Smart Technology for Water Quality Control: Feedback about use of water quality sensors

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Abstract**—*Water distribution networks can be subjected to accidental contamination or malicious attacks which could cause serious perturbations in the water quality. Such critical events threat the human health. Water utilities are concerned by the control of water quality. However, the traditional methods frequently used, are based on laboratory analyses and take several days. To prevent earlier water quality degradation, a real-time monitoring is required. The implementation of the smart technology in the distribution networks ensures a rapid detection of abnormalities. Since the use of this technology is recent, it requires a field application to evaluate its feasibility. This paper presents a field study of the use of this technology in a project conducted at the campus of the University of Lille within the European project "SmartWater4Europe". The campus is equipped with two types of sensors: S::CAN and EventLab. S::CAN measures multiple parameters such as turbidity and free chlorine, while EventLab measures the variation of the refractive index. We present in this paper the feedback of these smart devices, the analysis of water quality signals and finally a comparison with laboratory tests.*

Keywords: water quality, smart technology, sensors, online monitoring.

I. Introduction

The main purpose of water distribution system (WDS) is to deliver a safe drinking water to users. Water distribution networks are not inert transport systems, the high quality water produced at water treatment work is subject to a variety of complex and interacting physical, chemical and biological interactions [1]. Accidental or intentional contamination can degrade the quality of water, which can induce serious risks to human health. The water quality supervision is of high importance for water utilities. In general, water quality is monitored by taking samples manually from different locations in the distribution network. Two types of laboratory analyses are then executed: i) microbiological to determine the presence of pathogenic microorganisms and ii) physico-chemical to identify the organoleptic parameters of water. These conventional methods can take long time (from several hours to many days). In order to reduce the risks of contamination events, a rapid detection of water abnormalities is required. On-line water quality sensors can be used to enhance the monitoring of the water quality in real-time [2]. The deployment of smart technology throughout the distribution network improves the security of the water system. However, the use of smart systems in water quality control is recent. It requires both laboratory and field studies to test their efficiency. This paper presents the implementation of this technology in a large-scale demonstrator.

II. Water Quality Sensors

A. *S::CAN*

S::CAN micro::station is a water quality sensor that ensures an online monitoring of multiple parameters. The main components-spectro::lyser, sensors and controller- are assembled with required flow cells, mounting fittings and pipework on a compact panel [3]. A con::cube terminal with moni::tool software are used for the acquisition and display of data and for station control. Using a 3G SIM card, the transmission of data is ensured via a web server that can be connected to a Supervisory Control and Data Acquisition (SCADA) system. The measurements are provided, every minute, by four main probes:

- i::scan probe ensures measurement of the absorbance UV254, the TOC (Total Organic Carbon) and DOC (Dissolved Organic Carbon) as indicators of the amount of organic substances, the turbidity (EPA & ISO) that indicates the presence of microorganisms (bacteria, virus, etc.), the temperature shown by a bad flavor or odor and the color as organoleptic indicator.
- pH::lyser measures pH value for the corrosion control and the temperature.
- Chlori::lyser measures the amount of free chlorine as indicator of biofilm growth.
- Condu::lyser allows measurement of conductivity as indicator of the water mineralization and the temperature.

Using a safe drinking water, a stable line is established for each parameter. A significant deviation from this reference is considered as an event, induced probably by a contaminant.

B. *Optiqua EventLab*

EventLab measures continuously the variation of the refractive index (RI) as reliable indicator of water quality. Any substance dissolved in water affects this index [4]. The generic Optiqua EventLab sensor operates at a sensitivity level equivalent to parts per million (ppm) levels for any chemical contaminant [5]. It does not require any reagents or high cost of maintenance. This sensor is controlled remotely via a web server.

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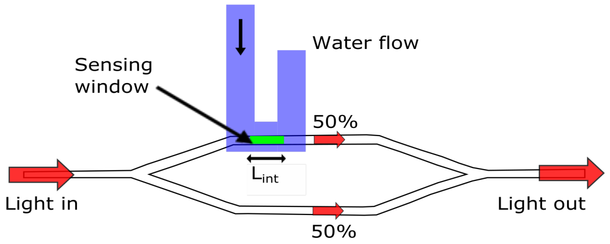

Fig. 1. Basic Layout of the Optiqua MZI sensor [4].

The system is based on the Mach-Zehnder Interferometer (MZI) principle as illustrated in Fig. 1. The basic layout of the MZI consists of an input channel wave-guide that splits into two identical branches, which are then combined again to form the output wave-guide [6].

The main output signal of EventLab is the variation of phase $\Delta\ \Phi_{m\ (measured)}$ of light propagating over the interaction window, given by the following equation [7]:

$$\Delta\Phi_m = (2\pi / \lambda)\ L_{int}\ (\partial n_{eff}/\partial n_{water})\ \Delta n_{water} \quad [radians] \tag{1}$$

where λ is the wavelength of the light in vacuum, L_{int} is the interaction light of the sensing window, $\partial n_{eff}/\partial n_{water}$=0.21 and Δn_{water} is the refractive index change in the water. With λ=850 nm and L_{int}=10 mm and using (1), the refractive index change Δn_{water} is given by:

$$\Delta n_{water} = 4*10^{-4}\ (\Delta\Phi_m/2\pi) \tag{2}$$

III. Online Monitoring at the Campus of the University of Lille

A. Pilot System

Since the smart technology is used recently in the water quality control, it is important to evaluate its efficiency. The feedback of the water quality sensors in the online supervision is very limited. A pilot system implemented in laboratory can enhance the evaluation of sensors capacity. To achieve this objective, a pilot station that reproduces the same conditions of water distribution network (pressure, materials, velocity, etc.) has been installed in the laboratory LGCgE (Laboratory of Civil Engineering and geo-Environment). The station is equipped with an injection system, where contaminants are introduced. Two types of contaminants: chemical and microbiological, have been injected. A reference line is obtained using normal drinking water during one hour. Then, contaminated water was introduced to test the response of sensors. The results can be summarized as follows [8]:

For chemical contaminants:

- EventLab proves a high reliability in the detection of low concentrations.
- S::CAN has a good capacity of detection.

For microbiological contaminants:

- EventLab did not detect this type of contaminants.
- S::CAN detected this type of contaminants from a bacterial concentration of 10^6 UFC/ml.

B. Site Description

The water distribution network of the scientific campus of the University of Lille is used in this study. The campus stands for a small town with around 25000 users. It includes 150 buildings and 100 km of urban networks (electrical network, sewage and heating, drinking water). The water distribution network is composed of 15 km of cast iron pipes which have diameter between 20 and 30 mm (Fig. 2). The network includes 49 hydrants, 250 isolations valves, purges and stabilizers [9]. The water is supplied to the campus at five sections.

C. Site Installation

The smart sensors were installed in two steps. The first installation was conducted in April 2016 at the engineering school Polytech'Lille, while the second was realized in October 2016 at Barrois restaurant. At both locations, a connection is taken from the nearest pipeline and sensors are installed on this connection. Water samples flow continuously throughout the sensors. The two sensors are controlled remotely using a 3G SIM card. Recorded data can be downloaded in csv files that contain parameters values every minute. Fig. 2 illustrates the location of the sensors installations.

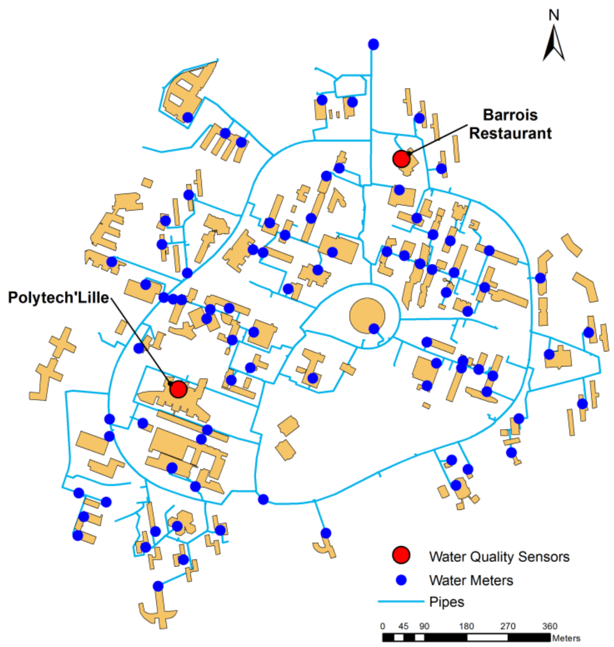

Fig. 2. Water distribution network of the campus with the locations of sensors.

IV. Water Quality Analysis

A. Water Quality Signals

Ten parameters are measured by S::CAN. Each parameter is represented by a water quality signal. The signal is constant and below standards for safe drinking water. The presence of contaminant in water is shown by a deviation from the stable line. However, it is important to differentiate between normal variation and that due to water quality degradation.

A first example of S::CAN response is illustrated in Fig. 3 at Barrois Restaurant during the period between December 1 and 15, 2016. In addition to the S::CAN parameters, threshold limits, based on the World Health Organization (WHO) standards, were plotted. As indicated in Fig. 3, the variation of signals is generally below the standards thresholds. The analysis of the water quality signals indicates a safe drinking water at this location.

Fig. 4 shows data collected by S::CAN at Polytech'Lille for the period September 1 and 15, 2016. During this period, most of signals are stable, but some events are detected. These events are characterized by an abnormal increase regarding the reference line. For the same period, Fig. 4 displays the variation of hydraulic parameters: pressure and consumption. The pressure profile could not explain the source of events. However, we observe that an increase in the water consumption is correlated with the peak of some parameters. This can be verified by the extraction of materials from the aging water pipes when the flow increases. In fact, events detected are generally observed in morning. During night, the consumption is lower and signals remain stable.

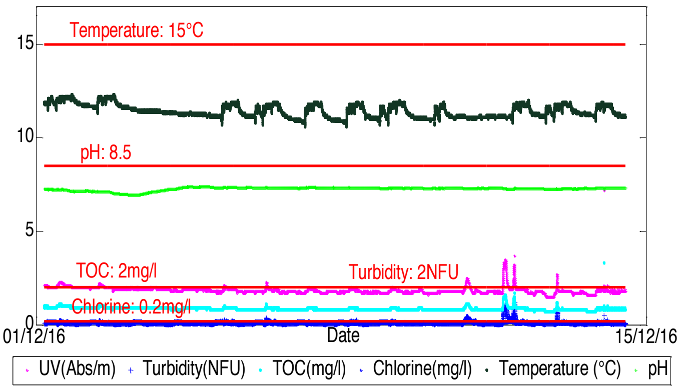

Fig. 3. S::CAN response with standards thresholds between December 1 and 15, 2016 at Barrois.

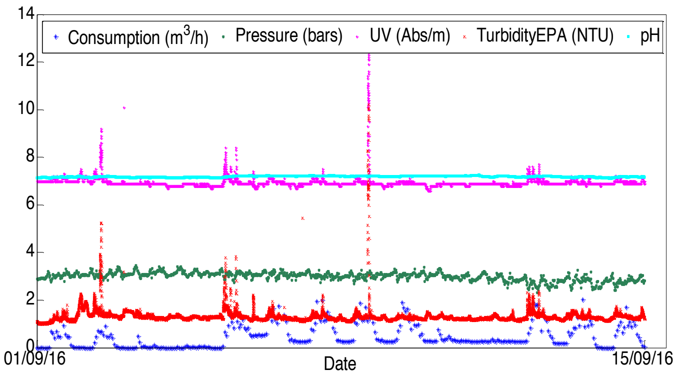

Fig. 4. S::CAN response with hydraulic parameters between September 1 and 15, 2016 at Polytech'Lille.

B. Analysis Of Phase Variation

As detailed previously, the main response of EventLab sensor is the variation of phase, which is proportional to the change in refractive index (RI). At each time step i, the system measures the phase Φ (i), then its variation is calculated as follows:

$$\Delta\Phi\ (i) = \Phi\ (i+1)\text{-}\Phi\ (i) \tag{3}$$

In general, the variation of phase as well as the change in refractive index (RI) is quasi-stable for a normal drinking water. We define an outlier as an exceeding from the normal variation ($\pm 3\sigma$) [10]. Event detected outside these limits should be analyzed to identify the possible presence of contaminant.

As example of EventLab measurement, we have plotted the variation of phase on July 1, 2016 for Polytech'Lille (Fig. 5). The corresponding variation of phase is below the accepted limits. However, some events are detected outside the thresholds (red circle in Fig. 5). To identify the source of such events, the consumption is displayed in the same graph. A sudden increase in the consumption is followed directly by a significant deviation in the phase variation. This can be attributed to by the drawn of suspended materials by the water flow.

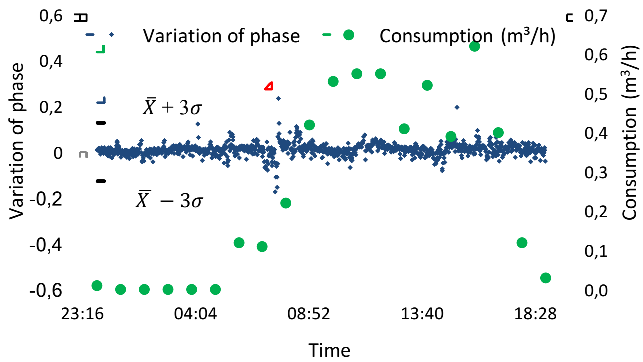

Fig. 5. EventLab response with consumption profile on July 1, 2016.

C. Laboratory Sampling Results

In order to validate the measurements of S::CAN sensor, samples were taken from the two locations for laboratory analysis. Microbiological tests measure the amount of some microorganisms such as Escherichia Coli. Also, the quantity of some metals, such as Arsenic and Aluminum was evaluated. Laboratory tests showed values below standards thresholds.

In order to compare the laboratory analyses with S::CAN data, all parameters (UV, Turbidity, Chlorine, etc.) given by S::CAN were measured in the laboratory. An example of the comparison is illustrated in Fig. 6. The relative error for most parameters, such conductivity, temperature, etc. is small. The comparison proves the good performance of S::CAN measurements. Based on laboratory results, some parameter adjustments were done to get more accurate data.

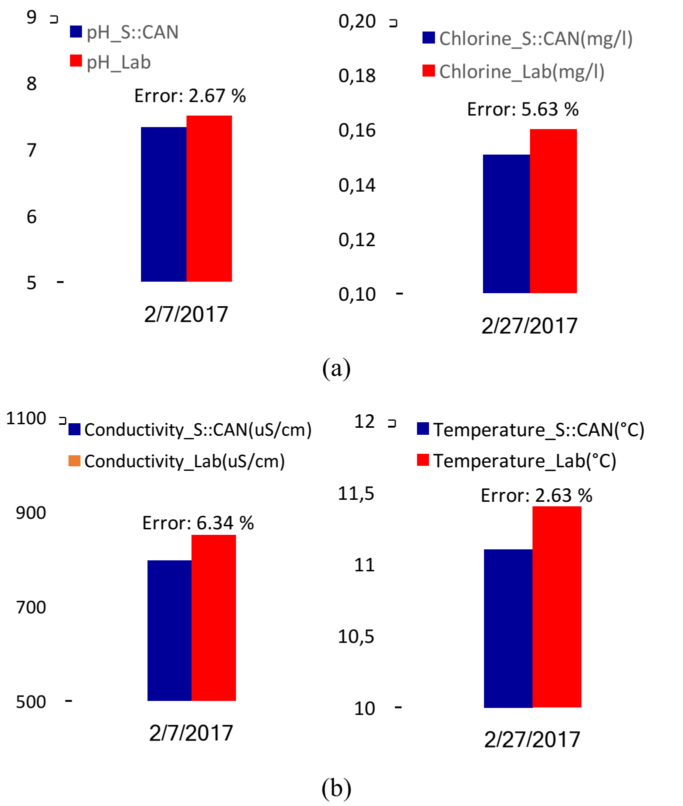

Fig. 6. Laboratory comparison. (a) Polytech'Lille; (b) Barrois.

V. CONCLUSION

This paper presented analysis of the use of two smart sensors (S::CAN and EventLab) for early detection of water contamination. The performances of these sensors were first verified using a pilot station. Then, these sensors were installed in the distribution network of the Scientific Campus of the University of Lille. Recorded data showed quasi-constant signals. Some events were detected. They coincided with the start of water consumption.

A comparison between recorded data and laboratory analyses confirmed the good performances of the tested sensors. The demonstration program continues in order to enhance our experience with these innovative water quality sensors.

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