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AN IEEE1451.X AND RFID COMPATIBILITY UNIT FOR WATER QUALITY MONITORING

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Abstract – Distributed sensing for water quality monitoring provides important data that can be used to evaluate the characteristics of water according to specific requirements. The measurement of water parameters in extended areas requires the utilization of a high number of sensing nodes including multiple sensors, which can make difficult the management of the sensing devices to obtain high reliability of the system. The work presents a solution of autonomous water quality measuring nodes that puts together elements from the IEEE1451.X standard for smart sensors and UHF RFID technology. The novelty of the implemented solution is the utilization of a Virtual Transducer Electronic Data Sheet and an RFID based selection of the individual sensing channel characteristics. Hardware design and implementation are described in the paper.

Keywords: smart sensor, RFID, on-line water quality monitoring

1. INTRODUCTION

Water quality (WQ) has become one of the most urgent environmental issues of our time. New measures of environment agencies (e.g. Environment European Agency-EEA) are oriented to improve water quality monitoring using distributed measurement system expressed by networks including huge amount of measuring nodes.

Periodical calibration and testing imply the transfer of the water quality transducers from field units to laboratory. After testing and calibration, the transducers are again transported and mounted in the automated filed measurement units normally expressed by acquisition, processing and data storage units with analog input channels characterized by 4-20mA or/and measurement ranges. In order to manage such kind of applications, which imply the utilization of a large number of sensors, the utilization of smart sensors represents an interesting option. Referring smart sensors standardization, the IEEE 1451 standard that appeared in the late '90s, promotes a smart transducer interface [1][2][3][4] that permits an easy development of smart transducer manufacturing and an increasing connectivity of this kind of devices to networks. The IEEE1451.X family is a set of protocols for wired (IEEE1451.0, IEEE1451.1, IEEE1451.2, IEEE1451.3, IEEE1451.4, IEEE1451.6) and wireless (IEEE1451.5 and IEEE1451.7) distributed applications. Two of the main parts of sensing network implementation based on IEEE1451.X standard is related to the Network Capable Application Processor Implementation (IEEE1451.2) that assures the connectivity, and the transducer interface module (TIM) that assures the interfacing of the network with measured or/and the controlled environment. The identification of different transducers is performed through the utilization of a memory denominated Transducer Electronic Data Sheet (TEDS) where are included the identification and the main characteristics of the transducer such as *Manufacturer ID, Model Number, Serial Number.* To read the TEDS, included in the TIM, data communication between the NCAP and TIM is required. The direct access to the transducer manufacturing and calibration information is available only for IEEE1451.X compatible transducers, which makes the standard less attractive for large scale aplications where most of the transducers are characterized by analog output (4-20mA). That is the also the case of water quality transducers. In order to include in some way this kind of transducers in the IEEE1451 compatible transducers an IEEE1451.4 protocol was developed. The IEEE1451.4 defines the hardware TEDS as a 1-wire memory associated to the transducer (e.g Futek AST LSB303).

The statistics shows that since 2005, when the IEEE1451.4 was created, few manufacturers (less than 50) included 1-wire memories to the traditional transducers they offer. On the other hand, users that include in their applications IEEE1451.4 compatible transducers must acquire a data acquisition device with TEDS reading interface for their measuring systems. In the market can be mentioned National Instruments (NI) solutions for this kind of sensors. NI promotes also an interesting version for TEDS, the *Virtual TEDS* [5]. Several implementation of IEEE1451.4 and virtual TEDS are referred in the literature [6]

To provide to users higher flexibility regarding the transducer information an RFID solution can be considered. Several solutions regarding tag–sensor association are presented in the literature [7][8].

The work presents and interesting approach concerning RFID technology and Virtual TEDS implementation. Considering the possibility to write the tags associated to the traditional sensors (passive tags), the hardware TEDS proposed by IEEE1451.4 can be replaced by a passive tag whose bytes are not only used for identification but also to store useful calibration parameters that are later used to process the signal acquired from the sensor.

2. THE WQ SMART SENSING NODE ARCHITECTURE

Two modules characterize the smart sensing node: water quality measurement module and sensor identification module based on UHF RFID technology (Fig. 1).

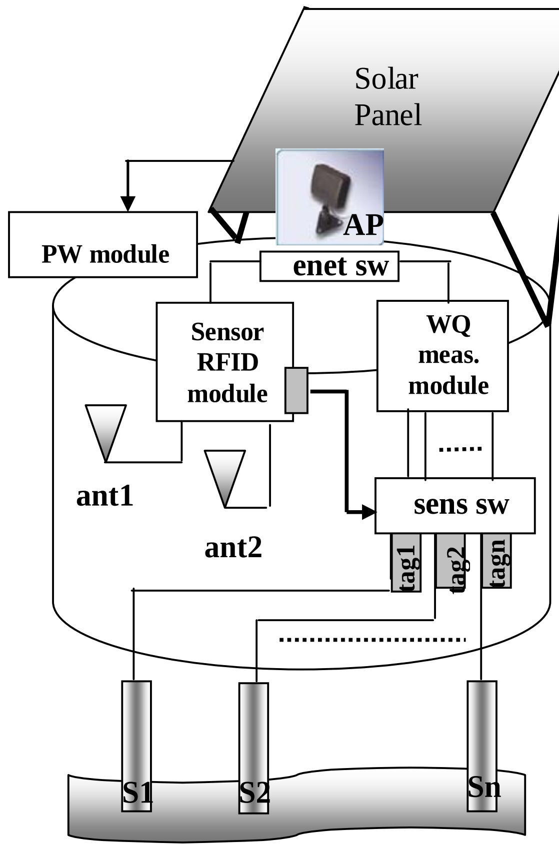

Fig. 1 WQ Smart sensing node with RF identification block diagram (Sj- WQ sensors; ant1, ant2 – RFID reader antennas; tagj- RFID tags; sens sw – commutation block; PW module - power supply module; enet sw – Ethernet switch)

The water quality measurement module and the RFID reader (Alien ALR-8800) are connected to a Wi-Fi access point (AP) trough GEB1040 Linksys Ethernet switch. The smart sensing node represents part of a distributed network of a Geographic Information System (GIS) designed for Sado Estuary Water Quality Monitoring [9]. The connection between field smart sensing nodes and GIS server is assured by a Wi-Fi communication using a high gain antenna. The WQ smart sensing node is powered using a solar panel that is connected to the power supply module.

2.1. Measurement Module

The measurement module is constituted by a set of water quality transducers from Global Water. The measurement of four WQ parameters was considered: temperature, pH, conductivity and turbidity measured using WQ101, WQ201, WQ301 and WQ770, respectively [10]. The sensors provide the information of the measured parameter as a 4-20mA analog signal. The current is converted into voltage using a conditioning circuit based on RCV420 that assures a 0-5V output voltage for 4-20mA input current. The voltage signals are applied to the analog channels (ACH0-ACH3) of a webserver module (Ipsil IPu8930) that includes a 16-bit analog-to-voltage converter (ADC) and a compact TCP/IP network controller. Thus, the analog voltage signals from the sensors are converted into digital format, $v_{Si}(n)$ (S_i- are the WQ sensors) and transmitted to the GIS application through the Wi-Fi connection. At the GIS level, an application is used to convert the voltage digital codes $v_{Si}(n)$ into WQ physical values. The voltage-to-WQ conversion is based on the information stored in the WQ sensor RFID tag memories that are read using the sensor RFID module capabilities associated with UHF RFID reader.

2.2 Sensor RFID module

During field operation the WQ sensors require calibration and testing. Thus, it is important to be able to track them not only during calibration but also when they are used in the field. By adding a low cost passive transponder, usually called “tag” (ALL-9540-02 World Tag 860-960MHz in the present case) the WQ analog sensor can be used as a smart sensor according to the IEEE1451.4 standard. Thus the minimal TEDS (*Transducer Electronic Data Sheet)* informations for each WQ sensors are stored on the RFID tag memory level. Regarding the used tag characteristics, ALL-9540 delivers industry leading EPC (Electronic Product Code - reference standard for UHF RFID applications)[11] Gen 2 range and reliability at competitive prices. ALL-9540 inlays are also World Tag compliant, enabling inlays that operate consistently across the diverse frequencies (Europe compatible) [12]. The main characteristics of the used tag are: EPC class1, RF communication protocol ISO/IEC18000-6 CEPC Class 1 Gen 2 (generation 2 – read and write many times), EPC Memory Size: 96 Bits, Access Control: 32Bits, Kill Code: 32Bits. The typical distance between the reader and tags (read range) is about 4m and uses electromagnetic coupling.

The identification process of the sensor with RFID label begins when the reader is switched on: it starts emitting a signal at the selected frequency band (860MHz-960MHz). The tags reached by the reader’s field will “wake up” (supplied by the field itself). Once the sensor’s tag has decoded the signal, it replies to the reader, by modulating the reader field (backscattering modulation).

Considering the implemented sensing architecture where multiple sensors identified by tags are present, they will reply at the same time to reader. In order to extract the information received from each tag, the reader (ALR-8800 from Alien) uses an anti-collision algorithm designed to allow tags to be sorted and individually selected.

Considering the memory size of the used sensor’ tags (96 bits for ALL-9540), a user configurable Basic TEDS format according IEEE1451.4 [13][14] was used. Table 1 identifies the Basic TEDS fields that are mandatory to comply with IEEE1451.4 and that are stored in the tag's memory.

Table 1. Implemented Basic TEDS fields.

Components	Number of Bits	Allowable range
Manufacturer ID	14	17-16381
Model Number	15	0-32767
Version Letter	5	A-Z
Version Number	6	0-63
Serial Number	24	**0-16777215**

The Basic TEDS .Dot4 field is filed using the values that correspond to one of the used WQ sensors (conductivity sensor WQ301) according with specification given by the manufacturer in classical form (Global Water Sensor Manual). Using a passive tag characterized by extended memory (greater than 96 bits) IEEE1451.4 optional fields can be materialized on the tag writeable memory: Standard Templates TEDS, Calibration TEDS template and User Data.

Each template has a specific ID. Templates 25 through 39 are transducer-type templates that contain properties needed for the specific types. For the particular case of WQ transducers characterized by 4-20mA-output signal, the implemented IEEE1451.4 template fields are next presented [4]:

- Measurement Function: Physical Measurand expressed by Minimum Physical Value (MinPhysVal), Maximum physical value (MinPhysVal) - a set of 46 case selectors are specified by the standard. As an example are mentioned pH=0 minimum physical value and pH=14 maximum physical value for WQ201 according to the Global Water WQ manual [10].

- Electrical Signal Output Function: Full Scale Electrical Value Precision: Minimum Current Output, Maximum Current Output – a set of 2 case selectors is specified by the standard. As an example are mentioned 4mA minimum current output and 19mA maximum current output for WQ201 according to the Global Water WQ manual.

- Power Supply Function: Loop Powered versus external powered described by minimum compliance, maximum compliance, power-supply level-nominal, power supply level-min, power supply level max, power-supply type. As example of template implementation on the server level are mentioned: 12 VDC, power supply level nominal. 10 VDC power supply level-min, 30VDC for WQXXX according with the Global Water WQ manual where XXX=101, 201, 301 and 770

- Calibration Information Function: Calibration Date, Calibration initials, Calibration Period. As example are mentioned 20-06-08 (dd-mm-yy) calibration date, AF calibration initials, 360 days calibration period.

In order to write the custom information associated with the sensors of smart sensing node we considered the capability of ALR-8800 RFID reader that is designed to read and also to program EPC Class 1 Generation 2 tags. Two external circular polarized antennas, ant1 and ant2 (ALR-8610-AC), operating at 850-875MHz and with 6dBi gain, are used to read the tag fixed on the transducers or to write the memory of tags including new elements during operation. The ant 1 works as transmit antenna while ant 2 works as the receive antenna (Fig.2).

Considering the field sensor calibration requirement, an additional reader is used together with an automatic calibration system [15] to program the transducer tag according with the latest calibration values.

The Ethernet communication interface of the ALR-8800 is used to perform its remote control using the TCP/IP protocol and remote control commands.

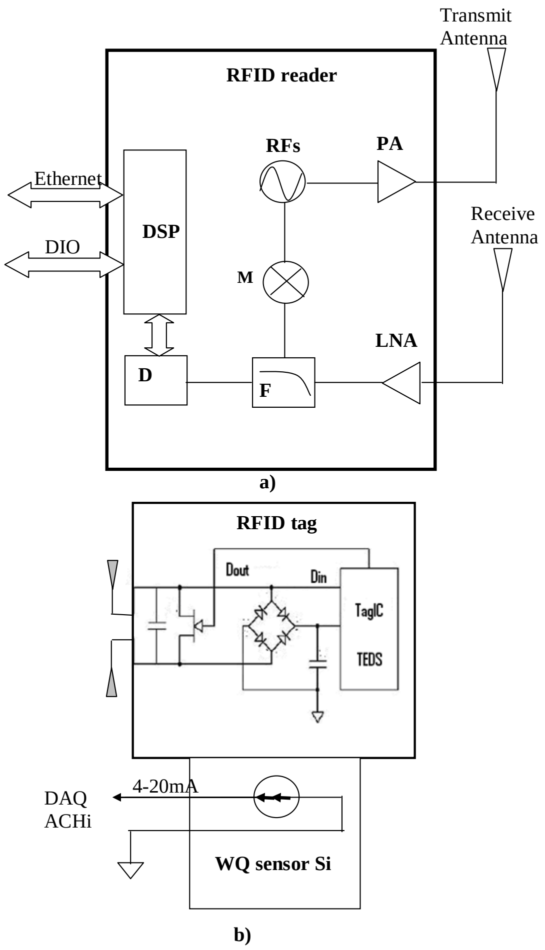

Fig. 2 Reader and tag block diagram: a) RFID reader main block, b) RFID tag and WQ sensor module as part of IEEE1451.4 mixing mode standard

Additionally, the used reader presents a DIO port that is used for on/off switching of different measurement channels in order to identify the correspondence between the read tag and the analog input channel. Thus, the information stored in the memory tag level (*Standard Template TEDS* ID 31:

Current Loop Output Sensors in the present case) is used to perform the current-to-WQ parameter value conversion.

Reading the near sensor' tag does not guarantee that the signal acquired on the ACH0 corresponds to the transducer identified by the tag0, the signal acquired on ACH1 corresponds to the transducer identified by tag1 and so on. That makes impossible to assure the right conversion of the acquired signals. To extract the correspondence an additional sens-sw commutation block was implemented and tags connected according to a pre-defined order.. The sens-sw works under reader's DIO port control and permits to read one channel at the time when the other input channels are connected to GND. The correspondence between the acquired signals and tags is presented in Table 2.

Table 2. Acquired signal – tag correspondence

DIO	S1	S2	S3	S4
1000	1.2	0	0	0
	TEDS1	TEDS2	TEDS3	TEDS4
0100	0	2.5	0	0
	TEDS1	TEDS2	TEDS3	TEDS4
0010	0	0	1.7	0
	TEDS1	TEDS2	TEDS3	TEDS4
0001	0	0	0	3.6
	TEDS1	TEDS2	TEDS3	TEDS4

Analysing the table for the particular case of above WQ transducers, one can notice that the transducer with the tag TEDS1=1C02 0042 06A5 9000 is connected to ACH0, the transducer with tag TEDS2=1C02 0042 02A5 9000 is connected to the ACH1, the transducer with tag TEDS3=1C02 0042 0AA5 9000 is connected to the ACH2, and the transducer with tag TEDS4=1C02 0B42 02A5 9000 is connected to the ACH3. The TEDS labels associated with the sensors channels are organized in order to respect the following correspondences: TEDS1-ACH0, TEDS2-ACH1, TEDS3-ACH2, TEDS4-ACH3 … TEDSn-ACHn-1. Thus, when a new tag is detected (e.g. TEDSp), the system will start a procedure to verify that the sensor connected to the analog input p-1 works properly using the Basic TEDS stored in the tag memory to access the database, known as virtual TEDS, to calculate the physical values associated with acquired voltage signal.

2.3 Power Supply module

The autonomy of the WQ smart sensing node is assured using a solar panel (Suntech) with following characteristics: related maximum power 20W, current at Pmax 1.19A, voltage at Pmax 16.8V, short circuit current 1.21A, open circuit voltage 21.4. The solar panel is connected to 12V, 18Ah battery through a solar charge controller (Ateca) that assures also the 12V for the charge expressed by the Sensor RFID module, Meas. Module and Ethernet switch.

3. WQ SMART SENSOR NODE SOFTWARE

The WQ smart sensor node software implemented at the host PC level, that is wireless connected to the smart sensor node, includes the two main components associated with the RFID sensor module and Measurement module. Both software components were implemented in LabVIEW.

On the Alien RFID reader case, which runs Telnet server application, specific Telnet functions (*Telnet open connection, elnet write, Telnet close connection*) are used to perform commands such as tag list commands, (e.g. *get TagList* for Tag List reading, *Clear TagList* – clear the list of active tags on the RFID reader), and acquisition commands (e.g. *get AcqG2Cycles*, *set AcqG2Cycles* – to obtain the number of acquisition cycles to perform during each class1/Gen2 tag read action). The digital input signals of the sens-sw module to perform the tag-measurement channel identification are based on I/O commands that are sent to RFID reader during telnet session.

Referring to the measurement module programming, a set of LabVIEW TCP/IP functions were used to control the acquisition of the signals delivered by the WQ measurement channels. The acquired voltages are processed to extract the WQ parameters values (e.g. C=20mS/cm, pH=7.23, TU=27 NTU, T=17.4°C) using the information that was read from the sensor' RFID tags.

The utilization of the Basic TEDS form (64 bit form), caused by tag' memory constrains, did not provide enough elements that can permit to convert the V_{WQ} acquired voltage array from the embedded web server into scaled engineering units. However elements such as manufacturer ID, and Model Number can be used as inputs for extended Virtual TEDS database to extract the parameters for voltage to WQ values conversion. The RFID technology permits to automatically extract the voltage-WQ parameter conversion coefficients without typing any information by the operator.

4. RESULTS AND DISCUSSION

Different case studies were carried out to underline the smart sensor node capabilities mainly referring the IEEE1451.4 implementation using the RFID tags memory. The power consumption of the smart sensor node devices was also evaluated taking into account the large autonomy requirement.

4.1. Case study of sensor RF identification

During experimental tests were considered different scenarios in order to evaluate the system efficiency regarding optimal reading of the sensor identification. Thus, a study concerning different positions of the circular polarized antennas and different distances, d, between the antennas and tags were considered. Fig. 3 presents the evolution of system efficiency, SE, number of detected tags from total number of tags, for 0dB and 15dB attenuation and different distances between ant1 and ant2 and the UHF tags.

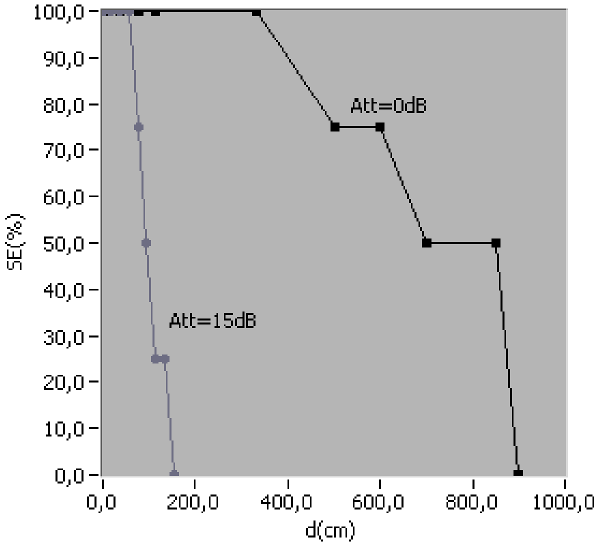

Fig. 3 System Efficiency, SE, versus antenna – tag distance for different attenuations of the emitted power of transmission RF signal

During the experiences the antennas were disposed at the same plane that is perpendicular to the floor with no distance between the antenna boxes. The distance between the antennas centres line and the floor was 75 cm. The number of tags used in the present study was 4, which corresponds to the number of WQ measurement channels. The tags' labels were fixed on the WQ sensors connection cable near the connector of the websensor analog inputs.

4.2. WQ parameter measurement

The implemented software assures TCP/IP communication with the embedded webserver module. Thus, the acquired voltages from WQ sensors channels are received from time to time (Δt={30;60;300}[s]) through wireless communication and processed based on the coefficient voltage-to-WQ parameter conversion that are extracted using the sensor tag binary data. For the particular case of temperature and conductivity measurement channels the WQ evolution during the testing time is presented in Fig. 4. In the figure are included elements about conductivity sensor Basic TEDS and also some controls related to the control of data acquisition and tag reading. Additional results will be presented in the final form of the paper.

4.3. Case study of smart sensor node power consumption

In order to measure the power consumption of the smart sensor node for water quality monitoring, a power measurement system was implemented. The values of power consumption associated with the Alien reader ALR-8800 is less than 15W while power consumption of the WQ measurement module expressed by the webserver and the measurement channels characterized by 4-20mA signal output is less than 5W. Additionally, one must take into account the Ethernet-Wi-Fi bridge and the Ethernet switch power consumption, which is less than 3W.

Taking into account that the UHF RFID reader consumption is too high, we will consider in the future to use a more compact low consumption RFID module.

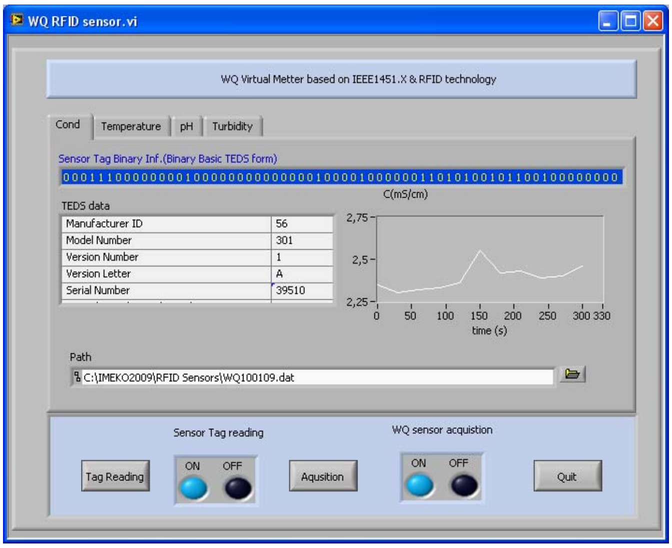

Fig. 4 The evolution of conductivity versus time for a RF identified measurement channel

4. CONCLUSION

This paper presents an architecture of smart sensor nodes for water quality monitoring that uses the RFID technology in order to assure the IEEE1451.4 compatibility for WQ sensors characterized 4-20 mA signal output. Important work was developed on system development and software implementation to assure tag writing with the BasicTEDS as well as the measurement channel data acquisition in order to provide information about the water quality parameters. An important experimental work was developed concerning sensor tag optimal reading and accurate water quality measurement based on standard TEDS template that are accessed automatically using the read basic TEDS stored in the sensor tag.

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