Paper:

Solar-Powered Field Server and Aerator Development for Lake Palakpakin

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We have designed, developed and deployed a robust system of sensors in a small and shallow – 1 km diameter and about 7 m deep – inland lake used for aquaculture. The sensor system currently measures and sends out telemetry data on dissolved oxygen, conductivity and temperature in the lake at two depths – 0.5 and 2.5 meters – every 30 minutes. The measurements are sent out via SMS to a central server 80 km away and displayed in near-real time on a website which can be accessed by local fishermen, researchers and other stakeholders. The system also features an aerator, which operates automatically during the evening and early morning 12 hours at a time, and can also be turned on outside this period via missed-call (dropped call) from a cellular phone. This system can aid in decision-making of local fishermen, making it a potentially powerful approach to lake management, and in conjunction with other measures and long term planning, for averting or mitigating fishkill events.

Keywords: water quality, wireless sensor network, lake management, aquaculture, field server

1. Introduction

Lake Palakpakin is one of the Seven lakes in San Pablo City, Laguna, Philippines and for several years, teams of researchers from Ateneo de Manila University have been monitoring Lake Palakpakin's water quality due to impacts of anthropogenic activities particularly aquaculture and effluents coming from the lakeshore community [1]. This effort eventually led to the development of sensor systems that can monitor the lake's water quality. In this community, the multi-stakeholders want successful fish farming, agriculture, and lake tourism and will necessarily need to have best practices for lake resource management.

A critical problem facing aquaculture on fresh water lakes in the Philippines is the frequent incidences of fish kill events in freshwater lakes. Compounded by climate change effects, pesticide runoff, accumulation of waste products and fish food sediments, parasitic and bacterial infections, reduced photosynthesis caused by algae blooms and diminishing of oxygen levels caused by increased biological oxygen demand [1], fish kills present an annual problem for fishermen not only in inland lakes but also in coastal and brackish waters [1–7]. Poor water quality affects overall fish health and feed-to-mass conversion ratios and ultimately results in revenue loss for fish culture operators and caretakers.

In a preliminary effort [8] to understand the present state of the lake and to propose corrective measures for an already over-burdened ecosystem, Ateneo researchers have up to now been measuring key parameters like Dissolved Oxygen (DO), water temperature, and turbidity on an intermittent basis. This situation has changed significantly with the design, development and deployment in Lake Palakpakin of a system of sensors and actuators with the following new capability:

- Suite of sensors on a floating platform: dissolved oxygen, water conductivity, temperature at two depths – 0.5 and 2.5 meters.
- Twenty-four-hour-operation with updates every half hour delivered to AIC website (www.ateneoprojects .org) for remote lake management by local stakeholders and research collaborators.
- Solar-powered sensor package for all-weather use.
- SMS reporting of data from the field over common carrier infrastructure and 'bargain' cellphone rates.

As we learned several years ago, the DO levels in the fish cages support good fish growth only to depths of 2 meters, while the cages themselves are 5 meters in depth [9]. Fishermen have had to under-stock and lengthen their grow-out periods to 5 months in some cases [1]. This article also includes a description of our novel aerator system, working in conjunction with our sensor buoy, currently deployed in Lake Palakpakin. This new aerator system has the following system parameters:

- Thirty-Watt air pumps with 60 liter per minute capability; AC pump driven from DC-AC inverter.
- Solar-powered hut system design, so several pumps can operate off the solar panels and battery system at the same time.
- Automatically timed aeration, corresponding to parameters obtained from Alsons Aquaculture, with turn-on at 6 PM and off at 6 AM the next day.
- Cellphone turn-on by local operators using missed-call (drop call) and SMS to aerator's Android phone.
- LED attractor light incorporated in the aerator design to enhance the oxygen uptake by attracting the fish (and shrimp) towards the aerator, and enable photosynthesis at 2.5 meters.

2. Design and Development of a Field Server with Sensors and Aeration System

2.1. Field Server and Aerator System Design

The field server is composed of the following sensors: dissolved oxygen concentration (Clark cell sensors); temperature (NTC thermistors) and conductivity (custom designed stainless steel rods). The field server is mounted on a floating buoy. The aerator system is composed of an air compressor powered by a solar panel. Shown in **Fig. 1**, both the field server and the aerator are incorporated in a floating platform. Also shown in the figure are the field server powered by its own 50 W solar panel and battery and the aerator powered by four 50 W solar panels and four batteries housed in a hut nearby the floating system, as the aerator requires more power than the field server. The sensor electronics consists of an Arduino board and an Android phone for preprocessing of the signal and telemetry. Together activated with the air compressor is an LED floodlight.

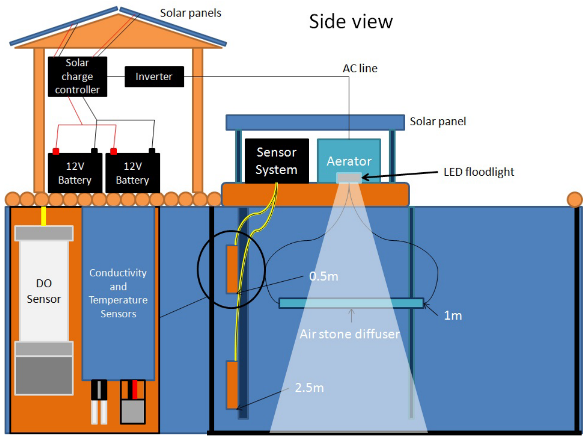

Fig. 1. Cross-section view of the Lake Palakpakin sensor/actuator system. The inset on the lower left part of the figure is a zoomed-in detail of the sensors housed inside the PVC pipe.

Fig. 2. One of the authors holding the sensor package before being attached to the floating field server. The two packages at 0.5 m and 2.5 m house DO, conductivity, and temperature sensors.

2.2. Field Server and Sensor Design

The water monitoring system records three measurements of water quality: Dissolved Oxygen (DO) concentration; temperature and conductivity at two depths: 0.5 m and 2.5 m. These two depths were chosen because previous measurements on this shallow lake (5 m maximum depths) show that usable DO concentrations do not penetrate lower than 3 m. We measure temperature to watch for potential thermal gradients that may cause convection currents that can affect depth dependent DO concentrations. The thermistor circuit is calibrated by measuring the resistances in water with temperatures ranging from 11.1°C to 65°C, cross-calibrated with thermometers before fielding. The conductivity of the water is measured using a sensor constructed by the researchers using two stainless-steel rods separated by small displacements (2.2 mm for 0.5 m sensor and 1.9 mm for 2.5 m sensor) and a 5 kΩ transimpedance for these rods. These conductivity sensors are tested and calibrated by comparing our results with the range of values for literature reports on distilled water, tap water and water with soap and then determining the right range for monitoring lake water [10]. Standard calibration techniques are used with the DO sensors.

The sensor package assembled before attaching to the field server is being held by one of the authors (D.S.) as shown in **Fig. 2**. At each depth, the three sensors are housed inside a protective PVC tube with screen filters to allow water access with little contamination from solids, such as leaves and algae that can distort the readings of the sensors and damage from fish which can bite off the wires and parts of the sensors. These sensors and their respective wires are attached to a 3 m PVC pipe, which in turn is attached to the buoy housing the monitoring system. This is done so that the stress of the sensors is not on the wires but on the pipe holding the sensors and the buoy holding the pipe. In the foreground is the actual floating field server, to which the sensor tube is attached. The field server is actually a buoy with flotation tubes, and a waterproof case carrying the Arduino board, Android phone, motorcycle battery and charge controller. Also onboard the field server is the aerator pump and an LED flood lamp. In the foreground and clearly evident is the 50 W solar panel that powers the sensor system and the containers for the Arduino, Android phone, charge controller, inverter and air pump. In the background is the hut and the fish cages where testing is done. Solar panels on the roof of the hut power the aerator system from batteries and a DC-to-AC inverter drive for the pump located inside the hut.

The 6 sensors give us voltages within a range of 0 to 5 V. Converting these voltages, we get the values in the correct units. In order to do so, we connect the sensors to a homemade board, which also include an Arduino PCB and a Bluetooth shield. To avoid errors in the readings, the Arduino is programmed to read the value coming from a sensor 100 times in one second and then computes the average of these values. The 6 averaged readings are then transmitted by Bluetooth to our Android phone that we call transmitter phone, programmed to send these data using a text message to another Android phone located in Ateneo, that we call receiver phone, which uploads the data to an online database. The data collected from the sensors are compared and calibrated against ideal aquaculture pond conditions as maintained in world-class aquaculture operations such as Alsons Aquaculture.

2.3. Aerator Design and Construction

There are several aerator designs for lake management. In principle, they are air pumps or water pumps [11, 12]. In our first aerator design, we chose the air pump.

Together with the water monitoring system deployed is an aeration system. A 32 W 220 VAC air compressor attached with rigid air diffusers is used to pump the oxygen to the water in the fish-cage. Working with the air compressor is a 10 W 220 VAC LED floodlight which serves to attract the fish to the aerated area. A relay circuit, which is controlled by the same Arduino-Android system controlling the sensors, acts as a switch between the inverter and the air compressor and LED floodlight.

The Arduino-Android controller automatically switches on the aerator system at 6 PM and then turns it off at 6 AM. However, it can also be activated or deactivated by the stakeholders, either by sending a specific text message or drop-calling the Android phone.

Fig. 3. Aerator operating with bubbles evident in water. A missed-call (drop call) can control the aerator on/off.

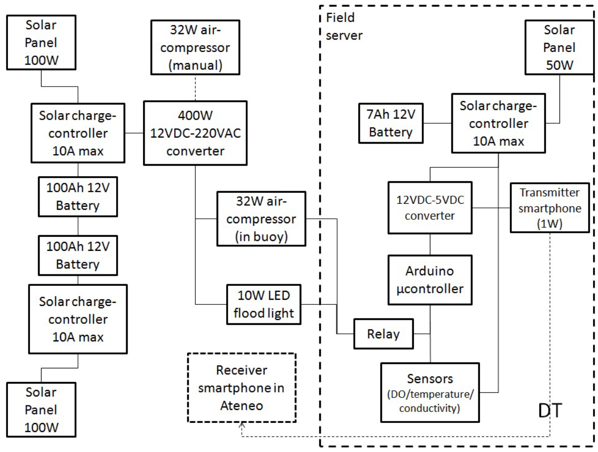

Fig. 4. System diagram of the field server and aerator. The broken-lined encloses the field server subsystem. They two are linked by the wired connection to the relay, a part of the field server. The link DT indicates data transmission.

Shown in **Fig. 3** is a close-up view of the field server/aerator while it is operating. We are still experimenting with good thermal management, so reliable pump operation can occur with little intervention. The local operators can turn on and off the aerators 'manually' by SMS or a missed-call (drop call).

Included is another 32 W air compressor housed inside the hut. This can be activated manually for backup purposes in case of non-operation of the main aerator.

2.4. Power System

The energy source of the field server is separate from the aerator (see **Fig. 4**). This is to enable the field server to operate without interruption due to depletion of energy source by the active aerator.

The sensor system is powered by one 12 V 7 Ah motorcycle battery, which is connected to a solar charge controller (10 A max), to which also connects a 12 V 50 W solar panel. Both Arduino microcontroller and Android phone connect to a USB car charger adapter to get power from the charging system. Both car charger and charge-controller act as safety features of the field-server, preventing damage of electronics in case of power surges from the battery and the solar panel. Both air compressor and LED floodlight are powered by 4 50 Ah 2SM car batteries. These batteries are connected to a two solar charge controllers, two batteries for each which also connect to four 50 W solar panels, also two panels for each controller. One of these charge controllers is set to always switch on and connects to a 12 VDC – 220 VAC power inverter, to which the air compressor and the LED floodlight connect.

As shown in the cross-section view (**Fig. 1**), the electrical power for the aerator comes from the hut, which houses several solar panels and a battery bank. The 12-volt batteries in the hut are wired to an AC aerator pump, which runs through a DC-to-AC inverter. In the prototype we used a 32 W air compressor and a 10 W LED flood lamp, for a total of power consumption of 42 W per aerator.

The power requirement for operating the aerator with solar power has been studied by the authors. One 2SM battery has a nominal energy capacity of 600 Wh. However, based from one of the author's experience, the battery, fully-charged on a good weather (clear sky from 9 AM – 3 PM) by a 50 W solar panel, can only provide 200 Wh energy per day. Therefore, if weather conditions are not favorable for solar charging, battery can be charged up to as low as 30 W-h. Using this assumption, if we want to operate the air compressor and the LED for 12 hours straight, the energy requirement is around 504 Wh energy. Therefore, the authors decided to use the said power configuration to provide a maximum of 800 Wh to the aerator per day. The estimated power requirement of the field server is 3 W, making the 7 Ah battery and 50 W solar panel sufficient to operate the field server 24/7.

3. Telemetry, Network and Web Application System

3.1. Field Server Telemetry

It is very practical to use mobile technology for the data transmission since the field server is around 80 km away from our reliable internet server. **Fig. 5** shows how the data from the sensors are transferred to the cloud-based web application. The Arduino microcontroller is programmed to wait for a trigger coming from the Bluetooth connection to perform the measurements. On the other side of this Bluetooth connection is our Android phone that we call transmitter phone. Transmitter is continuously running an application. Every half hour, this application triggers the Arduino to collect the sensor readings through the Bluetooth, and then receives these readings. Then, it sends this data as text message to another phone located in Ateneo, which we call receiver phone. In addition, the transmitter phone keeps a backup of all the data on its micro SD card. One month of data is around 100 KB (one year of data is around 1 MB) so memory is not an issue. The Receiver is also running its own application, which intercepts the incoming text message, extracts the content, and then uploads it to an online database using a wireless internet server in Ateneo. This allows us to have a real-time monitoring of the lake, as the whole process is really fast.

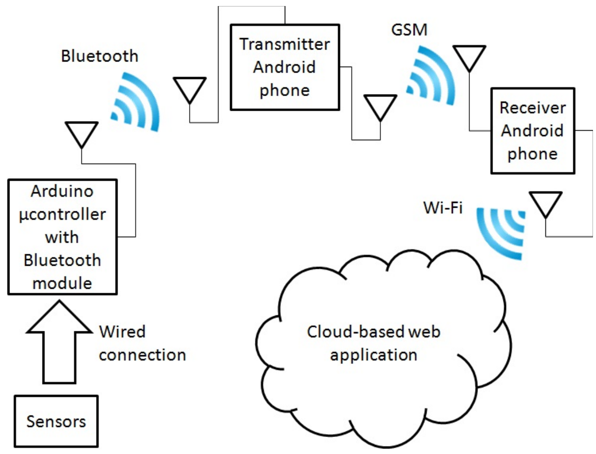

Fig. 5. Diagram of the field server telemetry. Transfer of data starts from the sensors at the lake and ends at the web application. Bluetooth, GSM and Wi-Fi are involved in the data transfer.

We use SMS for data transmission for several reasons. First, it is very affordable as we pay P200 per month for unlimited text (Smart promo). The volume of data is very light, it does not require a 3G connection. In addition, the classic GSM network is way more developed and reliable than the 3G. It is also available all around the Philippines.

3.2. System Monitoring Website

We have coded a website to display the data saved inside the database. It's based on PHP, JavaScript and a MySQL. The website uses a lot of open source frameworks like Bootstrap, Slim, Chart.js, Moment.js, JQuery, etc. The website displays a graph up to the current readings for the day. There are two plots, one for each sensor depth (blue – 0.5 m and red – 2.5 m). The graph is displayed is the desired quantity vs time of the day. The site also displays the current reading of the sensors and what time those readings are taken. For the DO, there is a horizontal line drawn at 3.2 mg/L, the minimum amount of dissolved oxygen at which the water is in good condition to support aquaculture [9]. With the use of Google Maps, the website also displays the location of the sensor. It also indicates when the aerator system is activated and for how long since it has been activated. People involved in the project can access the website at www.ateneoprojects.org/projects/palakpakin_system0.php.

4. Results

The sensor data can be viewed on our website (www.ateneoprojects.org), and it shows the DO, con-

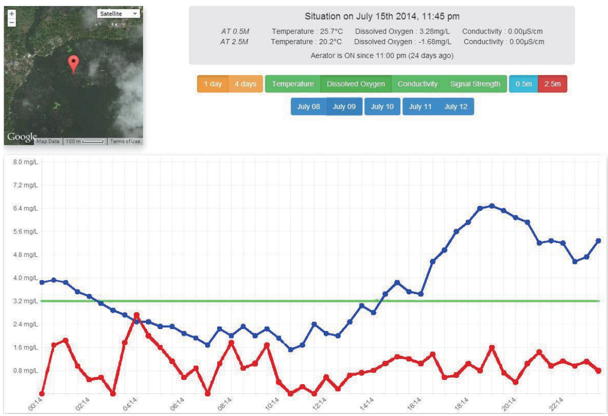

Fig. 6. Web display of the DO readings at 0.5 and 2.5 meters during July 10, 2013. In this date the aerator was turned on around 2:30 PM for two hours, then shut off until the automatic turn-on at 6 PM. The elevated levels of oxygen overnight result directly from the aerator action. Note also the very low level of DO at 2.5 meters throughout the day.

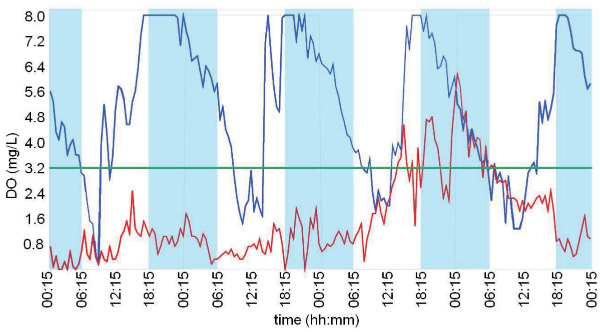

Fig. 7. Four-day readings (August 2-5, 2013) from website of dissolved oxygen at 0.5 m (blue) and 2.5 m (red) with aerator operation at 1.0 m depth from 6 PM to 6 Am everyday.

Fig. 8. Rising air bubbles coming from air stones at 1 meter below the surface illuminated by the LED flood lamp.

Fig. 9. Pond scum appearing consistently in Lake Palakpakin for a few hours in the morning.

ductivity and temperature at different depths over time. Shown in **Fig. 6** is a day's worth of data for DO – the upper trace (blue) for 0.5 meters and the lower trace (red) for 2.5 meters. Important to note here is that life-sustaining oxygen should at least be at the 3.2 mg/L level, indicated by the blue horizontal line on the graph. Clearly the 2.5 meter reading indicates a lake in serious trouble. The action of the aerator is tested by turning on the aerator at around 3 PM for around two hours and then again at 6 PM overnight. This is clearly indicated by the rise of elevated DO levels lasting through the night.

In our first deployment, the system operation continued for over a month with DO, conductivity, temperature readings taken at 0.5 m and 2.5 meters. On the website the daily readings for Aug. 2-5, 2013 can be viewed with updates every 30 minutes. Aerator operations scheduled from 6 PM to 6 AM everyday, as seen by the higher DO after sundown. Shown in **Fig. 7** is a four-day record of DO as viewed in the site.

We show in **Fig. 8** air bubbles photographed by our underwater camera. The aerator stones are a meter below the surface and 60 cm in length, creating a strong flow of bubbles towards the surface. At night the fish see the bubbles moving upward as illuminated by the LED flood lamp. This bubble movement adds to the effectiveness of the aerators by attracting fish to the light and the continuously rising bubble stream. We are presently modeling the aerator performance enhancement by the use of the LED flood lamp at night. After installation of the LED flood lamp, a spike in DO readings from the 2.5-meter depth was observed. We hypothesize that phytoplankton react to the LED light and begin photosynthesis, and thus adding to oxygen concentration in the water.

One interesting observation of the team during the field trials is blue green algae scum appears on the surface at around 8 AM, lasting until around 10 or 11 AM, when the winds pick up (**Fig. 9**). This scum may be rising to the surface as it creates oxygen and later drop to lower depths. This could be why the DO is really low at 2.5 meters for extended periods. This remains speculative until we do further investigation but we realize that images of this scum ought to be routinely taken.

A multiple aerator-sensor system design for future deployment is schematically depicted in **Fig. 10**. The power requirement for operating several aerators with solar power can be the subject of several engineering tradeoff studies. If the LED attracts sufficient fish to the aerators at night, the effectivity of the aerators for a given

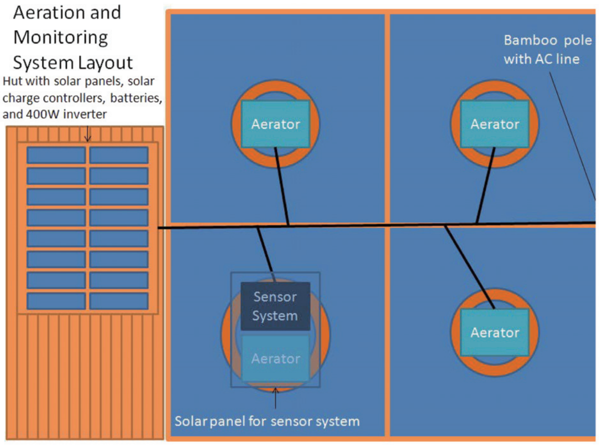

Fig. 10. Aerator hut design with sensor system in one of the fish cages. The power option shown is an AC system with an inverter located in the hut and AC power delivered to the aerators. A conservative engineering design may require 400 W of solar power to accomplish 12-hour operation everyday with two aerators alternating between two sites.

input power can be increased. With limited power we can opt to alternating between fish cages in alternate days. This will be the subject of a further engineering study. This hut design for our future deployments looks schematically like **Fig. 8**. The sensor system will be located in a fish cage near the hut and the power grid will feed several aerators in the adjacent cages. We believe that this is a good engineering target for lake management systems.

The hut-based design for a solar-powered sensor and aerator system shown above can form the core of a Lake Management System for Philippine Lakes.

We envision expanding the sensor to include light measurement at the surface and 2 meters below. In addition, we will be deploying a new 24/7 turbidity sensing system for rough measurements of phytoplankton density and a vision system for fish activity monitoring.

5. Conclusion

Water quality monitoring methods have always been dependent on scientists going to the field and taking measurements at different monitoring stations. This takes time and effort, not to mention that it hardly ever involves local stakeholder participation. The development and deployment of an ICT-assisted monitoring system in Lake Palakpakin presents innovation in water quality monitoring in two ways: (1) through real-time delivery of information to local stakeholders and researchers in different parts of the world through the Internet; and (2) it presents the information in simple terms (e.g., DO readings over time) that fishermen understand and can inform real-time, on-site decision-making; making it a powerful tool in averting fish kills.

We have demonstrated a novel sensor system for Lake Palakpakin that provides sensor data – DO, temperature, and conductivity in two depths over time. The sensor system has been operated continuously and reliably for several months. While a lot more engineering work needs to be done, we already see the benefits of having the DO and conductivity results in assessing the different precursors to fish kills. This sensor system can be developed as a stand-alone monitoring system for lake management.

In addition we demonstrated a novel aerator system coupled to our sensor system. The aerators can be programmed to turn on at 6 PM and run until morning and the DO levels clearly respond to the oxygen being pumped into the water. Several features have been included in our design to enhance the efficiency of oxygen delivery – an LED flood lamp is included to attract fish to the aerators and a missed-call (drop call) option for the local operators to turn on the aerators, when signs of oxygen deficiency are evident.

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- "Engineering Clean Water System for Off-Grid Sites," 2^{nd} Engineering Research and Development for Technology, Conf., Synergy in Multi-Disciplinary R&D, Feb. 20, 2009, Diamond Hotel, Roxas Boulevard, Manila, Philippines

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Main Works:
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