Signal Processing in Embedded Systems

Signal processing as an opportunity to increase functionality of industrial instrumentation

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Basic and advanced signal processing algorithms run in a large variety of ABB products that are equipped with embedded electronics, from small domestic motion detectors, to sophisticated control units for medium- and high-voltage switchgears. In field devices in particular, signal processing provides an opportunity to improve the quality of measurements and the overall functionality of instruments.

The PILD (plugged impulse line diagnostics) algorithm is an example of such an improvement. It has been developed to alert operators to blockages in the impulse lines of pressure transmitters. Such a warning system allows users to switch from preventative maintenance programs to more cost-effective, event-driven, predictive practices.

Embedded system technologies

Signal processing usually brings to mind audio applications, image processing or communication technologies, but a glance at ABB's product portfolio reveals a much wider picture. Signal processing applications are found in many of ABB products, both in automation and power technology. Many of the applications are integrated in devices, such as control units and industrial instruments, and run on embedded platforms.

Power line communication modems, for example, use a wide variety of digital signal processing (DSP) algorithms. Key topics are digital modulation and demodulation, digital filtering, Fourier transforms, sampling rate conversion, frame acquisition, carrier phase and symbol timing synchronization, channel estimation and equalization, and error detection and correction. The basic principles of signal processing are well established, and used in all of today's communication systems. However, a considerable R&D investment is required to meet the increasing requirements of power-line communication systems. Increasing processing power will support higher data transfer rates per channel, and channel bandwidths will increase from the traditional 4 kHz to ~32 kHz. In the long-term future, single systems may offer flexible (configurable) support of much higher bandwidths, up to 1 MHz. Such truly broadband power line modems will have to implement further efficient signal processing algorithms.

Today's protection and control units for switchgears and circuit breakers provide a large variety of electronic protection functions for the electrical systems they supervise. These devices work by measuring current and voltage and then digitalizing and processing the acquired signals. This is generally achieved by means of Fourier analysis: the harmonics of the electrical signals are computed and become the major inputs for most of the protection functions. These include over-current, over-voltage, and differential and distance protections.

ABB field devices and analytical instruments are normally equipped with an electronic part that acquires signals from the sensing part of the device: pressure transmitters, for example, acquire a signal from a piezo-resistive sensor chip, magnetic flow meters read the voltage induced by the generated magnetic field, temperature transmitters read the signal from a thermocouple. So, in general, inside an industrial instrument, one or more electrical signals are acquired from the sensing part (sometimes referred to as the primary part) by the electronic part (the secondary part). In general, all these sensor signals need to be amplified, analogue filtered, converted from analogue to digital and then digitally processed in microprocessors or DSS. Signal processing is also important in today's sensor systems for modelling the sensor characteristic curves, to compensate for non-linearity and influencing effects.

Signal processing is an opportunity for improving field devices

Field devices are becoming more intelligent, mainly because of rapid improvements in the semiconductor industry, particularly in terms of cost and power consumption of the components. In this context, signal processing provides an opportunity to improve sensor properties, in spite of the abundance of influencing effects, such as manufacturing variance, hysteresis, drift, ageing and cross sensitivity, which are unavoidable and represent a systematic source of uncertainty [2]. Additionally, customers now require industrial instruments with an extended set of functions, besides the primary goal of the device. Device and process diagnostic functions are particularly appreciated because they promise to reduce maintenance costs and to improve the general reliability of the instruments. Competitors are clearly confirming this trend and "diagnostics" is now a common keyword in the market requirement specifications of new generation instruments. Up to now, this process-supervision functionality has usually been provided at the control-system level of a plant, where much higher computation power is available. But improvement of the embedded platforms now allows integration of complex algorithms at the device level, rather than in PCs and control systems. In other words, the current trend is to shift intelligence from the system down to the field devices and instruments. The last part of this article discusses an example of this.

1 Differential pressure transmitter in a harsh environment: access for maintenance is hard

Limitations of the embedded platforms

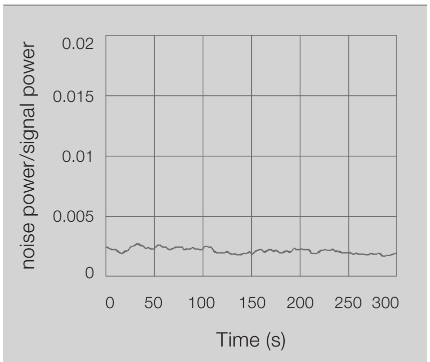
It is well known that electronic components such as processors, memories and chips, have been improving dramatically for a number of years, increasing their performance and reducing their size and cost. This applies to every chip market segment, from personal computers to smaller embedded architectures of industrial applications. Nevertheless, in the embedded platforms typically used in ABB devices and instruments, cost and power consumption remain a challenge:

In the industrial instrumentation market, price plays a very important role in the maintenance and increase of market shares. Very often, competing products are comparable in quality and customers' decisions are based mainly on price. However, as described above, the general trend for chips is to become cheaper, and, while the cost of electronics normally represent a significant portion of the production costs for a device, the manufacturing and material costs of the instrument can sometimes be much higher. Therefore, from a cost point of view, today's embedded architectures for industrial instrumentation have the potential to improve calculation power and memory: more advanced algorithms and additional intelligence can be added easily.

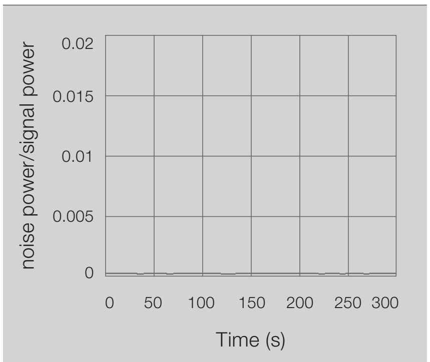
Many embedded architectures have limitations on the power they can consume. For example, battery-powered devices have specific battery life requirements and are, therefore, limited in terms of power consumption. There are devices that normally work with an auxiliary power supply (110 / 220 V) but which, in case of emergency, must work without this supply, albeit with limited functionality. This is the case for many control units for circuit breakers. The solution here is either a battery or a self-supply strategy, (eg, power taken from the current flowing through the circuit breaker).

2 Noise level in the differential pressure signal under various conditions in the impulse lines

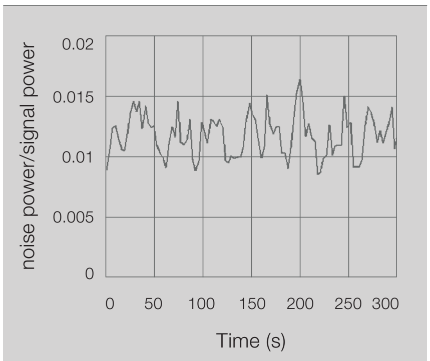
a Lines not plugged



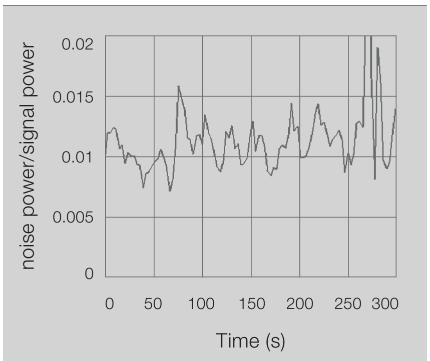
b Both lines plugged



c (+) line plugged



d (-) line plugged



Many instruments are supplied through the 4–20 mA channel, which is also used as the main analogue input or output channel. These devices, known as two-wire instruments, can consume only a few tens of milliwatts. The intrinsic safety provided by this low power consumption is an advantage for industrial two-wire instruments and is actually one of the key reasons that customers still strongly support this type of power supply. However, power consumption became a limiting factor for the improvement of electronics, and therefore functionality, some years ago, and it remains a particular problem for two-wire devices.

Signal processing provides an opportunity to improve sensor properties, in spite of the abundance of influencing effects, such as manufacturing variance, hysteresis, drift, ageing and cross sensitivity.

An embedded signal processing application: PILD

The PILD (plugged impulse line diagnostics) function is a signal processing algorithm that was recently integrated in ABB differential pressure transmitters, one of the most commonly used field device types. This R&D project showed both the potential of signal processing for improving field devices and also the constraints imposed by their limited embedded architectures.

Differential pressure transmitters are instruments for sensing the difference in pressure between two points of a process. They can be installed in harsh environments where access for maintenance can be difficult 1. The main application of this device is computing the flow rate inside a pipeline. This is achieved by measuring the pressure drop caused by a primary element, typically a Venturi tube or an orifice plate. Through this measurement, and with a knowledge of the geometry of the primary element, the flow rate can be computed.

Differential pressure transmitters are connected to the process through two pipes called impulse lines. They normally have a small diameter, less then 1 cm, and can be very long. During the life of a device, the impulse lines can become partially or completely clogged by solid process material (eg, sand), sediment, or deposits that build up inside the lines, or by frozen water.

Differential pressure transmitters that automatically identify plugged impulse lines have the potential to cut costs by reducing preventative maintenance efforts.

In contrast to most other field device malfunctions, a plugged impulse line has no impact on the device hardware and, if it goes unnoticed, the process value will remain in a valid condition. By plugging the impulse line, the current pressure state becomes trapped and decoupled from the true process state. The control system continues to use the pressure value in control loops, not realizing that it is "frozen". The only indication the process operator has for such an event is the misbehaviour of control loops, which could also, and is actually more likely, to be caused by valve wear.

The maintenance effort required to identify and unblock a plugged impulse line is high. Moreover, if a process fluid has a known tendency to cause plugging, costly preventive maintenance will usually be carried out. Differential pressure transmitters that automatically identify plugged impulse lines have the potential to cut costs by reducing preventative maintenance efforts.

The PILD alogrithm

The principle of plugged impulse line detection is based on the observed characteristics of pressure signals over time. Flow processes are affected by fluctuations in the pressure value caused by other devices and machines, such as pumps, that interact with the process. These fluctuations can be seen as noise in the differential pressure signal. Under normal operating conditions, with clear impulse lines 2a, this process noise is mostly cancelled out because the device measures pressure from two points that are relatively close together, normally only a few centimetres apart. If one impulse line becomes blocked 2c 2d, the pressure fluctuations are no longer cancelled out and the process noise is fully apparent in the differential pressure signal. If both impulse lines become blocked 2b, the process noise will be reduced almost to zero because the pressure connection between sensor and process will be lost completely.

So, the PILD function first measures the noise level in the differential pressure signal when the impulse lines are clear (training phase). Then, during normal device operation, it statistically compares the noise level with values stored during the training phase. If the statistical analysis shows a significant difference between the live values and those acquired during the training phase, an alarm signals that one or both impulse lines are plugged.

The training phase is a configurable time period, during which the algorithm "learns" the nominal process conditions so that it can later identify readings that indicate plugging of the impulse lines. A reliable and effective training is the key to the success of the PILD function. Differential pressure transmitters are used in very different process conditions, in terms of media (high viscosity liquids, water, steam, gases etc) and environmental conditions (temperature from –40 to 85° Celsius, and absolute pressure up to 600 bars). Without an automatic way of adapting the algorithm to this large variety of conditions, the PILD function would be useless.

The PILD function was developed between 2003 and 2005. The function has recently been integrated in the new release of ABB 264 Differential Pressure Transmitters with Foundation Fieldbus interface.

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