IoT stations for monitoring a district metered area of Guanajuato city

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***Abstract*—This paper presents the first phase toward the implementation of a monitoring and diagnostic pilot system for a district metered area (DMA) of the water distribution network (WDN) of Guanajuato city. Such a system consists of two main components: (1) a grid of stations equipped with Internet of Things (IoT) technology, where hydraulic and quality data are measured and sent to a web platform, and (2) algorithms based on artificial intelligence and control theory for providing early diagnosis of faults and quality deviations. Specifically, this work describes the architecture and installation of the first and second stations, which were located at the DMA input and in a public hospital. Moreover, some preliminary uses of the recollected data are presented to show the potentiality of metering drinking water.**

Keywords*—IoT applications, real-time monitoring, remote sensing, water quality, cloud storage, hydroinformatics.

I. Introduction

A smart water system is one of the six ingredients that make up a Smart City; the rest are systems that involve the management of energy, mobility, buildings, public services and economy. The goal of integrating these systems is make cities more efficient to improve the quality of life of their inhabitants.

Generally speaking, a smart water system uses a holistic approach to manage this resource, as well as the infrastructure surrounding its supply, treatment and distribution. Technically, smart water systems use sensors capable of collecting data in real time and transmitting it to the cloud, that is, sensors suitable for the Internet of Things (IoT). These sensors allow execute essential maneuvers for a good management of the water distribution networks, such as, for example, the quality monitoring and the leak detection.

In this regard, SIMAPAG together with the II-UNAM and the Universidad de Guanajuato undertook the implementation of a smart water grid system in Guanajuato city, which use IoT Technology to get real-time information from hydraulic and quality sensors placed in IoT stations [1,2,3].

In the context of this contribution, an IoT station is a physical space (e.g., a valve box or an area close to a water meter) that is made up of four systems: a power supply, an array of sensors, an IoT device, and a virtual space in the cloud: a web platform.

II. Description of the Guanajuato WDN

The drinking water requirements of Guanajuato city are fulfilled, in part, by the water treatment plant called *Filtros*, which is supplied by *La Soledad* and *La Esperanza* dams. 40% of the city's water demand is covered by the water treatment plant, while the remaining 60% comes from wells. The WDN of Guanajuato city has a length of about 130 km and has pipes with diameters that range from 4 to 16 inches. More than 72% of the WDN consists of PVC pipes and is divided into 34 macro DMAs, of which one is called *3 Estrellas*, which includes *Los Alcaldes* DMA: the area designated for the implementation of the first phase of the smart water grid system.

Los Alcaldes involves a middle-class neighborhood, a public hospital that has a 35-m^3 tank, and a bus station. In *Los Alcaldes* is delivered water to more than 1000 fixed customers, but there are floating customers (traveler and patients) that change the demand. The EPANET layout of the network is shown in Fig. 1. *Los Alcaldes* is supplied by a reservoir with a volume of 1000 (m^3) called *3 Estrellas*, which in turn is supplied with water that is sent by pumping from a station that receives water from the wells.

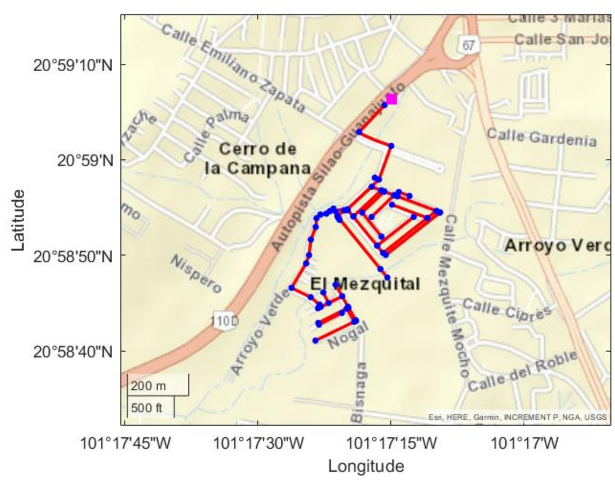

Fig. 1. EPANET layaout of *Los Alcaldes* .

A. *Description of the first IoT station*

The first IoT station is an underground space that can be accessed by descending stairs that are fixed to the wall. The main line (a 3-inch pipe), which delivers water to the subsector, passes through this station. A pressure reducing valve (PRV) is installed to the main line, which regulates the pressure at the input of the sector.

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Two pressure transducers were installed at the station: upstream and downstream of the PRV, respectively. In addition, a bypass was mounted to the main pipe, in which a pH/ temperature sensor was collocated and, in which other quality sensors will be installed. The main advantage of a bypass installation is that sensors can be easily isolated for maintenance without disrupting the supply. A flow meter was installed downstream the PRV in order to measure the consumption of the subsector users.

The station was designed to be autonomous, reason by which it has a photovoltaic power supply system with an energy storage capacity for operation for up to 30 days without sun. A picture of this station can be seen in Fig. 2.

Fig. 2. First IoT station.

The first station is equipped with three VERSE Technology® IoT devices that send the measurements taken by the sensors toward a web platform. One device sends the measurements provided by the pressure transducers, a second device sends the measurements given by the flowmeter and the pH/temperature sensor and a third device transmit measurements of free chlorine (see Fig. 3). All the IoT devices use different communication protocols to work with the diverse sensors that are connected to them, including analog and digital protocols: 4-20 mA, HART, RS-232/485, UART, SPI, I2C. Additionally, the IoT devices have a radio frequency communication module that is compatible with the 2G and 3G networks of any global cell phone carrier, which allows the communication between the IoT devices and the web platform, where data are received, displayed and stored for analysis.

The web platform, which manage the analysis and storage of data, use the Microsoft Azure® cloud computing services that include tools such as IoTHub and Stream Analytics, for handling the IoT devices, and SQL Server databases, for storing the information. The web platform was designed to be scalable and robust to receive and process large amounts of data. Furthermore, it was conceived to allow the use of complex algorithms that are essential for a smart water grid system.

The sending of data from both devices is non-synchronized with irregular intervals between 10 and 11 minutes. Stored data can be downloaded in the following data files: .csv, .pdf, .xls. The data are labeled with the names of the variables and have associated time and date stamps that indicate the sending of the measurements.

Fig. 3. Chlorine measurement device.

B. Description of the second IoT station

The hospital station is equipped with a telemetry device that transmits information from a flow meter and a pressure transducer. Its power supply system is made up of a bank of batteries that is recharged during the day with the energy of solar radiation that a solar panel captures. An image of this station is shown in Fig. 4.

Fig. 4. Second IoT station.

III. Preliminary Uses of the Information

Real-time monitoring of hydraulic parameters, as well as those associated with water quality, can allow those responsible for improving the distribution service, reducing water losses and minimizing maintenance costs by increasing the resilience of distribution networks.

However, real-time monitoring *per se* is not enough to achieve comprehensive network management. To achieve this goal, it is necessary to use real-time information as a feed for prediction algorithms. In other words, hydroinformatics is required to articulate the information that promotes efficient water distribution.

A. *Water Demand Analysis*

Many metrics are used to characterize water, such as the Average Day Water Demand (ADD) or the Peak Daily Water Demand (PDD). From these metrics, mathematical models can be formulated to describe and predict the behavior of water demand. These models, in addition to helping in the diagnosis of leaks, are key tools to project and plan new developments or expansions, such as storage tanks or pumping stations.

One of the most used metrics for the detection of leaks in a DMA is the Minimum Night Flow (MNF), which can be calculated from the information that is captured at the IoT stations. The MNF is the lowest average flow over a 24-hour period and is generally obtained between 00:00 and 4:00, i.e., when most tanks have been filled and users are asleep.

Another important indexes used for analyzing water demand are the Peak Demand Coefficient (CP), which is the ratio of the PDD against the ADD, and the Night Flow Ratio (NFR), which is the ratio between the NFR and the MNF. The CP can be used in approaches for forecasting the PDD, which in turn is often employed for the cost-effective and sustainable management and expansion of water supply infrastructure, while the NFR is a useful instrument in the leakage analysis [5][6].

TABLE I. shows the PDD, MNF, ADD, NFR and CP for some months corresponding to the years 2019 and 2020. Specifically, the values presented in the tables are the most probable values of the respective index during a month. From the values of these indices, it can be seen that July and March present the highest daily maximum demand. The reason: these are vacation months with high temperatures. PDDs during November and December are the lowest due to winter and low temperatures. Furthermore, during these months, the MNF and ADD values are also the lowest.

TABLE I. WATER DEMAND INDEXES PER MONTH (L/S)

Month	*PDD*	*MNF*	*ADD*	*NFR*	*CP*
June 2019	3.2	1.0	2.19	0.46	1.46
July 2019	4.7	1.0	2.23	0.21	2.1
August 2019	4.2	0.8	2.32	0.19	1.81
September 2019	3.6	0.9	2.04	0.25	1.76
October 2019	3.6	0.9	2.04	0.25	1.76
November 2019	2.9	0.3	1.93	0.10	1.50
December 2019	2.9	0.3	1.94	0.10	1.49
January 2020	3.8	0.7	2.19	0.18	1.73
February 2020	3.8	0.7	2.11	0.18	1.80
March 2020	4.2	0.5	1.08	0.12	3.89

Fig. 5 shows the PDD time series during the month of February 2020. Notice that the daily demand peaks are highlighted. These highlights allow us to observe that the highest demand was around 6 L/s, as well as that the daily demand peaks differ each day. That is why the most convenient models to represent and predict the peak daily demand should be stochastic [6].

The randomness of the peak daily demand can best be seen in the histogram shown in Fig. 6. In [4], it has been observed that the probabilistic distributions that better represent the water demand in its daily variation, vary according to the period of the day. In particular, the authors showed that the Gumbel and Log-normal distributions well represent the peak daily demand of an Italian DMA with a small number of users.

Fig. 7 shows the time series of the daily night flows during the month of February 2020. In this figure, there are two things to note: (1) the lowest MNF was around 0 L/s and (2) the MNF vary in value from day to day. The probability distribution of the MNF during the month of February is shown in Fig. 8.

Authors in [4] suggested that the known probability function that best characterize the MNF in a small DMA is the Poisson model. By observing the probability distribution shown in Fig. 8, It seems feasible to model the *Los Alcaldes* MNF with a discrete distribution function too, such as Poisson's.

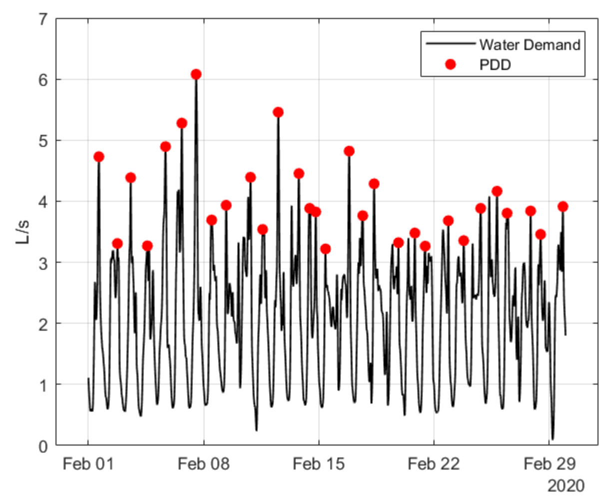

Fig. 5. PDD time series during February 2020.

Fig. 9 shows the hours with the peak demands during February 2020. In this figure it can be seen that the peak demand can occur between 8:00 and 21:00, but that most of the time it occurs at 20:00, i.e., after dinner time.

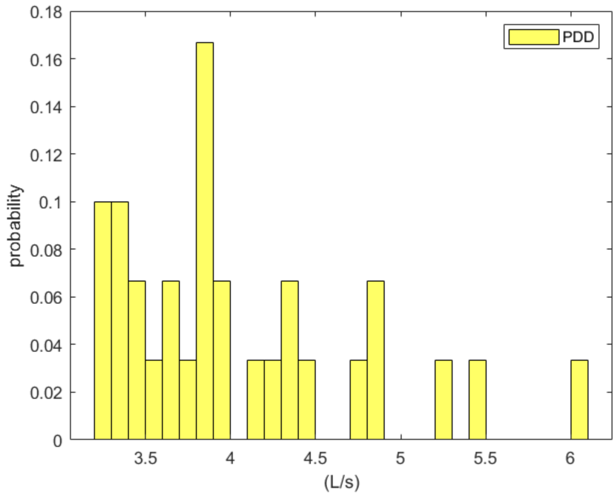

Fig. 6. PDD frequency distribution during February 2020.

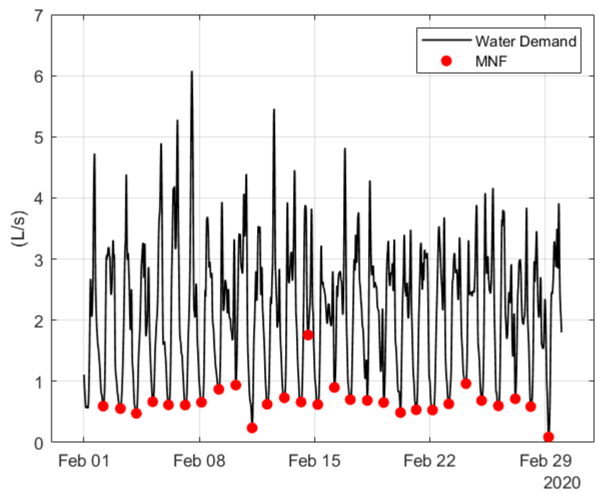

Fig. 7. MNF time series during February 2020.

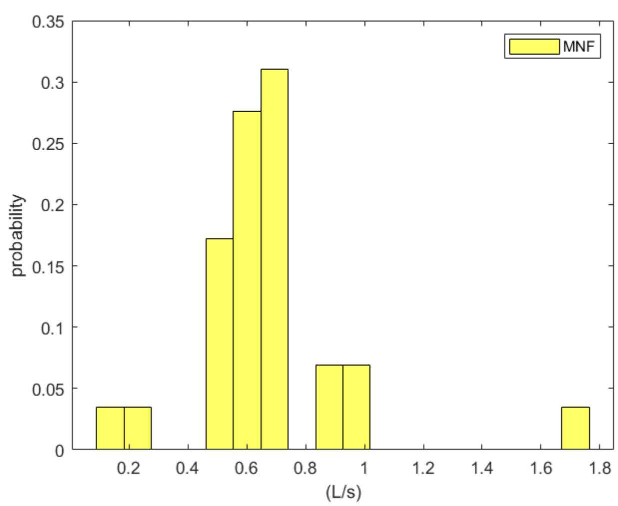

Fig. 8. MNF frequency distribution during February 2020.

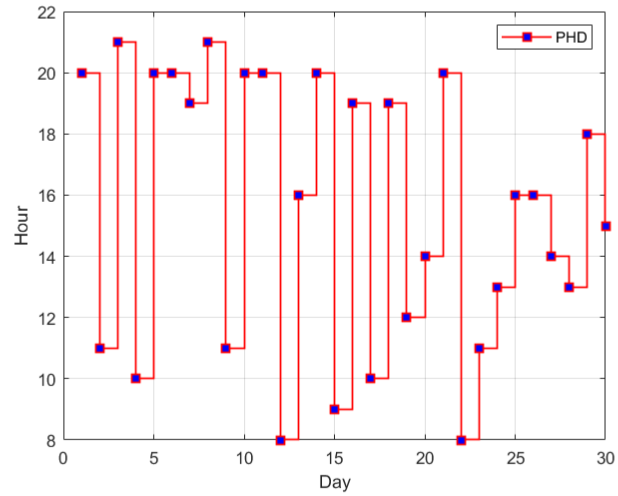

Fig. 9. Hours with peak demands.

B. *Quality Analysis*

To complement a good water distribution service, it must be ensured that the water is drinkable and suitable for human consumption, so it is necessary to measure physical, chemical and microbiological parameters associated with its quality. In this context, there are two types of water quality problems. The first is a chronic problem with the origin of the water, treatment processes and operator errors that affect quality. This type of problem is generally rectified in the treatment stage and can be detected by laboratory analytical methods. The second type of problem comes from intermittent or one-time quality disruption due to deliberate or accidental contaminant intrusion. These problems, which could cause catastrophic impacts on human health, cannot be detected with conventional sampling and analysis methods. Existing laboratory analytical methods, especially for analysis microbiological, do not provide real-time warnings and are too slow for development of operational response in the event of a failure event. Often when you get the laboratory results, the water has already been supplied to the consumers.

Therefore, online monitoring of the parameters associated with water quality is essential in a smart water system, as it would allow managers to quickly identify any potential problems and apply corrective measures to protect the consumers. Two of the most important parameters to monitor are pH and free chlorine.

Accurate measurement of free chlorine is essential because the presence of residual concentrations of this parameter is considered an indication of microbial drinking water in municipal distribution systems. Moreover, in COVID-19 times, the online monitoring of chlorine is very recommended to ensure the drinking water quality. If the concentration of free chlorine in the water is too low, it may not provide effective protection against SARS-CoV-2. On the contrary, high chlorine levels can cause pipe network corrosion and provoke severe skin and respiratory irritation to the consumers [8].

According to the Mexican norm NOM-127-SSA1-1994, the free chlorine must remain between 0.2-1.5 mg/L.

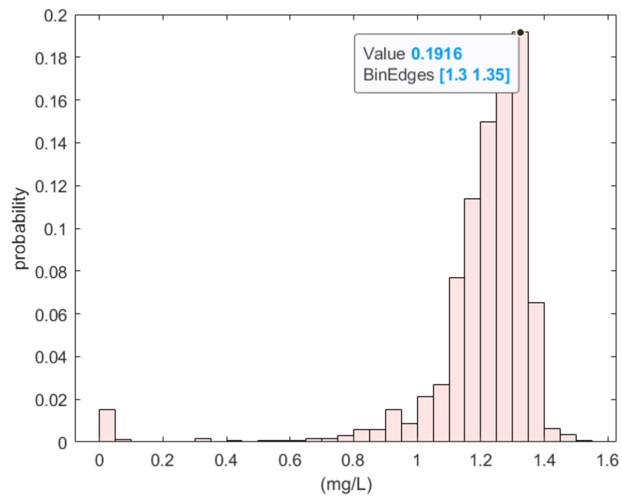

Fig. 10. Free chorine histogram during 2020.

Fig. 10 shows the distribution of the free chlorine measurements in *Los Alcaldes* during 2020. It can be checked that the most likely value is between 1.3 and 1.35 (mg/L). This means that free chlorine concentrations were within the permissible interval recommended by the NOM-127-SSA1-1994.

pH is one of the most important operating parameters of water quality. The NOM-127-SSA1-1994 norm recommends that the pH of the water should be between 6.5 and 8.5 (mg/L), preferably less than 8 for effective chlorine disinfection. Low pH may indicate leaching and nitrification, that is, damage to the distribution system. Extreme pH values may be the result of accidental spills, from contaminant intrusion into through broken or corroded pipes, from treatment failures or due to the presence of microorganisms that change pH by producing basic or acidic metabolic wastes. In the COVID-19 pandemic context, it has been demonstrated that SARS-CoV-2 is extremely stable in a wide pH range from 3 to 10 (mg/L), but it is also susceptible to standard disinfection methods [9][10]. Fig. 11 presents the probability distribution of pH during 2019. It can be notices that the most probable value is between 6.6-6.8 (mg/L) as recommended the NOM-127-SSA1-1994 norm.

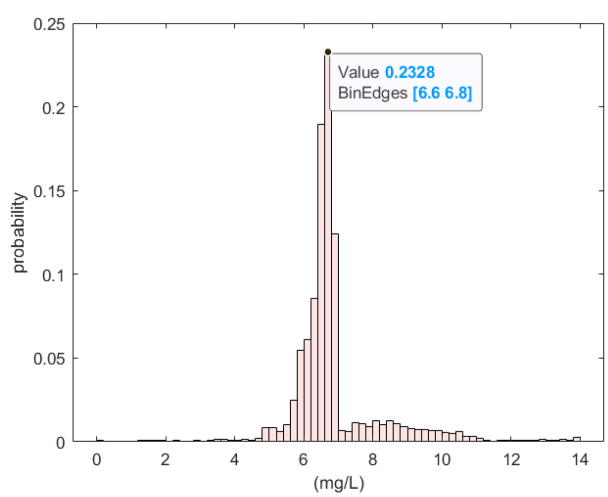

Fig. 11. pH histogram during 2019.

Another important factor on the water distribution, in the COVID-19 pandemic situation, is temperature, which is an enormously important factor influencing the survival of coronaviruses. According to, the coronaviruses tend to be promptly inactivated at medium temperatures (i.e., 20 ◦C) rather than at low temperatures (i.e., 4 ◦C).

Fig. 12 displays the probability distribution of the water temperature during 2020, which was measured at the first station. It can be seen that the water remained at temperatures above 27 ° C, that is, at temperatures not conducive to the survival of a coronavirus.

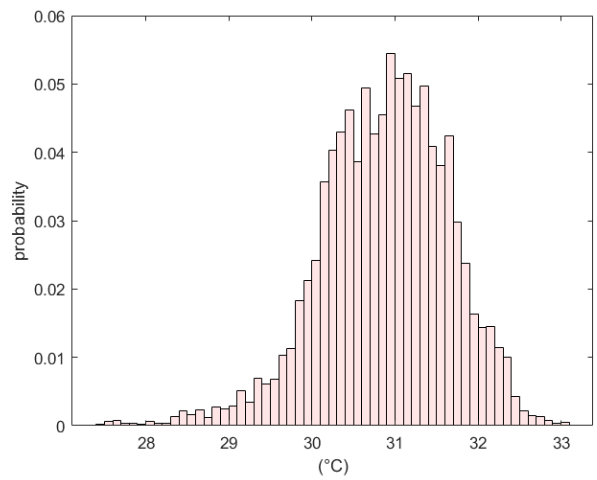

Fig. 12. Temperature histogram during 2020.

In summary, the survival period of SARS-CoV-2 in water is highly dependent on water temperature, pH, chlorine. Therefore, the constant monitoring of these three variables can ensure that the water consumed by citizens is free of SARS-CoV-2. But not only the measurement of these parameters can help ensure water quality, hydraulic variables are also useful for this purpose as they can be used to detect and locate leaks in a water distribution network with underground pipes. It is important to remember that leaks are an important source of contamination, especially at low pressures [11][12].

IV. Conclusions

This article presented the details of a pilot project to monitor and acquire information on the hydraulic and quality variables of a district metered area of Guanajuato city by using IoT technology. In particular, the architecture of two monitoring stations was described. Such stations were instrumented with chlorine, pH, pressure, flow, temperature and pressure sensors. Some possibilities that can be given to the information collected were also described, especially in times of COVID-19, since the water that reaches users is required to have the best possible quality.

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