

Optical Fiber Based Turbidity Sensing System

O. Postolache^{1,2}, J.M. Dias Pereira^{1,2}, P. Silva Girão²

¹*Instituto de Telecomunicações, Av. Rovisco Pais, 1049-001, Lisboa, Portugal*

Emails: poctav@alfa.ist.utl.pt, psgirao@ist.utl.pt

²*ESTSetúbal-LabIM/IPS, Rua do Vale de Chaves, Estefanilha, 2910-761 Setúbal, Portugal*

Email: joseper@est.ips.pt

Abstract- This paper presents a multi-path scattering turbidity sensing architecture that uses two bifurcated and two simple optical fiber bundles. Two optical infrared (IR) emitters and four receivers are coupled to the optical fibers assuring the IR excitation of the measured medium and the IR light scattering detection. The proposed turbidity architecture is rugged and permits to evaluate turbidity using IR light scattering and transmission measuring architectures with improved signal-to-noise ratio. A multifunction microcontroller based I/O interface is connected to a LabVIEW HMI interface (NI TPC-2006) that performs the turbidity sensing channel acquisition and control, and turbidity direct digital read-out based on a neural network. Additional wireless communication capability (IEEE802.11g) is included in the system.

I. Introduction

According to [1][2], turbidity is an "expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample". However, turbidity measurement schemes usually use the detection of both transmitted and scattered light in order to extract the turbidity value. The works reported in the literature [3] and our previous works [4][5] consider the scattering phenomena only in one or two directions according to the implemented method, which limits the sensitivity and accuracy of the system for low values of turbidity. At the same time, the utilization of optical emitters and detectors such as LEDs and photodiodes implies the utilization of waterproof protection.

In this paper, we present a new turbidity sensing architecture that uses a set of bifurcated [6] and normal optical fibre bundles to transmit the excitation light beams from the optical light sources to the medium under test and to transmit the scattered light to IR optical detectors. A practical approach concerning the capabilities of the proposed architecture for different types of the excitation light source (Red LASER Diode and infrared LED) was carried out.

Additional conditioning circuits assure different levels of the excitation currents for the optical emitters and different current-to-voltage conversion and appropriate amplification for the optical detector channels.

The voltage acquisition is performed using a multifunction interface based on a microcontroller that is RS232 connected to a LabVIEW HMI where and intelligent signal processing algorithm, expressed by single-input single output and multi-input single output neural network, is used to calculate the turbidity values. The design, test and implementation of the neural network use the experimental values obtained from a small number of formazine type turbidity calibration standard solutions. The voltages acquired from four light detectors channels are used to obtain the turbidity value displayed by the HMI and transmitted through an implemented water quality wireless network.

II. System Description

A. Hardware

The turbidity measuring system (Fig. 1) includes the turbidity sensing architecture based on bifurcated and simple optical fibre bundles, a two channel driver associated with the optical sources control (IR LEDs OPTEK OP293), and four light detector channels that include four infrared photodiodes (OPTEK OP999) and the corresponding transimpedance and programmable gain amplifiers based on OPA128. Some characteristics of the optical devices associated with the fibre bundle are: detector maximum sensitivity at 890nm wavelength, LED maximum optical power at 850nm wavelength for a beam angle less than 15°. The maximum current through the emitters is 50mA.

The light emitters (IR LEDs) switch on/off and excitation light beam control is assured by the current driver control that works under the control of the PWMA and PWMB output channels of a multifunction I/O interface based on a PIC17C752 microcontroller.

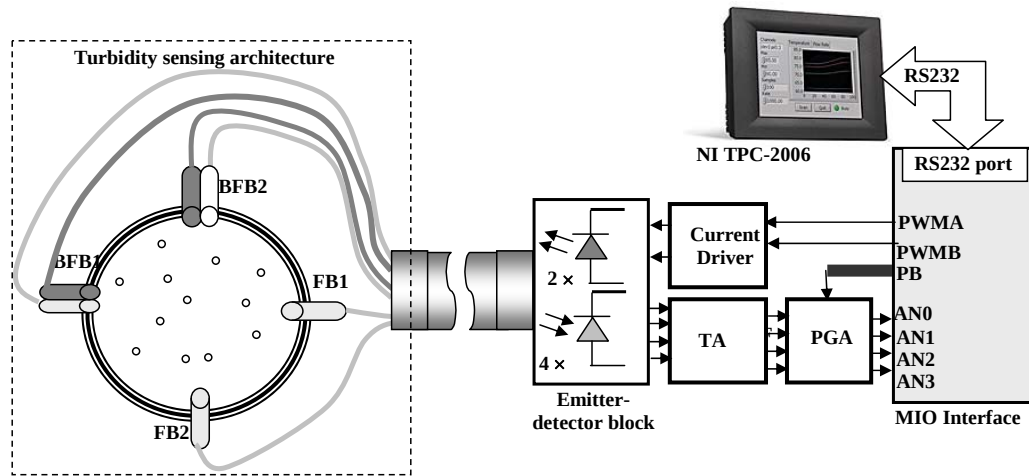


Figure 1. Block diagram of the turbidity measurement system based on optical fibres: BFB1, BFB2 – bifurcated fibre bundles, FB1-FB2 – fibre bundles, TA – transimpedance amplifier, PGA- programmable gain amplifier; PWMA, PWMB – pulse width modulation outputs, PB-digital output port, AN0, AN1, AN2, AN3 – analog inputs, NI TPC-2006 – LabVIEW HMI, small size industrial touch panel LabVIEW computer

Thus, imposing a duty cycle of 0%, the infrared LEDs are switched-off while for a duty cycle of 100% the excitation current of the LEDs is about 60mA. The implemented measurement procedure includes two phases: a) LED1=on, LED2=off; b) LED1=off, LED2=on. On each phase, all four detectors (D1, D2, D3, and D4 matched to the BFB1, BFB2 receiving fibres and FB1, FB2 fibres) are read. LED1 and LED2 are included in the emitter detector block and controlled through the current driver block. According to the LEDs control phase, four infrared detectors are used to measure the IR beam intensity. Four analog inputs (AN0, AN1, AN2, and AN3) of the MIO interface that includes a 10-bit ADC, are used to acquire the output voltage of the detector conditioning circuits, which include the transimpedance amplifier (TA) and the programmable gain amplifier (PGA). The amplification level is set independently for each channel according to the turbidity measurement procedure considering that each measurement phase (a or b) is characterized by different levels of radiation on the detector's surface. In order to evaluate the behaviour of the turbidity sensing structure for transmission, scattering and backscattering architectures, several tests for different types of solution under test (water, formazine standard solution) were performed. The evaluation of backscattering on the absence of the solution under test was carried out too. Different levels of excitation currents were considered.

The acquired values are transmitted to the LabVIEW HMI (HMI- Human Machine Interface) [7] characterized by 3 RS232 ports, an Ethernet and a USB ports. The HMI unit assures the processing of the acquired data to obtain the turbidity information. The HMI's Ethernet port associated with a wireless Ethernet bridge is used to transmit the on-line measured data or the compact flash (CF) memory stored data to a host PC for advanced data processing.

B. Software

The system software integrates the following blocks: turbidity sensing architecture control block, acquisition control block, advanced signal processing block based on a neural network embedded on the HMI computer and wireless data communication block based on IEEE802.11g protocol.

Considering that the MIO interface is connected to the NI TPC-2006 through an RS232 port, specific MIO commands (e.g. TA256 – set DC of PWMA at 25%) and LabVIEW Serial Communication Functions (e.g. *Serial Write*, *Serial Read*) are used to control the turbidity measurement procedure and to acquire the optical detector channels voltages. The data acquired for different values of formazine turbidity standard solutions is stored in the compact flash memory of the HMI and used for off-line

design of and advanced intelligent processing structure expressed by a neural network. The HMI front panel associated with the turbidity sensing structure calibration, including the calibration standard values expressed in NTU, and the voltages associated with the detectors channels are presented in Figure 2. The designed interface includes two “tabs” one associated with the calibration phase where the PGA gain can be set manually using the buttons associated with the interface, and a second “tab” corresponding to the measurement phase when the system is used for on-line measurement of turbidity.

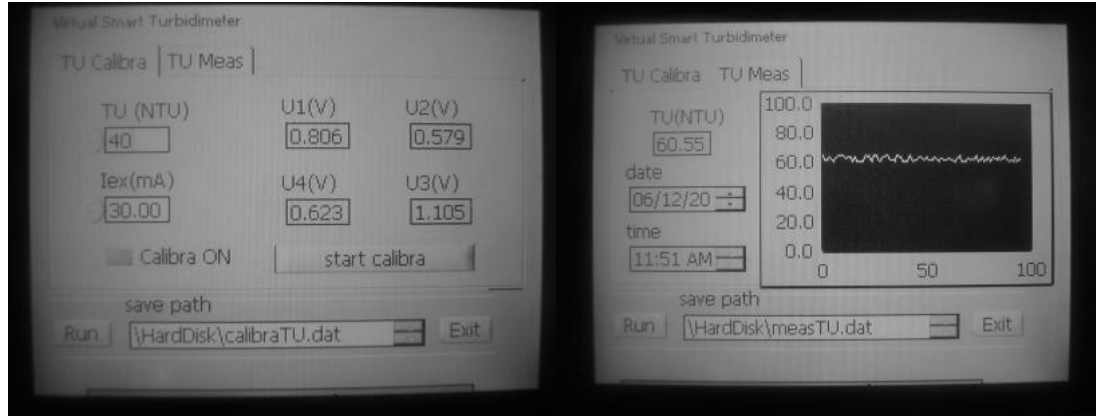


Figure 2. The calibration and measurement software panels associated with the used HMI NI TPC-2006

In order to obtain accurate turbidity values during the measurement phase, the voltage values from the detectors and the formazine turbidity standard solution values are used for the design of the neural network inverse model of the turbidity measuring channel. The media under test turbidity value calculation is based on a neural network processing module that uses the voltages acquired from the photodiode channels matched to the BFB1 and BFB2 receiving optical fibres and to BF1 and BF2. Two types of Multilayer Perceptron [8] architectures were tested: single-input single-output (NN-SISO) and multiple-input single-output [9] (NN-MISO) (Figure 3).

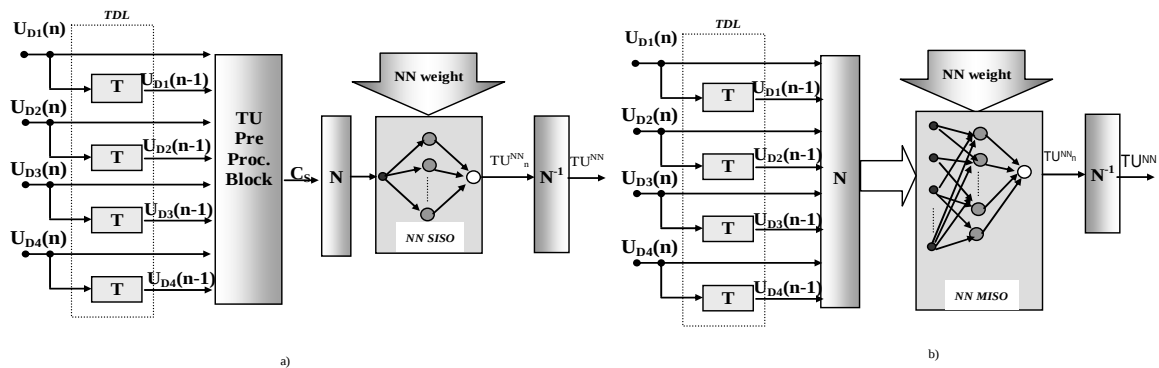


Figure 3. The SISO (a) and MISO (b) neural processing algorithm associated with turbidity sensing architecture (TDL - tape delay line, T - delay cell, N-normalization block, N^{-1} de-normalization block, NN - neural network processing block)

The turbidity processing based on SISO neural network processing architecture implies the utilization of a pre-processing block whose output is expressed by a scattering coefficient [3] defined as the arithmetic mean of scattering and transmission voltage ratios obtained at different stages of the turbidity measurement procedure, including also back-scattering information:

$$Cs = \frac{1}{2} \left(\frac{\sum_{i=1}^3 U_{s1i}}{U_{T1}} + \frac{\sum_{i=1}^3 U_{s2i}}{U_{T2}} \right) \quad (1)$$

where i corresponds to the scattering detectors associated with BFB1, BFB2 receiving fibres and to

BF1 or BF2 according to the turbidity measurement procedure, and U_{Si} and U_{Ti} are the voltages associated to the transmission beam (BF1 – for the first phase of the turbidity measurement procedure, BF2 - for the second phase of the turbidity measurement procedure).

The normalized values of C_s ($C_s^N=[0;1]$) that were calculated for different values of turbidity previously stored in the HMI compact flash and the normalized TU_s values are used to design the neural network (NN weight values calculation). Considering the neural network design complexity, which requires the utilization of software developed in MATLAB, the data from the HMI obtained during the calibration phase can be transmitted to the host computer through TCP/IP supported by the wireless network or by the ftp server service embedded in the TPC-2006. The experimental data (calibration phase data) is used as a training set for SISO and MISO neural network design using the Levenberg Marquardt training algorithm. A practical approach concerning the neural network complexity versus accuracy of the turbidity measurement channel model was carried out. Thus, different architectures characterized by number n_{hidden} of tansigmoid neurons with $n_{hidden}=[4;12]$ were designed and tested.

To perform on-line processing of the turbidity values, the calculated neural network weights and biases are transmitted and stored in the HMI compact flash. During the measurement phase, these values are accessed by the LabVIEW embedded software and used to calculate the turbidity of the medium under test using also the detectors voltages according to the above mentioned measurement procedure steps.

Referring to the MISO neural network architecture, the pre-processing block is not required, which makes this architecture better adapted to the particular geometry of the turbidity sensing structure. The normalized voltages associated with the tape delay line included in the processing scheme are applied to the eighth inputs of the MISO neural network. After neural processing, the turbidity values are displayed by the HMI and can be logged in the CF memory.

III. Results and Discussions

Different tests were carried out to evaluate the turbidity sensing architecture characteristics. Thus, the response of the turbidity sensor for the excitation current I_{ex} in the [5; 47]mA interval for transmission and backscattering optical measurement channel was obtained. Figure 4 presents the evolution of the turbidity sensing response for two experimental cases.

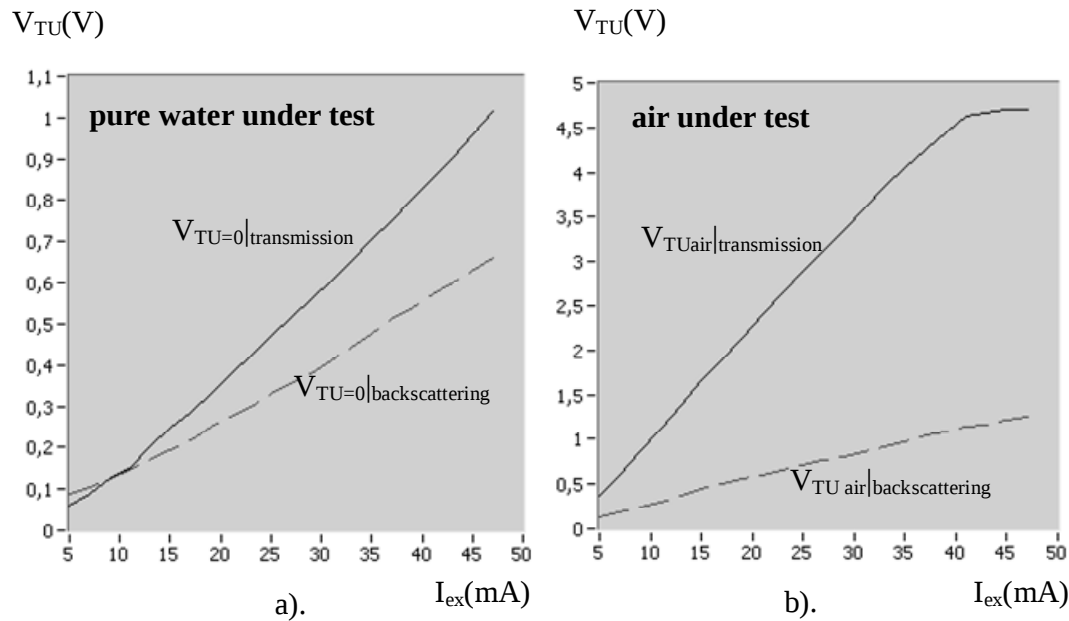


Figure 4. The evolution of the voltage obtained in the transmission and backscattering detector channels for different values of the excitation current, I_{ex} , of the IR LEDs and for different media ((a) pure water, b) air)

Analyzing Figure 4.a one can observe that for usual media under test (water, $TU \approx 0$ NTU) the output of the backscattering and transmission optical detection channels are about the same for low values of the excitation current but strongly diverge when the current increases. Referring to the backscattering

detector response, Figure 4.a and Figure 4.b show that it is lower than the transmission detector one, which is justified by the difference of the optical paths associated with transmission and backscattering and the corresponding absorption effects.

Figure 5.a shows the C_s evolution for different values of formazine turbidity standard solutions. Using a SISO neural network architecture (1 input neuron-4 hidden neurons-1 output neuron), the modeling error of $C_s(TU)$ characteristic is less than 1%. (Figure 5.b.).

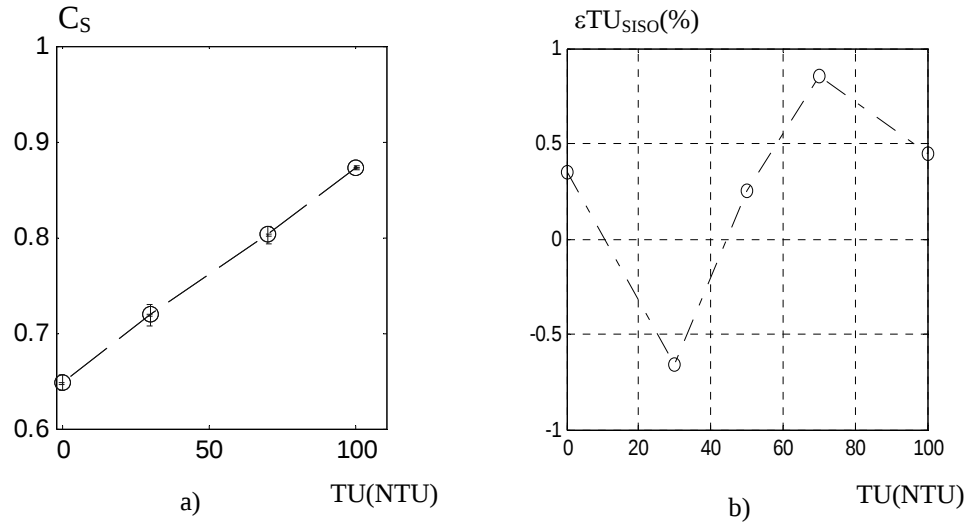


Figure 5. (a) The evolution of the scattering coefficient for different values of turbidity standard solutions; (b) SISO neural network approximation error for the [0-100]NTU turbidity measurement range

The results of a study concerning the number of hidden neurons and accuracy for the MISO neural network (8 input neurons – n_{hidden} hidden neurons – 1 output neuron) are presented in Figure 6. The training set used includes the voltages associated with $TU_{train}=[0;30;70;100]$ NTU standard solutions, and the testing set includes the voltage associated with $TU_{testing}=[20;40;80]$ NTU standard solutions.

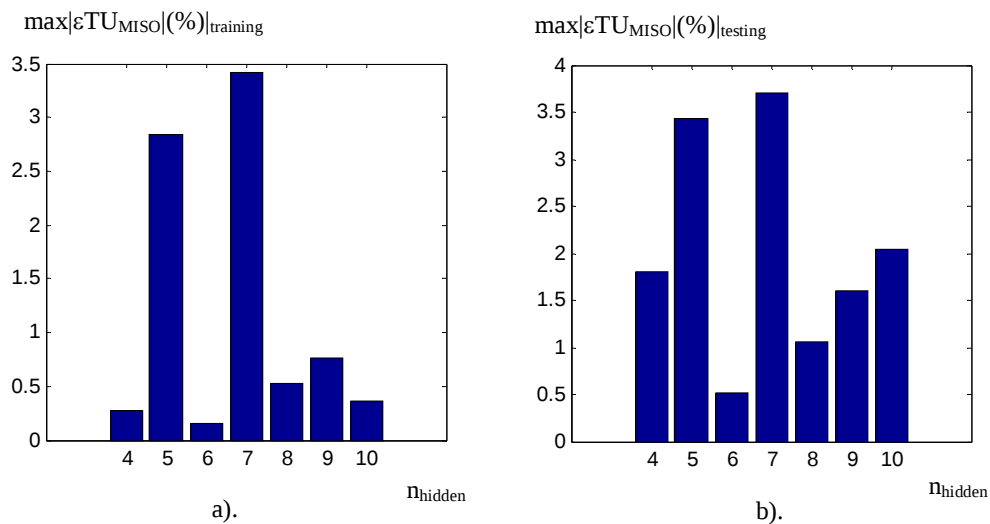


Figure 6. The evolution of maximum modeling error associated with the designed MISO neural network
a) training modeling error; b) testing modeling error

Referring to the neural network modeling of the turbidity measurement channel, the obtained results underline that the MISO modeling errors ($\varepsilon_{TU_{MISO}} \approx 3$ to 4% of FS) are higher than SISO modeling errors ($\varepsilon_{TU_{SISO}} \approx 1\%$ of FS). Better results can be obtained increasing the number of calibration points (increasing the size of NN training set), which implies higher calibration costs.

IV. Conclusion

A fibre optic based turbidity measuring system is proposed. The basic differences with other solutions proposed by the authors and by others are the utilization of bifurcated optical fibres and of a small size industrial touch panel LabVIEW computer. The new design does not require the utilization of a waterproof box for the system's electronics since the light beams to and from the solution under test are transmitted by optical fibres. The fibre bundles allow the measurement of the backscattered light that conducts to higher sensitivity of the turbidity measurement device. The signal processing combines a basic data processing (tape delay line, scattering coefficient calculation) with advanced neural network processing. The comparison between the results of single-input single output and multi-input single output neural networks recommends the SISO neural network model for small number of calibration points. MISO neural network architecture is a good option for a higher number of calibration points.

Referring to the system data processing and data communication, the embedded LabVIEW HMI is a compact solution with high degree of portability and flexibility; additional water quality measuring channels can be added to the system.

References

- [1] Omega Engineering, "Technical Reference Selection Guide - Turbidity definition", available at URL: <http://www.omega.com/techref/ph-6.html>.
- [2] International Standardization Organization, "ISO 7027, Water Quality - Determination of Turbidity", International Standardization Organization, Geneva, Switzerland, 1999.
- [3] A. García, M. A. Pérez, Gustavo J. Ortega, and J. Tejerina Dizey, "A New Design of Low-Cost Four-Beam Turbidimeter by Using Optical Fibers" *IEEE Instrumentation and Measurement*, VOL. 56, NO. 3, pp. 907-912, June 2007.
- [4] J.M. Dias Pereira, O. Postolache, P.M. Girão, H. G. Ramos, "SDI-12 Based Turbidity Measurement System With Field Calibration Capability", *Proc IEEE Canadian Conf. on Electrical & Computer*, Niagara Falls, Canada, Vol. IV, pp. 1975 - 1979, May 2004.
- [5] O. Postolache, P.M. Girão, J. M. Dias Pereira, H. G. Ramos, "An IR Turbidity Sensor: Design and Application", *Proc IEEE Instrumentation and Measurement Technology Conf.*, Anchorage, United States, Vol. 1, pp. 535 - 539, May 2002.
- [6] J. Faria, O. Postolache, J. M. Dias Pereira, P.M. Girão, "Automated Characterization of a Bifurcated Optical Fiber Bundle Displacement Sensor Taking into Account Reflector Tilting Effects", *Microwave and Optical Tech. Letters*, Vol. 26, No. 4, pp. 242 - 247, August 2000.
- [7] National Instruments, "Creating LabVIEW Applications to Communicate Between PACs and the NI TPC-2006 Industrial Touch Panel Computer", on-line at <http://zone.ni.com/devzone/cda/tut/p/id/3197>.
- [8] S. Haykin; "Neural Network - A Comprehensive Foundation", Prentice Hall International, USA, 1999.
- [9] O. Postolache, J. M. Dias Pereira, P.M. Girão, H. G. Ramos, "Smart Flexible Turbidity Sensing Based on Embedded Neural Network", *Proc IEEE Sensors*, Daegu, South Korea, Vol. I, pp. 658 - 661, October 2006.