Development of Unmanned Surface Vehicle for Smart Water Quality Inspector

Satetha Siyang[1], Teerakiat Kerdcharoen[2,3*]

[1] Materials Science and Engineering Programme, Faculty of Science,
Mahidol University, Bangkok 10400, Thailand (s.satetha@gmail.com)

[2] Department of Physics, Faculty of science, Mahidol University,
Bangkok 10400, Thailand

[3] NANOTEC Center of Excellence at Mahidol University, National Nanotechnology Center,
Bangkok 10400, Thailand (teerakiat@yahoo.com) * Corresponding author

***Abstract*—Effective and efficient management of water resources is becoming unprecedentedly more important nowadays due to the increasing demand from a growing population, increasing standards of living and changing supply due to climate change. Water monitoring technology has directly contributed to the effectiveness of water resource management. Traditional water measurement method, mostly done in laboratory, cannot help so much for making timely and informed decisions. The new method called Water Sensor Network can acquire and serve data in real time, but most of them are a type of fixed location platform that makes them lacking of mobility. In this paper, we present the combination of wireless water sensor technology together with unmanned surface vehicle (USV) to solve the problem. The overall system consists of water quality sensors, wireless communication system and mobility platform. The water sensors include temperature, pH, dissolved oxygen (DO), oxidation reduction potential (ORP) and electrical conductivity (EC). Software was developed using open source technology aiming at providing continuous and autonomous water quality measurement at substantially reduced cost. The integrated sensorized USV was tested to perform an autonomous mission for water quality assessment in a lake. Preliminary laboratory and field test results have demonstrated that the system has a capability to do water quality assessment mission in inland water resource. This USV can be used at various surface water spaces, such as domestic water sources, domestic water intake points and industrial water discharge points.**

Keywords—Wireless Sensor Network; Water Sensor; Unmanned Surface Vihicle; USV; Floating Robot

I. Introduction

The effective and efficient management of water resources are becoming unprecedentedly more important nowadays due to increasing demand from a growing population, increasing standards of living and tightening supply due to climate change [1]. Water monitoring system can serve as a useful tool directly to increase the efficiency of water resource management. The water management in the past and even at present has employed traditional water measurement to provide information for decision. Such methodology is usually accurate and low cost but lacking of capability to perform in real-time [2]. Therefore, the information cannot be used for making timely and informed decisions. Water sensor network was then proposed to solve the disadvantage of traditional method, by combining water sensors with wireless communication technology [3]-[5]. This method can capture and serve data in real-time so that user can take advantage of instant information. Faustine et al. [6] successfully demonstrated the deployment of wireless sensor network for water quality monitoring and control at Lake Victoria Basin. Their fixed point stations can detect water temperature, dissolved oxygen, pH, and electrical conductivity in real time and disseminate the information in graphical and tabular formats to relevant stakeholders through a web-based portal and mobile phone platforms. However, such stationary platform poses a disadvantage of lacking mobility [7], in which the information obtained from the network do not represent over all of area and to overcome this by installing sufficient stations would increase the cost dramatically [8]. Therefore, development of an alternative technology to enhance the effective and efficient water monitoring is necessary and unmanned surface vehicle (USV) technology apparently satisfies the abovementioned requirement.

Technically, USVs are relatively simple as compared to autonomous underwater vehicle (AUV) due to the operation at the water surface, thus allowing them to act both above- and under-water activities. In addition, USVs can use air-combustion engines and data transmission through the air.

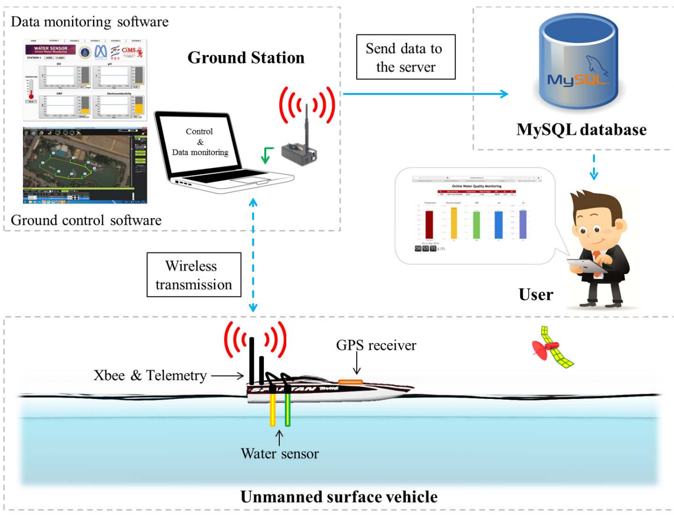

Fig. 1. The idea of wireless water sensor on unmanned surface vehicle.

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Fig. 2. The wireless water sensor USVs prototype.

In general, USVs can be remotely piloted and are expected to be controlled by operators in contrast to AUV [9]. Last but not least, USVs can share several electronics and sensors designed for unmanned aerial vehicle (UAV) which eases and shortens its development.

In this paper, wireless water sensor monitoring system, consisting of wireless water sensors and monitoring software, was developed and integrated into a USV. Fig. 1 shows the conceptual framework of this development. The floating water monitoring system was developed using open source software and an easily obtainable materials. Such USV can be used at various surface water spaces, such as domestic water sources, domestic water intake points and industrial water discharge points.

II. UNMANNED SURFACE VEHICLE WIRELESS WATER SENSOR PLATFORM

The main purpose for the development of USV wireless water monitoring system is to make an autonomous platform for replacement of human works in high-risk areas such as areas contaminated with radioactive materials as well as to enhance the human capability to collect data in hard-to-reach places [10]. Fig. 2 shows the prototype of wireless water sensor USV during a commissioning trial. To realize the applications of this invention, robustness of the USV platform, data accuracy and cost must be considered. In this paper, we have developed the wireless water sensor on USV by using components readily available such as RC boat and low-cost acrylic sheets for creating the robot body. The monitoring software was developed based on open source technology, which makes the cost of system quite affordable. The system can be classified into three main parts, namely, USV platform, wireless water sensor system and application software.

A. *Unmanned Surface Vehicle platform*

In this paper, USV was developed taken into account affordability, robustness and can operate in real world application. The standard requirement of our USV can be listed as follows: USV can be controlled by an operator through wireless communication on a mission instead of having human to collect water samples in the dangerous and difficult to reach area. Operator can design a mission plan for USV to explore and measure water data. USV can be deployed in general water resources such as lake, shrimp pond and even in the sediment pond of a factory. Fig. 3 shows the data flow chart of the system. The USV platform can be separated into 2 main parts as follows: ground control station and the USV platform.

1) *Ground Control Station*

The ground control station consists of laptop computer, a mission planner program and three communication modules linking with the USV as follows: (1) telemetry module to connect with Ardupilot to obtain sensor data related to mobility of the USV, (2) XBee module to collect sensor data related to water properties, (3) radio transmitter module for manual operation to control the USV.

The mission planner program is a free open source program developed by Michael Oborne and was used to control the USV in this research. Telemetry module was used to connect a mission planner program with APM 2.6 Ardupilot controller board. It is a small, light and inexpensive open source radio platform typically allowing ranges much longer than 300 m. Thus, the ranges can often be extended to several kilometers with the use of appropriate patch antenna. The telemetry is a 915 MHz version and use USB Serial Port to connect with a computer. Baud rate was set to 57,600 bits per second. The telemetry module allow for viewing in-flight data, changing missions and tuning the USV.

The data from water sensors are collected with an acquisition unit and transmitted by XBee wireless communication to the control station then to database server on the internet [11]. In this research, an XBee Pro Series 2 module from Digi company was used as a radio frequency (RF) transceiver module. The XBee product family is a series of modular products that make deploying wireless technology easy and cost-effective based on the IEEE 802.15.4/ZigBee [12]. An XBee is a self-contained, modular and cost-effective component that uses RF to exchange data between each modules. The module transmits on 2.4 GHz relying on their own network protocol. The module was configured to operate in a point to multipoint topology in a continuous-mode fashion. The XBee was programmed by using X-CTU software

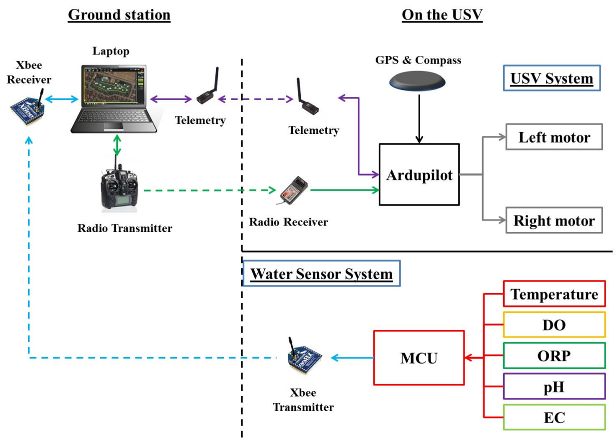


Fig. 3. Flow chart of the USVs water sensor platform hardware.

to be a coordinator in AT mode. Arduino Uno withstandard Wi-Fi and XBee shield was programmed to act as an aggregator node in the XBee network.

2) *Unmanned Surface Vehicle*

This USV was controlled by Ardupilot APM 2.6 board from 3D robotics company which was designed to covers all functions; especially it also includes sufficient sensors to build an autonomous mobile robot. An onboard accelerometer and compass are already included in APM 2.6. An external ground positioning system (GPS) module was used for navigation. The firmware of USV was loaded into the Ardupilot board and configured via the Mission Planner program. Body of the USV platform was built by using the hull of two off-the-shelf RC boats. The 47 inch (measured from head to tail) hulls were selected and connected together by an acrylic junction plate. The finished USV can accept payload up to 8 kg which is enough for this research. Finally, the radio and sensor calibration were done before testing.

B. *Wireless Water Sensor System*

The wireless water sensor system is the main building block of this prototype. It consists of water sensor unit, microcontroller unit, data logger and Radio Frequency (RF) transmitter module.

1) *Water Sensor Unit*

The water sensor unit is an important part used for measurement of water quality parameters. In this prototype, five sensors from Atlas Scientific Company for measuring oxidation reduction potential (ORP), pH, electrical conductivity (EC), dissolved oxygen (DO) and temperature were employed to provide general characteristics of water quality. However, the sensor node is scalable to allow more sensors to be plug-in for future needs. Table 1 summarizes the specifications for the sensors used in this prototype. The ORP, pH, EC and DO sensors are interfaced to their respective circuits from Atlas Scientific. Each circuit communicates with a microcontroller through the Universal Asynchronous receiver/transmitter (UART) protocol. Only the temperature sensor is connected directly to analog pin of the microcontroller. To connect the entire water sensors to Arduino board, a Tentacle shield from Whitebox Labs Company was used to be an isolating circuit. The tentacle shield has a good feature to isolates the sensor individually and eliminates issues with noise and ground loops for precise measurement even in a closed-loop system. The sensors were calibrated to correct operation and accuracy in the resulting water quality parameter values using their respective sensor calibration recommendation from Atlas Scientific.

2) *Microcontroller Unit*

The microcontroller unit consists of a microcontroller and a software program that determines the behavior of the sensors. Arduino Mega 2560 microcontroller, an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software, was used to acquire and process sensor data. The software program has been developed and uploaded into the microcontroller to allow the sensor node to measure water quality parameter at a time interval of 1 minute.

TABLE I. SPECIFICATIONS OF THE WATER SENSORS

S/N	Sensor	Model	Range of Detection
1	DO	ENV-40-DO	0 to ± 1,023.99 mV
2	ORP	ENV-40-ORP	0 – 20 mg/L
3	pH	ENV-40-pH	0.1 - 14
4	EC	ENV-40-EC-K0.1	11 µs/cm - 3,000 µs/cm
5	Temperature	ENV-TMP	-20 °C to 133 °C

The data are always stored in a SD card before transferring to the aggregator node on the control station.

3) *Application Software*

The application software was developed to acquire, store and visualize the data. This software module was developed using various technologies, such as MySQL, PHP, HTML5, Highchart as well as Java Scripts for web-based monitoring. The user can access the data over internet via smartphone or laptop computer in real time and everywhere in the world.

III. RESULT AND DISCUSSION

A. *Preliminary test*

Before installing the wireless water sensor network on the USV platform, the system was tested in an aquarium of our laboratory. The preliminary test has been done to observe the performance of the wireless water sensors by continuous operation for a week without interruption. The system was powered directly from 5 VDC/1A wall adapter power supply. The aquarium with clean water was used as a starting environment. The water sensor node was programmed to acquire data every 1 minute and then transmit the data to the aggregator node. The time interval can be changed depending

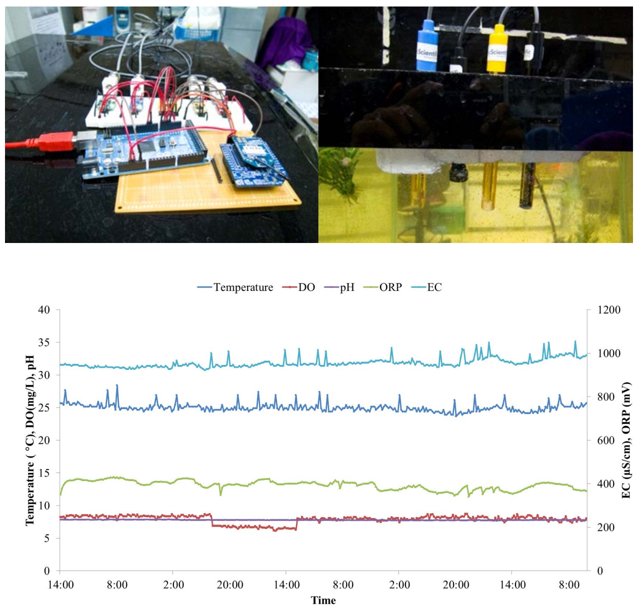
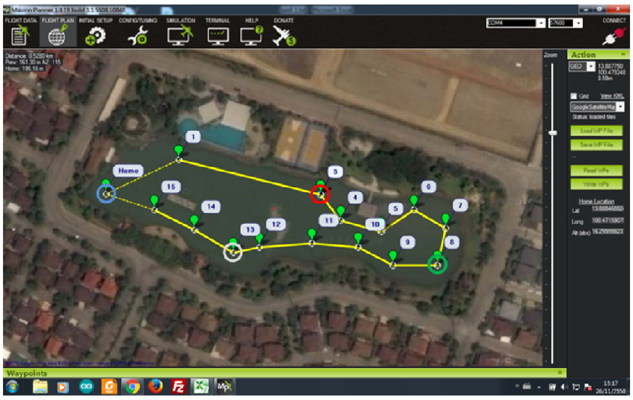
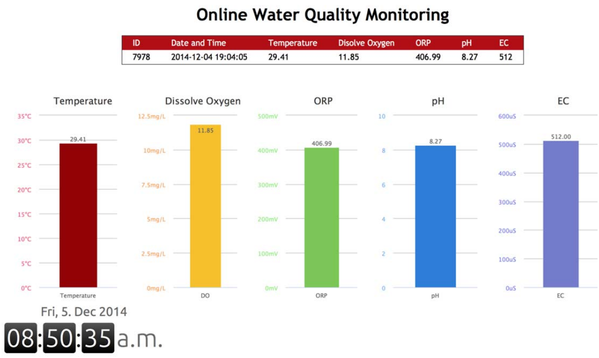


Fig. 4. The result of preliminary testing in aquarium of laboratory.

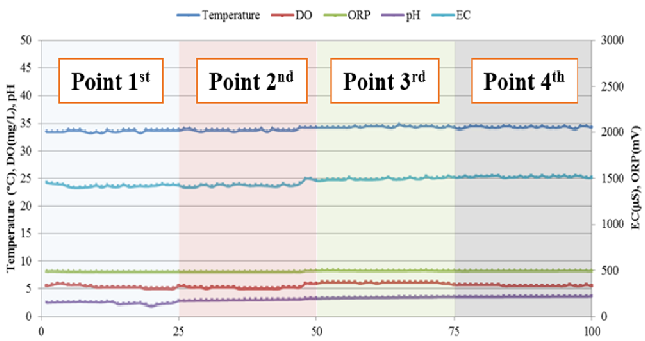
on need, especially when power needs to be conserved for longer battery life. The test results in the laboratory showed that the system works perfectly. The measurement data were acquired and transferred to the aggregator node every time without signal losing as shown in Fig. 4. However, some unusual values were observed and believed to arise from the signal interference between each sensor readout circuit. The problem can be eliminated by using the Tentacle shield from Whitebox Labs to isolate the sensor readout circuit individually. The results from lab testing have confirmed that this system can be installed on USV.



(a)



(b)



(c)

Fig. 5. The result of field testing: (a) Measured trajectory of the USVs around the Perfect Place Rattanathibet village's lake (b) Data visualization on the web browser. (c) The result of water quality measurement at 4 different points.

B. Field Test

For field testing, the water sensor system was installed on the USV platform and tested in a lake located at Perfect Place Rattanathibet village. Calibration was done before testing. The configuration of water sensor node was borrowed from the lab testing. The USV was programmed to measure the data for a period of 10 minutes at 4 checkpoints as shown in Fig. 5 (a). The USV's speed was set to be 2.0 ms-1. From the track record, it was found that the robot can smoothly reach every mission point.

Fig. 5 (b) and (c) shows the water quality results as visualized on a web browser. It confirms that in the field test the system worked perfectly without losing signals. The noise in the sensor data was eliminated when applying the isolator circuits. The monitoring software works very well on both laptop and mobile phone screen size. This ensures the functionalities of the proposed system and its practicality in actual operation. The sensorized USV water sensor gives water resources stakeholders' ability to test water quality parameters at selected sensitive sites continuously. Examples of such sites include domestic water sources, domestic water intake points and industrial water discharge points.

IV. CONCLUSIONS

In this work, the development and demonstration of a low cost, wireless water sensors on unmanned surface vehicle prototype is described. Low cost sensors were used and integrated software was developed using open source technology aiming at providing continuous and autonomous water quality measurement at substantially reduced cost. Preliminary laboratory and field test results demonstrated that the system has a capability to do water quality assessment mission in inland water resource. The measurement data were transmitted to the cloud internet in real time and made accessible via smart phones and computers. With the use of web-based portal and mobile phones platforms, the water quality can be displayed in a highly comprehensible fashion. In conclusion, this system has a potential to enhance accountability, transparency, and participation which attributes for good governance of water resources.

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