A Robust Sensing Node for Wireless Monitoring of Drinking Water Quality

Lorenzo Mezzera[1], Michele Di Mauro[2], Marco Tizzoni[2], Andrea Turolla[2], Manuela Antonelli[2], Marco Carminati[1]
[1] Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano
[1] Dipartimento di Ingegneria Civile e Ambientale, Politecnico di Milano
Piazza Leonardo da Vinci 32, 20133 Milano, Italy
{manuela.antonelli, marco1.carminati}@polimi.it

Abstract. In this work a low-cost and credit-card-sized electronic platform for continuous monitoring of water quality is presented. It performs a measurement of pH, temperature, conductivity, flow rate, pressure and a novel sensor for the thickness of surface fouling, either of chemical and biological nature. The system includes a GSM transceiver that allows the creation of a wireless sensors network for real-time monitoring of these parameters, enabling increased safety and, in perspective, automation and predictive maintenance of the water network. An external watchdog timer increases the robustness and the complete self-diagnostic ability of the solution. Preliminary results from field validation will be reported.

1 Introduction

Water is often called the “blue gold” of the 21th century. This is due to its relevant role for human life, agriculture and economy. Public opinion, in fact, is becoming increasingly aware of its limited availability and, thus, of its value for mankind. For this reason, public agencies managing the water cycle are under increasing pressure to grant safety, quality and quantity of the drinking water. In particular, monitoring of drinking water quality is fundamental in order to detect natural or deliberated contamination (such as in terroristic attacks). The system presented in this work can monitor the main chemical and physical parameters of the drinking water such as conductivity, pH, temperature and three parameters useful for the water network operators such as water flow, pressure and, by means of an innovative sensor, the thickness of biological (biofilm) or chemical (limestone) deposit on the inner surface of pipes. The system can thus provide an accurate and real-time overview of the network status with no need for traditional laboratory analysis that, despite being very accurate (and thus complementary), are more expensive, time demanding and, most of the times, not representative of the entire network. At the moment, on a pilot scale, a few of these sensing nodes are placed in strategic points of the network in order to model the system and improve maintenance and potabilization processes, optimizing the use of chemicals.

2 Sensors Platform and Electronic Circuit

The platform, which is the third evolution of past prototypes [1-2], is able to measure the basic parameters of drinking water: conductivity, pH and temperature (to compensate the temperature-dependence of other sensors). Flow rate, pressure along pipes and deposit thickness can also be monitored. The measurement of scaling and biofilm is the most original and challenging aspect of this project. With respect to other products available on the market, adopting optical or electrochemical principles [3], our system leverage impedance across planar microelectrodes to measure the thickness and type of deposit [4]. In this way the main goals of this project, i.e. robustness and sensitivity, can be fulfilled through the use of a very compact and low -cost sensor.

The system is managed by an Arduino Mega microcontroller (Fig. 1) that acquires data from the sensors, after conditioning by a custom analog electronic board, manages the data and, thanks to a GSM Shield with an external antenna, transmits them (every 15 to 60 seconds) to an IoT server (Thingspeak). This portal allows to manage the data and visualize the results (either raw or processed by proper models) on a web page compatible with both a computer and a smartphone. In order to increase the robustness of the solution, an external watchdog controls the correct execution of the code in the microcontroller and reset the system in case of failure.

The design specifications for resolution are: 0.5°C for temperature, 0.1 for pH, 2μS/cm for conductivity and sub-micrometric resolution for deposit. The spacing of the microelectrodes electrodes determines the measurable deposit thickness and the operating frequency. For 10μm electrodes, the operating frequency is around 2MHz. Thus, a synchronous demodulation scheme is adopted for the accurate measurement of impedance in the 1-10MHz range. A low-power DDS generates the sinusoidal stimulation and is used in combination with a transimpedance amplifier (TIA) that converts the sine current into voltage. This voltage is filtered by a second-order Chebychev low-pass filter (LPF) implementing a Sallen-Key configuration. This

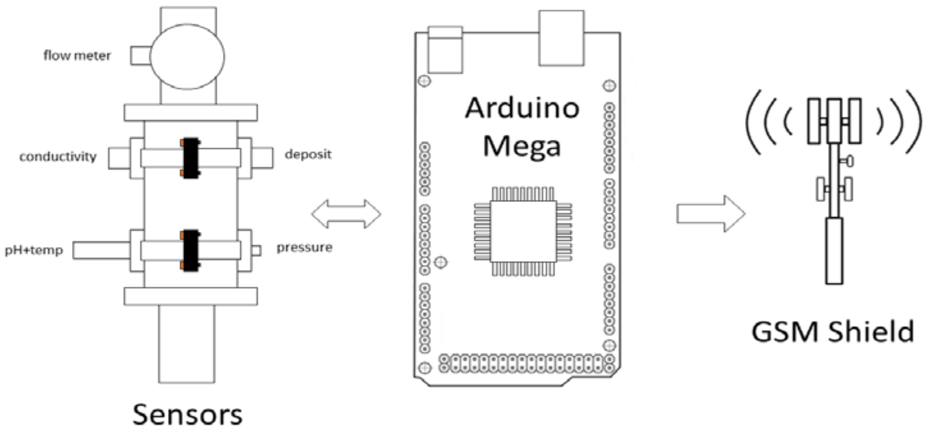

Fig. 1. Scheme of the whole platform including the sensors embedded in the pipe and the GSM shield for wireless communication.

stage is the driver of the forcing electrode. The current signal of the sensing electrode is collected by another TIA and sent to an analog multiplier with the reference sinusoid. Thanks with the last LPF, a DC signal inversely proportional to the resistance of the deposit is obtained. The measured resolution is better than 1µm [4].

Gold-coated connector pins [5] are used for conductivity sensing. Given the different geometry of the electrodes, here the operating frequency is lower (100kHz) allowing the use of a single-chip 12-bit FFT-based impedance detector, to save space and complexity, The conductivity value is also used by the algorithm estimating the deposit thickness. In order to increase the self-diagnostic capacity of the system four identical conductivity sensors have been inserted: thanks to their low-cost, physical redundancy is chosen. Instead, pH and temperature are measured by means of an industrial probe whose signals are acquired by a 24-bit ADC, setting a reference and reading the value from the sensor. The value measured by the manometer is read by the Arduino internal ADC since its performance are adequate. The flow meter provides a signal which is frequency-modulated by the water speed thanks to a Hall sensor. A key aspect during the layout of the PCB was the design of the power supply. Digital and analog parts are present at the same time and must be separately routed. The Arduino board supplies the digital power to the ICs with digital part and another separate LDO regulator is used only for the analog power supply. The 4-layer PCB (Fig. 2) is designed in order to separate with a ground layer the analog portion of the circuit from the route of the communication protocol on board, such as SPI and I2C.

3 Performance Assessment and Validation

The entire system has been thoroughly tested: initially in static laboratory analysis and then in a closed loop, to create similar dynamic conditions (of water flow and pressure) to those of a real distribution network.

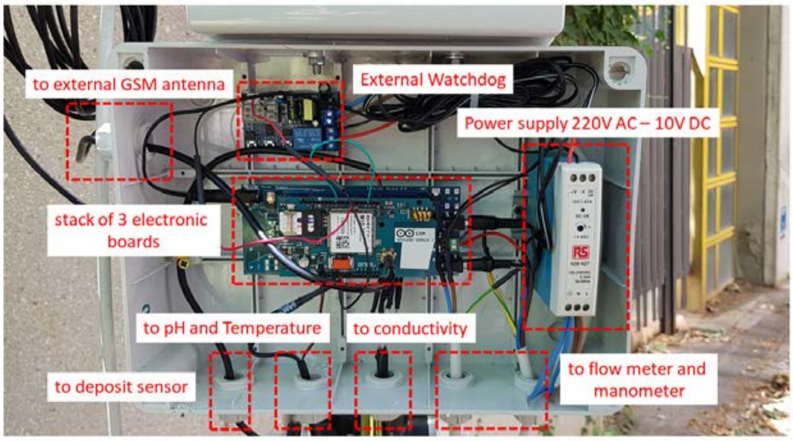

Fig. 2. Stack of the 3 electronics board and the external watchdog that performs the control on the code.

The experimental results confirm performances in agreement with design specifications and in line with what offered by commercial instrumentation, but with higher integration and lower cost and size.

In particular:

- temperature: resolution better than 0.1°C between 0 and 50°C
- pH: resolution better than 0.1 between pH 0 and pH 14
- conductivity: resolution better than 20 ppm between 50µS/cm and 2500µS/cm
- film monitoring: resolution better than 2µm between 5 and 35µm and better than 5µm between 35 and 350µm
- flow: resolution better than 0.1L/s between 2.5L/s and 80L/s
- pressure: the system was tested upon to 4 bar

The system has been tested for a continuous 3-week period within the loop. Among various tests of tracking the chemo-physical parameters of water, a measurement of the power consumption was performed by means of a DMM7510 multimeter by Keithley. Data show that the acquisition and transmission periods represent only a small amount of the total power consumption and the most of the energy is spent during the "sleep" condition. The adoption of the GSM technology, instead of an emerging IoT-oriented solution (such as Sigfox or LoRa WAN), is motivated by the lack of a standardization and by the excellent coverage provided by the traditional cellular network. Anyway, an auxiliary port for serial communication with different transceiver modules is present to adapt to various radio infrastructures, locally available along the network of pipes.

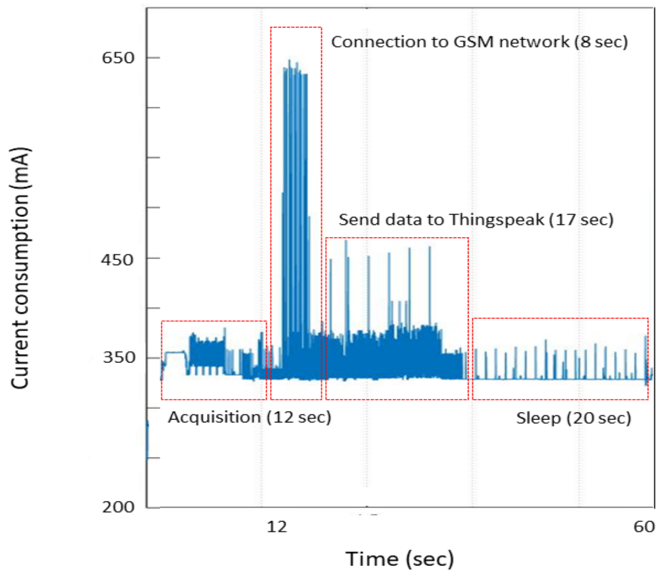

Fig. 3. Current consumption during an entire cycle of operation of about 60 sec.

4 Conclusions and Outlook

After the laboratory validation with the loop, three fully-equipped prototypes (Fig. 4) are currently under installation in a real water distribution network for a pilot validation in the field. On the other hand, the time tracking of power consumption shows that it needs to be reduced if an energy harvesting system (involving the use of an external battery) will be leveraged to allow installation of the nodes away from power mains. Preliminary tests were performed with an energy-recovering turbine in combination with a smart algorithm running in the Cloud and adapting the time delay between two different acquisitions, in order to maximize the charge of the battery. Simultaneously, a redesign of the entire board is in progress to reduce the consumption in stand-by condition. During the sleep phase, the microcontroller turns off the sensors acquisition and transmission sections, powering only the energy harvesting. The power consumption drops down to about 20mA, i.e. ten times smaller than the present average consumption of about 1.5W.

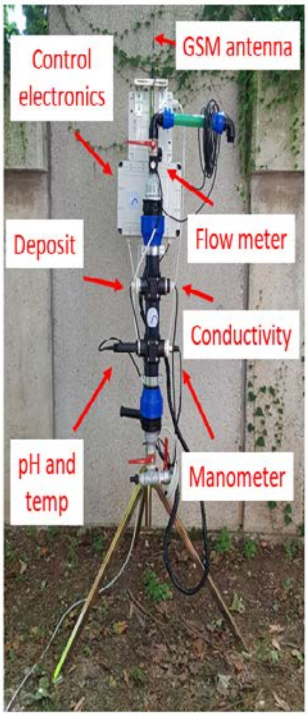

Fig. 4. Sensorized pipe mounted on a tripod with the protected electronics, ready for the installation in a drinking water network.

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