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Towards a Web-based Decision System for Philippine Lakes with UAV Imaging, Water Quality Wireless Network Sensing and Stakeholder Participation

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***Abstract*—There is a critical need for modern lake resource management in the Philippines because of climate change, disasters, intensive aquaculture and poor waste-management practices. To this end, we have deployed floating field-servers in Lake Palakpakin, one of the Seven Lakes in San Pablo City, Philippines monitoring conductivity, temperature, dissolved oxygen and turbidity at two depths–0.5 and 2.5 meters for over a year, with web access to data by SMS. We also have deployed UAVs to image the lake area to quantify fish cage density, water hyacinth coverage and disaster damage. The local fisher folk report daily lake activities–fish-feeding, harvesting, and fish-kill events by taking pictures and other measured data using smartphone applications. We describe how these measurements are being integrated into a web-based decision-support system.**

Keywords—decision-support system; water quality sensing; floating field server; UAV imaging; participatory sensing

I. Introduction

In this paper we describe the development of a lake management and aquaculture productivity monitoring system for the Seven Lakes of San Pablo City that addresses the multi-stakeholder needs of lake communities. Aquaculture of tilapia (*Oreochromis nilotocus*) is one of the main livelihoods in the lake. Other species the fisherfolk catch are clam (*Corbicula manilensis*) snakehead (*Channa striata*), silver carp (*Hypophthalmichthys molitrix*) and freshwater shrimps. The prevalent practice of excessive fish feeding and overstocking poses problems for the ecological status of the lake. Agriculture can contribute excess fertilizers and pesticides into inlet rivers. Both these activities though are major sources of livelihood of the lakeshore communities [1]. Poor waste management from farms and households is also a reality in the area. All these can lead to the eutrophication and low dissolved oxygen of the lake [2] [3] [4]. This may affect the prospect of tourism in the lake area. Climate change has complicated the situation since it has affected the growing seasons and can potentially destroy the livelihood of the lakeshore people [5]. In an attempt to regulate the usage of lake resource, policies crafted by local government units (LGUs) affect the livelihood of the people. Thus, lake management becomes a critical concern [6] [7] [8].

Management of lake resource is complex as several parameters are needed to be taken in account in monitoring the lake's water quality. The dissolved oxygen (DO) in the water is a crucial parameter for the fish and other aquatic organisms as it determines their growth and survival. Decomposing feeds lowers the DO of the water and contributes to accumulation of organic matter. Conductivity of the water has to be monitored with the excess nutrients from various sources which can lead to algal bloom. The amount of illuminance on water is part of determining the amount of photosynthesis in them and the DO produced from it. It is also important to know the depth at which light can penetrate the water by measuring the turbidity created by phytoplankton at near surface. Measuring turbidity at the bottom of the lake helps determine the amount of organic sediments present. Monitoring the amount of water hyacinths (*Eichhornia crassipes*) is important because they also compete for light with phytoplankton and for DO with aquatic species.

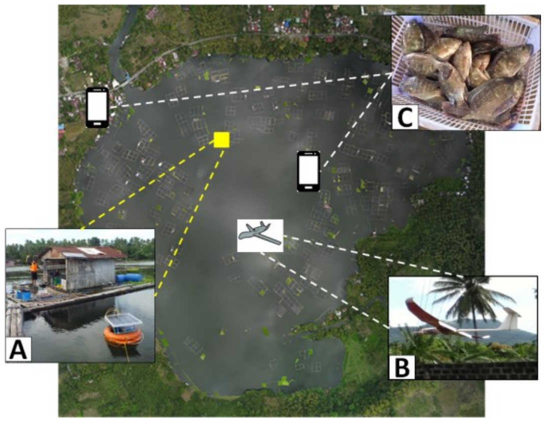

Fig. 1. Deployed components of the lake resource management system. We have deployed a solar-powered floating-field server with aerator system (A). This image of Lake Palakpakin was taken through our UAV imaging (B). We have deployed smartphones used by the local stakeholders for collecting information on the condition and the activities in the lake (C).

To this end we are executing a multi-phase development program of technology development leading to new lake management systems for decision support, especially during disasters [9], as shown in Figure 1. Phase I is the development phase for new field servers for near real time monitoring of water quality at different depths [10] [11]. This involved design, development and deployment of floating field servers and a low cost SMS-based telemetry system for web based data sharing. Phase II is the development of aerial imaging mapping, so the lake infrastructure and environmental challenges can be well characterized [12]. This has involved fixed wing flights and the gathering of high resolution imaging of different lakes. We describe how local stakeholders and government agencies can make full use of these new images for fishing regulation, disaster assessment or infrastructure development. Phase III is the integration or fusion of several data channels - near real time data, stakeholder input data from cameras and interviews, aerial maps, and lake productivity data - into a coherent lake management system for decision support. We are presently under development of Phase III and will describe a prototype design for our decision support system which pulls together the different data channels for all stakeholders to view. Figure 2 shows the interaction of the technologies of the proposed system.

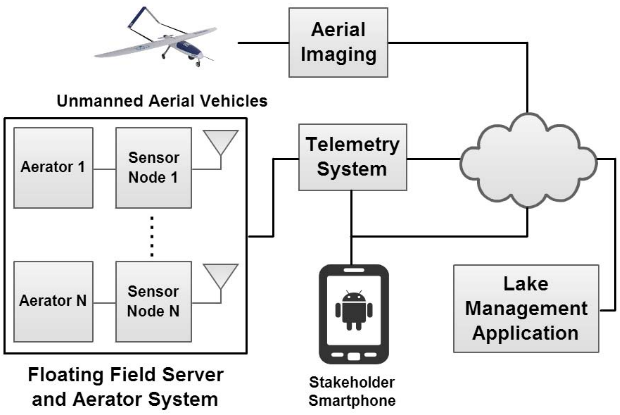

Fig. 2. Diagram of the proposed lake management system. Each field server node may have an integrated aerator system to control. Their data is transferred online through the telemetry system. This diagam emphasizes the use of UAVs for aerial imaging. Various data from the smartphone are uploaded online either directly or through the telemetry system. The sensor nodes of the system are scalable due to its low-cost telemetry system.

II. FLOATING FIELD SERVER AND AERATOR SYSTEM

A. Field server and aerator system design

The field server we deployed in Lake Palakpakin, one of the Seven Lakes, as shown in Figure 3, is composed of the following sensors: dissolved oxygen concentration; temperature and conductivity. These sensors measure at 0.5 and 2.5 m. We used commercial sensors to measure DO. Our temperature sensors are thermistor circuits cross-calibrated with thermometers while our conductivity sensors are made up of two stainless-steel rods separated by small displacements (2.2-2.5 mm) with 5kΩ transimpedances, which are calibrated by comparing our results with the range of values for literature [13] reports on conductivity ranges on distilled water, tap water and water with soap and then determining the right range for monitoring lake water.

The 6 sensors are interfaced to an Arduino microcontroller, which is programmed to average 100 values read from each sensor in one second. These readings are then transmitted via Bluetooth using a shield to the Android phone that we call transmitter phone, programmed to send these data using SMS. The field server sends the data to another Android phone located in Ateneo called receiver phone, which uploads that data to an online database. More details of this system are found in [10].

Fig. 3. 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. Inside the buoy are the aerator pump, LED, Android phone, Arduino interface, battery and charge-controller.

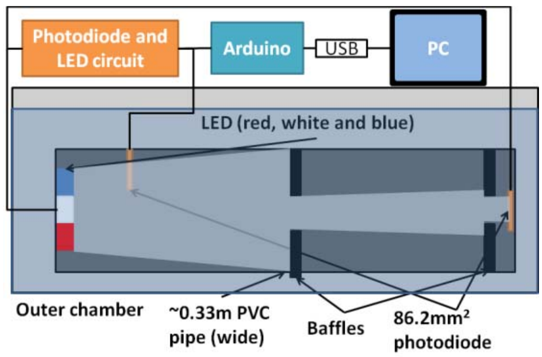

Fig. 4. Turbidity sensor design using a 0.33 m pipe. The Si photodiodes and the LEDs (red, blue and white) are made waterproof. Shown are two photodiodes for self-referencing. For the experiments, a computer reads the measurements from the photodiodes when the chamber is filled with water.

We are also developing a turbidity sensor as an additional sensor to the field server. The design, as shown in Figure 4, is a 33 cm PVC pipe with red, blue and white LEDs at one end illuminating two photodiodes: one in proximity with the LEDs for reference and the other at the end of the pipe to measure the light attenuation through the water sample. We designed the sensor chamber such that the photodiodes only receive light coming directly from the LEDs. An Arduino is interfaced to the photodiodes circuit. Using these values, we calculate the ratio of these powers for the transmittance of light through the water. In-lab experiments show exponential decay of transmittance in water, ranging from 3.27% to 0.10%, at increase in turbidity (simulated by milk concentrations ranging from 0 to 0.48 mL/L). In the lake we demonstrated measurement of turbidity in water by placing water from incrementing depths using a submersible pump until the inner chamber is filled with water, as shown in Figure 5. The results of the lake experiment, seen in Figure 6, show that there is a slight pattern of exponential decrease in transmittance of light as the depth increases. The transmittances at below 1 m correspond to in-lab transmittances using 0.12-0.18 mL/L milk/water.

Fig. 5. Demonstration of pumping method in Lake Palakpakin. This method is used for the demonstration of our sensor measuring water turbidity at different depths. At right is the presence of sediments in water pumped from 3 m.

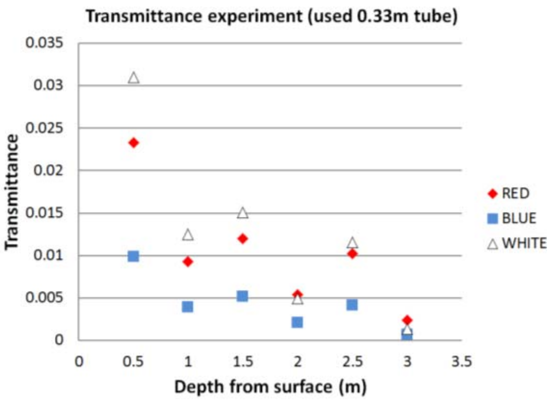

Fig. 6. Results from the turbidity measurement at the lake. It can be seen that light was attenuated the least at 0.5 m below surface and the most at 3 m deep. Light attenuation at 3 m indicates presence of sediments at the deeper parts of the lake.

We are making a new design using pumping method for the floating field server (Figure 7) instead of constantly exposing the sensor to the lake environment. A container houses all sensors to minimize changes in the composition of the water. Multiple inputs for different depths are connected to a selector using solenoid valves. To make a new measurement, the current sample is drained back to the lake using a solenoid valve. This method minimizes the exposure of sensors to elements that can potentially damage the sensors, prolonging their operation until the next maintenance. The sensors are easier to access at the housing making maintenance safer. This design is cheaper as only one set of sensors is needed. We are also designing a sensor to measure the illuminance of daylight on water using large-area photodiodes, cross-calibrated with a calibrated lux-meter.

Together with the field server, we also have deployed an aerator system in the lake using an air pump with air diffusers to supply oxygen to the water in a fish-cage and an LED floodlight to attract fish to the aerated area. With the Arduino-Android system of the field server switching the aerator, we demonstrated the control of its operation either through automatic timing (6 PM to 6 AM) or through a text message or a drop-call to the Android phone. In this way, a lake stakeholder can operate a solar-powered aerator to maintain sustainable DO levels in a fish cage at night. Details of this system can be found in [10].

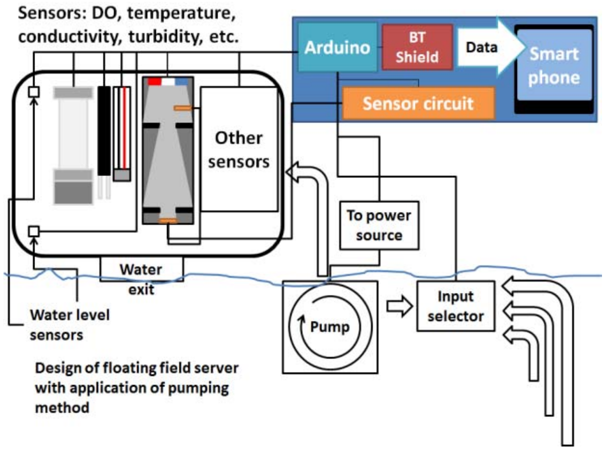

Fig. 7. Pumping scheme for measuring water quality at different depths. A submersible pump places water from a selected depth into a container. The sensors are placed in the container. Water exits at the bottom of container after measurement are made. The Arduino and water-level sensors control the pumping and draining of water.

B. Telemetry system architecture

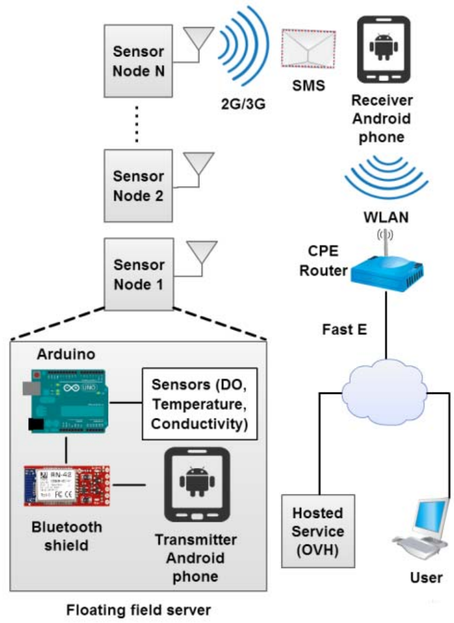

Fig. 8. Diagram of the telemetry system architecture. The use of SMS to transmit data across 80 km makes this system scalable to the use of multiple field servers deployable at the different parts of the lake or at different lakes.

It is very practical to use mobile technology for the data transmission since the field server is around 80km away from our internet server/gateway. Figure 8 shows how the data from the sensors are transferred to the cloud-based web application. The Arduino is programmed to wait for a trigger coming from the transmitter Android phone through the Bluetooth communication to perform the measurements. Transmitter is continuously running an application which, every half hour, triggers the Arduino to collect the sensor readings through the Bluetooth, and then receives these readings. After processing the data entry, it makes a backup of that entry in the phone's micro SD card and then sends it as text message to the receiver phone, which is located in Ateneo. Similar to the transmitter, the receiver also runs its own application which intercepts the incoming text message from the transmitter. After verifying the data coming from the transmitter, this application then extracts the content before uploading the measurement to the online database through Fast Ethernet.

On backing up the data, one month of data is around 100 KB or 1MB for one year. The size of the micro SD card is in gigabytes; therefore memory is not an issue. On data transmission, we use SMS for several reasons. First, it is very affordable as we pay PHP 200 (USD 5) per month for unlimited text, taking advantage of a carrier promo. The volume of data is very light; it does not require a broadband connection. In addition, 2G/3G technology is more widely deployed than LTE or WiMAX in the Philippines.

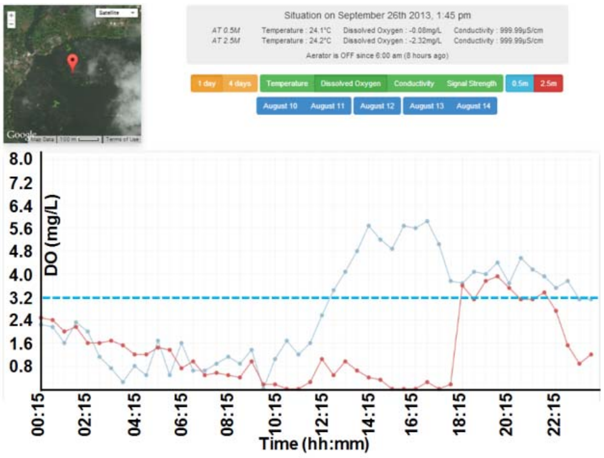

Fig. 9. Web display of the DO readings at 0.5 (blue) and 2.5 (red) meters during August 12, 2013. Each data point represents a sensor measurement every 30 minutes. The blue line at 3.2 mg/L is the minimum sustainable DO levels in the water.

Figure 9 shows the web display with DO data from August 12. The website displays a graph up to the current readings for the day. There are two plots, one for each sensor depth (blue - 0.5m and red - 2.5m). The graph is displayed is the desired quantity vs. time of the day. 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_system 0.php.

In our first deployment, the system operation continued for a year with DO, conductivity, temperature readings taken at 0.5m and 2.5 meters. We maintained the telemetry of the field server with link availability of ~81.87% from July 1, 2013 to July 15, 2014, until Typhoon Rammasun damaged the field server. On the website the daily readings for those days can be viewed with updates every 30 minutes.

III. UAV Imaging

Aside from taking water quality measurements through the field server, a key component of the system is providing updated aerial imagery of the lake. This has become more achievable through the rapid development of UAV technology. Data acquisition is done recently through low-cost custom UAV platforms using semi-professional and hobby-grade components combined with open-source software. Both platforms use commercial cameras. The post-processed maps of the lake are uploaded on VEDA, a common web-based platform, which stakeholders can access. Details of the methodology are found in [12]. A mission plan with altitude of 365 meters was used to map the extent of Lake Palakpakin, which had a lake surface area of one kilometer, and was then repeated monthly or quarterly depending on weather conditions. On a flight altitude of 150 m, we obtain a 3 cm resolution of the image of the lake. The mapping mission started on July 2011 and is still ongoing in order to monitor temporal changes of the lake. We are also extending the spectral bands of our imaging to near-infrared. With the help of our partners in the deployment site, fish pens in the resulting maps were labeled with their respective owners, as shown in Fig. 10.

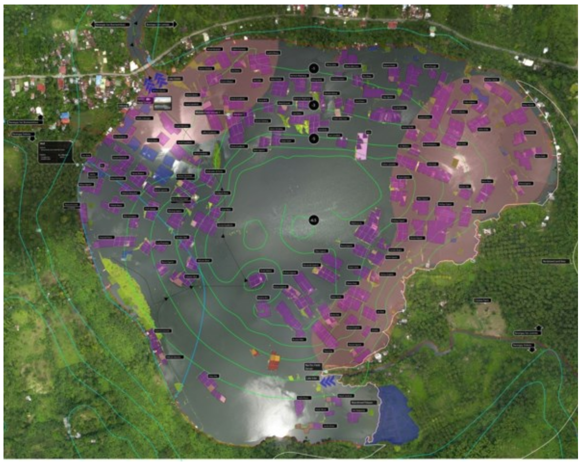

Fig. 10. Aerial image of Lake Palakpakin taken March 2013. This generated aerial map has been overlaid with bathymetry data and annotated information on fish pens. Based on image analysis, the fish pen coverage is at 13.86%, slightly higher than the legislated fish pen capacity of 10%.

A number of things can be studied and quantified using this approach. One example is the compliance with environmental directives of fish pen coverage of lakes. The legislated coverage of fish pens in the lake is 10% of 43 hectares. Based on local knowledge, the coverage is 9 hectares or 20.93% coverage, double the maximum capacity. However, based on fishpen analysis of the aerial image of the lake, the coverage was found to be approximately 5.96 hectares, resulting in 13.86% [12]. This also helped in tracking unregistered units. LGUs and members of Fisheries and Aquatic Resources Management Councils (FARMCs) expressed their satisfaction with the aerial imagery work, which gave them the necessary decision support to have a better understanding of the lake. It allowed them to work together on plans to improve water flow in the lakes via rearrangement of fish pens and determine future steps to promote eco-tourism in the area.

Fig. 11. Aerial image of Lake Palakpakin taken July 2014 after Typhoon Rammasun. It damaged houses, fish cages and destroyed trees. Inset photo is a fish cage with hut damaged by the typhoon.

The use of aerial imaging is also effective for the assessment of damage to buildings, infrastructures and agricultural industries in the lake area. On July 15, 2014, Typhoon Rammasun hit the southern part of Luzon, including San Pablo Laguna. The community of Lake Palakpakin sustained minimal number of casualties but a large amount of damages. These include trees, houses, public structures and fish cages. On July 21, a team was sent to fly over the lake area and was able to gather aerial images, as the weather condition that time was suitable for UAV flight. The generated map, shown in Figure 11, can be compared to the previous aerial maps to assess the damage sustained in the area. This assessment can be presented to institutions willing to provide funding for the rehabilitation of the area.

The aerial imaging can also be used to analyze formation of water hyacinths in the lake, as they can be flow blockages at the inlet and outlet and competition to the aquatic life for oxygen. Analyzing these in the map can help the stakeholders make strategies on the removal of these plants from water. From the map, we can also study the condition of the water through the analysis of turbidity or presence of algae blooms. This analysis can help fisher folk in the lake in decision-making on their aquaculture activities such as feeding, harvesting or introduction of fingerlings. Identification of land use around the lakes and development trajectories will also assist long-term infrastructure and zoning plans.

IV. Development of a Lake Resource Decision-Support System

Aside from collecting information from floating sensors and aerial imaging, the participation of lake stakeholders is a crucial component to the development of a lake resource management system. Their participation adds greater value to the use of the management system because they are the ones collecting information on the condition of the lake and the activities in it. To enable more participation from them, we deployed a low-cost Anrdoid phone to our partner stakeholders that they can use to record various activities on the lake through photo/video-recording or typing text, aside from using it for communication. We also installed an event-recorder in the phone, shown in Figure 12. It is based on the Anrdoid decision-tree application Usbong [14] (downloadable off the web [www.usbong.ph]), similar to Google forms, allowing the fish-farmer to record daily events in the lake. When the stakeholder finishes making an entry, the application converts its content into a text or a file that can be uploaded online either directly or through the telemetry system. The stakeholder can use the phone to take photos of his stock, feeding sessions, harvests and even fish die-off events, which he can upload online directly. He can also use the phone to switch on/off the deployed aerator system outside the timed-operation hours by texting or drop-calling the floating field server. This expands his participation in the management of the lake.

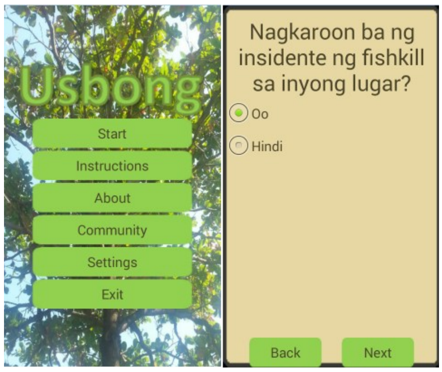

Fig. 12. Decision-tree application (using Usbong platform) on a low-cost Android smartphone for recording events in the lake such as fish kill. The smartphone use will enable engagement of the fish farmer stakeholder and will ensure reliable logging of events on the lake management system.

All data collected by the sensors, from field servers to aerial images to stakeholder Android phones, are combined into a web-based lake resource management system, as shown in Figure 13. In this application, a lake stakeholder can view all information about the lake collected by the field-server sensors, by the aerial imaging and by smartphones used by other stakeholders. Markers are overlaid on the aerial map display of the lake to indicate the deployed field servers. When a marker is selected, an updated collection of field-server data can be accessed. A viewer can also go through the water quality at a specific date. If an aerator is integrated with that field server, its status is also displayed. Other overlays that can be featured in the application are bathymetry data taken by on-site researchers and fish-pen data (owner, yield and species). A stakeholder can view photos he/she or other stakeholders uploaded. Annotations on these photos can be added by any stakeholder. He/she can also view the entries generated from the Usbong application of a stakeholder.

With this lake resource management system, the different stakeholders of the lake can do many things. They can interact with each other on decision-making regarding any activities, zoning and plans for the lake. They can use the information in the application to support or rebut crafted policies that can degrade the lake resource. For the fisher folk, they can also use the information to prevent or mitigate fish kills and increase their productivity, thus raising their profits. This management system can help them on building structures for tourism or farming in the lake area. Increase in information about the lake resource counteracts the complexity of the management of the lake resource and ecology and the decision-making involved. This lake management system is expandable to the other lakes in the Philippines, starting with the Seven Lakes of San Pablo.

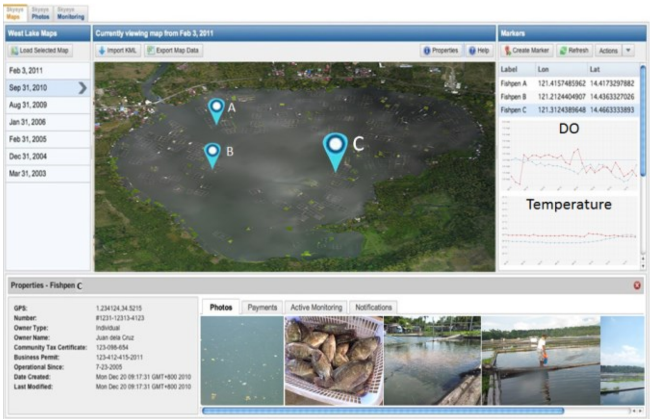

Fig. 13. Lake management system under development. In this application, overlaid in the map are the locations of floating field servers deployed in the lake. Data from each sensor node can be viewed beside the map. Below the map are the photos taken by stakeholders in the lake. The viewer can select an aerial image of the lake by date it was taken.

V. Conclusion

We have demonstrated a novel sensor system with aerator for Lake Palakpakin that provides sensor data at two depths over time. The sensor system has operated continuously and reliably for a year. We also have demonstrated UAV imaging over the lake to quantify fish cage density, water hyacinth coverage and disaster damage. We have demonstrated the participatory sensing by lake stakeholders through daily reporting of lake activities and events using smartphone applications. Finally, we have described how these measurements are being integrated into a web-based decision-support system. These technologies provided the stakeholders with better understanding of the lake and allowed them to make better decisions. We are planning to expand this system using the new field-server design throughout the Philippines in the future.

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