

# Simple Sensor-to-Personal Computer Interface by Using Virtual Instrumentation

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**Abstract** – A simple interface for resistive sensors based on pulse width modulation is presented. The interface is intended for computer-based measurement systems with specialized data acquisition (DAQ) cards in a LabVIEW environment. The highlight of such interface is its good cost/performance ratio. The experimental results show that, beside the relatively low measurement speed, the interface can be useful for measurement of slow varying physical quantities such as temperature or humidity. The performances of the interface circuit can be evaluated as satisfactory having in mind its simplicity.

**Keywords** – Passive sensor, virtual instrument, data acquisition

## I. INTRODUCTION

In the last decade, a lot of papers have been published on direct passive sensor interface (resistive and capacitive) to microcontrollers [1] and field programmable gate arrays (FPGA) [2]. Such interface allows direct connection of the sensor with the digital programmable device without any external active component and without analog to digital (AD) converter. Hence, when measured with such approach, the sensors have properties as to be called quasi-digital sensors. Following the same principles as in [1], [2] and [3], this paper deals with direct interface of a personal computer (PC) with passive resistive sensors in a LabVIEW environment.

To support the economic justification of the solution, an overview of several commercial data acquisition cards from two different manufacturers was performed. Some of the most important parameters of the DAQ cards for implementation of the sensor interface are summarized in Table 1. The selection of the DAQ cards was from two world's largest manufacturers: National Instruments [4] and Advantech [5]. The selection criteria was by several important parameters: number of input/output digital ports, timers/counters, digital channel properties, analog input channels, dedicated resistive sensor inputs and cost. For easier comparison, the current prices of the DAQ cards were normalized by the price of the cheapest DAQ card (USB-6501). It is expected that, even if the prices of the DAQ cards vary in the future, their price ratio will not be greatly affected. Having in mind that the direct sensor-to-(digital programmable device) interface is realized only by using digital input/output ports, this interface can be also realized with the cheapest DAQ card given in Table 1, which is National Instrument's USB-6501.

When compared to the classical resistive sensor signal conditioning techniques, where an output voltage from the

conditioning circuit carries the information about the measured physical quantity, it is necessary to use AD converter to be able to interface to a digital device. Hence, having in mind the data in Table 1 it can be seen that the DAQ cards containing analog channels (AD converters) are around 2-3 times more expensive than the DAQ cards containing only digital channels. All DAQ cards in Table 1 contain digital input/output channels and dedicated timers/counters for registering time events. Moreover, the price of the DAQ cards with special resistive inputs is approximately 4-14 times higher than those with digital channels. Such analysis shows that, where the performances of the direct sensor-to-PC interface are good enough, this approach has a better cost performance ratio comparing to the classical approach (with AD converter).

This paper deals with implementation of the "direct sensor-to-PC" interface when using a specialized DAQ card controlled by a virtual instrument in LabVIEW environment. The implementation and the experimental results presented are for resistive sensors, but similar methodology can be used to interface capacitive sensors.

## II. DIRECT SENSOR-TO-MICROCONTROLLER INTERFACE PRINCIPLES

In practice, the direct sensor-to-microcontroller interface is realized with some calibration technique. Three basic calibration techniques are proposed so far: single point [6], two point [6] and three signals method [7]. Each calibration technique has some advantages and drawbacks. Comprehensive analysis and comparison between the calibration techniques is given in [8]. Thus, the single point is the simplest calibration technique providing lowest accuracy, but however it is cheapest and it uses less interface connections which is very important in this case. Therefore, single point calibration is analyzed in this paper.

The implementation of the direct sensor-to-microcontroller interface with single point calibration is given in Fig.1. The measurement contains two phases. In the first phase, the microcontroller measures the time needed to charge a reference capacitor  $C$  through the sensor resistance  $R_x$  with the built-in timer. The measurement ends when the capacitor voltage reaches the higher threshold voltage of the input digital port  $V_{th}$ . Here, we point out that the interface can be also realized by measurement of the discharging time of the RC circuit. In the second phase, similarly, the microcontroller measures the charging time interval through a calibration resistor  $R_c$ . The state of the microcontroller ports and the signal waveforms are given in Fig.2. The charging time interval in the first phase is:

$$T_x = R_x C \ln \left( \frac{V_H - V_L}{V_H - V_{th}} \right), \quad (1)$$

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TABLE I  
COMPARISON OF THE PARAMETERS OF SEVERAL COMMERCIAL DATA ACQUISITION CARDS FROM DIFFERENT MANUFACTURERS

No.	Type	Manufacturer	Analog channels	Digital input/output channels	Pull-up/Pull-down	Buffer	Timer/counter	Input channels for resistive sensors	Price*
1	USB-6501	Nation. Instr.	/	24	YES	YES	1	/	1,0
2	USB-6009	Nation. Instr.	8	16	YES	YES	1	/	2,8
3	PCI-6601	Nation. Instr.	/	32	NO	YES	4	/	3,9
4	PCI-6321	Nation. Instr.	16	24	NO	YES	4	/	6,2
5	NI-9217	Nation. Instr.	/	/	/	/	/	4	4,9
6	NI-9219	Nation. Instr.	4	/	/	/	/	4	14
7	PCI-1780	Advantech	/	16	NO	NO	8	/	2,8
8	PCI-1710	Advantech	16	32	NO	NO	1	/	5,0

\* The prices are normalized by the price of the cheapest DAQ card, USB-6501

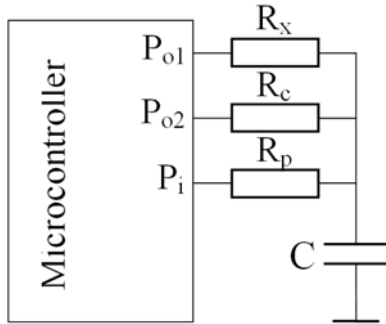


Fig.1. Direct sensor-to-microcontroller interface by using single point calibration

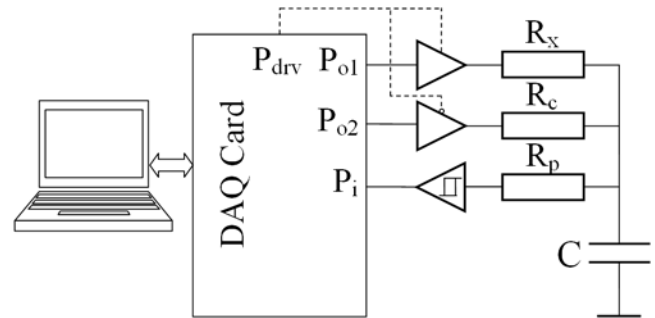


Fig. 3. Universal direct sensor-to-PC interface by using single point calibration

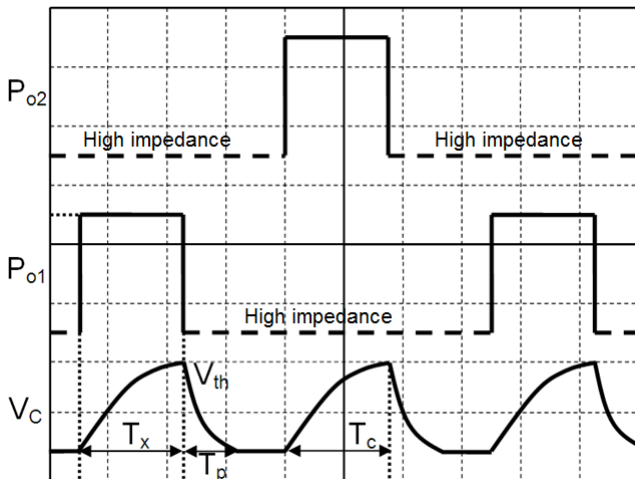


Fig.2. State of the microcontroller ports and characteristic signal waveforms for implementation of the single point calibration

where  $V_H$  and  $V_L$  are the voltage levels for a logic '1' and a logic '0' respectively. The discharging interval in the second measurement phase is given with:

$$T_c = R_c C \ln \left( \frac{V_H - V_L}{V_H - V_{th}} \right), \quad (2)$$

The single point calibration is realized by division of (1) and (2) to cancel out the "unstable" parameters  $V_H$ ,  $V_L$ ,  $V_{th}$  and  $C$ . The unknown sensor resistance is then calculated by:

$$R_x = \frac{T_x}{T_c} R_c \quad (3)$$

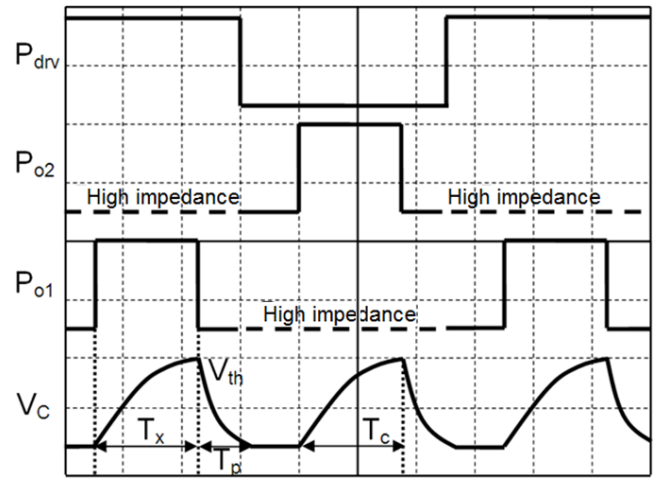


Fig.4. State of the DAQ card ports and characteristic signal waveforms for implementation of the single point calibration

Having in mind (3), the calculated sensor resistance depends on the measured time periods  $T_x$  and  $T_c$  and the calibration resistor  $R_c$ . However, the input/output resistances and leakage currents of the microcontroller ports introduce systematic errors in a form of offset, gain and nonlinearity. To keep these errors to minimum, in single point calibration, the calibration resistor value should be in the middle of the measurement range [6].

### III. DIRECT SENSOR-TO-PERSONAL COMPUTER INTERFACE

To implement the direct sensor-to-PC interface as explained in the previous chapter, the DAQ card should fulfill the following conditions:

- The DAQ cards should contain reconfigurable input/output digital ports,
- The digital ports should have three state buffers,
- The availability of hardware timers/counters is advantageous.

Having in mind the characteristics of the commercial DAQ cards given in Table I, it can be seen that only several of them fulfill the conditions above. Hence, the DAQ card number 1 and 2 contain three state buffers but they also contain pullup/pulldown resistors that prevent the implementation of the interface. The DAQ cards number 7 and 8 doesn't contain pullup/pulldown resistors but they neither contain three state buffers. Therefore, it is necessary to design universal solution that will be applicable to all DAQ card types. Such universal solution is given in Fig. 3 and the state of the DAQ card ports during operation are given in Fig. 4. The proposed solution uses two external three state buffers on the digital ports  $P_{o1}$  and  $P_{o2}$ , controlled by one additional digital pin  $P_{drv}$ . It can be seen that  $P_{o2}$  port buffer is inverted. Therefore, only one of the ports  $P_{o1}$  or  $P_{o2}$  will be active in a given moment. The equations (1) and (2) in this case become:

$$T_x = R_x C \ln \left( \frac{V_H - V_L}{V_H - V_{thsch}} \right), \quad (4)$$

$$T_c = R_c C \ln \left( \frac{V_H - V_L}{V_H - V_{thsch}} \right), \quad (5)$$

where,  $V_{thsch}$  is the high threshold voltage of the external Schmitt trigger port. It is clear that the implementation of the single point calibration e.g. dividing (4) and (5) will result in (3) leading to the conclusion that the direct sensor-PC interface will have identical metrological performances such as the direct sensor-microcontroller interface. However, selecting suitable external buffers with low output resistances and high input resistances will reduce the systematic errors as discussed in [6]. Additionally, the external Schmitt trigger port can reduce the noise interference effects of the input port  $P_i$  and increase the resolution of the measurements [9]. For the sake of simplicity, the measurement of  $T_x$  and  $T_c$  needed to implement the direct sensor-PC interface is performed by using a software generated time base. On the other hand, a software generated time base in the multitasking operating systems needed to run LabVIEW is affected by several uncertainty sources, such as the current processor unit occupancy. By giving the highest priority of the LabVIEW program and implementing a real-time operation program routines [10], the measurement of the time interval in LabVIEW is tested with a Fluke 5500A calibrator with absolute uncertainty of 25 ppm 15  $\pm$  mHz in the range from 100 Hz to 10 kHz. The Fluke 5500A signal's period is measured with the DAQ card USB-6009. The standard deviation of 500 consecutive measurements of the input signal with period of 50 ms was 0.27 ms. Hence, for Type A evaluation, the standard measurement uncertainty is calculated as:

$$u(T) = \sqrt{s(T_m)}, \quad (6)$$

where  $s(T_m)$  is the standard deviation of  $m$  consecutive measurements. According (6), the standard measurement

uncertainty of the software-based time interval measurements is  $\pm 0.51$  ms. Hence, for a maximal relative error of 0,1 % (time-related) and resolution of 10 bits, the time intervals  $T_x$  and  $T_c$  given with (4) and (5) should be larger than  $\approx 1.1$  s. Such performances limit the speed of measurements to around 0.5 samples per second (sps). However, even such low measurement speed can be sometimes useful, such as when measurement of a slow-varying physical quantities like temperature or humidity, or for applications like in [11], [12] etc.

#### IV. CONCLUSIONS

The paper proposes a virtual computer-based measurement system for passive resistive sensors. The sensor interface uses the single point calibration commonly used in direct sensor-to-microcontroller interface to perform the measurements.

Universal solution suitable for majority of the commercial DAQ cards containing digital input/output ports has being proposed. The program was implemented in LabVIEW environment and the metrological performances were tested with Fluke 5500A precision calibrator. The experimental results suggest that, for a resolution of 10 bits the proposed interface achieves relatively low measurement speed of around 0.5 sps which can be useful for measurement of slow-varying physical quantities like temperature, humidity etc. The performances of the proposed sensor interface circuits can be evaluated as satisfactory having in mind its simplicity.

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