



IEEE HNICEM

ISCIII 2014

Co-located with **ERDT Conference**

**7th International Conference on Humanoid, Nanotechnology,
Information Technology, Communication and Control,
Environment and Management**

joint with

**6th International Conference on Computational Intelligence and
Intelligent Informatics**

co-located with

10th ERDT Conference

November 12-16, 2014

Hotel Centro, Puerto Prinsesa, Palawan, Philippines

Technically supported by
IEEE Philippines Section and
IEEE CIS Philippines Chapter

Organized by Neuronemech

**Published by
HNICEM**

ISSN: 1908-6180



IEEE

Philippines Section

A GIS–Integrated Wireless Sensors Network Tool for Water Risk Monitoring – Case of Khanh Hoa Water Supply and Sewerage Company, Vietnam

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Abstract: This paper investigates the feasibility of deploying a wireless sensor network (WSN) to monitor raw water quality at 2 major water treatment plants (WTPs) sites, operated by the The Khanh Hoa Water Supply and Sewerage Company (KHAWASSCO) in Vietnam: Canh Vo and Xuan Canh on the Cai River. The main aim is to propose a WSN for both WTPs which includes 2 clusters of sensors with 4 nodes each in order to monitor various parameters of water quality. Data management is integrated with a geographical information system (GIS) tool in order to provide a comprehensive spatio-temporal database in real time. This will assist decision makers in improving the management of the raw water quality at Cai River.

Keywords: Wireless Sensor Network (WSN), Geographical Information System (GIS), raw water and real time

1. Introduction and Problem Definition

A number of studies have shown that monitoring water quality is an immensely complicated process, which requires both spatial and temporal monitoring of various parameters [1]. A geographical information system (GIS)-based approach to develop a comprehensive database that integrates pollution data, as well as all other measured parameters, such as salinity, turbidity, etc, would provide valuable assistance in water safety planning and management. Recent developments in smart wireless sensor networks (WSN) allow not only the simplification of the water monitoring task, but also to increase the efficiency – and alleviate liability – of water risk management.

1.1. Wireless Sensor Network in Water Quality Monitoring

A single WSN comprises of a number of sensor nodes that are geographically distributed and responsible for processing and transmitting data within the network to a base station [2]. In terms of functionality, a network of these devices is installed in the area under investigation where the transducers measure a subset of parameters in relation to surface water quality. Consequently the data collected is processed internally and eventually relayed to a base station by radio frequency (RF). The base station acts as a data transmitter between transducers and a proprietary data management system then provides continuous analysis and prediction [3]. Hence, using WSN in water quality monitoring can (1) address the shortcomings that are usually attributed to conventional sampling and laboratory-based techniques, thus contributing to significant cost reduction; (2) provide real-time analysis, thus speeding up the decision-making process; (3) allow for integration with GIS tools in order to generate a spatial and temporal database leading to the visualization of hotspots and the identification of hazards and their sources [4].

1.2. Problem Definition at the Khanh Hoa Water Supply Company

The Khanh Hoa Water Supply Company (KHAWASSCO) is one of the major water supply companies in Vietnam, responsible for the provision of safe drinking water and compliant wastewater treatment to approximately 72,000 households (or 455,000 people), representing a 94.16% coverage of the population area in the Khanh Hoa province, which is scattered around

Nha Trang city and Dien Khanh district [5]. Despite its considerable effort to provide safe drinking water, and in line with other water supply companies in Vietnam, KHAWASSCO faces a major issue in the monitoring of water quality in rivers and streams, and in particular, the Cai River which is its main water source. To date, the company applies a conventional method which relies on the selection of permanent sampling sites where samples are collected manually to monitor the raw water quality. The results of such conventional method are limited by cost and geographical constraints.

As mentioned above, the Cai River is the main source of water intake for KHAWASSCO's two water treatment plants (WTPs): Canh Vo and Xuan Canh. Due to the physiography of the river, as well as the local climate and several modes of transportation flowing along it, the Cai River has shaped its own water quality resource characteristics. Along with salt water intrusion to the river during the dry season, the company is faced with not only shortage of water, but also a lack in quality of raw water intake [6]. In 2002, the Company reported that sea salinity had deeply infiltrated the river, approximately 6km from the estuary [7].

Also, as result of weak regulations on protecting water resources, the Company has to deal with various challenges. For example, waste dumping (residential waste and, occasionally, dead animals) and illegal sand exploitation from the river banks have an implication on changes of stream flows [6]. Moreover, at least 5 drainage pipelines are directly connected to the Cai River. This adds up to an alteration of the raw water quality of the river. All the above factors provide an impetus to carry out a pilot study for developing a WSN on the Cai River in order to collect various environmental (chemical alterations, waste effects and pollution information) and physical (salinity level, turbidity, temperature, water level, etc) parameters from the river. Hence, following an overview of existing WSN technology in relation to, both, power management and communication, this paper presents a theoretical framework for WSN implementation and optimization at KHAWASSCO's aforementioned two water treatment plants sites. Moreover, the paper suggests a WSN that not only provides real-time monitoring of various chemical and physical parameters, but also integrates with GIS applications to spatially and temporally visualize the magnitude of risks and hazards in order to assist in predicting and managing the quality of surface water at the Cai River.

2. Theoretical and Practical Perspectives of WSN for Water Quality Monitoring

WSN technology has undergone a radical transformation in terms of advanced technological communications, power management and type of sensors [8]. It is known that a WSN is an ad-hoc network and an intelligent system which automatically performs an array of monitoring tasks corresponding to specific changes [9]. Commercial sensors and monitoring systems for measuring water level, pH values and temperature are widely available on the market. Monitoring changes in the chemical parameters of water quality is a more complicated process due to the complexity of its nature. Hence, the WSN for this task is diverse in terms of communication technology (telemetry, Bluetooth, etc) and energy management. Some prototypes are designed to combine the water level parameters with a set of chemical sensors (measuring parameters such as pH, dissolved oxygen, conductivity, turbidity, dissolved organic carbon and dissolved metal ions), thus forming a complex transducer (node) with the data being spatially analysed [10].

2.1. WSNs Structure and Functioning

Theoretically, according to Capella et al. [11], a WSN is generally comprised of 3 components: data acquisition, control and communication, and data a management subsystem. For data acquisition, a number of transducers measure a set of specific parameters pertaining to the problem under investigation. As soon as a parameter is sensed, a filter removes all unwanted noise within certain frequency ranges and the analogue signal is transformed into a digital signal by an ADC (analogue-to-digital-converter). At this point, as part of the communication and control subsystem, the data is available in a digital form and ready for further processing [1]. An RF communication module, which is integrated inside the sensor node, is in charge of transmitting data to a base station, or sink node. A base station gathers all data from all sensor nodes and possibly intelligently processes the information it receives and resends it to the data management subsystem.

Recently, IEEE 802.15.4 became the WSN transmission standard for the physical and medium access control layers within a short range communication system. At the physical layer, the IEEE 802.15.4 framework defines a total of 27 half-duplex channels across the three bands: (1) the 868MHz band allows 1 channel with 20kbits/s data rate with a transmission range of approximately 1km, (2) the 915MHz band includes 10 channels with a rate of 40kbits/s and a similar transmission

range, (3) the 2.4GHz industrial, scientific and medical (ISM) band comprises up to 16 channels with a data rate of 250kbits/s and the transmission range is up to 220m. The standard presents 2 basic topologies (star and peer-to-peer) for multi-hop self-organising network, however other topologies, such as cluster and tree are also supported by IEEE 802.15.4 (Buratti et al, 2009). Bluetooth wireless technology has also been used in water quality monitoring due to low-cost benefit, with many countries operating Bluetooth RF in the unlicensed ISM band at around 2.4GHz. In 2006, the European Union proposed an ultra-low-power Bluetooth technology which is designed to be efficient for small data package transmission at very low latencies to other Bluetooth-enabled devices integrated at the physical layer to allow 1Mbit/s data rates of transmission but with up to 10m range [12]. Ultrawide bandwidth radio, ANT technology and Z-wave have also been widely been developed for WSN design.

2.2. WSN in Practice

Currently, many WSN systems for water monitoring purposes have been deployed worldwide. For example, a WSN was deployed at Songhua River in China in order to monitor chemical spill incidents [13]; a WSN comprising of 50 nodes with 6 different floating sensors was installed at Wivenhoe Lake in Brisbane, Australia [14]. In the UK, the Automatic Water Quality Monitoring Stations (AWQM), with approximately 50 fixed stations and a range of sensors (measuring dissolved oxygen, temperature, pH, conductivity, turbidity, ammonium, blue-green algae and chlorophyll), operate along the Thames River. Dinh et al. [15] proposed a WSN consisting of 5 sensor nodes that monitors depth, temperature, pH, conductivity, dissolved oxygen and turbidity, and covers a predefined area of 2km x 3km in the region Burdekin, Queensland, Australia. The interval time of measurement is every 15 minutes and the transmission range is approximately 855m. Dubabin et al. [16] developed a mobile device called Autonomous Surface Vehicle that is capable of measuring a range of water quality parameters powered by solar energy. This device is able to carry out inter-node sampling and in-situ calibration of the existing sensor nodes.

3. Proposed WSN for KHAWASSCO's Water Treatment Plants

3.1. Aim

The aim of a low-cost WSN deployment is to monitor physical and chemical pollutants that can compromise the water quality of the Cai River as well as the catchment area under KHAWASSCO's management. The testing field has a size of 3km x 0.12km and is located between the 2 WTPs. The sensor nodes include multi transducers that are capable of monitoring various water pollutants.

3.2. Input Information

The Cai River has a length of 79 km and a basin area of 1,904 km². The river begins from the mountain areas of Khanh Vinh district, flows through Dien Khanh district and Nha Trang city and eventually to the South China Sea. The geographic information related to the testing sites is as follows:

- Vo Canh WTP which processes water at a rate of 60,000m³/day is located approximately 200m away from the river;
- Xuan Phong WTP processes has a capacity of 15,000m³/day and is located closer to the Cai River and in close proximity of the salinity dike (140m). In theory, the salinity level at this point of the dike is higher than the stream running close to Vo Canh WTP. The distance between two banks of the river is about 0.12km;
- The distance between Vo Canh and Xuan Phong is approximately 2.6km;
- The distance between Vo Canh and the KHAWASSCO main office is approximately 6km;
- The distance between Xuan Phong and KHAWASSCO's main office is approximately 5km.

3.3. Design

WSN Cluster 1: Xuan Phong WTP is located approximately 6km from the estuary and 140m from the salinity dike. This WSN will target the monitoring of the physical parameters of the river, i.e., the salinity level, turbidity, temperature and water level.

WSN Cluster 2: Vo Canh WTP is located approximately 3km from Xuan Phong WTP. This WSN monitors chemical parameters, such as pH level, phosphate and chlorophyllII concentrations.

The topology of the network uses a cluster-tree model, with each cluster consisting of an array of 4 sensor nodes that can be randomly distributed but are fixed points floating on the surface of the river; hence the WSN consists of 8 nodes. The distance between sensor nodes is scattered approximately 100m apart. Communication is through WiFi compliant with IEEE 802.15.4 standards.

Fig. 1 describes the WSN setup for the study. The shape of the Cai River as well as the locations of 2 WTPs and KHAWASSCO in the model are a snapshot from Google Earth. Based on either Bluetooth or WiFi transmission protocols, sensors relay data to a sink node which is in turn

transmitted to the Xuan Phong and Vo Canh WTP monitoring stations via internet and eventually transferred to the main KHAWASSCO office where data storage, analysis and management activities take place. Power supply such as batteries or solar panels can be used (Corke et al., 2010). The data on water pollutants and sources will be collected and mapped spatially and temporally by a GIS tool - ArcGIS Version 10 for Windows. Transportation hotspots, water pipelines, sewerage channels and waste dumping material will be built into the GIS database in order to assist with the decision support system and effective management of raw water intake quality.

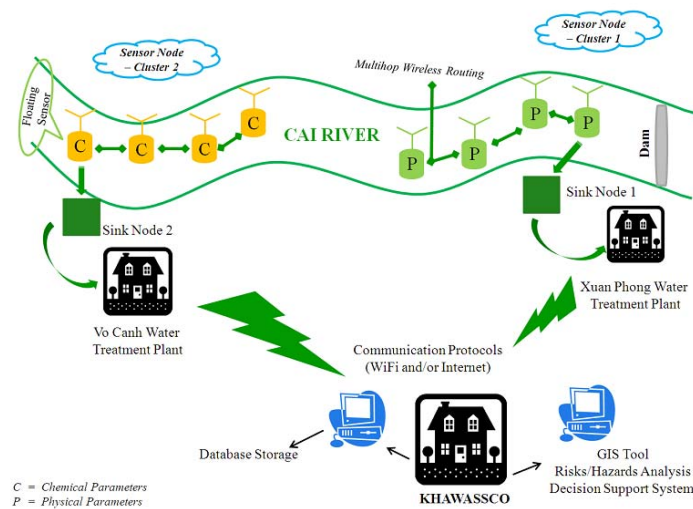


Fig. 1. A Wireless Sensor Network Model for Water Quality Monitoring at KHAWASSCO

Other relevant information, such as operational history review, as well as safety threshold values based on the Vietnamese surface water and groundwater quality standards and regulations will also be entered into the database. In addition to the provision of detailed spatial visualisation by the GIS database, when integrated with a decision support module, the system will enable the performance of rigorous analyses identifying and predicting all possible risks that are related to chemical spills, incidents and ecological changes occurring along the river. Finally, this will allow the evaluation of the water quality in the catchment area under KHAWASSCO's responsibility, so that just-in-time solutions and strategies can be taken. In order to support the analysis and decision support system, a number of statistical techniques (such as Factor Analysis, Principal Component Analysis, One-Way Analysis of Variance, etc) will be used to estimate the risk factors and their magnitude, in other words, correlate cause and effects parameters.

It is also noteworthy to mention that, as seasonal changes drastically affect the quality of water and ecology of the river, the evaluation period will span over 3 months to include both typhoon and dry seasons.

4. Conclusions

In addition to the general benefits accrued from applying advanced technology into water quality monitoring, the use of a WSN can also result in specific benefits to the company:

- Raising the understanding and awareness of the various stakeholders (KHAWASSCO management board, staff and neighbouring communities) of the potential hazards and pollutants

that affect the quality of raw water source, transportation routes, etc.

- Improving the process of risk identification/analysis at water source (or catchment). This will lead to the improvement of the whole risk analysis steps of the WSP manual of the company. Eventually, this will assist in an improvement of the water safety investment plan of the company since such plan is based on risk analysis.
- Identifying more comprehensive control measures as a result of improved risk analysis and predictive techniques. A comprehensive database with real time data capture within catchment areas will be developed.
- In addition to the above benefits, this study will also promote biodiversity, reduce pollutant load and optimise water source use.

Moreover, the dissemination and replication of this model for water quality monitoring and catchment management to other provinces and cities in the country will undoubtedly contribute to the consolidation of the best practice processes learnt.

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