Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Data Acquisition Systems

WORKREADY ELECTRONICS

Data Acquisition Systems

A data acquisition system, sometimes referred to as a DAQ system, is a collection of electronic devices including a computer that is used to acquire input signals from a variety of sources including sensors, digitizing those signals then storing them in a computer. From there this data may be analyzed, processed, and ultimately displayed on the computer screen in a variety of formats. Or alternatively, it may be printed out or otherwise recorded for convenient use.

The heart of any data acquisition system is the computer and its software. The computer is usually a personal computer or laptop that stores the acquired data then does the analysis and processing. Special software is used to display the information for use.

Module Overview

Data acquisition systems are very widely used in industry process control, manufacturing, factory automation, testing centers, and research labs. As an electronic technician or engineer, you are very likely to encounter a data acquisition system in your work. This module provides an introduction and overview of data acquisition systems.

Prerequisites

This module is designed to be used in upper level courses in a two-year community or technical college curriculum. Ideally, you should have completed courses in the following:

Basic knowledge of analog and digital electronics

Personal computer operation and capabilities

Data conversion (AD and DA)

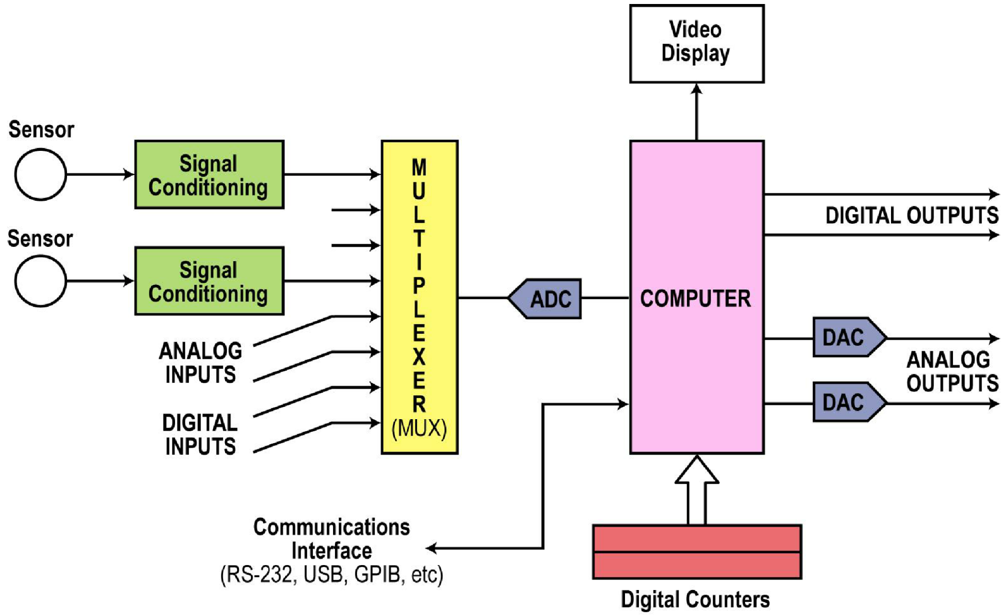
Digital signal processing (DSP)

What Technicians Need to Know

- Definition of a data acquisition (DAQ) system
- Main components of any DAQ system
- Sensor and signal conditioning
- Types of DAQ systems
- Data logging systems
- DAQ software capabilities
- Output control possibilities
- Data communications in DAQ systems

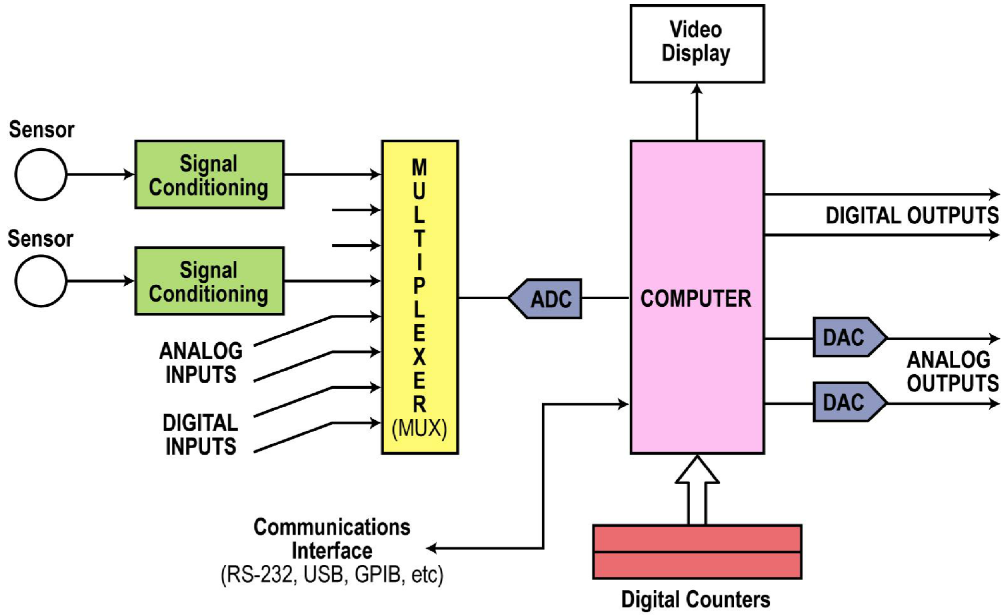
Introduction to Data Acquisition Systems

Data Acquisition System Overview



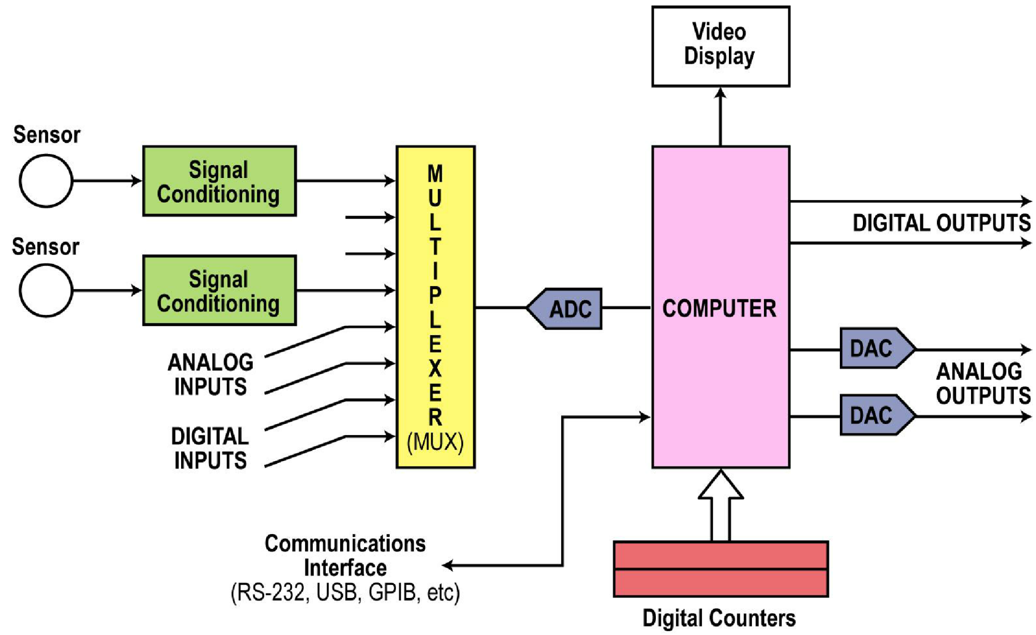
A data acquisition system, as shown in the block diagram above, is an assembly of electronic components, circuits, and subsystems that is used to collect data from one or more sources, store or record it, then analyze it, and finally display the results.

Use of Data Acquisition Systems



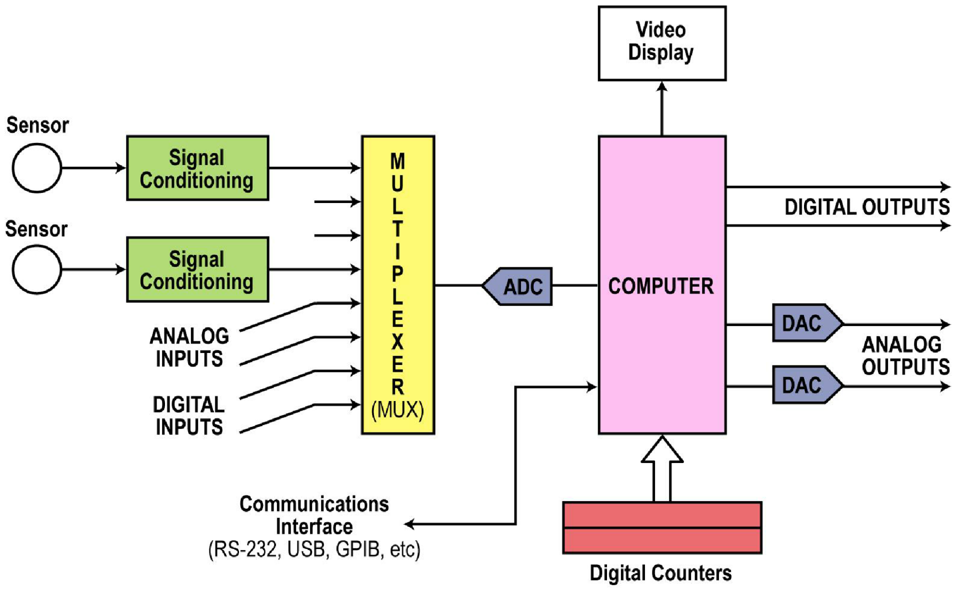
Data acquisition systems are widely used in industrial control, testing, and manufacturing to monitor multiple sensors or other data sources for the purpose of determining the state of a variety of physical conditions.

Operation: Sensor Information



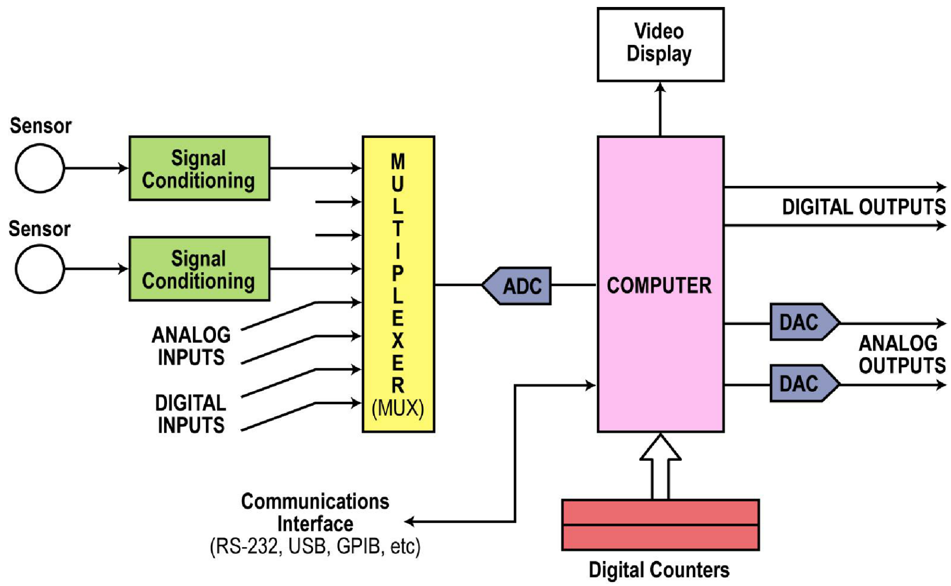
The sensors measure the various physical characteristics such as temperature, pressure, light level, and many others. Such information is needed to properly carry out certain manufacturing or control operations in a chemical plant, factory, or other facility.

Collected Data



The collected data may also be processed mathematically to provide additional critical information. The collected data, or some processed version, is then displayed visually or recorded on paper. Finally, the data may be used as part of a closed-loop control system to provide control functions based upon the collected data.

DAQ System Description



The main parts of a DAQ system are the analog or digital input signals, sensors, signal conditioning circuits, multiplexer (MUX), analog-to-digital converter (ADC), computer (PC or laptop), software that is used for data organization, analysis, and display, output interfaces, and the data communications links.

Sensors and Input Signals

The input signals are the data to be acquired, stored, and processed. These may be analog or digital and the source may be any component, circuit, device, or product that is being observed, analyzed, or controlled.

Digital inputs are binary and are derived from some CMOS or TTL circuit. The input voltage range is usually zero to +5 volts. Other special inputs such as bipolar (± 5 V) may also be used. These digital inputs may come from digital logic circuits or be produced by mechanical switch closures or openings.

Input Signals

Analog inputs typically come from sensors. These sensors are transducers that convert some physical characteristic into a proportional analog voltage. The sensors measure the physical value. The sensor output signals are usually very low level DC voltages that vary slowly over time. AC signals or pulses may be generated by some sensors.

Most sensor outputs require further conditioning before they can be used or acquired.

Sensor Types

Sensors are available for all of these common physical characteristics and other special characteristics. Most produce a very low level (< 100 mV) DC signal.

- Temperature: thermistors, resistive temperature devices (RTDs), or thermocouples
- Pressure/weight/force: strain gauge, piezoelectric
- Liquid flow rate: rotational flow meter
- Physical position: linear pots, optical encoders, linear voltage differential transformer (LVDT)
- Liquid level
- Sound: microphone
- Light intensity: photo cell
- Moisture content
- Air speed
- Gas presence
- pH level

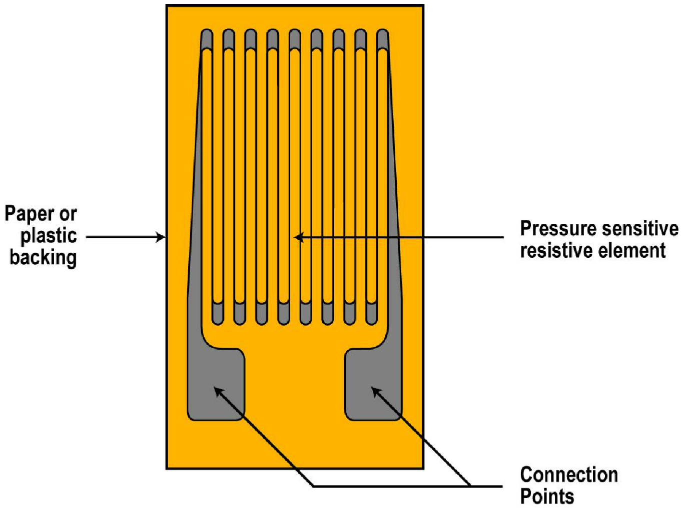
Signal Conditioning

Signal conditioning is the term that describes the ways the sensor signals are processed to make them more suitable for acquisition and measurement. The most common types of signal conditioning are:

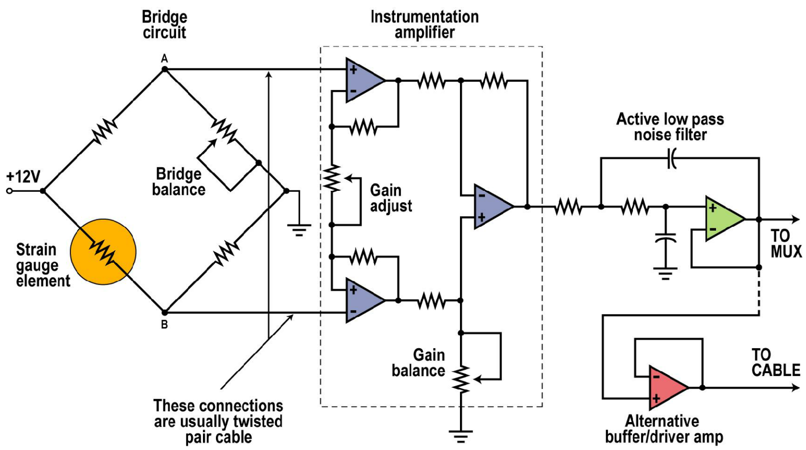
- Conversion of sensor characteristic to a signal voltage
- Application of voltage to a resistive element in a voltage divider, through the use of bridge circuit
- Amplification with gain selection
- Attenuation: decreasing signal level when required
- Isolation: keeping circuit grounds separate with transformers or opto isolators
- Filtering: use of low pass filters to minimize noise
- Buffering for long distance transmission
- Impedance matching
- Linearization: making a non-linear sensor signal linear

Signal Conditioning Example

The figure shows a typical sensor called a strain gauge. This is a pattern of conducting material on a flexible base that creates a resistor whose value can be changed by applying pressure to it. Stretching the resistor increases its resistance and compressing it decreases its resistance. The amount of resistance change is proportional to the pressure or weight put on the strain gauge.



Strain Gauge Circuit



To convert the resistance change into voltage, one or more strain gauge resistor elements are connected into a bridge circuit. A fixed DC voltage is applied to the bridge. When the bridge is balanced, no voltage appears across the bridge between points A and B. When pressure is applied, the resistance value of the gauge changes and unbalances the bridge producing an output voltage. Because the resistance change is so small, the output voltage is also very small, typically only microvolts.

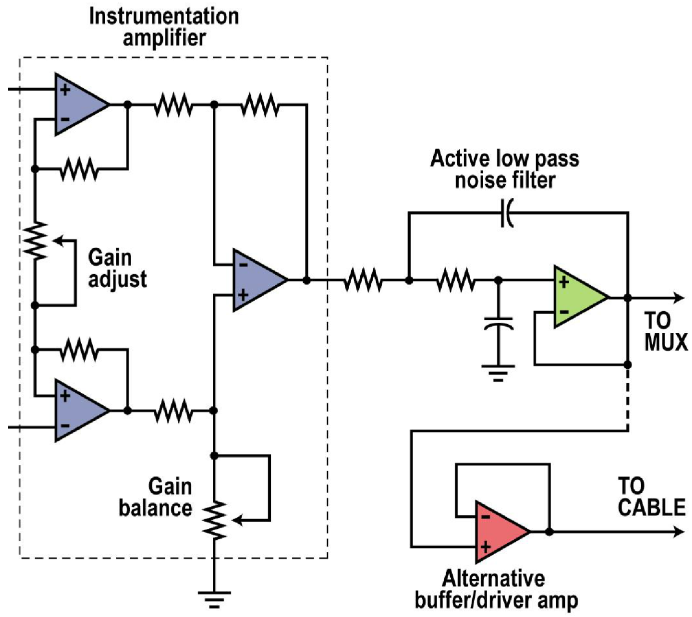
Conditioning Example: Bridge Signal

The bridge output signal is balanced to ground or floating rather than single ended. Therefore, a differential amplifier is needed to increase the signal level. A differential amplifier has two inputs balanced to ground.

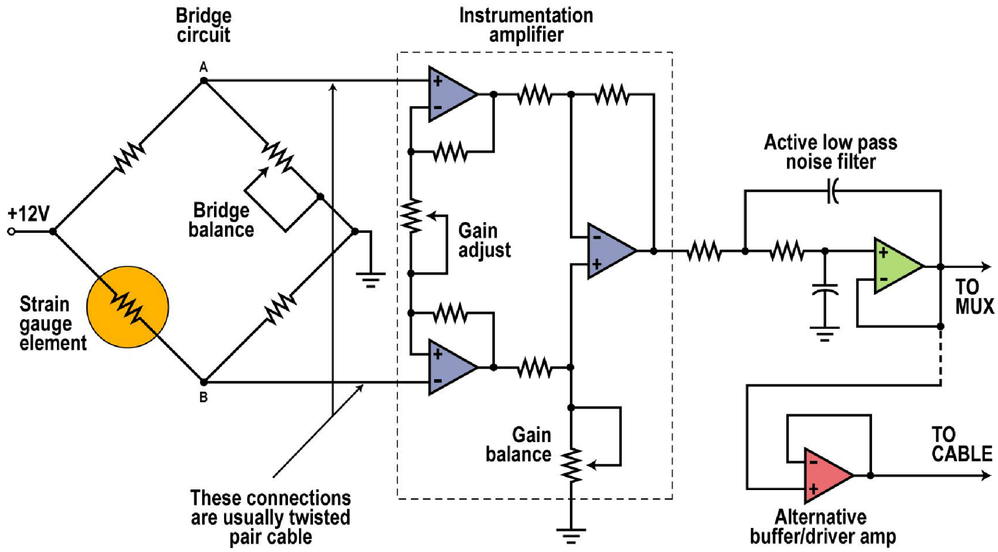
The signal from the bridge circuit is usually transmitted over a twisted pair cable. Since the cable is balanced to ground, any noise signals picked up are automatically cancelled in the differential amplifier because of the common mode operation. This characteristic is essential when using strain gauges because the signals are so small. Furthermore, the environments in which they are used are typically noisy and the electrical interference produced by power lines, motors, relay switching, and other phenomenon can overwhelm and obscure the signal to be measured before it can be amplified.

Conditioning Example: Amplification

Amplification usually takes place in an instrumentation amplifier with differential inputs, high input impedance, and adjustable gain. After amplification, the signal may further be processed depending upon the application. A common process is low pass filtering to further remove noise which occurs at higher frequencies. An active low pass filter is shown in the figure but a conventional passive LC low pass filter may also be used. The output goes to one of the multiplexer inputs.



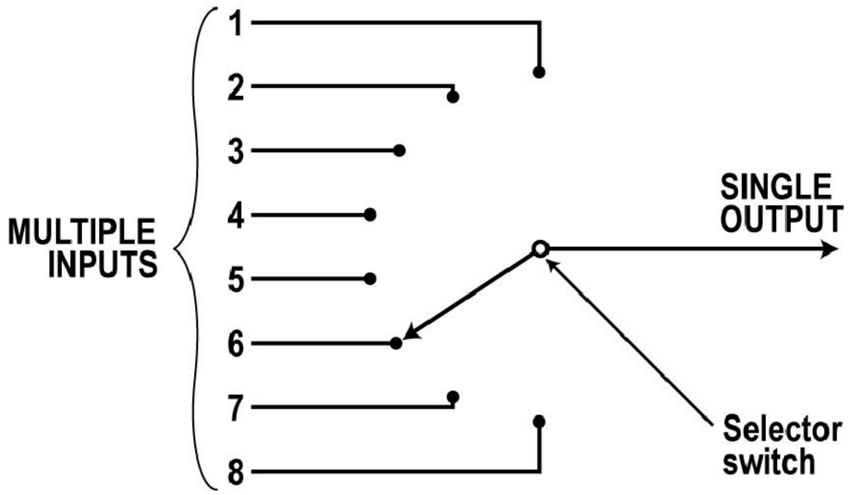
Conditioning Example: Amplification



If the signal is to be transmitted over a cable, it may be applied to a buffer such as an op amp follower to provide the power to drive the longer connecting cable to the multiplexer.

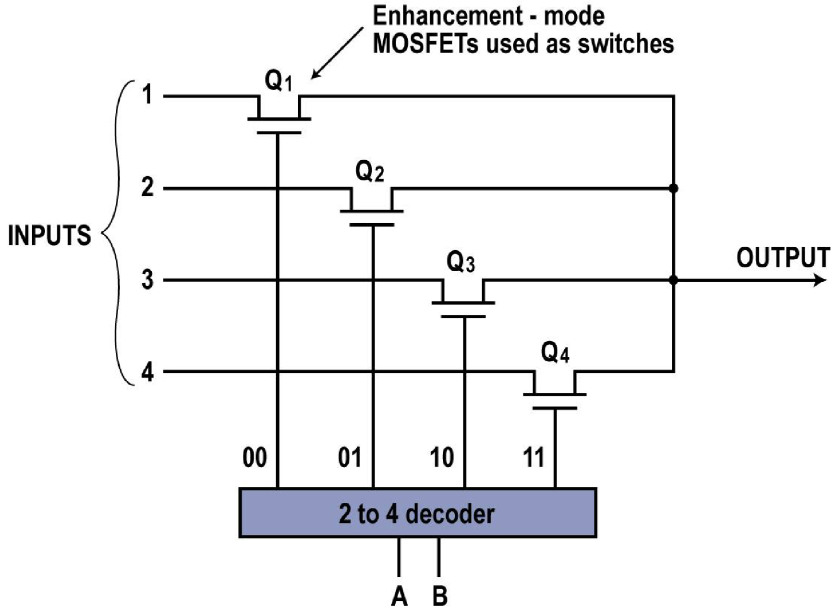
Digital signals may be conditioned by converting their voltage level or polarity and by buffering and filtering as well.

Multiplexing



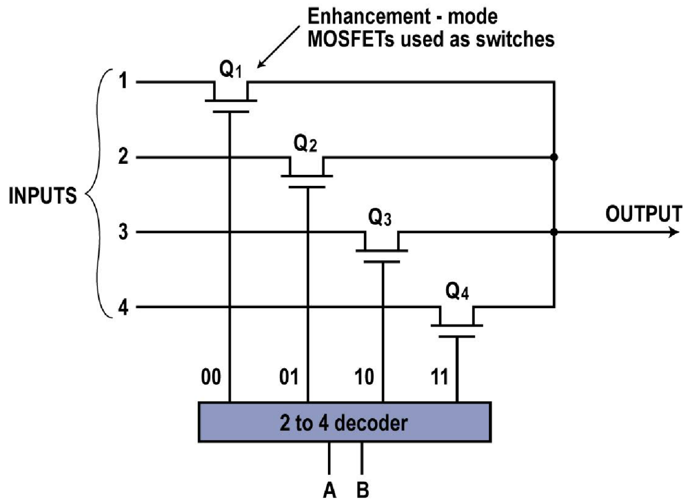
Multiplexing is the process of allowing two or more signals to share the same bandwidth or communications path. A multiplexer has two or more inputs and a single output. One of the inputs is selected to be connected to the output. The multiplexer is like a multiple position switch.

Electronic Multiplexer



An electronic multiplexer uses MOSFETs as switches to connect the desired input to the output. In this figure, here there are four inputs each connected to a MOSFET. The gates of the MOSFETs are driven by a 2 to 4 decoder. With 2 input bits, $2^2 = 4$ conditions from 00 to 11 are defined.

Electronic Multiplexer Operation



When the binary input AB is 01, the second output of the decoder goes positive causing MOSFET Q_2 to turn on. All other decoder outputs are zero and all other MOSFETs are off. Only the signal on input 2 appears at the output.

Most data acquisition system multiplexers have 16 inputs with a 4-bit binary selection input. This binary code comes from a computer. The number of inputs may be expanded by various methods depending on the manufacturer.

Analog-to-Digital Converter (ADC)

The analog-to-digital converter (ADC) converts the analog input signal from the multiplexer into a sequence of binary words. The ADC samples the signal at a rate at least twice the frequency of the input signal.

If the signal is varying at a 100 Hz rate, the sample rate must be at least 200 Hz; the more samples per second the better the accuracy of conversion. Most sensor signals are slowly changing DC so high sampling rate is rarely necessary.

A sampling rate may only be one sample per minute up to many thousand of samples per second (S/s).

Signal Conditioning Circuits

Most ADC chips require an input signal in the 0 to 5 or 0 to 10 volt range. Alternately, some ADCs accept an input of ±5 volts. The signal conditioning circuits are responsible for producing a signal in this range.

However, in some cases, a programmable gain amplifier may be connected between the multiplexer and the ADC input to assist in meeting this requirement.

Some DAQs are packaged with the signal conditioning circuits on the same PC board as the ADC. In other cases, the signal conditioning circuits may be in a separate piece of equipment.

ADC Resolution

Depending upon the frequency of the input signals and the desired resolution of measurement, different kinds of ADCs may be used. For most applications, the successive approximation converter is the most common. 10, 12, and 16-bit converters are available with 12-bits being the most popular. For very high precision of conversion of DC or very low frequency signals, sigma-delta converters are used to give up to 24-bits of resolution with good noise immunity.

Computer

The stream of binary words from the ADC must be stored in a memory before that data can be analyzed or displayed. In most applications, the ADC words are simply fed into the memory (RAM) of a personal computer or laptop. From there, this data can also be stored in a file on the hard disk drive.

The computer also forms the base for most additional signal processing. The computer can carry out statistical analysis on the collected data or it may be used in digital signal processing (DSP). Special software installed on the computer is used to process the data.

The computer video screen also serves as the output display device. Again, software defines how the data is displayed whether it is tabular, graphical, or animated.

Software

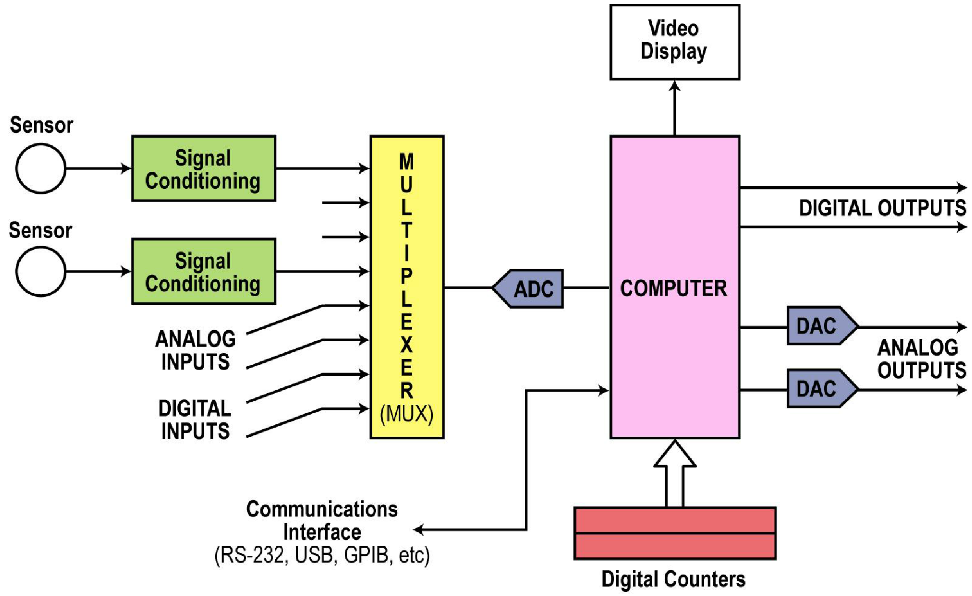
Most data acquisition systems use software to handle the data captured by the ADC. In most cases, the primary need is to display the data for practical use. While a tabular display of the data samples can be provided, it is not very useful. Instead, the data is usually processed prior to graphical display. For example, the data may be presented as histograms, pie charts, graphs and plots (shown in the figure above), oscilloscope displays, frequency spectrum displays, or special animated graphics.

Processing

The software may also be able to perform other processes on the data. For example, the data may be analyzed statistically and presented in the appropriate display. The data may also be processed by digital signal processing (DSP) techniques. Filtering is performed by common DSP methods.

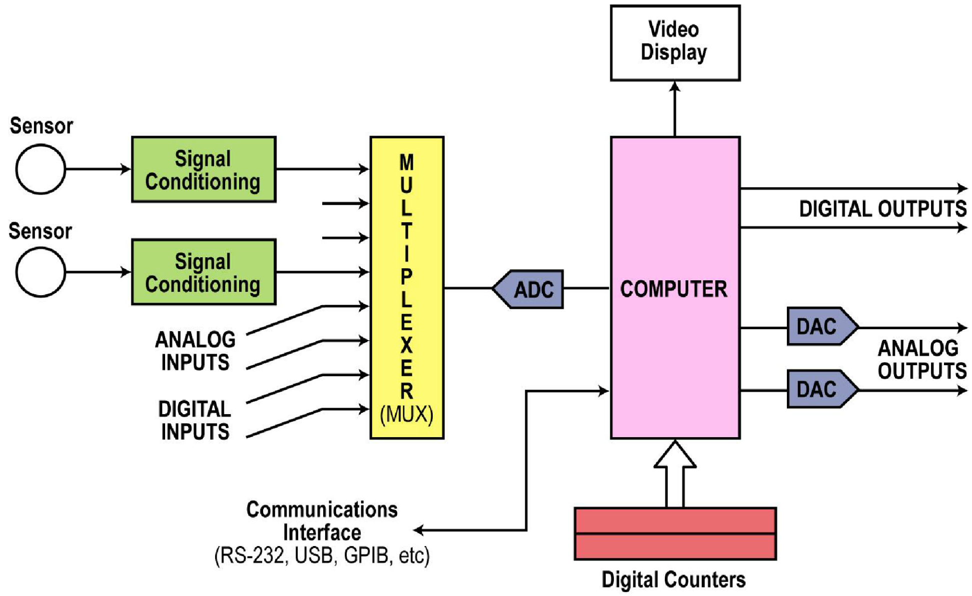
In some applications, the data may be processed to produce output signals to be used elsewhere. A common example is the development of output signals that can be used in a closed loop process. The output signals may be digital or analog. Digital signals may be pulses to turn other devices off or on. Motors, relays, solenoids, lights, valves, etc. are examples.

Output Interfaces: Analog



Other outputs may be analog signals to control motor speed, the proportional opening of a valve, or flow rate. Analog output signals are produced by digital-to-analog converters (DACs) which are fed data from the computer. Almost any shape analog signal can be synthesized by appropriate processing.

Output Interfaces: Digital



The digital outputs may be standard binary CMOS or TTL signals or special DC levels as required by the devices to be controlled. Typical voltage ranges are zero to 48 volts. A common output is a variable 4 to 20 mA current which is widely used to control industrial components.

Counters and Timers

Some DAQ systems also contain digital counters. These are usually long binary counters such as 16, 24, or 32-bits. These can be driven by input signals or by internal clock generators. The internal clocks are crystal oscillators with a frequency of 100 kHz, 20 MHz, or some other useable frequency.

The counters can be used for frequency division, counting external events, timing, pulse generation, delay generation, pulse width modulation (PWM), and any special timing need. The counters are usually programmable with the system software.

One application is to provide a time signal that can be recorded along with a data reading so that the data can be related to a specific date and time.

Data Communications

Today, many data acquisition systems use data transmission techniques to transport the data from one place to another. Once the signals have been digitized, they may be transmitted serially by one of several popular data communications interfaces. The most common are the RS-232, RS-423, RS-422, and RS-485 interfaces. For higher speeds and PC or laptop compatibility, a common USB interface or Ethernet port is used. Distances may vary depending upon the applications and may be only a few feet to thousands of feet.

The availability of wireless technology today also makes remote data acquisition possible. Popular wireless methods include Wi-Fi or 802.11a/b/g wireless LAN and special industrial-scientific-medical (ISM) band radios such as ZigBee that are designed for this purpose.

Data Loggers

A term sometimes used in place of data acquisition system is data logger. A data logger is similar to the DAQ system described here but its primary application is to capture data that can be stored and used later. In other words, the data logger just captures the data and stores it on a hard drive or some other storage medium. In these systems, no real time data processing is used. Instead, the data is processed off line.

Data loggers collect the data but another computer with additional software may be used to process and manipulate the data multiple times in different ways.

These features generally make the data logger simpler and much smaller than a fully functional DAQ system.

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