Auto Calibration of Stand-alone Field Operating Sensors for Distributed Water Quality Monitoring Systems

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Abstract- The paper presents and describes a solution for on-line, in-situ automatic cleaning and calibration of stand alone sensors that measure quantities used in the assessment of rivers and lakes water quality. The system, which was also designed to extract water samples for measurement, includes a set of pumps and electro-valves that are controlled by a microcontroller (PIC17C752) based unit. The control and primary data processing is performed by a LabVIEW Real Time controller (FP-2000) that communicates RS232 with the microcontroller based unit. The advanced data processing is made on a laptop PC that works in a Wi-Fi based network including the FP-2000.

I. Introduction

The importance of water quality (WQ) monitoring and assessment is undisputable and is increasing. Rivers and lakes waters are particularly critical both because of the impact its quality has on fauna and flora life and because of its use by humans. Real time monitoring and quality assessment of those waters requires measuring systems with multiple measuring nodes (distributed measuring systems). These nodes, installed at different points of the area to monitor, include sensors able to output information related with the quantities elected to characterize water quality and the hardware required to power the sensors and to process their outputs. Data collected at the different nodes is preferably transmitted to a central land-based station where it is further processed to yield the desired information. The nodes must then also include hardware for data transmission and usually some kind of processing unit (e.g. microcontroller) able not only to format data for transmission but also to transform sensors' output voltages into values of the measured quantities. In previous papers, the authors have presented solutions of distributed measuring systems for water quality monitoring and assessment [1-5]. In a paper on turbidity to be submitted for publication we introduced the hardware to include in each measuring node to extract a sample from the water under test and to introduce the sample in a cuvette where the sensors are installed.

The quantities commonly used in the assessment of water quality are: temperature, pH, conductivity, turbidity, dissolved oxygen, and heavy metals concentration. With the exception of temperature, the performance of the sensors for these quantities is highly dependent on periodic cleaning and calibration. Logistic issues recommend that measuring nodes equipment have and autonomy of at least one month and preferably much more. Thus, such nodes must be provided with the means to automatically clean and calibrate the sensors. Due to the nature of the problem, these processes involve standard liquid solutions. The purpose of this paper is to present and describe the solution the authors designed for on-site, automated cleaning and calibration of the measuring nodes sensors. A prototype based on Field Point technology [6] was implemented, but the design can be adapted to other technologies.

II. System hardware

Figure 1 shows the block diagram of the hardware of each measuring node that includes both calibration and measurement capabilities for four quantities: temperature, turbidity, conductivity and pH. The WQ field node architecture includes the control and processing unit (NI FP2000) that communicates RS232 with the WQ sensor calibration and measurement block through a microcontroller based control and acquisition unit (CtrlAcq unit). This smart node acts as an independent component in a WQ distributed network and communicates with a host Windows computer that performs advanced data processing and implements the web server functionalities (LV webserver). The field node to host computer (laptop) connection is based on IEEE 802.11b wireless standard using a DWL-810+Ethernet wireless bridge (EWB).

Referring to the calibration block it includes:

- $n \times m + 2$ centrifugal pumps - Jabsco Pumps 42510-000, 12 VDC, 1.5A, 7.5 l/min – where: n represents the number of sensors requiring periodic calibration (n=3 in the present case, turbidity, conductivity and pH); m is the number of calibration points equal to the number of standard solutions (SSi) used. In Figure 1, three standard solutions for each considered sensor are used (e.g. OAKTON pH 4.01, 7 and 10 standard buffer solutions for pH). The additional 2 pumps are used one (CP) to pass the cleaning solution from the cleaning vessel to the test cuvette, and the other (WP) to empty the test cuvette either to the waste vessel (calibration phase) or to water under test (measurement session);

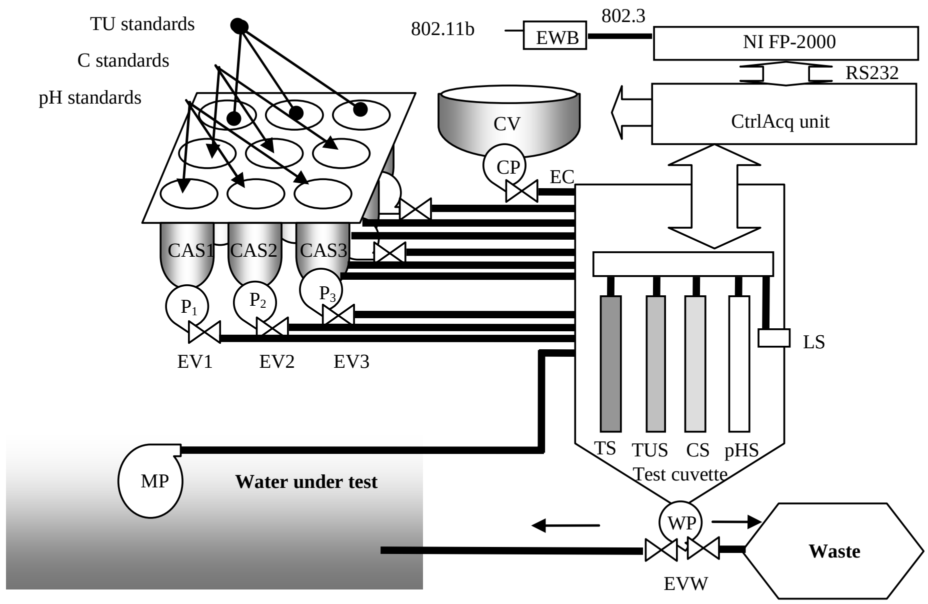

Figure 1. The WQ field node architecture: CV-cleaning vessel, MP-measurement pump, LS-level sensor, TS-temperature sensor, TU-turbidity sensor, CS- conductivity sensor, pHS – pH sensor, CAS_i-calibration solutions, P_i – calibration pumps, CP- cleaning pump, EC-cleaning electro-valve, WP-waste pump, EVi-calibration electro-valves, EVW- waste and measurement electro-valve.

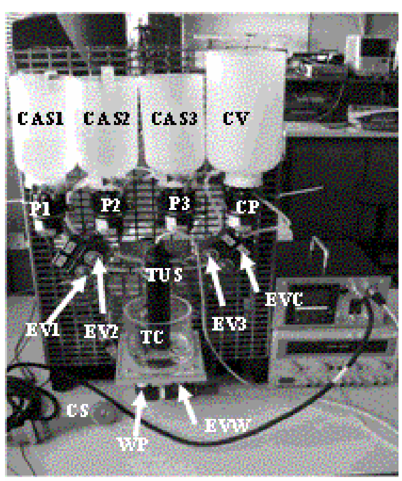

Figure 2. Prototype of a WQ field node: CAS1,CAS2, CAS3 – calibration solution vessels, CV – clear solution vessel, P1,P2,P3-calibration solution pumps, CP – cleaning solution pump, EV1, EV2,EV3- calibration electro-valves, EVC – cleaning electro-valve, TUS- turbidity sensor, CS- conductivity sensor, TC-calibration cuvette, WP-waste pump, EVW-waste electro-valve.

- 1 submersible 12 VDC, 2.5A, 49 l/min Johnson pump (MP) to assure the circulation of the water between the monitored area and the test cuvette;
- n×m + 2 electro-valves - Bergamo 0-15 bar, 12 VDC, ¼”, associated with the above mentioned pumps;
- n×m – 2000 ml vessels for standard solutions (CASi);
- 1× 5000 ml cleaning solution vessel (CV);
- 1× 1000 ml test cuvette.

The control of pumps and electro-valves is performed using the PA, PB and PC digital ports of the control and acquisition unit, configured as outputs, through 12 VDC relays and BD139 based current buffers.
Figure 2 is a photo taken from a prototype of a field node when only the turbidity and conductivity sensors were in the test cuvette.

Figure 3 represents the flowchart of the calibration session.

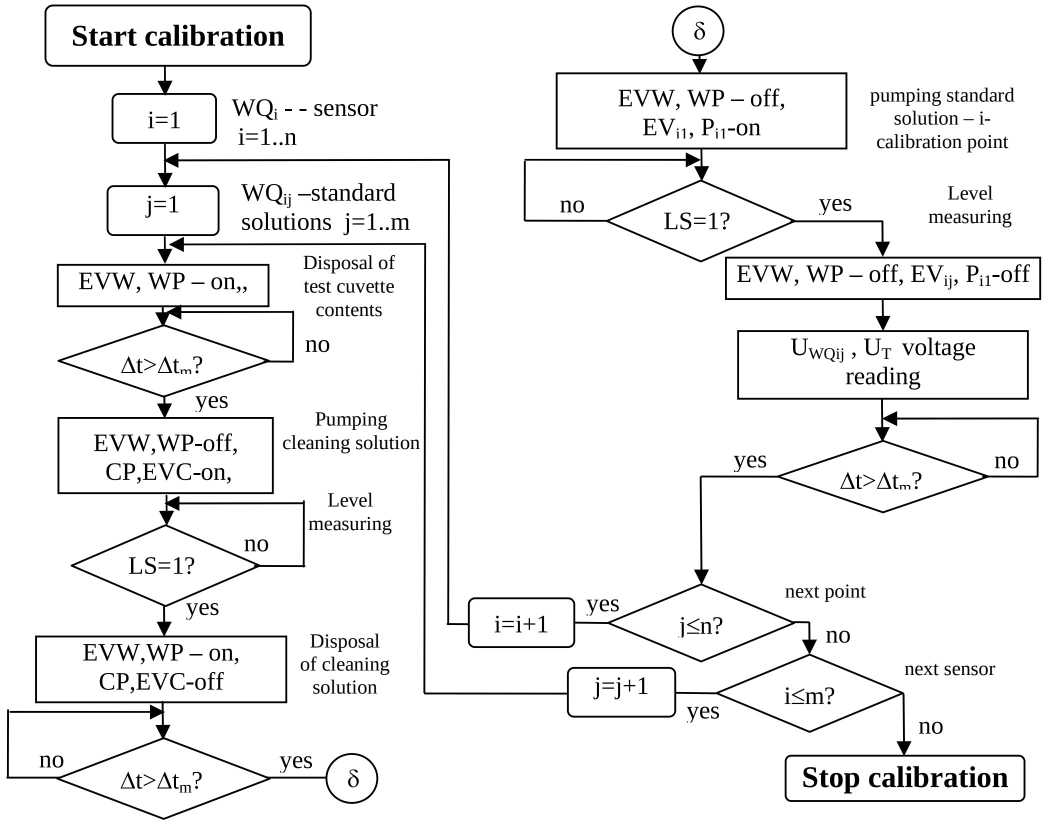

Figure 3. Calibration flowchart: $U_{WQ}ij$ –voltage associated with sensor j for the calibration point i, U_T – voltage associated with the temperature measuring channel, n – number of calibration points, m – number of sensors, Δt_m – time interval associated with disposal of test cuvette contents.

III. System software

The system software includes two parts, one related with the smart node and another represented by the software of the host Windows computer. The smart node software is implemented at the LabVIEW real-time field point controller (NI FP-2000) and includes the following components: WQ sensor field calibration, WQ measurement, and multi-client server TCP-IP communication. The DRAM memory size (16MB) and processing speed limitations force WQ data advanced analysis to be implemented at the host computer, which works as a client of the FieldPoint based node.

Smart node software

The smart node software includes the digital control of the WQ sensor field calibration unit materialised by the pumps and electro-valves control sequence. The specific ASCII commands are sent through RS232 lines from the FP-2000 unit to the PIC17C752 microcontroller which is “the brain” of WQ field calibration and measuring unit. According to the flowchart presented in Figure 3, pumps or electro-valves actuation are followed by voltage acquisition of the WQ calibration or measurement channels (pH, T, conductivity or turbidity). For the particular case of three calibration points (m=3) the following solutions were considered: pH standard={4.01,7,10}, C={1500, 5000, 10000} μS/cm and TU={200, 400, 1000} NTU). The LabVIEW serial port write and serial port read functions are used to send the acquisition commands (e.g. RD0, RD1) and to receive the 10-bit digital codes (n_{WQ}).

The time interval between two successive calibrations ($\Delta tc_{1,2}$) for one or multiple WQ measurement channels depends on the performance of the sensors. The operator can automatically setup $\Delta tc_{1,2}$ for values of several hours or days. (e.g. 48 hours). Nevertheless, and to prevent incorrect data to be stored or transmitted between the field node and the host computer, the performance of each sensor is assessed based on the evolutions both of its output and on the water quality [5] and a re-calibration executed if pre-defined parameter limits are exceeded.

Data logging and data communication and publishing

Considering that the FP-2000 provides 16MB of DRAM and 32 MB of Flash memory, the acquired data is stored in the non-volatile memory and accessed from time to time (e.g .twice a day) by the laptop computer through Wi-Fi communication and an embedded FTP server program.

To obtain the the smart node level information a multiple connection server application is implemented at the FP-level. The WQ parameters values, obtained after some processing, are associated with a WQ array global variable and transmitted to the TCP/IP server application that runs simultaneously in the FP-2000. Using a developed TCP/IP application, the laptop receives the values of T, C, TU, pH measured by each field unit. Based on received data the evolution of the WQ is published in a web page using the laptop LabVIEW web server.

IV. Results and Discussion

Calibration and measurement

Using the above mentioned calibration and measurement system and the associated software components several laboratorial and field tests were carried out. The GUIs associated with the calibration and measurement phases are shown in Figures 4 and 5, respectively.

From Figure 4 one can notice that the calibration GUI permits to setup the number of calibration points according to the used standard solutions (e.g. TU={200,400, 800} NTU). GUI main display graphically shows sensors' output voltages as a function of the input quantity (TU, in this case). The system permits to measure the temperature of the individual standards used in the calibration. The Calibration data table shows the temperature, standard value and output voltage that are used to obtain sensor's inverse model [7]. For each calibration two files are stored in the calibration data directory. The file name indicates the date and time of the calibration (e.g. c26-02-2005-12-37.dat). During the calibration the operator can observe the state of pumps and electro-valves. If anomalous functioning occurs the alarm led is activated and the calibrator is turned off.

The WQ measurement software is running in the FP-2000 under LabVIEW Real Time and assures the control of the electro-valves and pumps and the acquisition and processing of the data associated with the WQ sensors. In Figure 5 are presented a set of LabVIEW digital controls used to input polynomial coefficients that can be used to convert a sensor output voltage into the correspondent quantity values ($U_{TU} \rightarrow TU$, $U_C \rightarrow C$, $U_{pH} \rightarrow pH$) according to the inverse model:

$$pH(U_{pH}) = \sum_{i=0}^{n_{pH}} a_{pH\,i} \cdot U_{pH}^{i} \quad C(U_C) = \sum_{i=0}^{n_C} a_{C\,i} \cdot U_C^{i} \quad TU(U_{TU}) = \sum_{i=0}^{n_{TU}} a_{TU\,i} \cdot U_{TU}^{i} \qquad (1)$$

In the depicted case, the coefficient values were automatically calculated by the calibration software that controls the calibrator and process the voltage-WQ standard values pairs.

Power consumption

As a field calibrator and measurement unit, a smart node must have an adequate autonomy, which means that power consumption is a very important issue. The system is powered by a 12 VDC battery and tests were conducted to obtain the evolution of current and power during both calibration and measurement sessions.

The calibration session involves n×m cycles according to the number of sensors and calibration points. Figure 6 shows the current and power evolution during the calibration of one point for the TU sensor. The total time (Δt_i sum) is 178 s, for an average current of 1.67 A and an average power consumption of 20.19 W.

In the measurement phase, which takes about 200 s, the current consumption is 1.25 A.

Thus, using for instance a 6 Ah battery and making one calibration and 10 measurements daily, the system autonomy is about 8 days. This value is well below our objective. The use of less power demanding pumps and electro-valves is under consideration, but the final solution will probably include a cellular panel to periodically re-charge the battery.

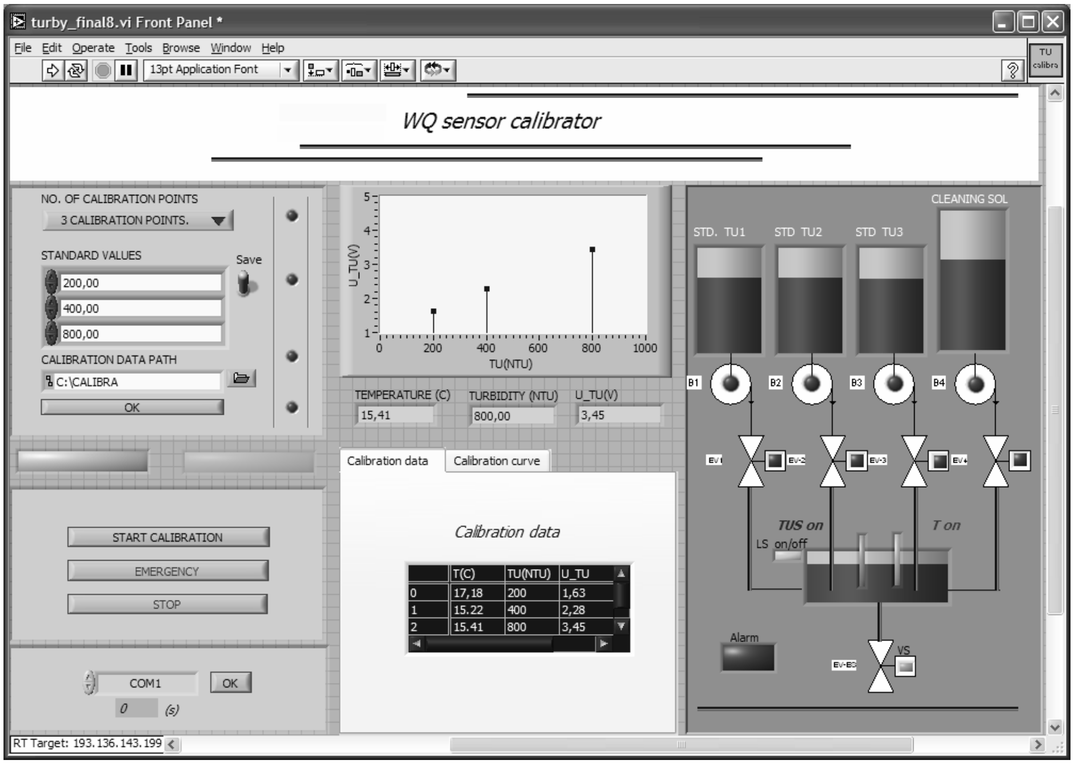

Figure 4. The WQ sensor calibrator GUI.

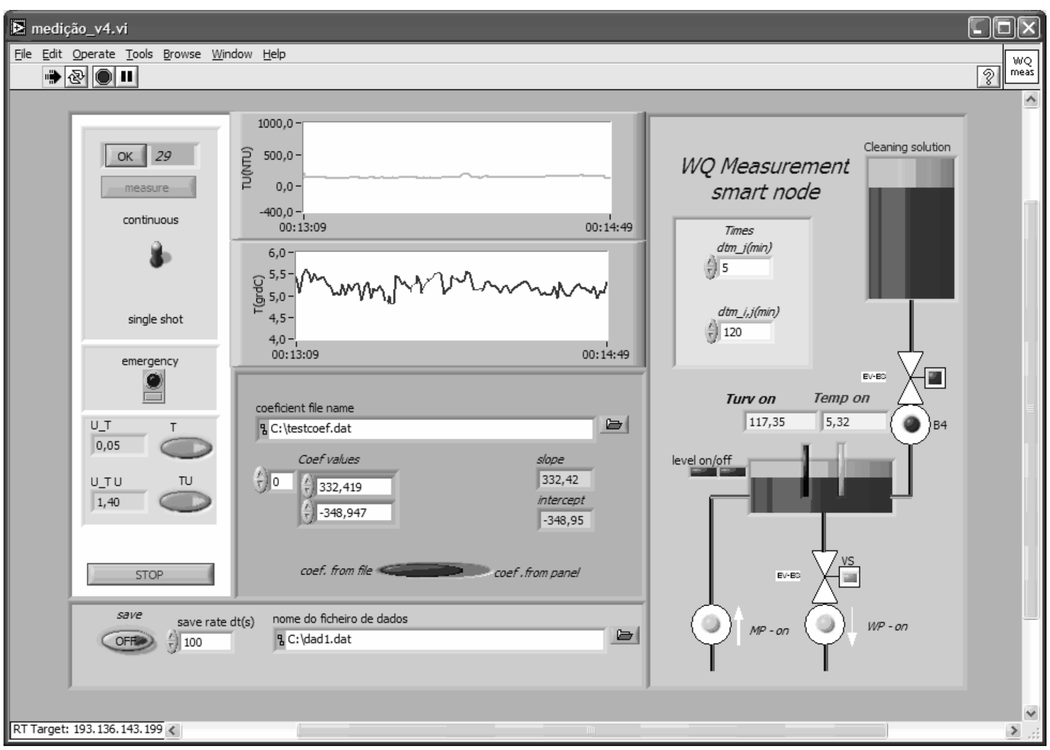

Figure 5. The WQ parameter measurement GUI.

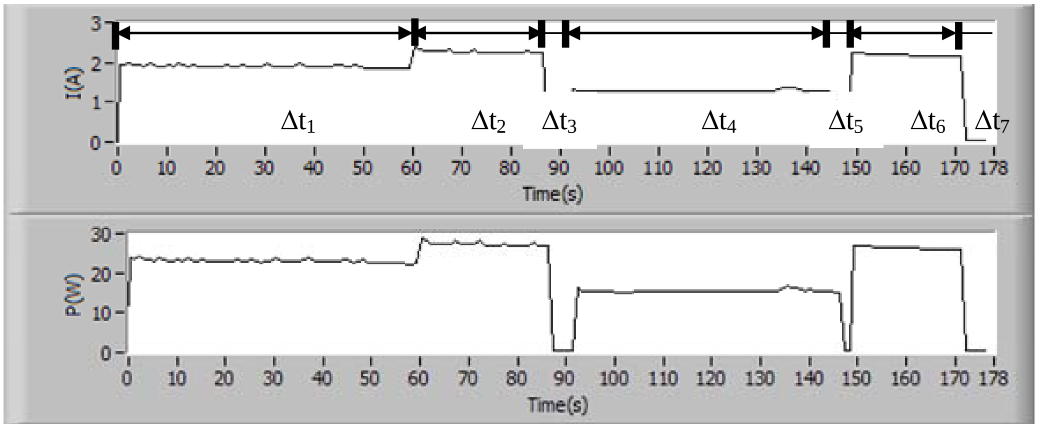

Figure 6. Current and power for a single calibration point: Δt_1- disposal of the test cuvette contents and calibration standard solution preparation, Δt_2 – filling of the test cuvette with the cleaning solution, Δt_3 – cleaning solution measurement –sensor measurement test (U_{TU} and U_T data acquisition), Δt_4 – disposal the test cuvette contents, Δt_5 – no operation, Δt_6 filling of the test cuvette with the calibration standard solution, Δt_7 – standard solution measurement (U_{TU} and U_T data acquisition).

V. Conclusion

The hardware and software proposed solution makes not only viable stand-alone smart sensing nodes for distributed water quality monitoring and assessment but also increases the accuracy of the measured quantities and assures equipment autonomy and life time, reducing, in particular, maintenance costs. The level of autonomy achieved is however still insufficient and less power demanding solutions are under study.

Another important feature of the solution now presented is fault detection and diagnosis capabilities at sensing nodes level.

References

[1] O. Postolache, P.M. Girão, J. M. Dias Pereira, H.G. Ramos; "An Internet and Microcontroller Based Remote Operation Multisensor System for Water Quality Monitoring", Proc. IEEE Sensors, Orlando, USA, Vol. 1, pp. 254 - 259, June, 2002.

[2] O. Postolache, P.M. Girão, J. M. Dias Pereira, H.G. Ramos; "Wireless Water Quality Monitoring System Based on Field Point Technology and Kohonen Maps", Proc. IEEE Canadian Conf. on Electrical & Computer , Montreal, Canada, Vol. 3, pp. 1873 - 1876, May , 2003.

[3] O. Postolache, J. M. Dias Pereira, P.M. Girão, H.G. Ramos; "Smart Wireless System for Pollution of Rivers and Estuaries", Proc. Conf. on Electronic Measurement & Instruments - ICEMI, Taiyuan, China, Vol. 2, pp. 1139 - 1143, August, 2003.

[4] P.M. Girão, O. Postolache, J.M. Dias Pereira; H.G. Ramos; "Distributed Measurement Systems and Intelligent Processing for Water Quality Assessment", Sensors & Transducers Magazine, Vol. 38, No. 12, pp. 74 - 85, December, 2003.

[5] O. A. Postolache, P.M.B.S. Girão, J.M.D. Pereira, H.M.G. Ramos, “Self Organizing Maps Application in a Remote Water Quality Monitoring System”, IEEE Trans. on Inst. and Meas., Vol. 54, n. 1, pp. 322-329, February 2005.

[6] FP-2000 LabVIEW Real Time FeldPoint Controller Interfaces with Ethernet, National Instruments Measurement and Automation Catalog, 2005.

[7] J. Patra, A. Kot, G. Panda, “An Intelligent Pressure Sensor Using Neural Networks”, IEEE Trans. Instr. Meas., Vol. 49, No. 4, pp. 829-834, Aug. 2000.