Flow Rate AMS - Automatic Measurement System

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Abstract. The aim of the measurement and control activity is to carry out accurate and reliable measurements of a lot of physical quantities in the shortest possible time. Over the last few years, the evolution of electronics, information technology and telecommunications has made it possible to develop automatic measurement system to accomplish complex measurements in ever faster times, with a high degree of reliability and storage capacity. This work focuses on design, implementation and testing of a flow rate automatic measurement system.

1. Automatic Measurement systems

Nowadays, the companies want high quality manufacture standard in very short production time. In this point of view, the automatic measurement systems (AMS) are mandatory in order to keep high quality for the productive process. Manual measurements through operators are not suitable for systems in which the measurement speed is fundamental in order to perform real-time checks of system processes. The technological development of the electronic and IT sector allowed to meet these needs and over the last decade the market provided measurement systems always cheaper, more accurate and reliable. As known, a quality test involves different resources and activities, like design and control of the test cycle, acquisition of data and computation. Such activities can be automatically implemented and managed with an appropriate automatic measurement system composed by these 4 blocks [1-2-3]:

- Sensor: it detects a physical quantity and provides a corresponding electrical output;
- Signal conditioning system: it elaborates and optimizes the outcome from the sensor in order to adapt this signal to the following stages;
- A/D converter: it converts the analog signal into a digital signal (sampled and quantized signal);
- Control system: it stores and processes the digital output of the A/D converter. Finally, it provides the measure information’s to the operators.

In order to implement a measurement system for multiple signals, it would be necessary to implement the same system for each physical quantity. Since this solution is economically expensive, most of the acquisition systems are designed using a multiplexer [4]. A multiplexer is a device that selects one of several analog input signals and forwards the selected input into a single line. A multiplexer of $2^n$ inputs has $n$ select lines, which are used to identify which input line to send to the output. In this way, the designers could use only one A/D converter and one control system, which are the two most expensive components of the measurement chain. Figure 1 shows a generic architecture for the measurement of $n$ different physical quantity, where: $x_1$, $x_2$, ..., $x_n$ are the physical quantities to measure, $S_i$, $S_2$, ..., $S_n$ are the sensors, $PA_1$, $PA_2$, ..., $PA_n$ are the analog amplifiers, and $F_1$, $F_2$, ..., $F_n$ are the others possible needed signal conditioning components.
The constantly growing flow of information provided by systems that are used to control technological processes, monitor environmental conditions and test industrial facilities presents increasing challenges in terms of equipment and maintenance costs, as well as timing of information delivery. A data acquisition system (abbreviated by the acronyms DAS or DAQ), includes a set of hardware for sampling, conversion, storage and primary processing of input analogue signals received from sensors installed. It offers an approach towards the optimization of information flows [5]. A data acquisition system must therefore not only be able to make the measurement, but also to make the information contained in it available for immediate or future use [6]. Generally, DAQ system has multiple inputs and outputs and could be interconnected with a PC through a USB serial bus.

Data acquisition applications are usually controlled by software programs developed using various general purpose programming languages, such as LabVIEW; it is a system-design platform and development environment for a visual programming language from National Instruments [7].

2. Flow measurement system

Traditionally, the flow measurement is obtained indirectly considering two pressure measurement in different sections of a flow bench, and elaborating them through fluid dynamics fundamentals, like Bernoulli theorem. Generally, in order to measure these pressures, non-electronic component (e.g. differential pressure gauge) are used. The advantage of this measurement system is the fulfilment easiness and the accuracy of the results. Otherwise, there are several disadvantages, such as the huge dimension of the system and the impossibility to identify fast variation of the flow. Therefore, some electronic devices (e.g. piezoelectric pressure sensor and DAQ) are used to implement an AMS to solve the previous issues.

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals and some ceramics) in response to applied mechanical stress. A piezoelectric sensor is a device that uses this effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge [8].

For this work, as pressure sensors, the FREESCALE MPX5100AP (see figure 2) have been chosen. They are an integrated silicon pressure sensor on-chip signal conditioned, temperature compensated, and calibrated. This type of piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications [9]. This patented single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

The sensor transfer function is defined as:

$$V_{out} = V_s \cdot (P \cdot 0.009 - 0.095) \pm 2.5 \cdot 0.009 \cdot TM \cdot V_s$$

(1)

Where: $P$ is the absolute pressure measured by the sensor, $V_s$ the supply voltage of the sensor, and $TM$ a multiplicative factor (it is depending on temperature, but generally is $TM=1$).
3. Case study

The AMS proposed in this paper is reported in figure 3. It is composed by three sensors, two for the flow measurement and one for controlling the functionality of the whole system.

![Figure 2. MPX5100AP block diagram](image)

Figure 2. MPX5100AP block diagram

The flow measurement is an indirect measurement, using a Venturi tube and measuring the pressure in two different sections, then the continuity equation of Bernoulli gives the flow result [10]. For this work, the Bernoulli equation has been elaborated and improved considering the non-ideal of the system. The volumetric flow $Q$ is given by:

$$ Q = C \left( \frac{\pi}{4} \right) \sqrt{\frac{2}{\rho} \left( p_1 - p_2 \right)} $$

(2)

Where: $C$ is the outflow coefficient, $d$ diameter of the tube section, $p_1$ pressure in section 1, $p_2$ pressure in section 2 and $\rho$ air density. In the project $C=0.995$ and $\rho=1.225\text{kg/m}^3$ are considered.

The control sensor is close to the Venturi tube in the suction side, in order to verify the environment of the system. If the difference between the pressure of the control sensor and the other sensor, after a transitory, oscillates then the control system provides an error alarm.

The project has been realized on a breadboard. Each sensor is connected to the same supply line of 5V, using a stabilized network power supply of 12V and an integrated LM7805 (a voltage regulator, which allow to obtain 5V with a ripple lower than 70dB and provides a stable voltage to the sensors). Each sensor has its couple of by-pass capacitors in parallel with the supply voltage and physically very close to the sensors. A low pass filter is located to the output of the sensors with cut-off frequency of 700Hz (with a 680 Ω resistor and 0.33 μF capacitor), in order to reduce noise of the signal.

Figure 4 shows all the electrical connections of the project, figure 5 shows the sampling block, which is a small part of the Labview program.

![Figure 3. AMS developed for the case study](image)

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![Figure 4. Electric schematic of the project](image)

Figure 4. Electric schematic of the project

![Figure 5. Sampling block](image)

Figure 5. Sampling block
The DAQ device chosen for the project is a low-cost model NI USB-6003. A task has been created in the management devices software NIMAX, it uses the first three input channels, one for each sensor, with input voltage in the range 0-5V. The programming has been realized using multiple structures present in Labview, in particular the main program is a “for cycle” inside a “while cycle”. The sensors task has been sampled with continuous sampling with frequency and samples number variable from the front panel (set on 33kHz and 3000 samples). The main part of the Labview program is a “for cycle”: it manages the reading and elaboration. This cycle stops after 100 executions and provides as output a vector containing 100 instantaneous flow measurements. This vector will be generated for each iteration of the main “while loop”, then the instantaneous flow rates are analysed to evaluate if the measurement is reliable, i.e. if the values of the instantaneous flow rates are converging to a stable value. In order to evaluate the variability of the flow rate, the vector standard deviation is compared with a constant value, established a priori, representing the maximum acceptable standard deviation. In the meantime, the control system supervises the measure through the control sensor: if the pressure variation between the measure sensor output and the control sensor output is greater than a threshold value, the system turns on an alarm. The Labview interface provide a simple graphical output (led green or led red) for both the reliability measurement and the control system check.

The program section that provides the final measurement has been realized through the use of a shift register of the Boolean value which indicates the reliability of the measure. When all the last 10 values are true, i.e. when for 10 consecutives “for cycles” the measurement is reliable, an AND gate will provide a positive boolean and will terminate the execution of the program. At the same time, a case structure will be activated to average the values of the instantaneous flow rates of the last reliable for cycle: it will supply the measured values on the Labview interface.

4. Conclusions
The AMS implemented is a good alternative to classical measuring methods. Using this kind of system, it is possible to acquire a vast amount of information in real time that otherwise would not be possible to obtain, although the cost of realization is considerably higher. The simulation proved that Labview is an excellent tool for creating a system where needs can change over time and experience: the flexibility of the software is one of the strengths of this project. The obtained results highlighted the potential of the developed AMS and laid the foundations for a future optimization and extension of the system.

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