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SENSOR NETWORK FOR ENVIRONMENT MONITORING: WATER QUALITY CASE STUDY

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Abstract: The challenges of climate change, population growth, demographic change, urbanisation and resource depletion mean that the world's great cities need to adapt to survive and thrive over the coming decades. Slashing greenhouse gas emissions to prevent catastrophic climate change while maintaining or increasing quality of life can be a costly and difficult process. Two factors that directly affect the life quality in the XXI century cities are the water and air quality that can be monitored using the combination of low cost sensing modules, M2M and IoT technologies. In this context the work presents a wireless sensor network architecture that combines low cost sensing nodes and a low cost multi parameters sensing probe for reliable monitoring of water quality parameters of surface waters (lakes, estuaries, rivers) in urban areas. An extended description of the water quality measuring channels and several elements concerning the wireless sensor network implementation are included in the paper.

Keywords: water quality, turbidity sensors, wireless sensor network,

1. INTRODUCTION

The smart cities in the current worldwide ICT scenario means a constantly growing number of ever more powerful devices (smartphones, sensors, household appliances, RFID devices, etc.) join the Internet but also an increasing of the low cost sensors that can deliver information used to increase the quality of life. First steps were done in the field of air quality different systems being deployed monitor the concentration of gases such as NO2, CO as so as the evolution of physical parameters such as relative humidity (RH) and temperature [1][2]. Together the air quality condition the quality of surface waters such as lakes, rivers, estuaries might be considered taking into account the relation between the outdoor air quality and water quality.

The best example of a direct link between air pollution and water pollution is acid rain. Acidic gases (NOx and SOx) are emitted into the air by various sources. They combine with water in the air to form sulphurous and nitrous acids which then fall as rain to contaminate water in rivers and lakes by decreasing the pH. The acidic water leaches metals out of the rocks and sediments as soluble ions. These increase heavy metals (arsenic, lead, etc.) levels in the water. Taking into account these interrelations and also the health protection of the people that use the water for diary activity and for water sports, the existence of distributed measuring systems for on-line monitoring of the quality of water with capability to transmit the information using client-server architectures, including mobile technology, represent a new challenge.

Considering the example of air quality sensor architectures that were deployed in different cities in the last years [3], one of the conditions to assure a quick implementation is low price of the system. Also important is the capability of the system of monitoring the environment parameters in extended areas. In this context, we considered the development of a system that can provide information about the changes in the quality of water through the measurement of electrical conductivity, temperature and turbidity. Through the measurements of these variables we can detect changes in water environments and study if the causes of those modifications are natural or not, like in the case of pollution. For extended information about the water quality when pollution events are detected, it shall be possible to add to the system multiparameter water quality probes such as Hydrolab Quanta Multiparameter Sonde [4] or the Rosemount Analytical Model 1057 Multiparameter Analyser [5] for higher flexibility and interoperability.

Taking into account the above mentioned considerations, a water quality sensing module with conductivity, temperature and turbidity measuring channels was designed and implemented. Each sensing module is attached to a wireless sensor node equipped with primary data processing and wireless communication capabilities.

Referring to the conductivity measuring channel, a two electrodes cell was used due to its simplicity, easy to clean and desired range [6]. The temperature compensation associated to the conductivity measuring probe is based on the temperature information delivered by the temperature measuring channel that is expressed by an NTC thermistor and an appropriate conditioning circuit. The turbidity measuring channel was materialized using two detectors associated with the measurement of transmitted and scattered light emitted by a light source [7].

The signals provided by the measuring channels are acquired, processed, and transmitted by an NI WSN sensor node, through a gateway to a host computer internet connection that provides a water quality monitoring service using LabVIEW web server capabilities. Several signal processing algorithms can be implemented on the host computer including global representation of water quality evolution for the monitored area, pollution events signalling, short term and long term water quality prediction.

2. WATER QUALITY SENSING NODE AND NETWORKING

The sensing module associated to each node of the wireless sensor network for urban water quality monitoring is able to measure water electrical conductivity, temperature and turbidity and is connected to the NI analogue input block of the NI WSN-3202 (Figure 1).

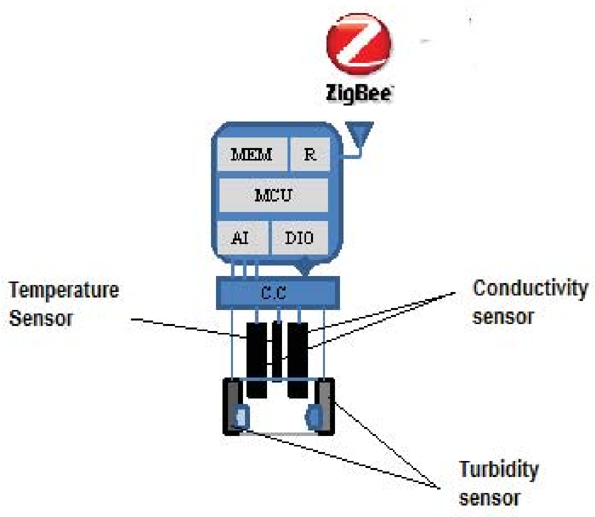

Figure 1. Block diagram of the water quality sensing node (CC-conditioning circuit, AI-analogue front end, digital input output, MCU-low power microcontroller, MEM-flash memory, R- IEEE802.15.4 transceiver).

2.1. Conductivity measuring channel

The electrical conductivity of a water solution reflects the ability of the solution to conduct an electric current and it depends on the amount of ions present in the solution. In the present case, two-electrode cell architecture was used to materialize the conductivity measuring channel. One important parameter of cell is the so-called *cell constant* which is the relation between the distance between the electrodes and their area determined by their geometric shape. In order to avoid the polarization phenomena, the voltage applied to the electrodes is alternated with a frequency of 4.5 kHz. This sinusoidal wave is generated by a "Wien Bridge" circuit oscillator. The electrical conductivity of the solution is measured by the voltage divider formed by "R1" and the electrical resistance of the solution measured by the electrodes probe represented as "Sensor" in Figure 2. The conditioning circuit includes a mean value detector circuit whose output is applied to a non-inverting amplifier circuit. The signal obtained at the conditioning circuit output is applied to the AI block of the water quality sensing node.

Several simulations were done and the results are presented in Figure 3. Thus the excitation, rectified, filtered, and amplified signals are represented in Figure 3.a and correspond to a water sample characterized by 25 µS/cm which was simulated through a resistance "Sensor" adjusted for 1kΩ. The ripple of the output signal is less than 10mV for C=12nF. The value of C was established taking into account the time constant. Performing simulations for different values of water conductivity (C1=16.5uS/cm, C2=20uS/cm, C3=25uS/cm, C4=33.3uS/cm, C5=50uS/cm C6=100uS/cm), one can observe the non-linear dependence between the signal conditioning output and the value of water sample conductivity (Figure 3.b). Thus, an inverse model was implemented in the sensing node microcontroller to perform voltage to conductivity value conversion.

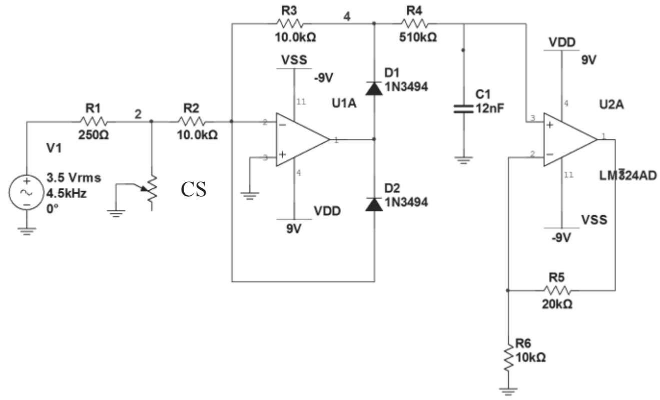

Figure 2. Conductivity conditioning circuit: CS-two electrodes conductivity sensor

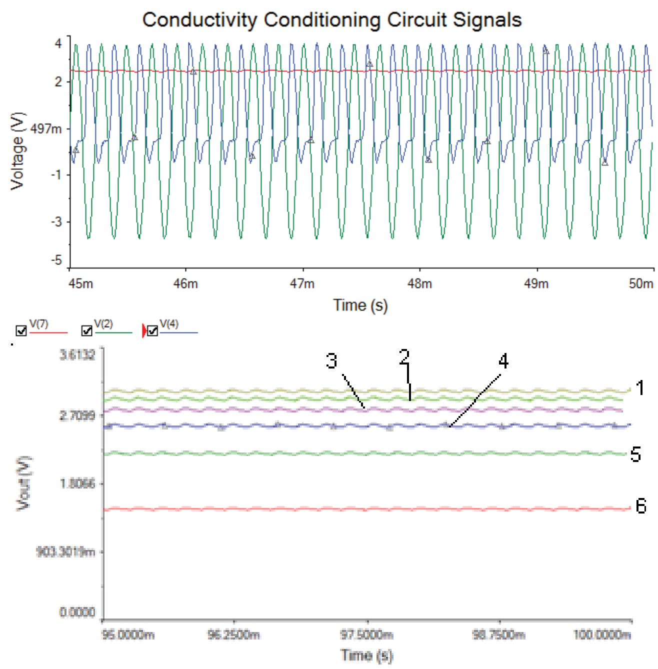

Figure 3. Conductivity conditioning circuit signals: a) input signal V(2), mean signal V(4), and output signal V(7); b) evolution of the conditioning circuit output for simulated values of water conductivity

2.2. Temperature measuring channel

An NTC thermistor materializes the temperature measuring channel. The conditioning circuit combines a resistive divider and a non-inverter amplifier based on the LM324 circuit.

Taking into account the temperature influence on conductivity measurement, the temperature information is used as part of the algorithm for temperature compensation of conductivity values.

2.3. Turbidity measuring channel

The turbidity can be defined as an "expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample" [7]. In set-up used the turbidity measurement is made by a sensing cell that includes two infrared emitter diodes to generate the infrared beams and two photodiodes to detect the transmitted and scattered light. The on-off control of the conditioning circuit associated with the emitter diodes is done by DIO port of the water quality sensing node (see Figure 1). Appropriate conditioning circuit is implemented for the detection diode, the voltage output being applied to the AI block of the water quality sensing node. The sensor control is done by embedded software that assures the proper on-off timing in such way that only one LED is on at a time the voltage values obtained at the D1 and D2 photodiode conditioning circuit outputs, that corresponds to the transmitted and scattered light, are applied to the AI module of the sensing node. According to the diagram of Figure 4, the infrared LED conditioning circuit, ECC, is controlled using two digital output lines of the WSN-3202 module, while the output voltages of the detectors conditioning circuits are acquired by two of the analogue input channels of the above mentioned module.

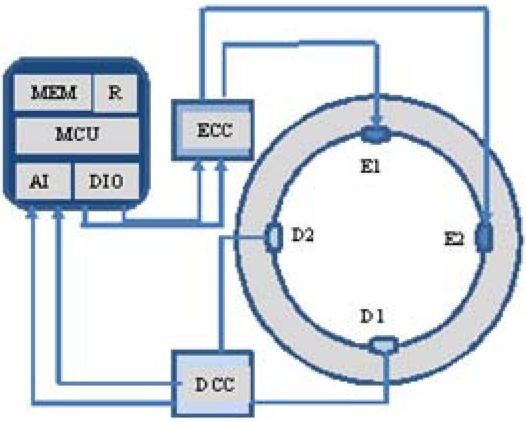

Figure 4. Diagram of the turbidity measuring system (ECC – emitters conditioning circuit, DCC- detectors conditioning circuit; D1, D2 optical detectors; E1, E2 optical emitters; AI- analogue inputs; DIO- digital input output port)

When "E1" is active for a short period of time (0.5s), the detected lights measured by "D1" and "D2" are acquired by the system. Then "E1" is switched-off and "E2" is switched on also for the same period of time, and the new values of "D1" and "D2" are acquired. The measured voltage values associated with transmitted and scattered light are used to calculate the turbidity coefficient (cm) given by:

$$Cm = \pm\sqrt{\frac{V_{21}}{V_{11}} \times \frac{V_{12}}{V_{22}}} \qquad (1)$$

where v_{11} is the voltage detected by "D_1" with "E_1" active, V_{12} is the voltage detected by "D_2" with "E_1" active, V_{21} is the voltage detected by "D_1" with "E_2" active and finally V_{22} is the voltage detected by "D_2" with "E_2" active. The conversion Cm to turbidity conversion is done using the Cm=Cm(TU) characteristic experimentally obtained for a set of Formazine turbidity calibration solutions. The Cm calculation and Cm to TU conversion are performed by the MCU of water quality sensing node.

2.4. Wireless Sensor Network

The I/O and wireless communication module is expressed by NI WSN-3202 as part of a ZigBee network [8][9]. The module can be configured as router (R) or end node (E) using the NI MAX utility.

The main specifications of the wireless sensing nodes with multifunction capabilities are: four analogue inputs (±10, ±5, ±2, ±0.5 V range), 16 bit resolution, and minimum sample interval 1s, 4 DIO lines. The communication between the host computer and the network nodes (end nodes WQ-WSN-Ei, and routing nodes WQ-WSN-Ri) is performed through the usage of NI WSN-9791 wireless sensor network Ethernet gateway (WSN-G) (Figure 5).

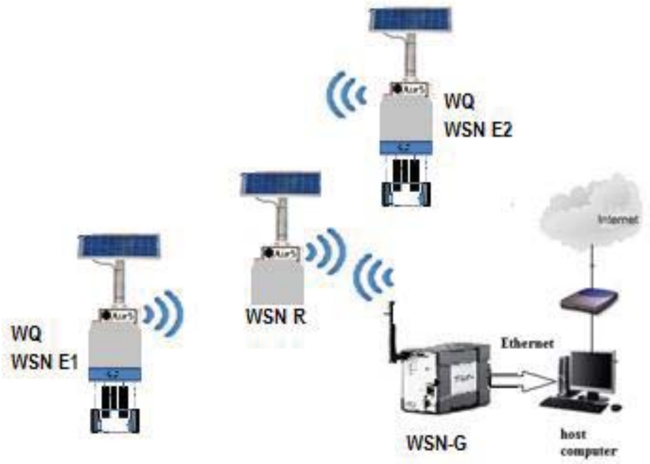

Figure 5. Water Quality wireless sensor network architecture (WQ WSN E1, WQ WSN E2 - water quality end nodes, WSN R – routing node, WSN-G – gateway)

Considering the limited ranges (up to 300m) of the wireless communication module, a 2.4GHz high gain antenna (15dBi) was used together with the WSN Ethernet gateway, which assures better coverage and permits to increase the distance between the gateway and the routing node (WSN-R). Because of their power consumption, the NI WSN measuring nodes are also part of an energy harvesting application based on a solar panel [10].

3. SYSTEM SOFTWARE

The system software has two components: embedded LabVIEW software associated with WQ WSN E1 and E2, and host computer LabVIEW software that receives the values from the sensor nodes and performs data logging and web publishing based on LabVIEW server capabilities. The development of the first component was done using LabVIEW Wireless Sensor Module Pioneer that permits to configure the wireless sensor network and also to manage sensor data through the use of shared variables associated with the analogue input channels (AI0, AI1, AI2, AI3) and digital lines (DIO0, DIO1, DIO2).

4. EXPERIMENTAL RESULTS

For accurate measurement of water quality conditions the measuring channel associated with WQ WSN must be previously calibrated and tested. In the conductivity measuring channel case, a reference conductivity measuring instrument that uses the same conductivity measuring cell was used. The values of conductivity indicated by the reference measuring system were associated to the voltages acquired (Vc) from the nodes conductivity measuring channels for water samples with different values of conductivity. This method allowed obtaining the characteristic curve for the conductivity measuring channel that is presented in Figure 6. Using a polynomial inverse model, the conductivity values are calculated from the acquired voltages from the conductivity measuring channel.

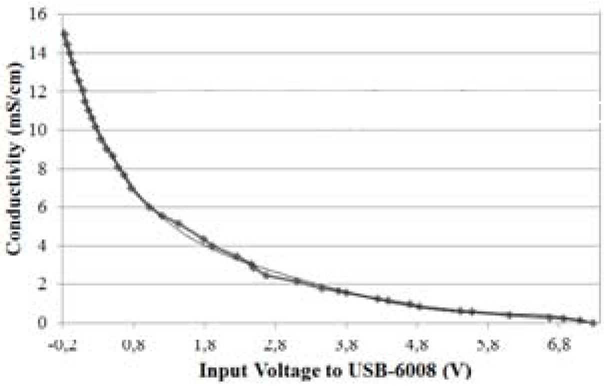

Figure 6. Characteristic curve of a conductivity input channel (the polynomial approximation is given by $y=-6.97x^5+146.07x^4-1170.4x^3+4621.1x^2-10153x+12748$ for $R^2=0.9987$-9

The temperature characteristic curve in Figure 7 was obtained using an oven with temperature control to impose the calibration points and to get the data required to calculate the linear regression of the temperature measuring channels characteristic.

For the calibration of the turbidity measuring channels, four formazin turbidity standard solutions of 10, 100, 200 and 400 NTU were used, since formazin solutions are reference material for turbidity instrument calibration.

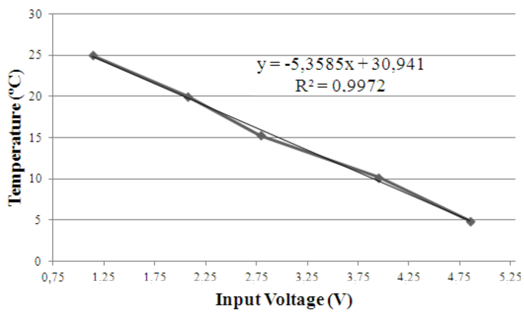

Figure 7. Characteristic curve of a temperature input channel.

After the turbidity coefficients are calculated, the turbidity characteristic curve and the corresponding linear approximation are obtained (Figure 8).

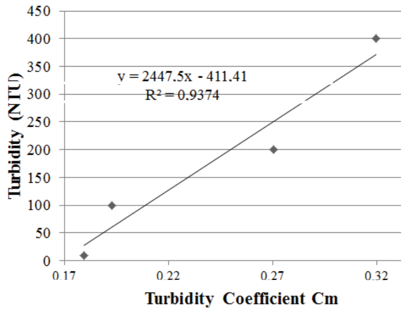

Figure 8. Characteristic curve of a turbidity measuring channel

Based on calibrated measuring channels associated to each WQ WSN Ei, several measurements and data communication tests were carried out. The values of the conductivity measuring channel with temperature compensation associated to WSN E1 obtained in a laboratory measuring session are presented in Table I. The accuracy obtained was 2%FS (0-15 mS/cm).

TABLE I. CONDUCTIVITY RESULTS (FULL-SCALE: 15 MS/CM)

Percentage of span (%)	Ref. value (µS/cm)	Measured value (µS/cm)	Error (%) FS
0	0	90	1
25	3930	3827	1
50	7610	7698	1
75	11520	11594	1
100	15000	15368	2

Tests on the temperature and turbidity measuring channels revealed accuracies of 1%FS (5-25 ºC) and 5%FS (0-400 NTU), respectively.

5. CONCLUSION

This paper presents the design and implementation of surface water real-time monitoring based on a ZigBee wireless sensor network.

Important part of the work is the development of a low cost multi-parameter water quality measuring probe attached to the wireless sensor node. Thus was designed, implemented and tested a conductivity measuring channel characterized by two-electrode cell in combination with a temperature measuring channel. As the third component of the probe, a turbidity measuring channel was developed based on the detection of the transmitted and scattered light caused by the particles in suspension in the water.

The laboratory tests of the implemented WQ WSN prove the capability of the system to provide accurate water quality information. Future work will be related with the field deployment of the WSN for continuous monitoring for long periods of time will be considered.

6. REFERENCES

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