# Water quality monitoring using STORM 3 Data Loggers and a wireless sensor network

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**Abstract:** Sustainable water management decisions are often made with the support of water quantity and water quality models with a focus on prediction uncertainty. Unfortunately, limited observational data severely constrains the design of accurate water models for these decisions. This paper presents our initial efforts to deploy STORM 3 data loggers and a wireless sensor network (WSN) to collect real-time and in-situ data at fine temporal granularities to monitor the pond at Lamar University in Beaumont, TX. Specifically, we present the details about how to set up STORM 3, integrate H-377 water temperature sensor probe from WaterLOG, and validate collected water temperature data. We further explain our prototype WSN and a variety of third-party probes to collect water Dissolved Oxygen (DO) and Water pH values. Our deployed STORM 3 and NI-based WSN have been able to collect water temperature, DO, and pH values consistently and periodically in a real-time manner.

**Keywords:** wireless sensor networks; WSNs; STORM 3 data logger; water quality monitor.

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## 1 Introduction

Sustainable water management decisions are often made with the support of water quantity and water quality models with a focus on prediction uncertainty. Limited observational data and scientific knowledge are often incompatible with the highly-detailed hydrodynamics and models. Therefore, there is an urgent need to integrate new technology to collect necessary data to develop models for water quantity and quality models.

Wireless communication has become ideal candidate to enable various efficient water parameter collection technologies (Xiao et al., 2011, 2012). The convergence of wireless technology and the internet makes it feasible to deepen our understanding of water resources and to develop models for their sustainable management. The real-time data collection could greatly help us understand water availability, quality, and dynamics.

Cloud hosted data collection platforms and distributed wireless sensor networks (WSNs) represent two of the most popular wireless communication technologies. In this paper, we report our initial research effort to deploy a cloud hosted data collection platform and a WSN to collect real-time and *in-situ* data at fine temporal granularities to monitor the pond at Lamar University in Beaumont, TX. Specifically, we utilise STORM 3 data loggers (Storm 3 Data Logger) from *WaterLOG* (Waterlog) as an example cloud hosted data collection platform and the WSN system from *National Instruments* (NI) as an example of WSN.

The STORM 3 Data Logger is solar powered and properly sealed. It also contains a GSM/GPRS modem to wirelessly transmit the collected data to a cloud platform, which could be accessed by remote researchers. For the sensor probes, we currently adopt H-377 (H-377 Temperature Probe), which utilises a thermistor and resistor combination for temperature measurement in the water. It could provide reliable data acquisition probe and it is calibration free. It may provide fast and accurate measurements in temperature values. Its sealed and corrosion-resistant enclosures also make it desirable to be deployed in a water environment (H-377 temperature probe).

We utilise NI 9791 (WSN-9791 Ethernet Gateway) as the Gateway and NI 3212 (WSN-3212) and 3226 (WSN-3226) as the wireless modules. NI 9791 is a programmable controller and integrated with NI LabVIEW (LabView) real-time module. It can be flexibly programmed to communicate with WSN devices. For the sensor probes, we adopt *Sensorex* (Sensorex) DO6400 series dissolved oxygen probe to measure dissolved oxygen in water. The submersible DO6400 features a large capacity electrolyte holder, positive fit, easy to replace membrane, and dependable galvanic cell technology for long term deployment. We adopt *Sensorex* S8000 pH Electrodes coupled with EM-800 battery powered unity gain amplifier to measure water pH values, and S8000 pH flat surface Electrode platform is designed for versatility and flexibility. It has a modular electrode and easily maintained.

The rest of the paper is organised as follows. We present related work in Section 2. In Section 3, we present the detailed design of our systems. In Section 4, we present the results of our collected dada. We conclude our paper and discuss the future work in Section 5.

## 2 Related work

Our proposed system lies in the intersection between cutting-edge wireless technology and water sustainability research. Over the past few years, there have been numerous products which utilise state-of-the-art technologies to collect various sensor parameters. Cloud hosted data collection platforms (Xiao and Xiao, 2013, 2014; Xiao et al., 2014) and WSNs are two of the representative examples in this respect.

WSNs (Akyildiz, 2002; Wu et al., 2005; Wang and Xiao, 2006; Liu et al., 2006; Xiao et al., 2010) have enabled various applications. However, most WSN deployments are designed for short-term experiments or proof-of-concept demonstrations, instead of long-term operations (Goodney and Cho, 2012; Tennina et al., 2009). There are still significant practical challenges when applying WSNs to multiple cross-disciplinary domains. Outdoor WSNs have been deployed in a wide range of scenarios and always been reported as a challenging task. In our initial work (Sun, 2014), we utilise the products from the *National Instruments* to build a proof-of-concept WSN to collect dissolved oxygen and water pH values. We are also building a WSN prototype based on the popular *eKo Pro Environmental Monitoring System* and *MicaZ/IRIS* motes (Memsic) and various third-party sensor probes. To the best of our knowledge, we are not aware of any other existing study which applies WSN measurements to surface water transport models, and assists the decision making on the sustainable water resource management. Some of our experiences and insides are presented in the paper and may be valuable for other researchers.

In the meantime, there also exist various third-party sensor probes to collect water parameters. For example, water pressure measurement sensors from *Stevens Water Monitoring Solutions* (Stevens), water temperature and velocity sensors from *Waterlog*, dissolved oxygen sensors and water pH sensors from *Sensorex* (Sensorex). Careful assembly is necessary to integrate these sensor probes to various wireless communication systems.

## 3 System design

Figure 1 illustrates the overall network architecture of our deployed system based on STORM 3 Data Logger and a WSN to monitor water quality of the pond close to the John Gray Center at Lamar University, Beaumont, TX. STORM 3 Data Logger, NI wireless modules, and their associated sensor probes are deployed around the pond. In the WSN based system, the collected data are transmitted wirelessly to the Gateway, which is connected to the internet. Students and Faculty members at *Wireless and Mobile Computing Lab* are able to remotely retrieve these data in a real-time manner. In the meantime, they will also be able to remotely monitor the health status of the deployed system over the internet. In the system based on STORM 3, the STORM 3 Data Logger utilises a cellular communication to transmit collected sensor data to *STORM Central server*, which could be accessed remotely through internet. The collected data are accessible to students and faculty members in the Hydraulic Lab at Lamar University for analysis and modelling.

We detail our design of these two systems in the following subsections.

### 3.1 STORM 3 based water data collection

#### 3.1.1 Deployed STORM 3 Data Logger

Two H-377 temperature probes are connected to STORM 3 and deployed to monitor the water temperature. The collected data are transmitted wirelessly to a cloud computing platform, where researchers could access remotely. Figure 2 illustrates the internal connection between the H-377 temperature sensor probes and the STORM 3 Data Logger.

**Figure 1** Deployment of a STORM 3 Data Logger and a WSN to monitor water quality in a pond close to John Gray Center at Lamar University, Beaumont, TX (see online version for colours)

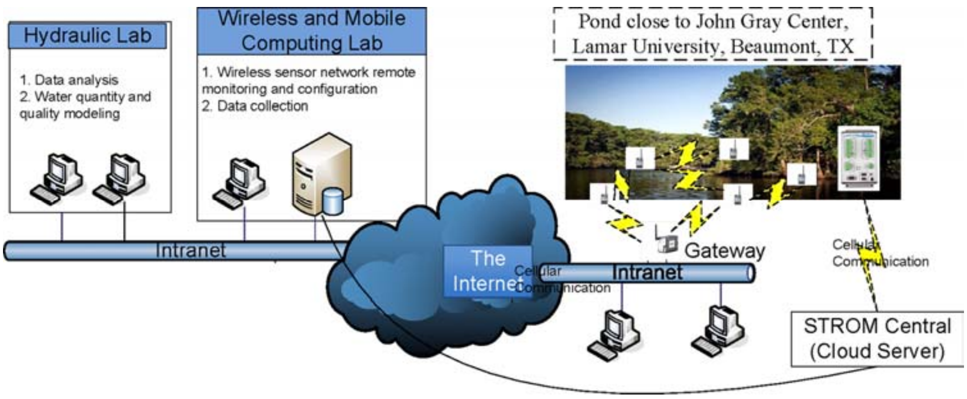
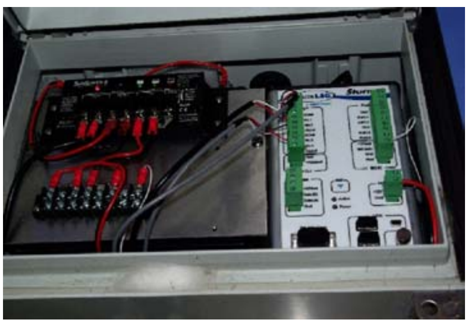



**Figure 2** Internal connection between the H-377 temperature sensor probes and STORM 3 Data Logger (see online version for colours)

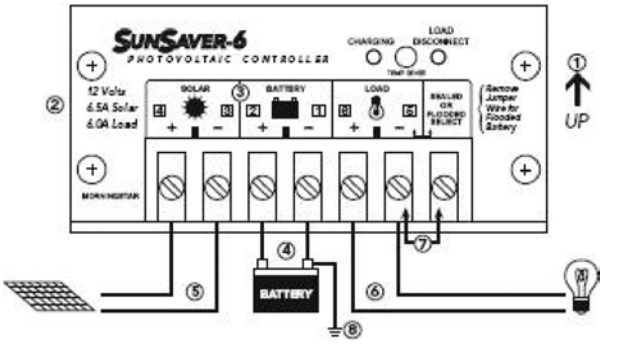


We are using *WaterLog* Storm Solution which includes Storm 3 Data Logger, cellular GSM/GPRS modem, fibreglass enclosure, 18 Arh Battery, 20 Watt solar panel, and SunSaver-6 photovoltaic system controller. STORM 3 is installed with a variant of the Linux based operating system. It is equipped with a GSM modem, which enables to transmit the collected water temperature data to a STORM Central, a platform based on cloud computing. Remote users in the *Wireless and Mobile Computing Lab* will then be able to remotely access these data through a browser-based graphical user interface, such as *Firefox* (Firefox) or *Internet Explorer* (Internet Explorer). The collected data are accessible to students and faculty members in the *Hydraulic Lab* at Lamar University for analysis and modelling.

We use *Storm Central* platform (Storm Central), a cloud based data collection platform, to host the transmitted data from *Strom 3 Data Logger*. This will enable researchers to view and download the collected data anytime and anywhere.

The *SunSaver* is a fully automatic photovoltaic system controller. Battery charging is managed by a constant voltage management controller so that it prevents reverse current leakage at night. Its connection diagram is illustrated in Figure 3.

**Figure 3** STORM 3 power supply system




### 3.1.2 *Configuration of STORM 3 Data Logger*

The configuration of the STORM 3 Data Logger includes the following steps:

- *Modem Setup*: STORM 3 Data Logger is equipped with a cellar modem GSM-GPRS, which is a built-in internal cell modem module. The service provider is CrossBridge. The name of the access point is *gprs02.motient.net*, which was provided by Waterlog when we purchased the service. The GSM Frequency band is dual 850/1900, which is standard GSM frequency. After the connection is successfully tested, the service provider IP will be displayed. The screenshot in Figure 4 demonstrates this process.

- *Storm Central Setup Configuration*. We configure the data transmission rate as once every 15 min. The server type is *Storm Central server*, in which all the data will be logged and saved in the STORM server. We need to obtain a registration ID from Waterlog in order for verifying registration.

The major setting of our system is displayed in Figure 5.

**Figure 4** Storm 3 modem and connection setting (see online version for colours)

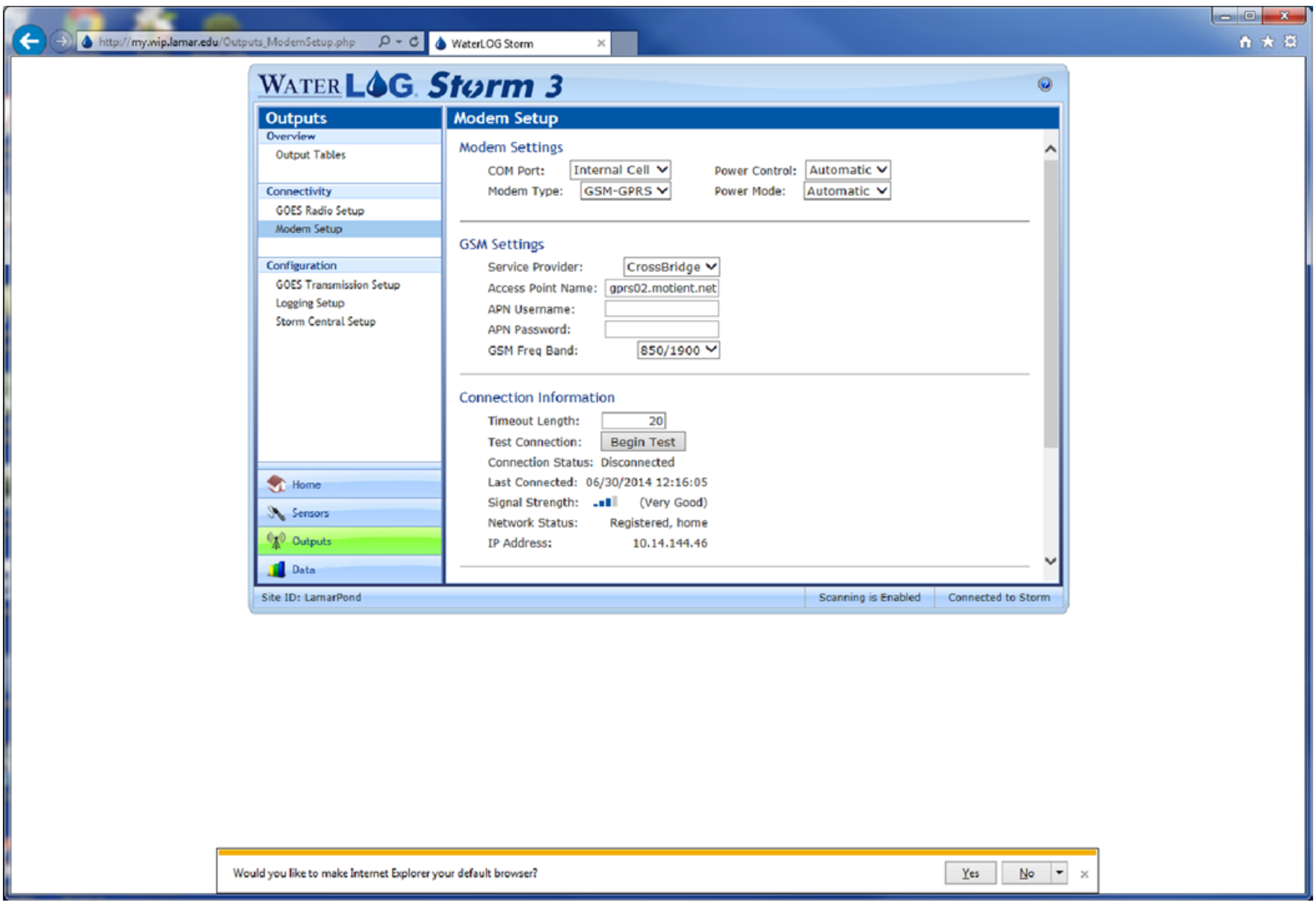
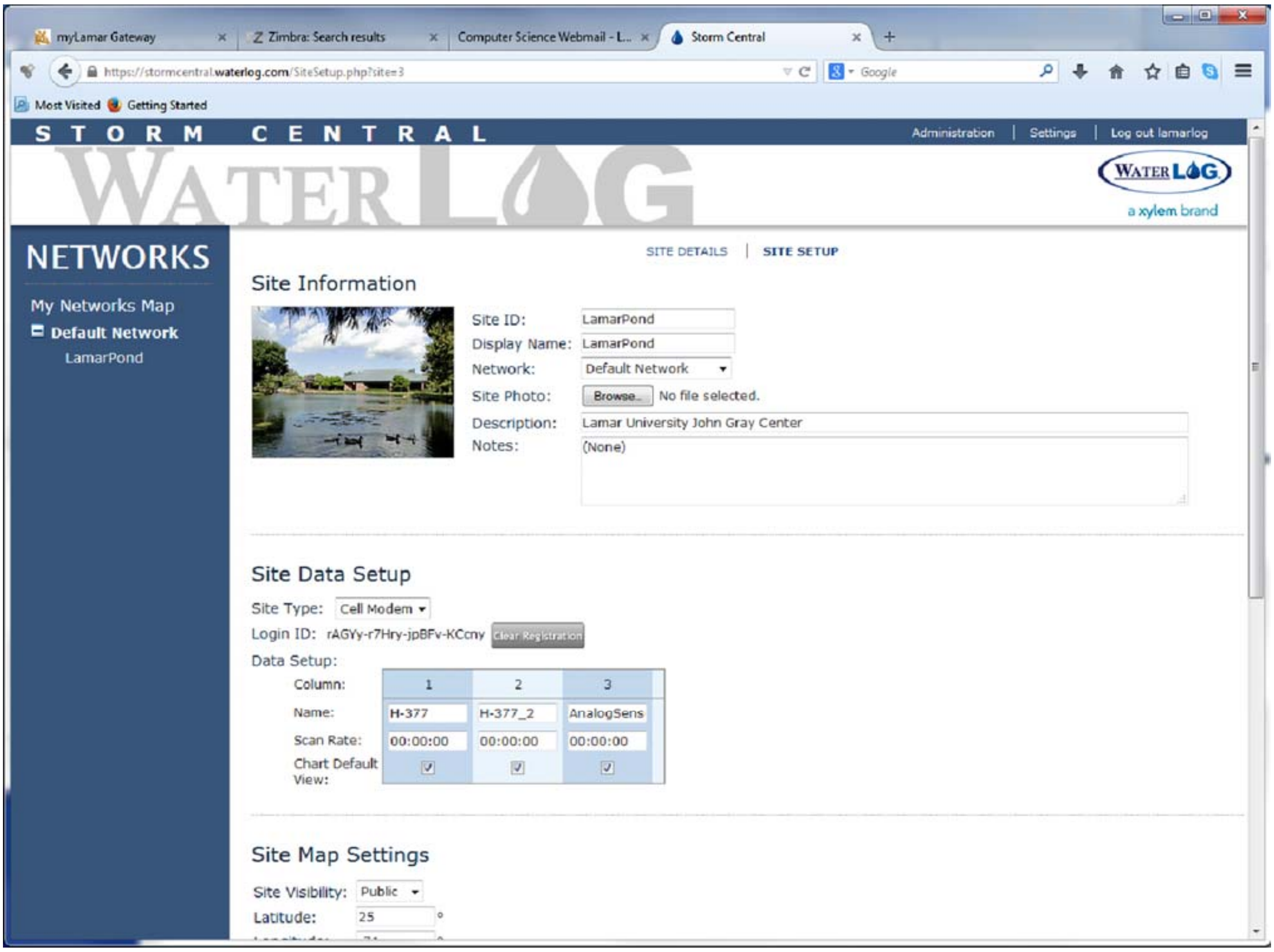


**Figure 5** Setting of STORM 3 Data Logger (see online version for colours)




### 3.1.3 Deployment of STORM 3 Data Logger

Our next task is to enclose the STORM 3 Data Logger and attach the water temperature probes. Proper enclosure is very important because ideally, nodes should be deployed outside for a long time. These nodes should be immune to bad weather, especially when it is deployed closed to the water. Luckily, *WaterLog* provides accessories to enclose the nodes.

After the STORM 3 Data Logger is properly assembly in the lab, we are ready to move to the field – the pond close to the John Gray Center at Lamar University. We select a location which is close to the pond, so that the H-377 water temperature probe could be deployed at the proper location in the water. We dig a hole deep into the ground to secure the pole. Because of the solar panel, we need to deploy it at location with enough sunshine. The final deployment is illustrated in Figure 6.

After the initial deployment, we head back to Lab 209 to check the system status of the deployed system. We periodically remotely access the health status of the deployed system to make sure it will collect the data successfully. Our experience indicates that the STORM 3 is quite stable, and little effort is required to maintain the system.

**Figure 6** Deployment of STORM 3 Data Logger and H-377 Temperature Probe to monitor the pond close to John Gray Center at Lamar University, Beaumont, TX (see online version for colours)

## 3.2 *Wireless sensor network based water data collection*

### 3.2.1 *Challenges*

Experience has demonstrated that developing large-scale, long-lived outdoor WSNs is challenging. Besides the fundamental challenges of WSNs, including power supply, limited memory, the need for unattended operation, and the lossy and transient behaviour of wireless communication, WSNs also need to be tailored to fit unique application domain requirements.

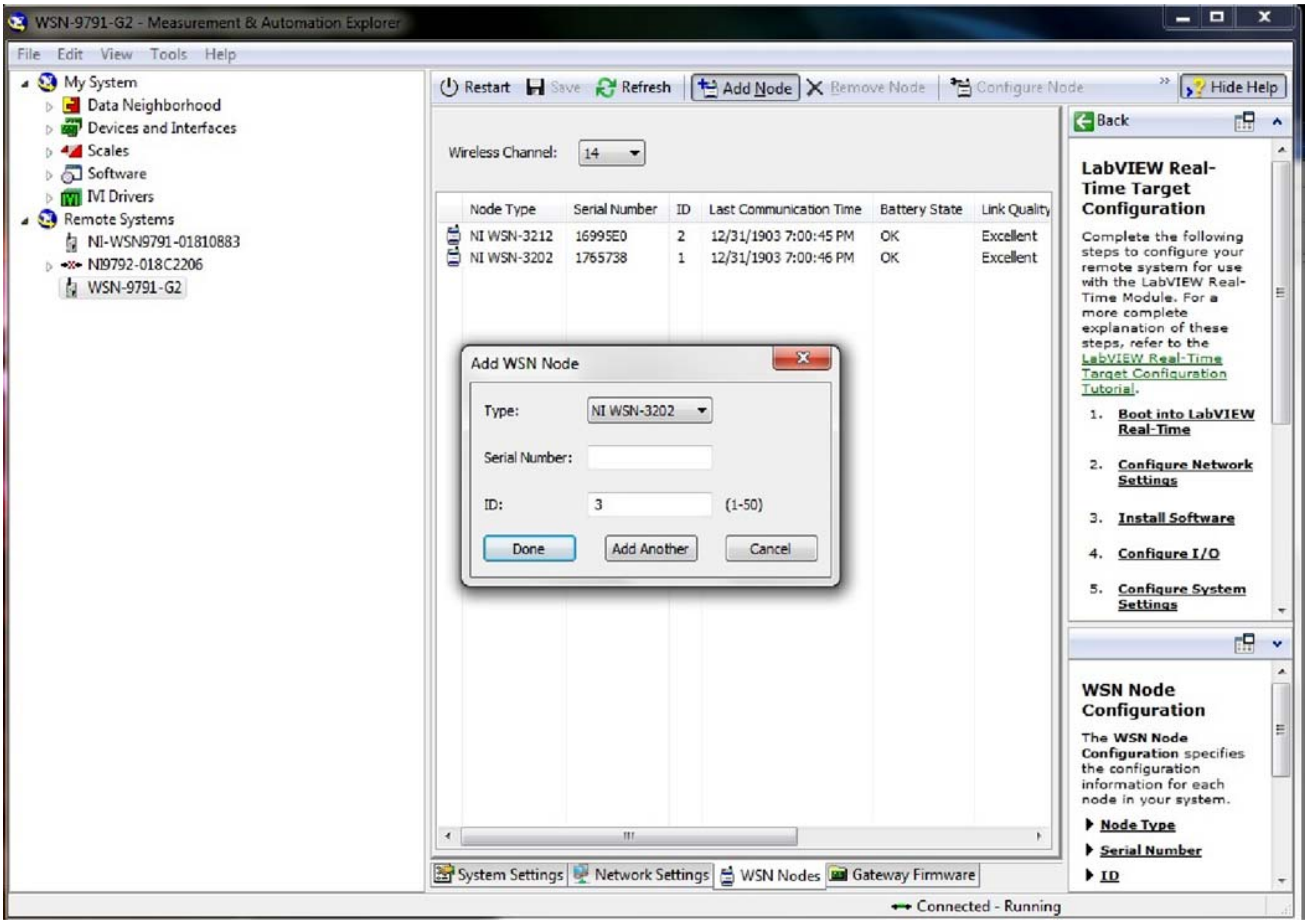
Besides the network infrastructure, it is also challenging to connect third-party sensors to wireless modules to measure various parameters. After making the prototype system in a lab setting, significant time and efforts are still needed to maintain the deployed WSN system in the field.

It is very time consuming and challenging to design and maintain a WSN. Wireless modules require low level operations to configure. Loss of connectivity is very common, owing to various factors, such as running out of battery, hardware failure, software fault, change of environment, etc. It is very time consuming to debug and to diagnose unexpected indoor and outdoor network problems. Moreover, compared to traditional computer science research which very often uses simulation techniques, deploying a realistic WSN requires significant amount of field work. Last but not least, compared to traditional equipment to measure water parameters, sensor probes used in WSNs are still relatively inaccurate. Much time and efforts are still needed to calibrate and verify them. Once deployed, these sensor probes require extra work to guarantee the accuracy of the collected data.

### 3.2.2 *Deployed WSN*

For our trial WSN system, we deploy the *NI WSN-9791* WSN Ethernet Gateway (*WSN-9791*). NI *WSN-9791* is a programmable controller and integrated with NI *LabVIEW* (LabView) real-time module, and it can be flexibly programmed to communicate with WSN devices. NI 3212 (WSN-3212) and *NI 3226* (WSN-3226) measurement nodes will be deployed offshore. *NI 3212* and *NI 3226* are programmable measurement nodes which can provide a radio transmission range up to *300* m. *NI 3212* provides four *24*-bit thermocouple input channels. *NI 3226* supports a wide range of measurement types. Both of them offer analogue input channels and digital I/O channels that a user can configure for input and output. *LabVIEW* software will be used in desktops to collect, analyse, and present data from the deployed WSN.

**Figure 7** How to remove one NI wireless module from one gateway and register this module to a different gateway



We use *Sensorex* (sensorex) *DO6400* series dissolved oxygen probe to measure dissolved oxygen in water, *Sensorex S8000* pH Electrode, and EM-800 battery powered unity gain amplifier to measure water pH values.

For any to-be-deployed NI wireless module, we first test this module in Lab 209 – wireless and mobile computing lab. After this testing, we then move this module to the field for deployment. We encounter one problem when we do this: we have two Gateways; one is for lab experiment and another has been deployed at field. For calibrating the sensors and testing the connectivity of wireless nodes, we have registered the wireless nodes to the lab gateway. After completing the calibration and testing phase, we have to register the wireless nodes to the gateway that has been deployed at the field. The problem occurred at the moment when we try to connect those nodes to the field gateway that have been already registered to lab gateway. According to the manual, a node can only communicate with one gateway at a time. To disconnect the nodes from connected gateway, we have to reset each node by pressing the reset button for 5 s. We then need to register those nodes by putting their serial numbers in new gateway using NI Measurement & Automation Explorer (NI MAX) application. Finally, we need to make sure that nodes are located within the range of gateway so they can establish communication.

Figure 7 illustrates how to solve this problem.

### 3.2.3 Calibration of DO and PH sensors

The pH sensor by *Sensorx* is connected to the NI WSN-3202 node. The pH sensor probe is calibrated based on a linear scale. At pH of 7, the value returned from the sensor should be 0. Therefore, to offset any error, there must be a y-intercept and slope ($b$ and $m$ respectively), and for each sensor this is a distinct $m$ and $b$ values. These values are fed into the multiplication tile as well as the raw data value from the sensor. The result from this operation is then fed into the addition tile and added to the calibrated $b$ value for each sensor. Figure 8 shows the calibration of pH Sensor probe S8000 pH Electrode.

The DO sensor is attached to the WSN- 3212 module. The dissolved oxygen value is measured in Parts per Million (ppm). To find this value, the following equation must be used:

$$DO_{ppm} = \frac{(mV\ \ from\ sensor\ (unknown))}{(mV\ \ from\ air\ Calibration)} \times ppm\ \ from\ chart\ in\ the\ sensor\ manual.$$

Therefore, the input array is all of raw data from the sensors in *millivolts*. Each one is then plugged into the equation above and the corresponding output array is displayed in the main interface. The air calibration value is found by putting a sensor in air and letting it stabilise. The mV reading then is taken of the air and plugged into the equation.

Figure 9 shows the calibration of DO sensor probe DO 6400.

**Figure 8** Calibration of pH Sensor probe *S8000* pH Electrode (see online version for colours)

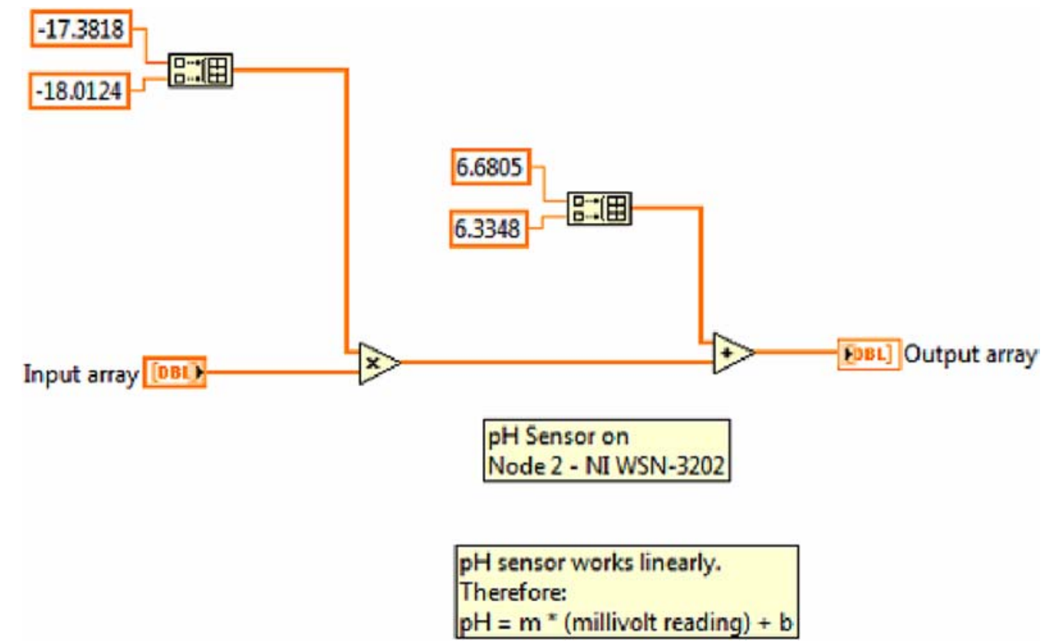
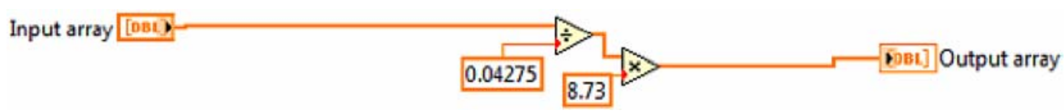



**Figure 9** Calibration of DO Sensor probe DO 6400 (see online version for colours)



### *3.2.4 WSN deployment*

Our next task is to enclose the NI Wireless modules and attach the calibrated DO and pH sensor probes to the modules. Proper enclosure is very important because ideally, nodes should be deployed outside for a long time. These nodes should be immune to bad weather. Luckily, NI provides accessories to enclose the nodes. We further use duct tape to seal the bottom two holes after attaching sensor probes. Each NI wireless node is powered through two AA batteries. We use lithium batteries because they have relatively large capacities.

There are some tall trees around the pond close to John Gray Center. We take advantage of these trees to facilitate our deployment of WSN nodes. In this way, we do not need to insert wood poles under the ground to mount our WSN nodes. We use screws to attach a wood board to the tree, and then attach our NI WSN modules to the wood board. In our system, both the cables for *DO6400* and *S8000* pH Electrode are 10 feet long. NI Wireless Modules are mounted to the trees close to the pond, DO and PH sensor probes are attached to the NI wireless modules. We carefully select the trees so that the cables are long enough to deploy these sensor probes to the water. A snapshot of the deployment is illustrated in Figure 10.

**Figure 10** Deployment of NI Wireless Modules and DO and pH Sensors around the pond close to John Gray Center at Lamar University, Beaumont, TX (see online version for colours)


The NI *WSN-9791* Gateway requires an external power and internet access. This significantly limits its candidate deployment locations, because every building usually only has a centralised internet connection for security purposes. After careful analysis, we finally deploy the gateway inside a room close to the pond. There are still several walls of obstruction from the gateway to the NI wireless modules outside.

After the initial deployment, we head back to Lab 209 to check the connectivity of the gateway node and the wireless modules. Our first test indicates that the signal strength from the wireless modules to the gateway is weak. This is because the restricted location of the gateway results in multiple walls between the gateway and the deployed nodes. To increase signal strength and network reliability, we therefore deploy a NI wireless module and configure in router mode to relay signals between the wireless modules deployed at field and the gateway.

We remotely monitor the deployed the WSN network using *Labview* software in the Wireless and Mobile Computing Laboratory at Lab 209 at Lamar University. We can monitor the signal strength of each node, and also see which node is still alive or dead from running out of battery or some other unexpected reasons.

## 4 Data results

In this section, we demonstrate our collected sensor data from the deploy STORM 3 and NI based WSN.

### *4.1 Data collected from STORM 3 Data Logger*

In STORM 3, data from the two H-377 temperature probes are collected once every 15 minutes. A temperature sensor from YRI has been used to measure the same location temperature for 7 days to valid the measurement. This is no difference between them to secure the accuracy of the data. Figure 11 illustrates the water temperature value in *Celsius* over one day (i.e., 18 December, 2014). The *x*-axis indicates the time of the day, while the *y*-axis indicates the water temperature value. By compared the water temperature with the weather data, the data are consistent to air temperature and dew temperature at the same day.

Figure 12 plots the average water temperature over one month (i.e., November, 2014). The *x*-axis indicates the days in November, while the *y*-axis indicates the average water temperature value in the corresponding day.

Figure 13 illustrates the average water temperature value everyday over five month (15 July, 2014 to 15 December, 2014). The *x*-axis indicates the day in every month, while the *y*-axis indicates the average water temperature value in the corresponding day.

### *4.2 Data collected from WSN*

We deployed two NI WSN-3202 modules and two NI WSN-3212 modules, respectively. These wireless modules were mounted at different fixed locations. Each of these modules was attached one sensor probe. Therefore, we have two DO sensors and two pH sensors deployed, respectively.

The sensor data were taken every hour since 11:00pm Dec. 19, 2013 and the results are illustrated in Figures 14 and 15, respectively.

**Figure 11** Water temperature change on 18 December, 2014 (see online version for colours)

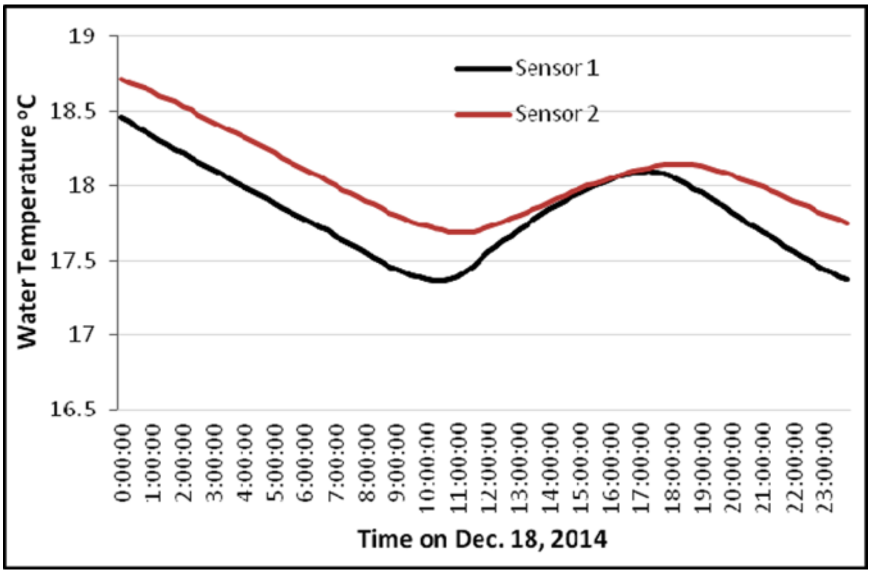



**Figure 12** Water temperature change over one month (November, 2014) (see online version for colours)

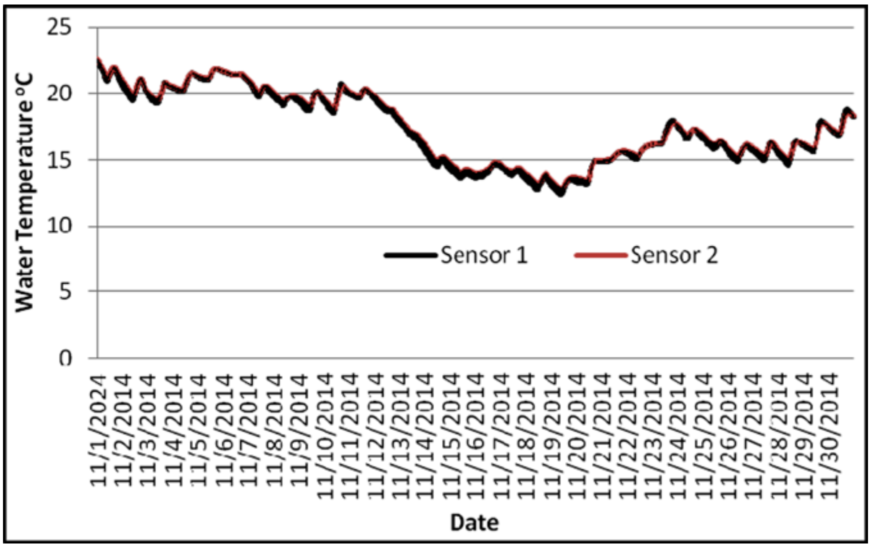



**Figure 13** Water temperature change over five months (see online version for colours)

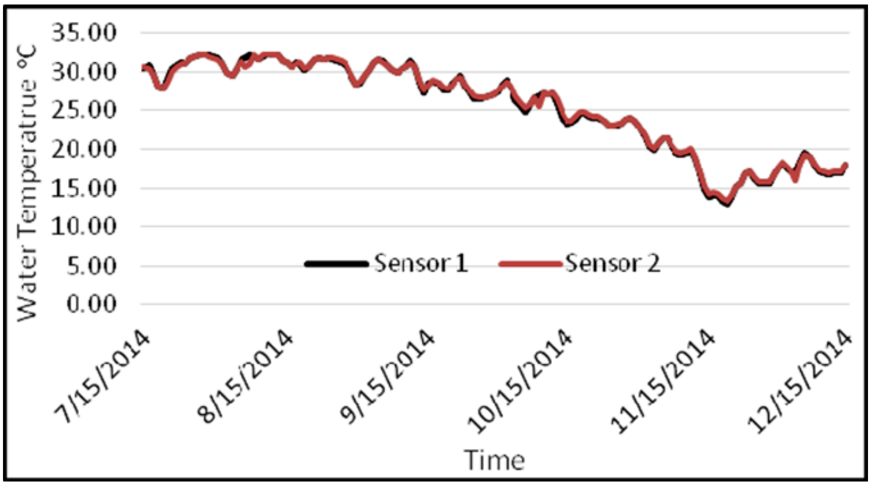


**Figure 14** Dissolved oxygen readings from two sensor probes deployed around the Pond at John Gray Center (see online version for colours)

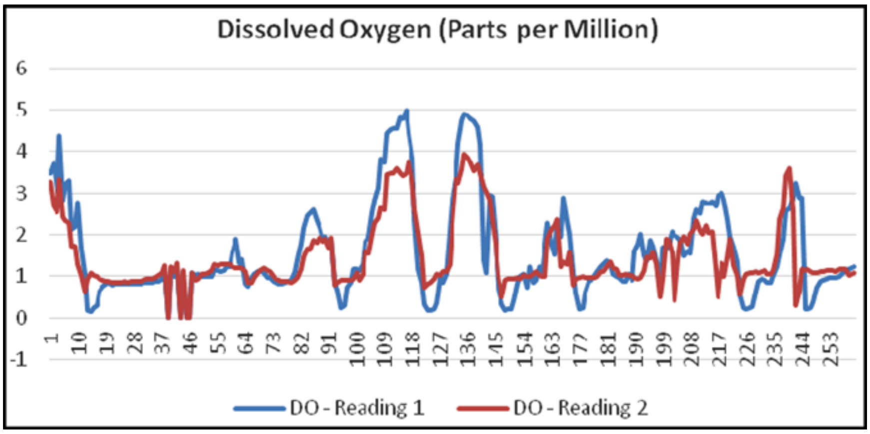
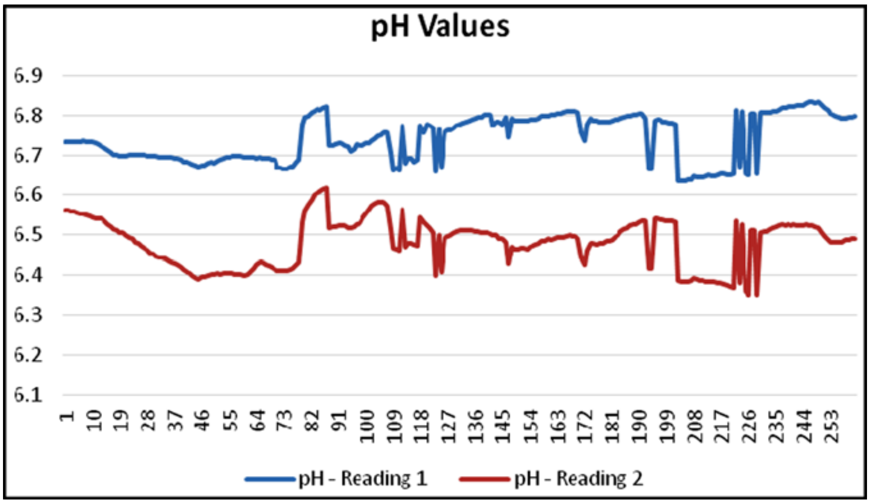



**Figure 15** pH readings from two sensor probes deployed around the Pond at John Gray Center (see online version for colours)




From Figures 14 and 15, we can have some basic ideas about the DO and pH value changes over time at the deployed locations. All these data will be further analysed in the Hydraulic Lab.

## 5 Conclusion and future work

In this paper, we report our preliminary work to deploy a STROM 3 Data Logger and NI-based WSN to monitor water quality in the pond close to John Gray Center at Lamar University, Beaumont, TX. We present the details about how we engineer and configure the node, interface the sensor probes to the wireless modules, deploy the nodes around the pond, and how we use to monitor and collect the data.

We only install water temperature probes for our testing purposes of the STORM 3 Data Logger. Regarding WSN based data collection system, we only have four wireless modules deployed and all these wireless modules are close to the gateway. Moreover, for both STORM 3 and WSN based data collection systems, we are monitoring a pond in Lamar campus, which does not present significant environment challenges.

We have important future work. We plan to attach more types of sensor probes to the Storm 3 Data Logger. Specifically, we are testing dissolved oxygen, water depth, and water pH values. We also plan to deploy more wireless modules. Scalability will become an issue when a large number of nodes are deployed. When we have accumulated enough experience about Storm 3 Data Logger and WSN to monitor the pond at Lamar University, we plan to deploy a WSN to monitor *Shangri La Botanical Gardens & Nature Center* in southeast Texas, which is more challenging. Our next step is to accumulate enough data and systematically utilise these data for water modelling research.

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