has been developed as an easy-to-use tool that can be employed in different educational scenarios, e.g. involving distance learning, b-learning with classroom (group) learning. Diverse teaching conceptual frames can be conceived within the main topic of Water Quality, confirming the vocation of this system to act as a proxy for improvements in Environmental studies. As this is a recently developed system, there is not yet much experience of its use in a realistic teaching scenario; nevertheless, some examples of use for developing student's learning and researching skills are suggested.

1) Ex. 1– Field of Ecology/Aquatic Sciences

Topics:

- Interactions between different water quality parameters in an aquatic system.
- Effects of excess carbon dioxide in water bodies.

Skills: understanding instrumentation (types, characteristics, operation), data logging, data transfer, data visualization, analysis and presentation; spreadsheet and database utilization for problem-solving, experimental design, and modeling; software utilization (Waterscan, Excel, SPSS, etc.).

2) Ex. 2 – Field of Aquaculture

Topics:

- System Carrying capacity and water quality
- Effects of different feeding regimes on water quality

Skills: the same as above.

3) Ex. 3 – Field of Wastewater Treatment

Topics:

- Studies on the performance of different biofilter configurations.
- Performance of CO2 stripping columns

Skills: the same as above.

4) Ex. 4 – Field of Environmental Chemistry

Topics:

- Chemistry of dissolved gases (O2, CO2) in different water matrices.
- Sensor biofouling evaluation and mitigation

Skills: the same as above.

5) Ex. 5 – Field of Analytical Chemistry

Topics:

- Sensor calibration.
- Sensor interference
- On-line sampling
- Data analysis

Skills: the same as above.

The following experiment elucidates the didactic potential of this R&D-in-aquaculture-based remote laboratory system. A continuous injection of gases (O2; O2 and CO2; only CO2) was done into the system. This could mimic either cyclic events in a natural lake, in a fish tank or in a stripping column. Responses of oxygen, pH, Temperature and ORP transmitters are depicted in Figure 7.

Result analysis shows the expected behavior: a drop in pH as CO_2 level increases and a concomitant fall and rise in ORP. If this test simulates a common fish farm situation, then water is oxygenated with pure O_2 to enable high fish densities in the tanks. This results in a progressive increase of dissolved CO_2 levels due to fish breathing. This excess of CO_2 has a pronounced effect on freshwater pH, which drops due to partial dissociation of formed carbonic acid (H_2CO_3), with release of H^+ ions. CO_2 is more water soluble than oxygen and if it is continuously added and there are no CO_2-stripping devices, in despite of a continuous O_2 addition, CO_2 levels will increase, promoting a pH decrease [8]. Oxidation-reduction potential (ORP) is a measure of the oxidizing or reducing water conditions. It depends on water pH, and whenever there are more H^+ ions (lower pH), oxidation reactions are favored and ORP rises. The inverse happens at higher pH. As CO_2 addition lowered the pH, ORP increased (due to O_2 depletion). Oxygen is vital for fish and the real-time recording and visualization of dissolved oxygen values can help to identify critical situations and/or system malfunctions.

IV. FINAL REMARKS

By simulating an aquaculture facility, the developed water quality monitoring system can be used to promote the students learning skills on sampling, sensors and actuators, data monitoring and analysis, allowing the comparison of real data vs. theoretical simulations/predictions. An industry oriented approach was followed resulting in a prototype instrumented for remote data acquisition, monitoring and control. This represents an innovative perspective as although some remote labs can be found in several Universities around the World, sharing some basic features with the present one (as the Water on the Web project, developed by the University of Minnesota-Duluth and the National Resources Research Institute, USA, related to lake ecology and management, http://wow.nrri.umn.edu), none of them offers such a flexibility of uses and real industry problem solving capability.

Further work is needed to validate obtained results and for exploring its potential either in undergraduate or post graduate students training.

It must be also stressed that in its present version, the system only promotes one remote control possibility (recirculation pump ON/OFF) due to funding limitations. Other possibilities can be open if this project is extended to more partners. Improvements may also include automated calibration protocols and regular maintenance schedules.

This sensitive experience in water quality area aims to contribute to the set of remote experiments already available to the under graduate/post graduate programs. The authors really believe that this kind of facilities may improve the students' knowledge and their ability to face new situations and the latest technologies, and they also expect those examples could be of interest to share with others universities.

Academic staff is constantly demanded to be involved in R&D activities and care has to be taken in using their outcomes, as much as possible, for improving their teaching and learning practices. This case is an example of the link between those two activities and the collaboration of two faculties to reach the present goal.

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