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Microcontroller based multi-sensing system for water quality assessment

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Abstract- The work presents a multi-sensing system based on a dual microcontroller architecture associated with temperature, conductivity and turbidity measurement. The sensor design, implementation and calibration and the multi-sensing system embedded processing and interfacing represent important part of the work. Embedded software was developed for the PIC18F4520 microcontroller using the MPLAB C Compiler for 18MCU from Microchip while the software for data communication, data logging and graphical representation of the WQ data was developed in LabVIEW.

I. Introduction

Water is essential to human life and to the health of the environment. Water quality (WQ) is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics [1].
To perform water quality assessment, different parameters are measured using field measuring systems with multi-channel sensing capabilities such Quanta Hydrolab and Seabird SBE 25 that are expensive equipments with proprietary software for remote control and data management. The main measured parameters are usually pH, conductivity, temperature, dissolved oxygen, and turbidity and different low cost measurement devices supported on friendly software are reported by different authors [2][3]. Different architectures regarding distributed systems for water quality assessment were implemented by the authors and significant results were published during the last 10 years [4][5].
Considering the importance of the WQ parameters, we used our laboratory facilities for instrumentation systems prototyping to develop a multi-sensing microcontrollers-based system for temperature, conductivity and turbidity measurement.

II. System Description

The dual microprocessor multi-sensing system architecture was designed to permit the measurement of an extended number of water quality parameters. The general architecture of the system is presented in Figure 1. Two microcontrollers are used to perform acquisition and digital control tasks associated with temperature sensing channel (TS), conductivity sensing channel (CS) and turbidity sensing channel (TUS). Appropriate conditioning circuits (Tcc, Ccc and TUcc) were developed part of them receiving controls from the microcontrollers through the DIO or PWM ports. Because it was necessary to provide the information of the primary processed data to the microcontroller in analogue format through the digital-to-PWM converter followed by a low pass filter, and since the used PIC18F4520 microcontrollers have only two PWM outputs, two microcontrollers are needed. At the same time, the distribution of primary processing tasks by two processing units proved to be a good option: higher reliability and modularity; reduction of the complexity of the algorithms implemented on each processing unit.

A. Sensors and Conditioning Circuits

The system sensors are a temperature sensor (TS) based on a NTC thermistor, a two-electrode conductivity sensor (CS), and a modulated four beam infrared (IR) turbidity sensor (TUS) [6]. The conditioning circuit used to convert the temperature variation ΔT of the thermistor into a voltage, $V_{T,}$ acquired by the acquisition, primary processing and communication unit includes a voltage divider with low tolerance resistors, a voltage follower, a differential amplifiers and an inverter yielding:

$$V_T = \frac{R_2}{R_1 + R_2} \cdot \frac{\Delta R_{th}}{R_{ref} + R_3} \cdot V_{bat} \quad (1)$$

where: ΔR_{th} - thermistor's resistance variation, V_{bat}- battery voltage (9V), R_{ref} - reference resistor associated with temperature operation range (5-25 ºC), R_1, R_2, R_3 - conditioning circuit resistors. The operational amplifiers used are the LF356. The temperature channel calibration was done using a temperature controlled oven.

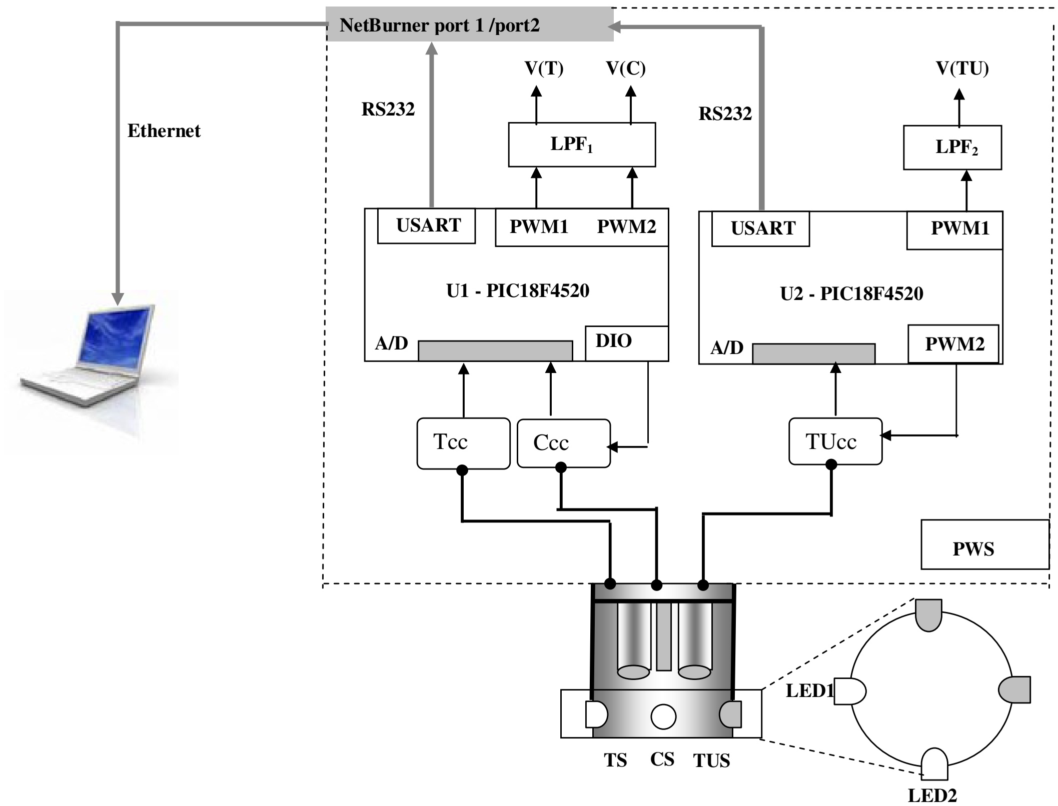

Figure 1. WQ multi-sensing system block diagram (U1,U2 – microcontroller units, PWS – power supply unit, TS-temperature sensor, CS – conductivity sensor, TUS- turbidity sensor, Tcc- temperature conditioning circuit, Ccc – conductivity conditioning circuit, TUcc – turbidity conditioning circuit, Netburner – 2XRS232/Ethernet bridge)

The conductivity conditioning circuit is based on a monolithic integrated circuit function generator XR-2206 that provides the AC excitation signal applied to the conductivity electrodes. The measurement of the conductivity cell impedance was done using different frequencies of the AC excitation signal. Good results were obtained for 10 kHz, 6Vpp AC signal. The impedance measurement circuit includes a LF356 based precision rectifier, a low pass filter, and a non-inverter scheme (G=5) based also on the LF356 operational amplifier. The conditioning circuit output voltage, V_C, corresponds to 0-5V for the conductivity measurement range

Considering the conductivity dependence with temperature, a temperature compensation algorithm that uses the voltage values acquired from the temperature (V_T) and conductivity (V_C) measurement channels was implemented at the microcontroller level.

The architecture for the turbidity sensor includes a set of two IR LEDs (LD271) and two infrared photodiodes. A pulse-width modulation signal is used for current drivers control to assure appropriate current for better sensitivity of the optical turbidity measurement cell. Thus, by varying the duty cycle of the control signal output by the microcontroller PWM1 ports, and using f_c=1Hz low pass filters followed by voltage-to-current converters, excitation currents up to 60mA are obtained, which guarantees a high optical excitation power for low range turbidity measurement values (0-100NTU). When higher values of turbidity are expected the measurement range is automatically changed through the usage of reduced value of duty cycle of the PWM signal meaning low excitation current applied to the IR LEDs. Referring to light detection, two IR photodiodes connected to the input of trans-impedance amplifiers provide the voltage sets during the four beam modulated turbidity measurement procedure [6]. Two sets of voltages (V_{11}, V_{21}) and (V_{12}, V_{22}) express the turbidity conditioning circuit output voltages during the turbidity measurement procedure and correspond to the following IR LEDs states: a) LED1=on, LED2=off; b) step2: LED1=off, LED2=on. This voltage values are acquired using two analogue input channels of U2 microcontroller (PIC18F4520) where are primary processed.

B. Microcontrollers and Interfaces

As mentioned before, the multi-sensing system includes a distributed architecture with two microcontrollers PIC18F4520 from Microchip (U1 and U2) both because of the limitation of the number of PWM output ports of the microcontrollers but also to profit from the advantage of parallel primary processing of the data acquired from water quality measuring channels. U1 acquires the voltages from conductivity and temperature measuring channels using the analogue input channels AN0 and AN1 associated with 10bit resolution ADC. Using two digital output lines of a microcontroller (AN2 and AN3) that controls a digital switch (DG303), the temperature and conductivity measurement channels are successively switched on/off assuring low level of interference caused by the conductivity measurement channel oscillator. Through this method a reduction of the power consumption is assured. Taking into account the nonlinearity of the conductivity measuring channel, a voltage to conductivity conversion algorithm was implemented. A polynomial model was calculated using the experimental characteristics of the conductivity measuring channel V_C=V_C(CSi) [uS/cm] where CSi represents the values of KCl standard solutions from Oakton included in 0-20mS/cm measuring range (e.g. CS1=2764uS@25°C, CS2=8974uS@25°C). A 3rd degree polynomial approximation was used and an inverse model [7] algorithm was implemented in the microcontroller as part of primary processing. The embedded software detail for conductivity acquisition, processing and RS232 communication is presented in Figure 2.

```
/*CONDUCTIVITY ACQUISTION*/
PORTA=0b00000000;  // Switch on the oscillator
Delay100mS(20);                    // during 2 seconds
Vc = ((int)(Acquisition(0x01))) * q ;        // Voltage
PORTA=0b00001100;  // Switch off the oscillator
          // Conductivity
if (Vc<1.5)
          cond = ((-1881.0) *Vc*Vc*Vc) + (12957.0 *Vc*Vc) - 26006.0*Vc + 17525;
else
          cond = (-522.822)*Vc + 2229.7 ;
          if (cond<0)
          cond=0.0;
// Float to char conversion
ftoa(cond,C,2,'f');
/*Send to the computer by RS232*/
putrsUSART((const far rom char *)"\n\rConductivity : ");
putsUSART(C);
```

Figure 2. Acquisition, processing and RS232 data communication software routine developed in C compiler

As it can be observed in the embedded software routine, the calculated conductivity corresponds to the calibration temperature (T_{cal}) and an additionally temperature compensation software module is implemented by the software running in the PC. Different temperature compensation algorithms for temperature correction are known [8] part of them developed by the authors. However, in this case, a simple linear temperature compensation relation was used:

$$C_T = C_{Tcal}(1 + \alpha \cdot (T - Tcal)) \tag{2}$$

where T is the temperature of the water, Tcal is the calibration temperature (25°C in the present case), and α is the temperature coefficient of the solution. In the present case α =2.03.

The temperature correction is performed in the PC as a component of a WQ monitoring software developed in LabVIEW.

A similar software implementation was considered for the temperature measuring channel. The values calculated for conductivity and temperature are converted into values of duty cycle associated with PWM1 and PWM2 microcontroller output lines. Using a low pass RC active filter (LPF1, fc=1Hz) the signals delivered by those lines are filtered and voltage values included in the 0-5V are obtained when the conductivity vary in the 0-20mS/cm considered interval.

The second microcontroller of the system, U2, is fully dedicated to the turbidity information extraction based on acquisition of the V_{11}, V_{21}, V_{12}, V_{22} voltages. The 4 beam modulated inverse model associated to the turbidity measurement channel is given by:

$$\boldsymbol{TU} = \boldsymbol{C}_0^{\boldsymbol{TU}} + \boldsymbol{C}_{01}^{\boldsymbol{TU}} \cdot \sqrt{\frac{\boldsymbol{V}_{11} \cdot \boldsymbol{V}_{12}}{\boldsymbol{V}_{21} \cdot \boldsymbol{V}_{22}}} \tag{3}$$

where V_{11}, V_{12}, V_{21}, V_{22} are the acquired voltages associated with the turbidity measurement procedure and C_0^{TU} and C_{01}^{TU} are the values of the coefficients that are obtained in the calibration phase when different formazine standard solutions (e.g. TUS1=20NTU, TUS2=80NTU) are used. The AN0 and AN1 analogue input channels are used for turbidity measurement. The calculated TU values can be transmitted using the RS232 communication protocol or converted in the duty cycle of the signal delivered by the PWM2 port of U2.

To assure the Ethernet communication compatibility of the multi-sensing system for WQ assessment, a NetBurner SB72-EX low cost, high performance Serial-to-Ethernet converter was used. Thus, the RS232 communication interfaces of U1 and U2 are connected to port1 and port2 of the SB72-EX appropriate configured. The commands from the PC through the local area network (LAN) that includes the multi-sensing system are sent using TCP/IP LabVIEW functions such as “write TCP”, “read TCP”. One IP and two ports number (e.g. 192.168.116.202, 23 and 24) are used to select and communicate with U1 or U2

The LabVIEW software implemented by the PC assures remote multi-sensing system configuration (e.g. turbidity measurement channel configuration), data reading, and advanced processing of the WQ values (e.g. temperature compensation, short time data prediction), data storage and a WQ data base that can be used to generate dynamical WQ web pages [8].

III. Preliminary results and discussions

In order to obtain the parameters associated with the inverse models for WQ measurement channels that permit the conversion of the acquired voltages into WQ value (e.g. voltage to temperature conversion, voltage to water conductivity conversion, voltage to turbidity conversion), an experimental work was done. Some results associated with the obtained inverse models for the particular cases of temperature and water conductivity measurement channels are presented in Figure 3.

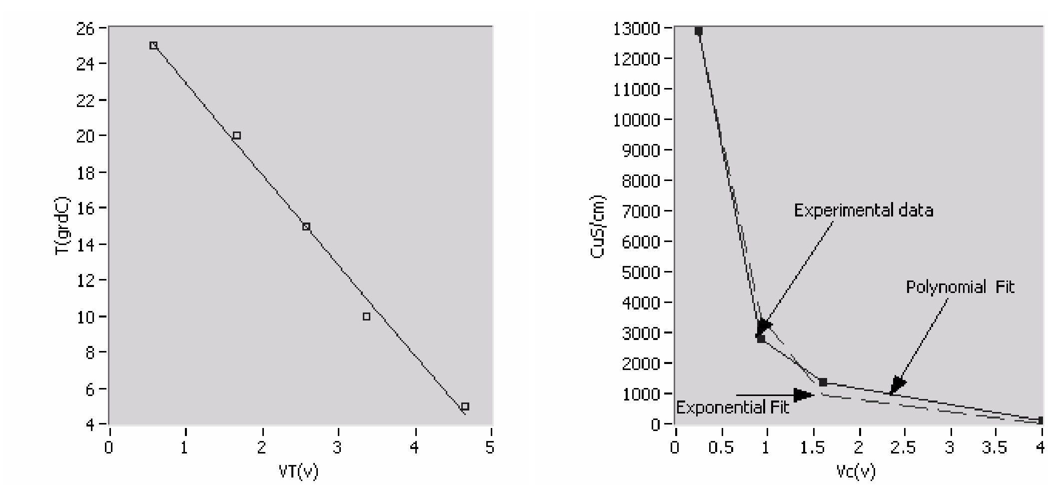

Figure 3. The experimental and fitting characteristics for temperature and conductivity measurement channels: a) temperature vs. VT(V) experimental and linear approximation (continuous line); b) conductivity vs. Vc(V) for exponential fit (dotted line) and polynomial fit (continuous line)

Using a temperature controlled oven, a set of five temperatures were imposed in the 5°C to 25°C interval and the linear approximation of temperature measurement channel characteristics was obtained and is represented in Figure 3.a.

The inverse modelling of the water conductivity measuring channel was done using a set of conductivity standard solutions from Oakton (CSS1=84uS/cm, CSS2=1413uS/cm, CSS3=2784uS/cm, CSS4=15000uS/cm). The acquired voltages were used to extract the polynomial approximation of $C_{Tcal}=C_{Tcal}(V_c)$ characteristic. The graphical user interface for the particular case of measured temperature graphical representation is presented in Figure 4.

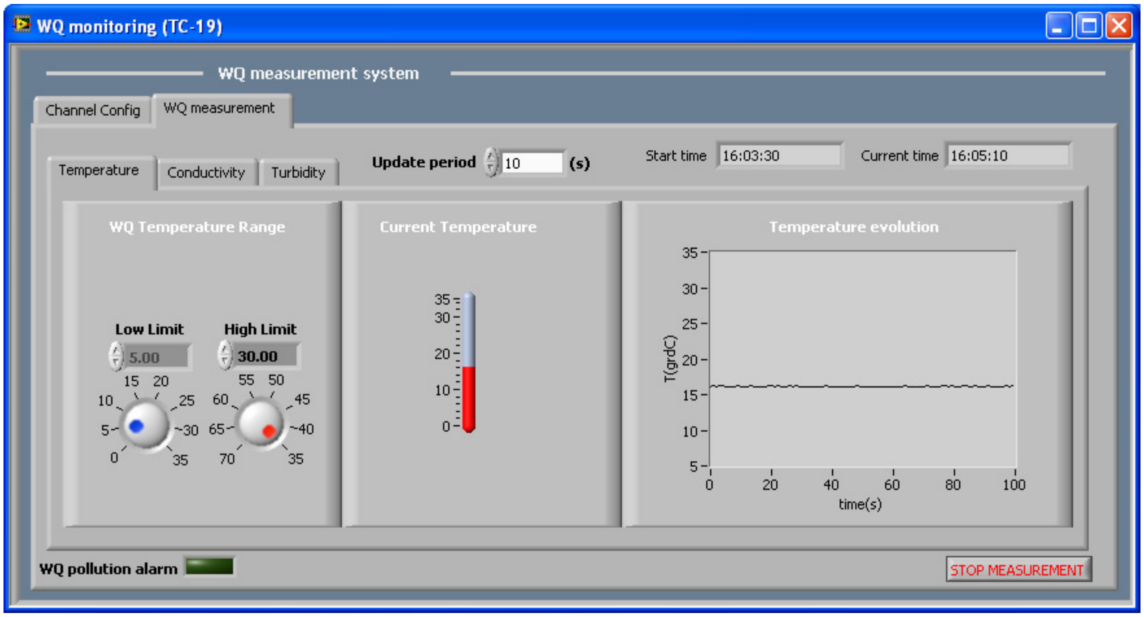

Figure 4. WQ measurement system GUI

In Figure 4 are indicated also the WQ parameter pollution setting limits (Low limit and High limit) as well as the evolution of the considered parameter (e.g. temperature) versus time. When the WQ measured values are out of the imposed measurement range a visual and acoustic alarm is generated (WQ pollution alarm LED becomes "red").

IV. Conclusion

A dual microcontroller based architecture for water quality multi-parameters sensing was designed and implemented. The temperature, conductivity, and turbidity sensing channels were designed and implemented and different laboratory tests were carried out. The embedded system assures the control and data communication associated with WQ quantities that are transmitted to a PC that performs data processing, data storage and data representation tasks. Through calibration and using appropriate inverse models for the measuring channels characteristics, accurate values of WQ measured quantities were obtained. A LabVIEW software was developed in order to assure the GUI, the data processing and the data storage.

Acknowledgments
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