Design and Field Testing of Water Quality Sensor Modules Designed for Round-the-Clock Operations from Buoys and Biomimetic Underwater Robots

Joongki Park, Juchan Sohn, Sunghoon Kim, and Jonghyun Park

Intelligent Robot Control Research Team,
Department of Robot/Cognitive Convergence System, ETRI
138 Gajeongno, Yuseong-gu, Daejeon, 305-700, Korea
{jkp,jcsohn,saint,jhp}@etri.re.kr

Abstract. At the point of monitoring coverage, the legacy technologies of water quality measurement show the weakness. It manually or semi-automatically measures various water quality information at just only small parts of a large area. In this paper, we propose new water quality sensor apparatus which can consistently provide high resolution water quality data as well as attachable and PnP type deployable to underwater robots and buoys. The water quality sensor module, as a result of going through three water system tests in Han River, Gold River and Gapchun respectively and benchmarking with the commercial water quality meter, shows not only outstanding performance but also receives an official experimental certification by the supervisor of the Korea Testing Laboratory.

Keywords: water quality sensor, robotic fish, biomimetics.

1 Introduction

The legacy water quality monitoring systems just measures manually in extremely small parts of a large location and measures through a semi-automated method [1][2][6]. For example, currently in 52 measurement stations in the 4 major rivers, only part items are measured amongst 5 common items (temperature, electric conductivity, pH, dissolved oxygen, total organic carbons) and 11 selective items (biology surveillance, flammable organic compounds, total nitrogen levels, total phosphorus levels, degree of turbidity etc.) and once a month water samples are manually measured through 1500 water quality measurement stations in national river/lakes/city/industrial areas. There are difficulties in maintenance and management as the sensors used for the measurement are high priced foreign-made [9].

Of foreign cases, in the case of New York's Hudson river in the US, a REON ((River & Estuary Observatory Network) project was jointly conducted from 2008 to implement a USN water pollution monitoring demonstration service by the Beacon laboratory and IBM, and apart from the wireless communication system, solar battery based self-charging mobile sensor nodes and the embedded compound sensors ((water temperature, EC, pH, DO, TOC)) are currently being developed [3][4][7].

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Fig. 1. Domestic examples of water quality monitoring systems

In this paper, we recognize the problems of legacy technologies as mentioned above, use a biomimetic robot which can freely navigate underwater on not just parts of the river but the entire river area, and design a small size and easy to use water quality sensor module which is requested for continuous and high resolution water quality surveillance.

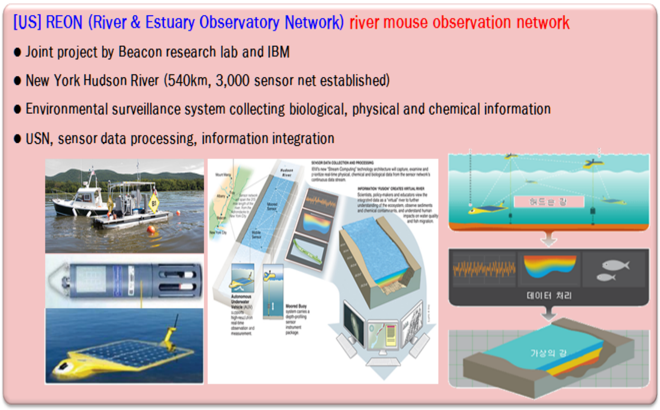

Fig. 2. New York's Hudson River's monitoring system

For example, our sensor modules are installed into a robotic fish as underwater vehicles to monitor water quality and pollution surveillance [5][8][10].

2 Design of Sensor Modules

Our apparatus of water quality measurement is a water quality sensor module in which continuous operation underwater is possible and is composed of the sensor module' s fixed shape, infrared light communication module, magnet, sensor module, sensor and sensor protection case.

The infrared light communication module is equipment which communicates sensing information and water quality sensor module and is designed with a wireless infrared communication module, not through a communication cable method connected with a cable. This is done to strengthen the operation ability under water and especially overcome invasions such as electric static of cables, thereby preventing distortion of electric signal treatment of water quality sensors.

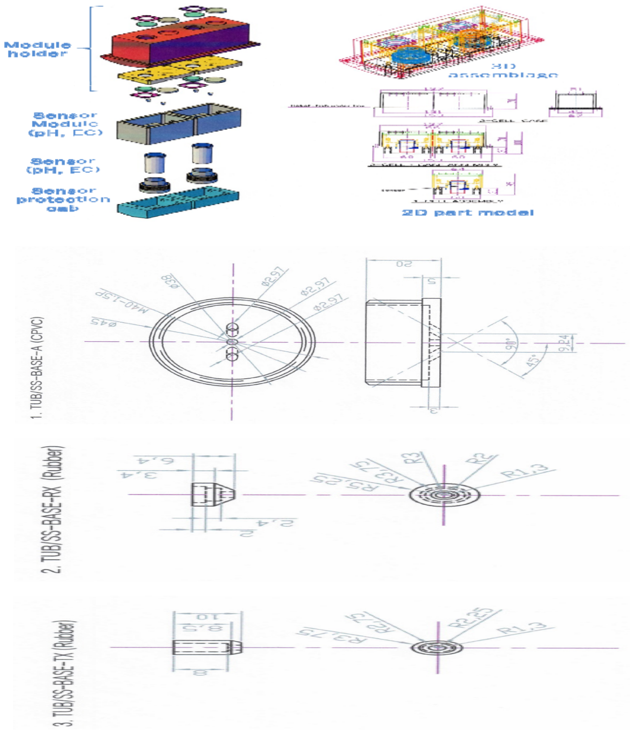

Fig. 3. Assemblage and 2D/3D CAD Model

The sensor outline is a fixed type outline in order to place sensors, sensor protection case, sensor modules and is installed in the underwater moving object which is loaded with the water quality sensor module equipment The underwater moving object refers to all moving objects that can independently swim underwater like biomimetic robot fish.

The magnet makes adhesion between the sensor module and module holder possible. A necessary and important requirement when constantly operating underwater is the simple maintenance capability. Taking these requirements into consideration, the magnet is used to organically connect the sensor module to the module holder. Screws instead of magnet can be installed because of prevention of interference to position sensor like gyro sensor or digital magnet compass.

The sensor module includes the sensor ’ s control board which observes the water quality sensor types rooted in the sensor module and performs the program and circuit drive which fits in each sensor. The sensor ’ s analogue signal is extracted and the operation and operated data is transmitted through the sensor fixed outline and infrared light method. Furthermore, it forms the sensor ' s overall information status (temperature, remaining battery life, and sensor is workable or not).

The sensor protection case is to protect the sensor and is composed of a cover form in order to continuously operate underwater. For example in the case of pH sensor, when operating by holding the standard solution in a glass tube, the glass tube can be damaged due to the obstacles underwater or water pressure. In this regards, the sensor protection case mounts by taking these points into consideration and is designed to eliminate if necessary.

3 Implementation of Sensor Modules

At the issue of implementation point of view, we have to set up principles in regarding with module size and power source. The board size is minimized by package on package and system in package strategies respectively. The most important consideration in design of power source is to improve the easy to use in real environment. Execution model of our sensor module is designed by PnP style. As the sensor module should be attached and run by oneself to any kind of unmanned underwater vehicles, battery source is embedded into the sensor module. Currently, Li-Ion battery with 3.7v/970mAh is embedded.

Sensor modules are consisted with 3 on-board modules, which are signal detection and amplification board, signal processing board and communication relay board. The role of SDAB is to detect and amplify the analog signal come from sensor such as pH and EC. SPB as a main sensor board processes signals from SDAB and make the measured value of each sensor. SPB supports dual-mode signal processing, that is, if pH or EC sensors connect to the SPB, then SPB run as pH or EC modes. The measured values are transferred to CRB via IR communication protocol. CRB is basically installed robotic fish and fulfills role of communication repeater between sensor modules and main controller of robotic fish. Key features and specifications are as follows.

	Range	Resolution	Accuracy
Turbidity Sensor Module	0.0 to 1,000 NTU	0.1 NTU	± 2.0% of Full Scale
DO Sensor Module	0.00 to 20.00 mg/L	0.01 mg/L	± 3.0% of Full Scale
pH Sensor Module	0.0 to 14 pH	0.1 pH	± 1.0% of Full Scale
EC Sensor Module	0.0 to 3,000 μS/cm	0.5 μS/cm	± 2.0% of Full Scale

Fig. 4. Major specification and features of sensor module

4 System Integration

As a moving object which can make the water quality sensor module equipment to freely move underwater, the robotic fish is shown as a real life example. The sensor module equipment is installed in the abdomen of the robotic fish' s body as the following.

Fig. 5. Conceptual view of installing sensor modules

The reason of installing in the abdomen is because the pH sensor and the dissolved oxygen sensor have transition standard solution, and in order to measure correctly, the standard solution should always be installed below the sensor [11][12]. Furthermore, if the light sensor such as the turbidity sensor or suspended solid sensor observes the water surface upside down or through its side, it is affected by the natural light (sunlight) and causes a defect in the measurement.

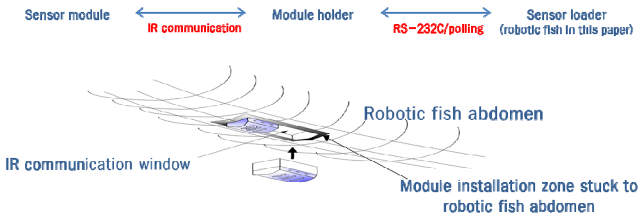

Fig. 6. Integration view of sensor modules

Module installation zone contains at most two different sensor modules respectively among pH, EC, DO, turbidity with marine thermometer. The module installment zone is fixed, and the fixed magnet is adhered to the sensor module and module installation zone. Communication between robotic fish and water quality sensor module is carried out by RS-232 Polling method. The communication protocol is designed as following.

4.1 Communication Protocol

Classification	Specifications
Communication method	RS-232C asynchronous method
Transmission specifications	9600 bps, 8bit, Parity None, Stop bit 1
movement method	Polling method (robot fish-host, measurement tool-slave)
Data transmission method	Half Duplex, block transmission
Mark code	ASCII

4.2 Command Code

Command code (host to sensor module)	Specifications	Sensor module response (sensor module to host)
0x02DATA0x03XX	request for real time measurement data transmission	data transmission (FORMAT-1)
0x02CCHK0x03XX	search Correction value (Request for transmission of corrected data)	data transmission (FORMAT-2)

5 Real World Experiments and Results

In order to analyze the performance and on-site operational capability between our sensor module and the commercial multiple water quality meters, benchmark tests are conducted in real environment such as Daejeon’ s Gapchun and Seoul’ s Han River. Table 1 shows the results as follows.

Table 1. Results of benchmark test in real field

Daejeon Gold River	DO (mg/L)	Turbidity (NTU)
Development Module	7.73 ~ 7.83	3.73 ~ 4.08
Commercial Meter	7.53 ~ 7.95	3.35 ~ 3.69
Error Rate	1.50 % ~ 2.65 %	9.56% ~ 10.19%

Daejeon Gapchun	pH	Water Temp.	EC
Development Module	8.6 pH	11.7	320.40 µS/cm
Commercial Meter	8.85pH	11.7	347.40 µS/cm
Error Rate	2.8%	0%	7.7%

Seoul Han River	pH	Water Temp.	EC
Development Module	7.1 ~ 7.3 pH	16.4	189.0 ~ 190.5 µS/cm
Commercial Meter	7.4 ~ 7.6 pH	17.3	193.2 ~ 195.4 µS/cm
Error Rate	4.05% ~ 3.95%	5.20%	2.17% ~ 2.51%

According to the result of benchmark test in real field, it is convinced that both of pH and electric conductivity sensor module satisfies the targeted performance. Especially in the case of Han-river’ s test site, the measurement value which was tough on the pH sensor’ s water pressure and water depth changes in velocity 1.5m/s, water depth 1m – 6m was shown to be within 20% of the relative accuracy requested for the formal approval of the environmental measurement equipment by the Agency for Technology and Standards regarding hydrogen ion concentration which uses electrodes.

In the case of Gapchun’ s test site, the difference in the measurement value of the development module and the commercial meter lies in the differences in measured water depth. The development module is measured in water depth of at least 1m and the commercial meter is measured in water depth around 70cm due to limited cable length.

In the case of the Han River test, the development module is measured by changing the water depth from 0.3m to 6m and the commercial product is measured in water depth of around 70cm.

In order to simulate the robotic fish, the Gapchun test preceded the experiment by loading the sensor modules in the RF based remote control ship and the Han River test loaded the sensor module in a motor-embedded duck boat.

Our water quality sensor module received an authorized test report from the Korea Testing Laboratory and was recognized for the credibility on the measurement result value. The official test certification numbers are 11-1596-114-1 and 2 respectively.

6 Conclusion

Based on this research, compared to the legacy water pollution monitoring system which measured manual work of various river information in extremely small parts of a large location or measures through a semi-automated method, this system can be used as the main sensor equipment which can conduct water quality surveillance by attaching the equipment on moving objects which can freely move continuously underwater to conduct water quality surveillance such as the robotic fish. Accordingly, by persistently managing the river’s water quality information as well as getting high resolution data of water quality, we can look forward to making prior actions before the river’s environmental changes spread widely.

Future works are to system integration test based on biomimetic robots such as robotic fish incessantly in real fields.

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