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CyanoSense: A Wireless Remote Sensor System using Raspberry-Pi and Arduino with Application to Algal Bloom

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***Abstract*—Wireless sensor systems have been used in several innovative applications during past few years. However, the key constraints like system design, energy, cost are significantly application dependent. In this paper, we design a wireless sensor system towards an important environmental issue of water quality - Cyanobacterial Harmful Algal Blooms (CyanoHABs). We present a low-cost, low-energy and low-footprint wireless sensor system which can be deployed remotely to monitor the CyanoHABs. We believe that ours is very first low-cost and solar energy based system developed in the domain of monitoring CyanoHABs that helps domain scientists in regular monitoring of freshwater body.**

Keywords- (wireless sensor, raspberry-pi, spectrometers, environmental surveillance)

I. Introduction

Wireless sensor and Internet of things applications are increasingly becoming popular these days. The intensive research and development activities carried towards low cost and low energy devices such as Raspberry-Pi, Arduino, Intel Galileo etc, has paved the way to many innovative sensing and monitoring applications in various domains. However, the choice of sensor, system design, energy and budget constraints of these Internet of things systems are highly application dependent. Water quality, is one such domain that brings vast interest from various researchers, political parties and society.

The quality of water has been severely deteriorating in the past couple of decades owing to several reasons such as wastage dumping, global warming, eutrophication etc. Among the various dimensions of water quality, Cyanobacterial Harmful Algal Blooms has gained a lot of attention recently because of its significant impact on ecology, economy, human and animal health. These blooms produce toxins also known as *cyanotoxins* which cause various health issues such as respiratory failure, gastro-intestinal problems, hay fever, skin rashes etc. As a result, authorities are looking for better ways to monitor the water quality in the city or state-level so as to take appropriate actions.

Fig. 1: CyanoSense kit deployed in Lake Oconee.

There are several water quality monitoring programs involving government and non-profit organizations. A few states have toxins monitoring programs, while others conduct event-based responses and some provide public education focused to human and animal protection from toxin exposure. However, the techniques are still insufficient to provide timely warning of the bloom development across large geographic areas.

Existing monitoring techniques falls into two broad categories: 1) Field based monitoring where domain scientist or government authorities visit lake with specific sensors and/or chemical kit that are very accurate, but are highly resource expensive, irregular and un-scalable; and 2) Remote sensing based monitoring using aerial photography and satellites that are scalable but provide varying levels of accuracies and cost. Although the remote sensing based are promising means of large scale monitoring, rainy/cloudy/foggy day completely prevents any useful data collection from these approaches. In addition, lack of CyanoHAB specific sensor in satellites results in large prediction inaccuracies.

Because of intrinsic accuracy-cost-availability trade-offs of these techniques, it is challenging to monitor CyanoHABs

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across every water body in larger scale. Thus, in CyanoTracker project at University of Georgia, we are integrating various modalities CyanoHAB data from satellites, news feeds, crowd-sensed social media and CyanoTracker mobile app data, and data collected from **CyanoSense** wireless sensor in an multi-cloud infrastructure. Towards, enabling such early warning CyanoHAB infrastructure, we have designed **CyanoSense** which is very first Raspberry-Pi based wireless sensor for assisting in early detection of CyanoHABs. CyanoSense is a low cost wireless sensor system and it overcomes several existing issues faced with traditional monitoring techniques. The design makes use of 2G mobile network and includes carefully choosen components to make the system work even during several overcast days.

We make the following contribution in this paper:

- Design and develop the CyanoSense sensor with careful consideration of factors such as cost, footprint and energy.
- We show energy consumption breakdown of individual components in the system.

In following sections we provide the background of our project followed by overview of remote sensing based algorithms to detect the presence of algal bloom. We then discuss about the choice of sensor, highlight the main goals we set forth for the sensor design and carry a detailed discussion on the sensor design itself.

II. BACKGROUND

A. CyanoTracker Project

In the CyanoTracker project at the University of Georgia, we are implementing an early warning system which monitors cyanobacterial blooms at geographic scale. This project implements a multi cloud framework that integrates community observations, remote sensing measurements, and multimedia data.

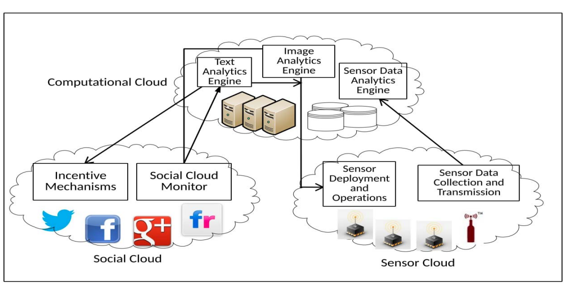

Fig. 2: Cyanobacterial Bloom in Georgia Pond.

Figure 3 shows CyanoTracker architecture, with three main components:- Text Analytics Engine, Sensor Data Analytics Engine, and Image Analytics Engine. Crowd-sensing data from social media and remote sensing data through sensors and satellites will be processed at core engine of the CyanoTracker. Since it is expected that the community generated and remote sensed data will be sparse owing to fewer participation, cost of sensors and spatial resolution of satellites, CyanoTracker will also exploit the domain knowledge and historical information to assess similarities in bloom patterns and develop models to estimate blooms as per the geographic region classification.

B. CyanoHAB and Chlorophyll-a Detection

Cyanobacteria are a class of algae species that contain a light-harvesting protein called *chlorophyll-"a"* to fuel the life process in them. In addition, cyanobacteria also contains another major pigment namely *phycocyanin* that acts as accessory to *chlorophyll-"a"* for food production. These pigments absorb the visible spectrum of sun-light at specific wavelengths (*phycocyanin*(620nm) and *chlorophyll-"a"*(665nm)). This optical property can be utilized by sensors to detect the presence of cyanobacteria.

Based on this principal a material can be identified from its remote sensing reflectance (R_{rs})[1] characterisitc:

Chlorophyll concentraion, NDCI[5] is formulated as:

$$C_{chl-a} \propto \frac{R_{rs}(708) - R_{rs}(665)}{R_{rs}(708) + R_{rs}(665)}$$

and

Phycocyanin concentration, PC3[6] is formulated as:

$$PC3 \propto (R_{rs}^{-1}(620) - (\psi R_{rs}(665))^{-1}) * R_{rs}(778)$$

, where

$$\psi = \frac{R_{rs}(560)}{R_{rs}(665)}$$

, $R_{rs}(665)$ and $R_{rs}(708)$ are spectral reflectance intensity at 665 nm and 708 nm respectively.

III. CyanoSense Goals

The following are the main goals we addressed while designing CyanoSense for monitoring harmful algal blooms:

- **Cost effectiveness** - The system must be cost effective to support large adoption.
- **Low Footprint** - The entire setup must be of low footprint so that it's deployment doesn't raise question from lake managers.
- **Low Energy** - The system should have low energy requirement to make the system operational even during several overcast.

[1]http://www.oceanopticsbook.info/view/overview_of_optical_oceanography/reflectances

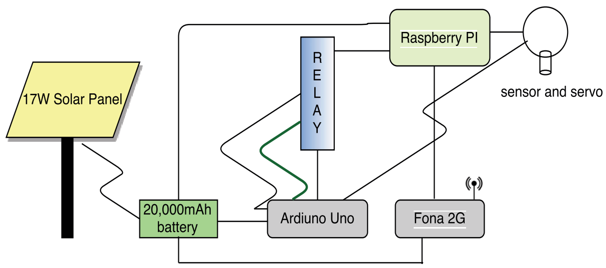

Fig. 3: CyanoSense System Architecture

IV. SYSTEM OVERVIEW

Towards attaining the above goals, CyanoSense makes use of several components. In this section we describe each component, the overall system design and discuss how each of our objectives are achieved.

- **Spectroradiometer Sensor** - Spectrometers are designed to measure the spectral characteristic of a target. We chose STS-VIS hyperspectral sensor from Oceanoptics [2] because it can collect the spectral data in a series of narrow spectral bands thus providing a clear absorption spectra at each and every wavelength. This sensor works in visible wavelength range of 350nm-800nm which covers the required bands for NDCI and PC3 calculation.
- **Battery** - To achieve low footprint goal, we chose portable power bank that can be charged and discharged simultaneously and can resume power supply automatically without manual intervention. After much research we found that Voltaic power banks [3] can be simultaneously charged and discharged and it can automatically resume power supply after draining out completely.
- **Servo** - The sensor needs to take scans of both sunlight intensity(downwelling) and the light intensity reflected back by water(upwelling) in order to calculate the remote sensing reflectance. We included a 180° servo to which the mounted sensor can be optimally utilized instead of investing in two fixed sensors.
- **Adafruit Fona** - To enable wireless data transfer to our cloud server, we included a FONA[4] GSM cellular module. The module is powered by 3.7V LiPoly battery and provides a slot where mobile sim-card can be inserted.
- **Raspberry Pi** - These are tiny system-on-chip devices costing under $35. Since STS-VIS sensors are manufactured to be operated with any USB device driver, it can be easily integrated with Raspberry-Pi's USB output. We install Seabreeze[5] device driver on Raspberry-Pi to operate the sensor and also talk to GSM module for transferring the collected data.

[2]https://goo.gl/IKbjZI
[3]https://www.voltaicsystems.com/v72
[4]https://www.adafruit.com/product/1946
[5]https://oceanoptics.com/api/seabreeze/

- **Arduino** - Arduino is a low cost (< $15) microcontroller used for many Internet-of-Things applications. Couple of main issues with Raspberry-Pi inspired us to include Arduino. First, Raspberry-Pi do not have internal clock to auto-wake up and trigger a scan every day, thus it would need to be powered-on continuously consuming a significant amount of battery juice. Second, if Raspberry-Pi shuts down due to any reasons such as over-heating, it would not power-on by itself unless the input power bank toggles off-on thus needing manual intervention.
- **Relay Switch** - Relays are electrically operated switch that can be toggled via Arduino's GPIO pins. We chose 2-switch relay, one(RS1) to control the input power supply to raspberry-pi and another (RS2) is always kept ON to draw 50mA of current that counts for minimum of 120mA of power is drawn all the time from power bank.
- **3 port USB** - This USB is power interface between power bank and Arduino, Raspberry-Pi and LiPoly battery. In addition to Arduino and RS2, it is always kept on thus counting towards consuming 120mA current in total and preventing voltaic battery from shutting down.
- **Solar Panel** - Since the overall energy requirement of our design is under 20Wh per day, we chose a 17W solar panel to power our system. This panel also provides low footprint.

Fig.3 shows the connectivity of the components described above. The battery serves Arduino, Fona 2G and Raspberry Pi via USB ports. However, Arduino is programmed to drive the overall operation and hence acts as central unit. It controls when the Raspberry-Pi can turn on and off. When Arduino decides to capture a scan, it turns on relay switch which is connected to Raspberry-Pi and simultaneously sends signal to the servo so that the STS-VIS sensor's eye points to the sky for measuring downwelling intensity.

The Raspberry-Pi's boots up, turns on the Fona to synchronize time using NTP servers and triggers seabreeze driver script to allow the sensor to scan the down-welling intensity. After couple of minutes, Arduino sends signals to the servo so that it point the mounted sensor to the water for collecting upwelling intensities. Once the data for upwelling and downwelling is collected, the Raspberry-Pi serially sends the data files along with our sever's ip-address to the Fona module, which then transmits the data to cloud server via 2G mobile network. Finally, Raspberry-Pi turns off Fona, undergoes soft shutdown and Arduino turns off the relay switch thus disconnecting the power from battery to Raspberry-Pi. The system's design achieves first three goals of low cost, low energy and low footprint as described earlier.

A. Cost Breakdown

We study the cost breakdown and the energy breakdown of our system (Table I). The total cost of the standalone system is approx. $2000 with additional cost of $10/month for the 2G

Part	Cost USD	Part	Cost USD
Raspberry Pi	35	**STS-VIS**	1500
Ariuno	15	**17W Solar Panel and battery**	259
Fona 2G	40	**Servo**	12
Relay	9	**Ting module/sim**	10
Misc	100	**Total**	**1980**

TABLE I: Cost breakdown of individual CyanoSense components.

mobile data provider. It is evident that hyperspectral sensor is the most expensive part and owes 75% of total system design cost. However, the usage of servo helped in optimally utilizing the purchase of another STS-VIS sensor saving \$1500. Thus our design meets *cost effectiveness* goal.

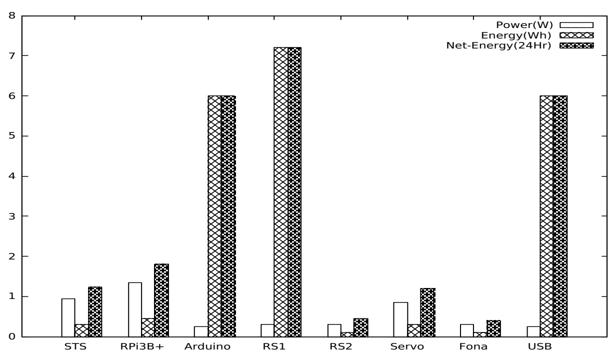

Fig. 4: Net-Energy Consumption break down of various CyanoSense components

B. Energy Breakdown

Fig.4 shows the net-energy consumption breakdown of our system. Though Arduino, USB hub and the relay switch 1(RS1) together seem to consume almost 80% of the net energy requirement, it greatly helps in preventing the battery from shutting down and avoiding a need for manual reset. The net-energy consumption of our system is reduced by about 2.5 times(Table II) by using the power-Optimization techniques.

	W/ Power Optimization	W/O Power Optimization
Net Energy (W/day)	23.65	63.76

TABLE II: Comparison of total Energy consumption per day with and without power optimization design.

V. RELATED WORK

There are few work related to wireless sensors for water quality monitoring. Libelium[7], a commercial company has manufactured Waspmotes that can measure various water quality parameters using sensors that are submerged in water. The waspmote can also transfer the data to cloud using mobile network. However, the current state of art for detecting cyanobacteria requires utilizing the optical characterisitc of it and to the best of our knowledge, our work is the very first wireless sensor system that completely relies on solar energy and detects the CyanoHABs using state of art sensors.

VI. CONCLUSION

The proposed sensor system, CyanoSense, provides a low footprint, low power and low cost solution for the monitoring algal bloom remotely. The use of Arduino and Raspberry Pi makes it efficient and reliable to work in remote environment with no or limited access to electricity. We have deployed the sensor kit in four public lakes and private ponds and have been able to continuously acquire the spectral data for over 6 months now. The CyanoSense system has greatly assisted field scientists and reduced the resource intensive trips.

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