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HIGH-CAPACITY DATA ACQUISITION SYSTEMS

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OUTLINE

1. Introduction to data acquisition
2. Basic components of the data acquisition and control systems
3. Data conversion
4. Data acquisition board
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1. INTRODUCTION TO DATA ACQUISITION

Data acquisition systems (DAQ) are today at the backbone of modern electronics.

They provide o broad range of circuits (analog, digital), digital systems for signals processing, standard communication interfaces, together with the related software tools.

Signal acquisition is not an end in itself.

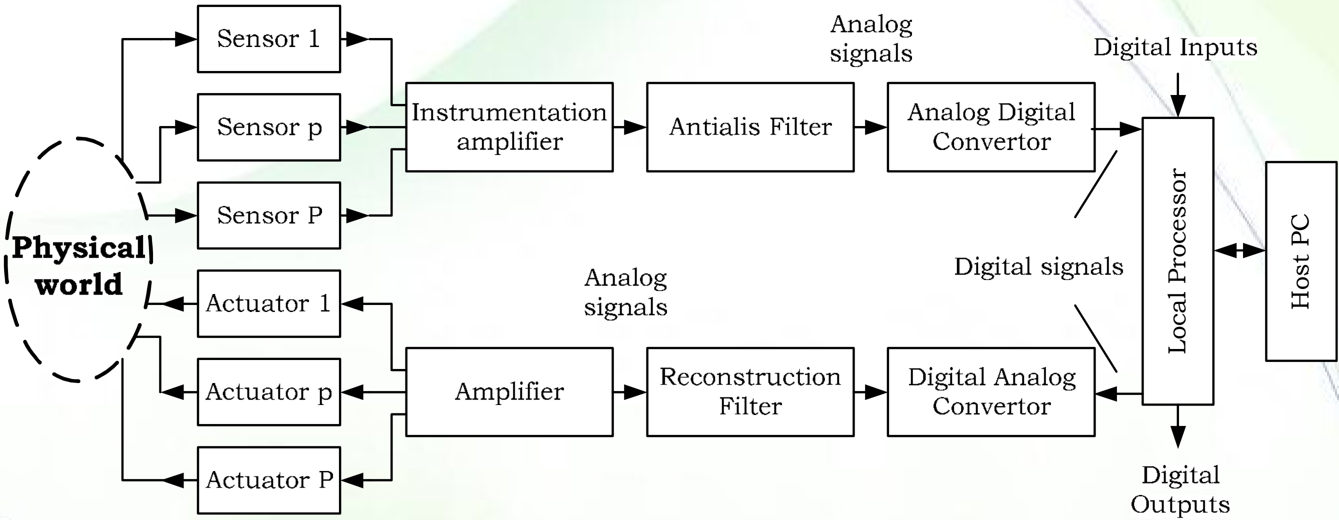
There are two main types of data acquisition and control system:

- data acquisition systems for general use, used in various purposes (research, education, etc.)
- data acquisition systems used in industry

DAQ for general use

- Such systems are primarily designed to acquire data in a particular process for further processing.
- There have been implemented development environments for software applications specific to data acquisition and processing systems (MATLAB and LabView- “virtual instruments”).
- The user interaction with the DAQ, through is a specialized graphic-user interface.
- From the point of view of the physical implementation DAQ materialize themselves in the following forms:
  - as boards equipped with components, included in the computer;
  - PCIe (Peripheral Component Interconnect Express), or PCI eXtensions for Instrumentation (PXI), ISA (Industry Standard Architecture);
  - as stand-alone devices, which can be connected externally to the computer (USB (Universal Serial Bus), serial port, parallel port).

The basic structure of a DAQ for general purpose and its integration in the control of a physical process



The system architecture is organized on two levels:

- one for data acquisition;
- the other for data distribution.

DAQ for general use

Signals to be acquired are provided by several sensors, which interact with the process serviced. These signals are firstly conditioned and then converted in numerical form.

Conditioning involves operations such as amplification, filtering, adjusting the level of the continuous component, etc. ("instrumental amplifier"), so that the conditioned signals correspond to the input range of the analog-to-digital converter (ADC).

The analog-to-digital conversion involves firstly signal sampling (in time), followed by analog-to-digital conversion itself (the quantization in value). These operations are performed by the circuitry included in the ADC block.

The anti-aliasing filter preceding the ADC converter has a low-pass filter behavior. It is intended to limit the spectrum of the signal applied to the input of the ADC, so that for the frequency with which sampling is made the sampling theorem is satisfied. Thus, errors resulting from aliasing, as a result of an insufficient sampling frequency, are reduced.

The lower level of the architecture is mainly designed to provide to the output the necessary signals to control the actuators, based on numerical information provided by the processor block. For this purpose it is used a digital-to-analog converter (DAC) block, followed by a reconstruction filter and conditioning circuits (the output amplifier block).

A number of digital inputs-outputs complete the system functionality.

The multiple functions provided by the processor block are (usually implemented as a microcontroller system or, sometimes, as a digital signal processor):

- it governs the functioning of the entire system, with the role of control device or acquisition control circuit;
- it makes a local preprocessing of the acquired data;
- it ensures the interface with a host computer.

Software is as important to data acquisition systems as hardware capabilities. Inefficient software can waste the usefulness of the most able data acquisition hardware system. Conversely, well-written software can squeeze the maximum performance out of mediocre hardware.

The acquisition system for industrial applications

These systems are obtained by connecting a variable number of transducers to a central processing and control unit, which interfaces with the human operator.

Depending on the nature of the serviced industrial process, the transducers system covers a geometric area more or less extensive, which requires to solve some specific problems:

- the problem of remote transmission of information acquired,
- the necessity of establishing an optimal balance between the amount of information processed locally (near the transducer) and the information transmitted and processed in the central processing and control unit.

The growth during time of the performances of digital signal processors (higher processing speed, information represented by more bits, etc.) allowed the implementation on industrial DAQ of some data processing algorithms more and more sophisticated, giving those characteristics of intelligent behavior (“smart sensors” and “smart transducers”). The increasing degree of “intelligence” of industrial transducers is a current problem.

2. BASIC COMPONENTS OF THE DATA ACQUISITION AND CONTROL SYSTEMS

Transducers – sensors and actuators

Most real-world events and their measurements are analog.

That is, the measurements can take on a wide, nearly continuous range of values. The physical quantities of interest can be as diverse as heat, pressure, light, force, velocity, or position. To be measured using an electronic data acquisition system, these quantities must first be converted to electrical quantities such as voltage, current, or impedance.

A transducer converts one physical quantity into another. The sensors convert physical quantities into electrical ones, for use with electronic instrumentation.

Since the transducer is the “front end” of the data acquisition system, its properties are critical to the overall system performance.

Some of these properties are sensitivity (the efficiency of the energy conversion), stability (output drift with a constant input), noise, dynamic range, transfer function and linearity, signal-to-noise ratio.

Analog signals conditioning

Nearly all transducer signals must be conditioned by analog circuitry before they can be digitized and used by a computer. This conditioning often includes amplification and filtering, although more complex operations can also be performed on the waveforms.

Amplification (or occasionally attenuation) is necessary for the signal's amplitude to fit within a reasonable portion of the ADC's dynamic range.

The most common analog circuit semiconductor component is the *operational amplifier* (oa- the op amp).

Filtering must usually be performed on analog signals for several reasons.

Additional analog signal processing functions include modulation, demodulation, and other nonlinear operations.

Another special analog circuit, extremely useful in data acquisition applications, is the *sample-and-hold amplifier (S/H)*. This is used to get a stable sample of a changing analog signal, prior to using an ADC. In addition, many high-speed ADCs incorporate a sample-and-hold amplifier in the integrated circuits (IC).

There are several other types of analog amplifier circuits besides the op amp, commonly used for data acquisition purposes. Theses include instrumentation amplifiers, programmable gain amplifiers, and isolation amplifiers.

An *instrumentation amplifier* (IA) is used to provide a large amount of gain for very low-level signals, often in the presence of high noise levels. The major properties of IAs are high gain, large common mode rejection ratio (CMRR), and very high input impedance.

Programmable-gain amplifiers (PGAs) are a special class of instrumentation amplifiers that have selectable gain, either through external component selection or, more commonly, through digital control lines.

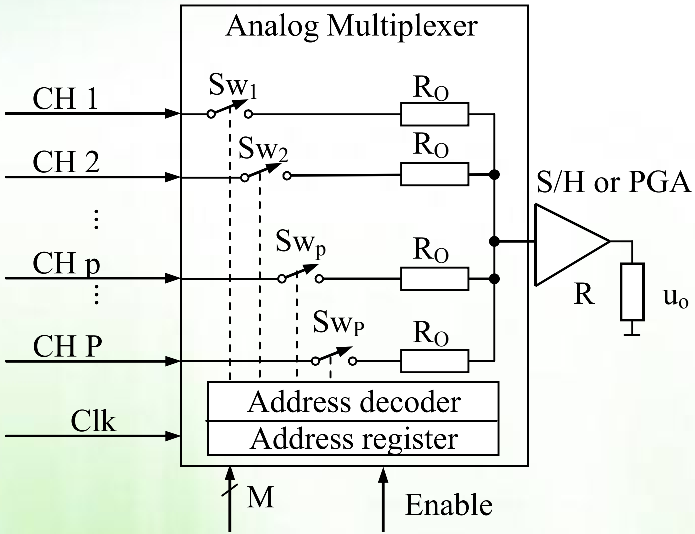
Isolation amplifiers are used to boost low-level analog signals when electrical isolation between input and output is needed.

Analog switches and multiplexers

An analog switch is a digitally controlled device that is used to pass or interrupt an analog signal, analogous to a mechanical switch or relay.

Multiple analog switches can be arranged in a single IC to produce a multiplexer with multiple inputs and a single output.

The device's digital control lines determine which input is steered to the output.



Binary Codes

For N binary lines to represent 2^N levels, each line must have a different value or weight.

For a natural binary code, having any value from 0 to 2^N-1, integers are represented by a series of weighting bits ($[b_m]$) having the value 2^m (where m varies from 0 to N-1). The bit number m is zero for the least significant bit (LSB) on the far right and increases to N-1 for the most significant bit (MSB) on the far left.

Sometimes it is necessary to represent both positive and negative integer values, as when dealing with a bipolar voltage.

The most common binary code for this is called twos complement, which can represent values from (-2^{N-1}) to ($+2^{N-1}-1$).

One additional coding system is fractional binary.

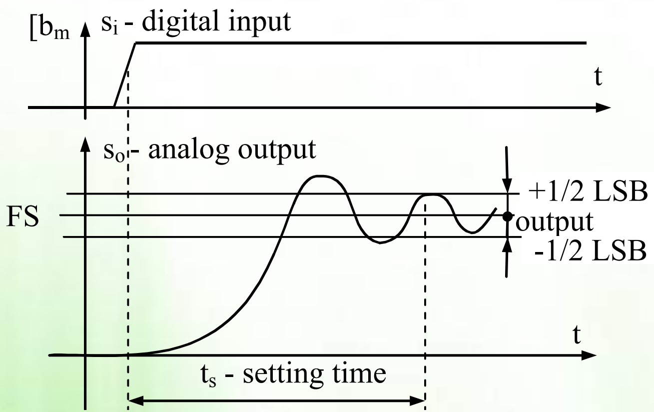
3. DATA CONVERSION

Digital to analog converter

Some important criteria must be considered when choosing a DAC.

The first parameter to determine is the number of bits of resolution. This is selected by knowing the desired dynamic range of the output signal (8, 12, 14, 16-bit).

The settling time, which determines the speed of conversion is the amount of time required for a DAC to move to and stay within its new output value (usually to ±1/2 LSB), when the digital input changes (typically a few hundred nanoseconds).



Linearity is another major DAC parameter. It is the maximum deviation of the DACs transfer curve from an ideal straight line, usually expressed as a fraction of the full-scale reading.

One final DAC parameter to note is monotonicity. If the output of a DAC always increases for increasing digital input, the DAC is considered monotonic.

Analog to digital converter

The most important ADC parameters are resolution and sampling rate.

Another important ADC characteristic is its absolute accuracy, which is the measure of all error sources. This is sometime referred to as the total unadjusted error (including offset error, a linearity or gain error, etc.).

A multitude of techniques are used to produce an analog-to-digital converter:

- The *successive-approximation converter*

It is not unusual to find successive approximation ADCs with conversion rates well over one million samples/second and resolution as high as 16 bits.

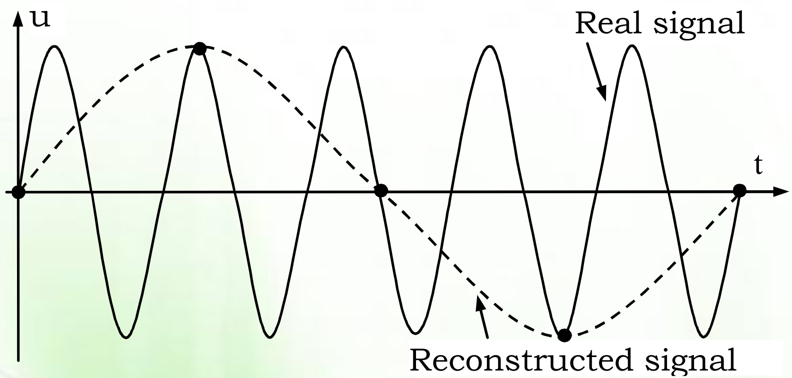
- The fastest type of ADC is the *flash converter*. It has a conversion rate measured in speeds ranging from millions of samples per second (MSPS) to over a billion samples per second (GSPS).

- A fairly new commercial converter is the *sigma-delta ADC*. This device is a low-cost, high resolution ADC, suitable for low conversion rates. Sigma-delta ADCs typically have 16 to 24-bit resolution, with a usable input signal frequency range of a few Hz to a few kHz.

Sampling and signal reconstruction

For an analog signal to be accurately digitized by an ADC, it must be sampled at a rate at least two times the highest frequency component in that signal. To put it another way, only signals whose highest frequency components are no more than one-half the sampling frequency can be accurately digitized. This maximum signal frequency is called the *Nyquist frequency* and this rule is called the *Nyquist theorem*.

When a signal is sampled too slowly (it contains frequency components above the Nyquist frequency), the digitized waveform is distorted. This distortion is called *aliasing*.



4. DATA ACQUISITION BOARD

When choosing a data acquisition board, many different selection criteria are used: speed, resolution, accuracy, and number of channels are all important considerations.

In addition, there are different architectures used within the data acquisition device itself that can affect the decision.

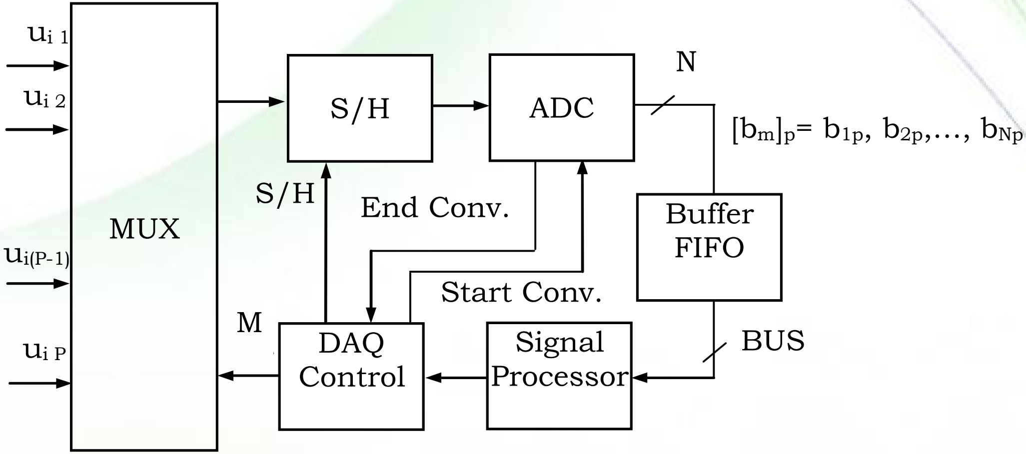
The two most common architectures in analog input design are:

- Multiplexed architectures use one ADC for many channels.
- Simultaneous architectures use an individual ADC for each channel.

It is considered that prior to the application of each analog signal u_{ip} to the multiplexer input, they have already been processed (conditioned), that is amplified by an instrumental amplifier, usually with programmable gain, and/or noise filtered, etc.

In any case, it is not recommended the multiplexing of low level signals (below 50 mV), due to excessive errors that occur.

Multiplexed DAQ architectures



The analog signals at the input of the acquisition system are connected in succession, to the input of the sampling and holding circuit via the multiplexer (MUX).

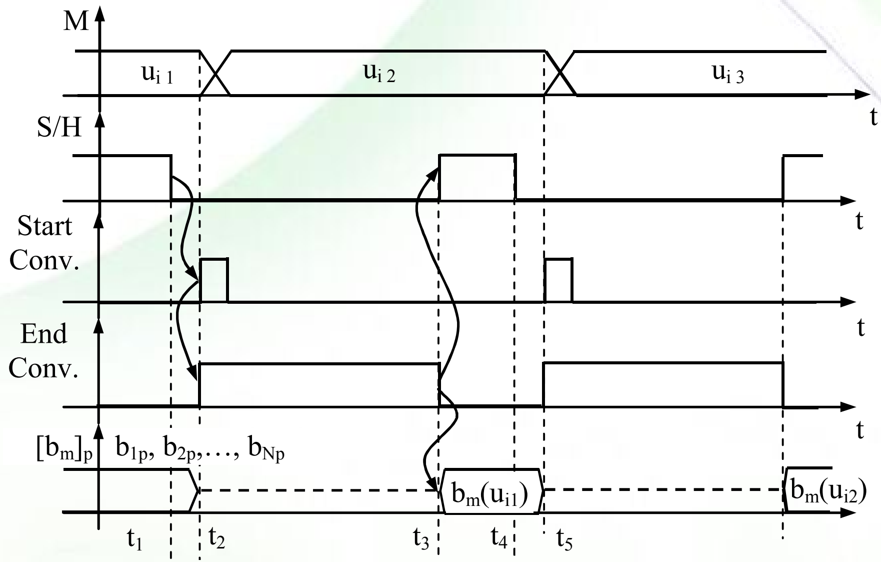
The sampling and holding circuit (S/H) has the role to collect values from the analog signal, at time intervals equal to the sampling step T_S.

The ADC achieves the transformation in numerical form of the input analog signal. The result is a sequence of data that represents the values of input samples, with an accuracy given by the resolution of the ADC.

The data sequences $[b_m]_p$, from the ADC output, using a buffer, are then transferred, to the local signal processor, for numerical processing.

The acquisition control circuit (DAQ Control) makes the interface between the DAQ circuits and the processor, for the proper functioning of the data acquisition system. Thus, it controls the multiplexer by the means of the numerical signal M, the sampling and holding circuit with the signal S/H, the A/D converter with the signal *Start Conv.* and, when appropriate, the programmable gain amplifier with the gain signal. In the same time, the DAQ control provides to the computer a signal reflecting the state of the conversion process (*End Conv.*). In fact, in terms of construction, often the DAQ Control is part of the local signal processor.

The data acquisition process



The acquisition process is carried out periodically, by collecting and numerically converting samples of all P analog signals from the input of the acquisition system.

The acquisition period T_S means the time interval required to acquire one sample from each of all the P signals from the DAS input:

$T_S = P\ T_{s-p}$, where T_{s-p} represents the minimum sampling period of a signal p.

5. CONCLUSIONS

The data acquisition system with analog signals multiplexing at the input has the simplest architecture, due to the fact it uses for the acquisition of several analog signals only one S/H circuit and only one ADC.

The value of the minimum acquisition period is directly proportional to the number of the input channels of the DAQ.

At the same time, because it serially acquires only one sample from each input signal, this DAQ is the less rapid with respect to any other data acquisition structure.

The stabilization time t_m of the multiplexer output does not intervene in determining the acquisition period T_S or T_{s-p}.

A problem with multiplexed systems which is eliminated with simultaneous ADCs is channel to channel crosstalk. Crosstalk occurs when the signals on one or more multiplexed channels couple, or interfere, with the signal on the channel that is being measured. Crosstalk is inherent to the multiplexing process, and gets worse as you increase the channel count and/or the signal frequency.

Thanks for your attention!