REAL-TIME HYPOXIA MONITORING PLATFORM: FINAL TECHNICAL REPORT

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Abstract:

The persistent environmental problem of bottom water oxygen depletion (hypolimnetic hypoxia) in Lake Erie requires efficient monitoring and abatement programs, which are presently hindered by the lack of affordable instruments that can match the scale of this phenomenon. Using support provided by the Lake Erie Protection Fund and our respective universities, we designed, constructed, and field-tested a low-cost water quality monitoring platform, the Oxybuoy 2. The platform consists of a surface buoy equipped with data logging and communication electronics and an optical dissolved oxygen sensor. The instrument is capable of measuring oxygen concentrations (and, optionally, other water column parameters) and transmitting the obtained data to the shore based facility in real-time. The use of commercial off-the-shelf components allowed us to assemble this fully functional prototype at a fraction of the cost of other existing monitoring platforms. Because of its relatively simple design, low cost, and reliability, the Oxybuoy 2 may form the backbone of a future hypoxia monitoring network in Lake Erie.

Introduction:

Hypoxia, i.e. dissolved oxygen (DO) depletion in the lower part of the water column (hypolimnion), caused by terrestrial, mostly anthropogenic, nutrient loading is an emerging regional, national and global problem. Reduced hypolimnetic oxygen availability negatively affects biological resources, including fish and key invertebrate species (e.g. mayflies). To mitigate the environmental impacts of hypoxia, the phenomenon requires extensive study. However, the dynamics of hypoxia development is poorly understood. Traditional approaches to monitoring DO concentrations rely on using research vessels to collect water samples for subsequent chemical analysis or to deploy DO sensors. These approaches necessarily limit the resolution of time-series as they are expensive due to the vessel operation costs. The measurements are weather-dependent as the ship DO sampling gear cannot be operated in rough seas. In Lake Erie, hypoxia tends to occur over a large area in the central basin and with a single ship it is impossible to measure DO concentration in several diverse locations simultaneously. The lack of real-time basin-wide data matching the scale of the phenomena hinders hypoxia modeling and abatement efforts.

The limitations of traditional approaches stress the need for new high-resolution real-time monitoring tools such as unattended monitoring platforms (buoys). Because hypoxia covers almost the entire central basin of Lake Erie, to monitor and model it properly an array of such buoys deployed in the lake is needed that can record the DO concentrations around the clock at multiple locations simultaneously and relay the data to the researcher. Some sensors will need to be deployed up to 20 miles offshore. Wireless communication at such distances requires high masts and other design options that would make the cost of the buoy prohibitively expensive. However, due to the limited data sampling rate (hours as opposed to seconds), satellite network can be used for data transmission.

Although the technology for creating a hypoxia-monitoring network is available, the market for such sensor platforms is small. Therefore commercial companies would have to charge large premiums to recoup their development costs. Another commercial strategy is to develop a sensor platform that could be used for a variety of studies. Such platform tends to contain features that are not necessary designed for studying hypoxia. Both approaches push the price of a commercial instrument outside the price range where extensive hypoxia studies can become feasible. Meanwhile, advances in electronics and sensor technology enable such a platform construction from of-the-shelf components at costs that make large-scale hypoxia studies practical.

A proof-of-principle Oxybuoy (aka Sensobuoy) prototype have been assembled and tested in our earlier experiments under controlled laboratory and small lake conditions (Nor et al. 2009). The trial runs included a 10-hour wireless data transmission test, incubation in a hypoxic (DO 1.5 mg/l) tank at the University of Akron fish facility, extended battery usage tests to determine the power configuration requirements, and the test deployment with satellite transmission in a small hypoxic lake near Akron, OH. Thus, the goal of this Lake Erie Protection Fund sponsored project was to improve the design and test a fully functional prototype of the Oxybuoy in coastal Lake Erie.

Activities and timelines

This project took place in 2009-2011 and involved the following steps:

- Re-design and assembly of a functional prototype.

- A set of field experiments that exposed the platform to the hydrologically and biologically contrasting environments and allowed us to test the performance of sensors and transmitter under various depths, temperature, and dissolved oxygen conditions.

We configured the Oxybuoy 2 to operate interchangeably with two optical DO sensors: the stand-alone Zebra Tech's D-OPTO and the YSI's 6920 V2-3 compact multi-parameter data sonde (extended deployment). These sensors are equally or more precise at low oxygen concentrations than the commonly used polarographic membrane sensors and have fewer problems with bio-fouling and loss of calibration. The DO sensors were calibrated using the Winkler titration method.

1. **Architecture Description**

The Oxybuoy2 electronics design contains the following main components: Gumstix Overo Air ARM Cortex-A8 OMAP3503 based computer-on-module connected to a Palo 35 expansion module, PIC12F683 Microcontroller, 9602-N Satellite Modem, USB to Serial Converter, YSI V2 6290 optical sensor, switching relay, 4 port USB Hub and a switching voltage regulator. The Oxybuoy 2 architecture diagram is shown in the Figure 1 below. The main data processing and control over the other devices is carried out by the Gumstix embedded system. The expansion board for the Gumstix device provides a wireless module and a USB interface to connect all other devices. A 4-port USB hub is used to connect all USB devices to the Gumstix device. For data storage, a two Gigabyte SD flash card is installed on the Gumstix system. The YSI optical

sensor is controlled by sending commands from the Gumstix to the sensor using a RS232 serial communication. To connect the sensor to the Gumstix we use a USB to RS232 Serial converter. For real-time transmission of data, a satellite modem is used. The satellite modem is controlled by the Gumstix via RS232 Serial communication. To connect the satellite to the Gumstix we use a USB to RS232 Serial converter. The satellite modem allows real-time data to be transmitted to a server for data consolidation. The wireless module on the Gumstix allows backup and debugging communication channel to the system. The PIC processor is used to implement the low-power operation of the system. The PIC turns a device on and off using switching relays. The PIC processor takes input instructions from the Gumstix device via RS232 Serial Communication. The PIC processor is connected to the Gumstix through a USB to RS232 Serial converter. The PIC and Gumstix compliments each other. Gumstix provides flexible user and programmer interface and ease of data storage and retrieval while PIC has low power consumption.
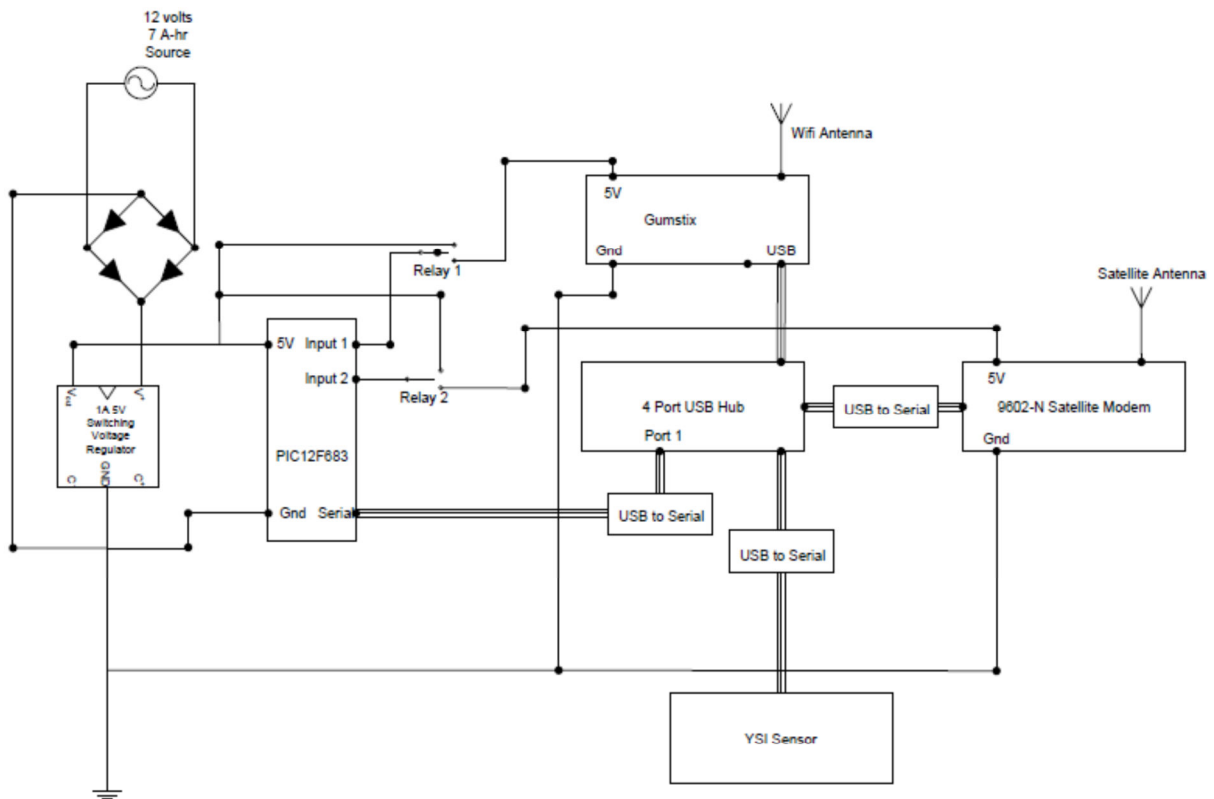

Figure 1. The Oxybuoy 2 architecture diagram

2.   Electric Power Design

There are two modes of the system operation: active sampling mode and power saving sleep mode. The system alternate between these two modes. In the active sampling mode the system draws about 350 mA, while in the sleep mode the system draws only 10 mA. The current drawn is measured using an ammeter connected in series with the device. During the sleep mode, the PIC microprocessor is the only component that remains powered on. The PIC microcontroller keeps track of the clock cycle for the next sampling time. The PIC is programmed to switch to

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active sampling mode during the next sampling time. In active sampling mode, the Gumstix is first turned on. The Gumstix device will then send commands to the YSI sensor to read data collected by the YSI sensor and prepare it for transmission. The Gumstix device will then issue a command to the PIC microcontroller to power on the satellite device to transmit data. The satellite will send data and return an acknowledgement to the Gumstix device upon successfully transmitting. After receiving an acknowledgement from the Satellite, the Gumstix device will calculate the next sampling time. It will then instruct the PIC to switch into sleep mode for the given next sampling time. If transmission fails, the system will save the data information for later transmission. The system components require a reliable 5V DC power. We use a 5V 1A switching voltage regulator to provide stable voltage to the system. This regulator has conversion efficiency of up to 90% which helps to minimize power consumption. The YSI sensor uses its own internal battery storage.

### 3.   Programming and Operation

Gumstix main processor runs an open embedded operating system, a flavor of Linux for embedded systems, which allows us to easily interface programming environments on the Linux kernel. Programs in python are written and loaded into Open Embedded to handle communication between devices and system maintenance tasks. The system operation is as follows. When Gumstix is powered up, Gumstix communicates through the USB to RS232 serial converter to request a reading from the YSI sensor. The data is saved into a local database on the Gumstix SD card. After collecting the data, Gumstix instructs the PIC to turn on the satellite device. The Gumstix will then checks its database and prepare unsent data to be sent via the satellite. During satellite communication, the Gumstix waits for 2 minutes till the signal strength is sufficiently for transmission. If it is not sufficient, the data is saved and transmitted during the next cycle. When the signal strength is sufficient, the Gumstix will send the data. The satellite modem will return an acknowledgement upon successful transmission. If the Gumstix fails to receive an acknowledgement, it will try for at most 3 times to retransmit the data. If transmission still fails, it will save the data for transmission during the next cycle. After satellite communication, the Gumstix will update sent and unsent data on the database. Gumstix will then calculate the next sampling time and instruct the PIC to power down the system for the given sampling time. During its uptime Gumstix powers up the wireless card and remains accessible over the wireless channel for status checks and configuration updates. Gumstix is programmed to receive control commands from the satellite. In particular the sampling rate can be changed remotely.

4. The buoy construction

We constructed a buoy (Fig. 2) that can be deployed down to 80-feet depth. The buoy has inner and outer shells. The outer shell is a hermetically sealed 6" PVC pipe housing the ballast and the battery. The inner shell (3" PVC pipe) houses the electronics. The cable connecting the oxygen sensor and the satellite antenna are fed through the silicone-sealed holes in the screw-on pipe cover. We computed the weight of the ballast to have the buoy submerged about three-fourths in the water so that it is stable yet the top of the buoy with satellite antenna is above the water. To provide stability against waves and lake currents, the buoy is moored with two anchors separated 50 feet at the bottom level. The DO sensor is attached to a data wire that is suspended separately and secured at the bottom by a 12-feet steel pipe serving as both an anchor and the instrument separator. The instrument itself is held 4 feet above the bottom by a float. The anchors are

attached by a galvanized sheathed steel cable. To reduce the wave-action wear on the cable, we used 10 feet of chain to attach the cable to the anchors. The buoy and its electronics equipment were tested on-land prior to a lake deployment. The buoy was attached by a chain to a single anchor point. We first tested the seal in a separate short deployment. After the week-long deployment the design proved sound. Although, some moisture permeated the outer shell, the electronics remained dry. In the test deployments described below the buoy design proved robust enough to support the instrument in protected and semi-protected coastal waters. However, they also indicated that deploying the Oxybuoy in the high energy environment of open Lake Erie and/or in combination with a wave-driven vertical profiler would require a larger, heavy-duty buoy and anchoring system. Purchasing or constructing such a buoy was beyond the means and scope of this pilot project.

Fig. 2. The Oxybuoy 2: A the electronics packaging, B – the outer buoy shell, C – test deployment in Lake Erie (OWCNERR)
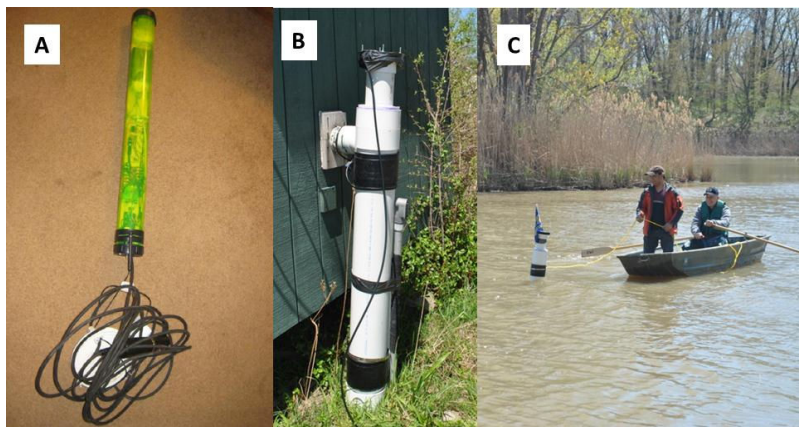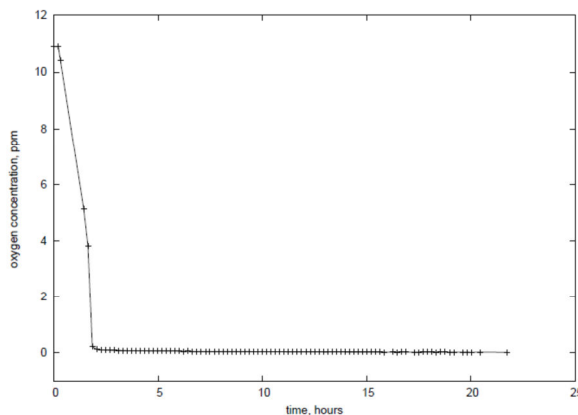
5.   Field Tests:

In 2009, the Oxybuoy was deployed in Bath Lake. Before the main deployment we tested the operation of the electronic components through wireless connection then through the satellite messages. During the deployment we did not use the multi-mode operation due to interference with DO sensor measurements. We used active sampling mode only and allowed the buoy to run until the battery charge was exhausted. During the deployment, Oxybuoy reported DO measurements 6 times per hour. Running in this mode, Oxybuoy remained operational and reported DO measurements for over 18 hours (Fig.3)

Fig. 3 Dissolved oxygen readings transmitted over a satellite link.

In Fall 2010, the buoy was further tested in the White Star Quarry, which has sufficient depths to simulate conditions in the central basin of Lake Erie. Although the initial testing proceeded well, the subsequent in-situ test was marred by an accident. During the deployment from a small boat, the communication electronics module,

which is designed to operate at the surface, became submerged at 60 ft depth due to a human error (an entangled wire). Eventually, we recovered our equipment with the help of a scuba diver (Dr. Francisco Moore, University of Akron Biology, Fig 4).
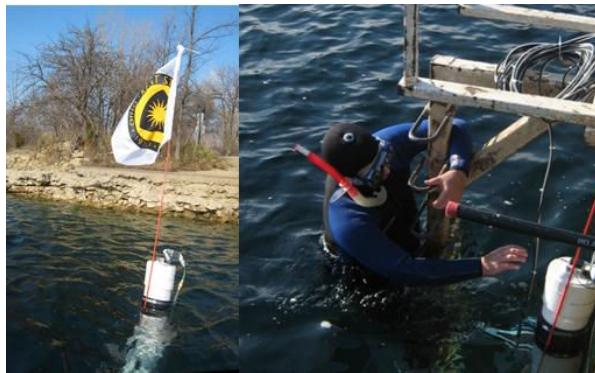

Fig. 4 The Oxybuoy 2 in the White Star Quarry

The electronics have been mostly rebuilt and we needed to purchase a few parts to get the instrument ready for additional testing. A further delay was caused by Iridium when it discontinued the satellite modem that we used in the original prototype. Its replacement, Model number 9602-N, became available in 2011.

In May and October 2011 we conducted a set of field experiments at the Old Woman Creek National Estuarine Research Reserve in Huron, OH, where the sensor platform was tested in the hydrologically and biologically dynamic environment of coastal Lake Erie. A set of water quality parameters, including water temperature, conductivity, DO, and chlorophyll a, was recorded every 10 minutes for several days using the YSI data sonde and transmitted through a satellite link to our laboratory PC (Fig. 5). During the October deployment the instrument continued operating normally despite being subjected to the fluctuating water level and storm-induced turbulence. Thus, the Oxybuoy prototype can be deemed fully functional.
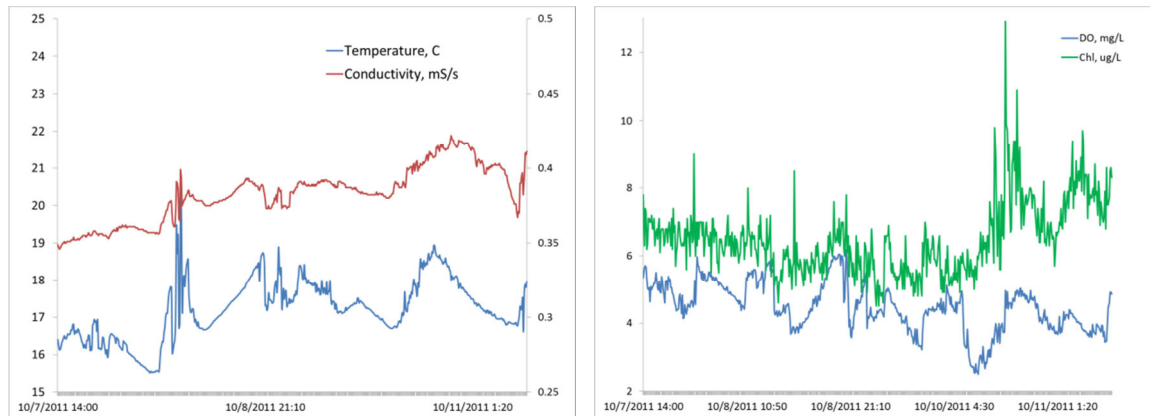

Fig. 5. The water column parameters recorded and transmitted by the Oxybuoy 2 during the October 2011 deployment at OWCNERR.

The Appendix A shows cost estimates for constructing the Oxybuoy. If configured with the coastal buoy and the stand-alone DO sensor, the platform can be built for slightly less than $5,000. The addition of the data sonde with CTD and optical DO and chlorophyll a sensors will increase the cost to $6,500. If these components are installed on a heavy-duty offshore buoy the platform will cost ca. $21,000, which is roughly equal to the daily operation cost of a fully-equipped research vessel such as the US EPA Lake Guardian.

APPENDIX A. Oxybuoy Cost Estimate (Parts Only):

Hardware	Description	Units	Price*	Total
Gumstix Overo (Computer on Module)	The Gumstix Overo® Air COM is a tiny, ARM Cortex-A8 OMAP3503 based computer-on-module that communicates via 802.11g and Bluetooth, is low cost, high performance and production ready. Network connect your product and manage it wirelessly, while the Cortex-A8 delivers the performance you crave.® Air COM is a tiny, ARM Cortex-A8 OMAP3503 based computer-on-module that communicates via 802.11g and Bluetooth, is low cost, high performance and production ready. Network connect your product and manage it wirelessly, while the Cortex-A8 delivers the performance you crave. https://www.gumstix.com/store/product_info.php?products_id=226	1	199.00	199.00
Palo 35 Expansion Board	An expansion board for any Overo COM features USB Host, USB OTG, USB console, stereo audio, a power input jack and a 40-pin header SV1 for A/D, GPIO, SPI, PWM, I2C, 1-wire and 2-wire. https://www.gumstix.com/store/product_info.php?products_id=242	1	59.00	59.00
5V US Power Adapter	Power Supply for development https://www.gumstix.com/store/product_info.php?products_id=70	1	10.00	10.00
2GB Micro SD	2GB of storage in a card smaller than a postage stamp! https://www.gumstix.com/store/product_info.php?products_id=200	1	20.00	20.00
USB to RS232 Serial Cable	GWC UC320 USB 1.1 to Serial Converter Cable http://www.newegg.com/Product/Product.aspx?Item=N82E16812107108	3	15.00	45.00
PICAXE 8 Pin Proto Kit	Basic beginner's kit for 8 pin PICAXE microcontrollers. http://www.sparkfun.com/products/8321	1	3.95	3.95
PICAXE 08M2 Microcontroller (8 pin)	PICAXE is a neat entry-level microcontroller system that is relatively cheap to get started with. The chip is programmed with a simple serial connection http://www.sparkfun.com/products/10803	1	2.95	2.95

Communication Device				
9602-N	Model 9602-N is a pocket-size satellite modem designed to operate with the Iridium network in SBD-only data mode. Similar to a standard land-line modem, the 9602-N can be controlled by any DTE (data terminal equipment) capable of sending AT commands via a serial port. A DTE can be a desktop computer, a laptop computer, a PDA, or even a micro-controller. Model 9602-N has the same DB25 multi-interface male connector as on the A3LA series and, therefore, can be retrofitted into existing SBD only applications that utilize the A3LA-based products. http://www.nalresearch.com/IridiumHardware.html	1	455.00	500.00
SAF5350-A	Model SYN7391-C is a small, inexpensive L-band antenna designed to operate with the NAL Research's A3LA and 9601 satellite modems and trackers. It is optimized to operate under various data modes specifically for SBD.	1	45.00	45.00
Sensors (alternative)				
YSI 6920 V2-3	YSI compact data sonde with optional optical DO and standard CTD sensors and 90 ft data cable http://www.ysi.com/productsdetail.php?6920-V2-3	1	5,000.00	5,000.00
D-Opto SDI-12	Zebra-Tech Ltd Stand Alone Optical DO Sensor with a 25 ft data cable http://www.globalw.com/products/d_opto.html	1	3,375	3,375
Buoy hardware (alternative)				
Coastal buoy used in this study	PVC pipes, caps, buoyancy material, epoxy, chains, steel wire, anchor, misc. hardware All parts are available through local and online venders such as Home Depot, Ace Hardware, Grainger etc.			~450.00
Heavy-duty offshore Great Lakes buoy	Nexsens CB-1500 http://nexsens.com/products/nexsens_cb-1500.htm	1	15,000	15,000

*The prices and part availability were current at the time this report was written.