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Data Acquisition System

Ankit[1] and Ashish Kumar[2]

[1]Assistant Professor, Department of Electronics and Communication Engineering, CBS Group of Institutions, Fatehpuri, Jhajjar

[2]Department of Electronics and Communication, CBS Group of Institutions, Fatehpuri, Jhajjar

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Abstract

Engineering and natural science today highly depends on large sets of data which are usually collected, processed and stored for later usage. In order to create a data acquisition (DAQ) system, two main questions must be answered: how to provide adequate and optimal system for data collection, and how to analyze and process large data sets. An answer can be found in applying a new concept - Internet of Things (IoT) and the well-known data mining techniques which together represent a DAQ system that can be successfully implemented in educational research. Therefore, this paper proposes a DAQ system, based on low cost hardware, IoT principles and open source and freely available data mining tools, what enables its widespread usage in educational research.

Keywords: *Internet of Things (IoT), Data Acquisition System, Sensor.*

Introduction

Data acquisition is the processing of multiple electrical or electronic inputs from devices such as sensors, timers, relays, and solid-state circuits for the purpose of monitoring, analyzing and/or controlling systems and processes. Data acquisition instrument types include computer boards, instruments or systems, data-loggers or recorders, chart recorders, input modules, output modules, and I/O modules. Computer boards are self-contained printed circuit board with full data acquisition functionality; typically plugs into a backplane or motherboard, or otherwise interfaces directly with a computer bus. Instruments or systems are fully packaged with input and output, user interface, communications capability, etc. They may include integral sensors. Data loggers and data recorders are data acquisition units with instrument functionality with specific capability for data storage. May be for general purpose or application-specific data acquisition, chart recorders generate real-time plots, graphs or other visualizations of data. Input modules are devices (module or card) configured to accept input of sensors, timers, switches, amplifiers, transistors, etc. for use in the data acquisition system. Output modules are devices with specific functionality for output of amplified, conditioned, or digitized signal. I/O modules have both input and output functionality. Digital or discrete I/O includes on-off signals used in communication, user interface, or control. Common form factor for data acquisition devices include IC or board mount, circuit board, panel or chassis mount, modular bay or slot system, rack mount, DIN rail, and stand-alone. Common device specifications to consider when searching for data acquisition products include differential analog input channels, digital I/O channels, sampling frequency, resolution and accuracy. Common signal inputs available for data acquisition products include DC voltage, DC current, AC voltage, AC current, frequency, and charge. Sensor inputs include accelerometer, thermocouple, thermistor, RTD, strain gauge or bridge, and LVDT or RVDT. Specialized inputs include encoder, counter or tachometer, timer or clock, and relay or switch. Transducers and excitation are also important to consider when searching for data acquisition. Many products have integral sensors or transducers. These sensors can have voltage or current excitation. Common outputs for data acquisition products include voltage output, current output, frequency output, timer or counter output, relay output, and resistance or potentiometer output. Considering the user interfaces available is important when searching for data acquisition products. User interfaces available include no display, front panel and display, touch screens, hand-held or remote programmers, and computer programmable. Host connection choices include direct backplane interface, RS232, RS422, ST485, USB, research 1394, GPIB, SCSI, TTL, parallel, Ethernet, modem, and radio or telemetry. The transmission rate of data is important to consider. Many products are web enabled for web addressing. Common applications for data acquisition products include general lab or industrial, environmental, vehicular, marine, aerospace or military, seismic or geotechnical, weather or meteorology, and medical or biomedical. Additional specifications to consider when searching for data acquisition products include application software, memory and storage, network specifications, filter specifications, amplifier specifications, and environmental parameters.

Data acquisition (DAQ) systems - products and/or processes used to collect information to document or analyze some phenomenon, are an important part of daily life, work and education. Today, natural science relies on large sets of data gathered by monitoring real phenomena and thus requires a strong DAQ system. With the rapid advancements in Information and Communication Technologies (ICTs) data acquisition has been simplified and made more accurate, versatile, and reliable through electronic equipment. These systems bring modern electronics in science and technology teaching, and a laboratory established on them supported by various sensors and actuators is also called a microcomputer-based laboratory [1]. Bounding such laboratories with the advances of the future Internet, known as Internet of Things (IoT), provide anytime and anywhere access to information in novel ways and contexts, and brings people, processes, data and things together in unprecedented ways. In other words, the IoT application in education enables creation of systems for data aggregation and processing through interconnection of people with many things (media, pictures, data, etc.) and with physical objects (RFID, sensors, actuators, robots, etc.). Relying on this approach, various DAQ systems presented in [2-5] usually generate large volumes of data which have to be followed by high quality analytics. Utilization of these systems in educational research includes the exploration, description, explanation, or prediction of the educational phenomenon with the help of systematic data collection and analysis procedures. All aforementioned elements drive new ways of teaching and learning in engineering and natural science.

Today, most scientists and engineers are using personal computers with PCI, PXI/Compact PCI, PCMCIA, USB, IEEE1394, ISA, or parallel or serial ports for data acquisition in laboratory research, test and measurement, and Industrial automation. Many applications use plug-in boards to acquire data and transfer it directly to computer memory. Others use DAQ hardware remote from the PC that is coupled via parallel or serial port. Obtaining proper results from a PC-based DAQ system depends on each of the following system elements –

• The personal computer

• Transducers

• Signal conditioning

• DAQ hardware

• Software

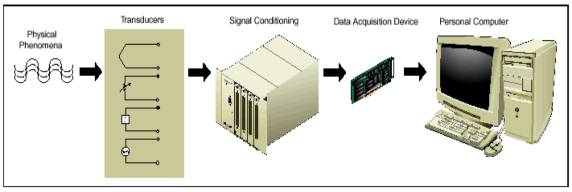

Figure 1: A Typical PC based DAQ System

Data acquisition system is a process of sampling signal that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by the computer. It typically convert analog waveforms into digital values for processing. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software. DAQ is a process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure or sound with a computer. Compared to tradition measurement systems, PC-based DAQ systems exploits the processing power, productivity, display and connectivity capabilities of industry standard computer providing a more powerful, flexible and cost effective measurement solution.

The field of data acquisition encompasses a very wide range of activities. At its simplest level, it involves reading electrical signals into a computer from some form of sensor. These signals may represent the state of a physical process, such as the position and orientation of machine tools, the temperature of a furnace or the size and shape of a manufactured component. The acquired data may have to be stored, printed or displayed. Often the data have to be analyzed or processed in some way in order to generate further signals for controlling external equipment or for interfacing to other computers. This may involve manipulating only static readings, but it is also frequently necessary to deal with time-varying signals as well. Some systems may involve data to be gathered slowly, over time spans of many days or weeks. Other will necessitate short bursts of very high speed data acquisition – perhaps at rates of up to several thousand readings per second. DAQ is used widely for laboratory automation, industrial monitoring and control, as well as in a variety of other time-critical applications. The most central reason for using the PC for data acquisition and control is that there is now a large and expanding pool of programmers, engineers and scientists who are familiar with the PC.

The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Parts of Data Acquisition System

1. Sensors

The measurement of a physically phenomena such as temperature of a room, the intensity of light source, or the force applied to an object, begins with a sensor. A sensor, which is a type of transducer, is a device that converts a physical property into a corresponding electrical signal (e.g., Strain gauge, thermistor). An acquisition system to measure different properties depends on the sensors that are suited to detect those properties. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used. The signal may need to be filtered or amplified in most cases. Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. For transmission purposes, single ended analog signals, which are more susceptible to noise, can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors. Depending on the type of sensor, its electrical output can be voltage, current, resistance or another electrical attribute that varies over time.

2. Data Acquisition System Device

DAQ hardware is what usually interfaces between the signal and a PC. It could be in the form of modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in the motherboard. Usually the space on the back of a PCI card is too small for all the connections needed, so an external breakout box is required. The cable between this box and the PC can be expensive due to the many wires, and the required shielding.

DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs. A controller is more flexible than a hard wired logic, yet cheaper than a CPU so that it is permissible to block it with simple polling loops. For example: Waiting for a trigger, starting the ADC, looking up the time, waiting for the ADC to finish, move value to RAM, switch multiplexer, get TTL input, let DAC proceed with voltage ramp.It primarily functions as a device that digitizes incoming analog signals so that a computer can interpret them. The three key components of a DAQ device used for measuring a signal are –

2.1 Signal Conditioning

In electronics, signal conditioning means manipulating an analog signal in such a way that it meets the requirements of the next stage for further processing. Most common use is in analog-to-digital converter. Signals from sensors or the outside world can be noisy or too dangerous to measure directly. Signal conditioning circuitry manipulates a signal into a form that is suitable for input into an analog to digital converter (ADC). This circuitry can include amplification, attenuation, filtering and isolation. Some DAQ devices include built in signal conditioning designed for measuring specific types of sensors. Signal inputs accepted by signal conditioners include DC voltage and current, AC voltage and current, frequency and electric charge. Outputs for signal conditioning equipment can be voltage, current, frequency, timer or counter, relay, resistance or potentiometer, and other specialized outputs.

2.2 Signal Conditioning Process

Signal conditioning process includes:

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2.2.1 Filtering

Filtering is the most common signal conditioning function, as usually not all the signal frequency spectrum contains valid data. The common example is 60 Hz AC power lines, present in most environments, which will produce noise if amplified.

2.2.2 Amplifying

Signal amplification performs two important functions:

1) Increases the resolution of the inputted signal.
2) Increases its signal-to-noise ratio.

For example, the output of an electronic temperature sensor, which is probably in the millivolts range, is probably too low for an Analog-to-digital convert (ADC) to process directly. In this case it is necessary to bring the voltage level up to that required by the ADC.

2.2.3 Isolation

Signal isolation must be used in order to pass the signal from the source to the measurement device without a physical connection: it is often used to isolate possible sources of signal perturbations. Also notable is that it is important to isolate the potentially expensive equipment used to process the signal after conditioning from the sensor.

Magnetic or optic isolation can be used. Magnetic isolation transforms the signal from voltage to a magnetic field, allowing the signal to be transmitted without a physical connection (for example, using a transformer). Optic isolation takes an electronic signal and modulates it to a signal coded by light transmission (optical encoding), which is then used for input for the next stage of processing.

2.3 Analog to Digital Convertor

An analog-to-digital converter (abbreviated ADC, A/D or A to D) is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude. The conversion involves quantization of the input, so it necessarily introduces a small amount of error. Instead of doing a single conversion, an ADC often performs the conversions ("samples" the input) periodically. The result is a sequence of digital values that have converted a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal.

An ADC may also provide an isolated measurement such as an electronic device that converts an input analog voltage or current to a digital number proportional to the magnitude of the voltage or current. However, some non-electronic or only partially electronic devices, such as rotary encoders, can also be considered ADCs.

Analog signals from sensors must be converted into digital before they are manipulated by digital equipment such as computer. An ADC is a chip that provides a digital representation of an analog signal at an instant in time. The samples are transferred to a computer over a computer bus where the original signal is reconstructed from the samples in software.

2.3.1 Sampling Process in Analog to Digital Converter

2.3.1.1 Sampling

The data is acquired by an ADC using a process called sampling. Sampling an analog signal involves taking a sample of the signal at discrete times. This rate at which the signal is sampled is known as sampling frequency. The process of sampling generates values of signal at time interval as shown in following figure.

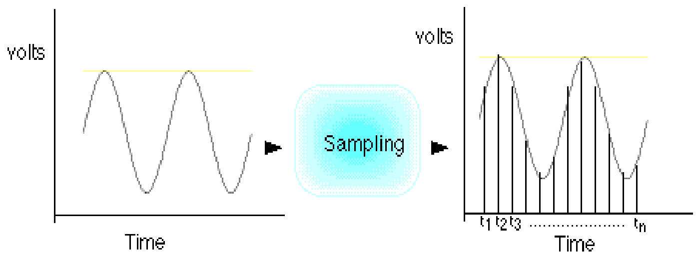

Figure 2: Sampling Process

The sampling frequency determines the quality of the analog signal that is converted. Higher sampling frequency achieves better conversion of the analog signals. The minimum sampling frequency required to represent the signal should at least be twice the maximum frequency of the analog signal under test (this is called the Nyquist rate). In the following figure an example of sampling is shown. If the sampling frequency is equal or less than twice the frequency of the input signal, a signal of lower frequency is generated from such a process (this is called aliasing).

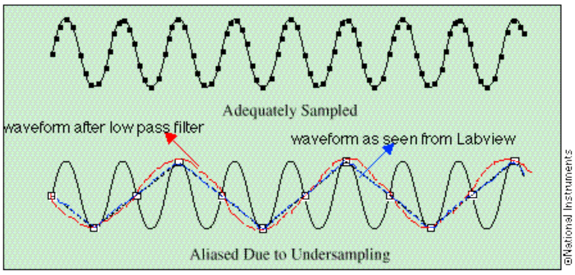

Figure 3: Effects of Sampling and Aliasing Due to under sampling

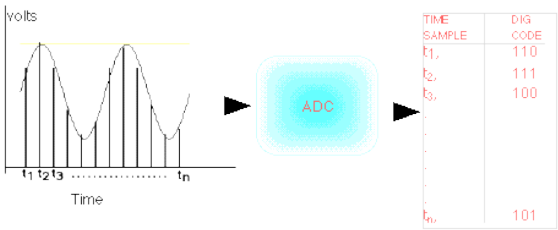

Figure 4: Analog to Digital Conversion for a 3-BIT ADC

Commercially available boards have different sampling frequencies. The DAQ boards in the EE Undergraduate Lab have a 12 bit ADC with sampling rate up to 40 KHz. There are 3 high speed DAQ boards that have a 12 bit ADC with sampling rate up to 100 KHz.

Most boards also have a multiplexer that acts a like a switch between different channels and the ADC. Therefore with 1 ADC, it is possible to have a multichannel input DAQ board. All boards in the EE Undergraduate Lab are 16 channel analog input boards. This makes it possible to acquire up to 16 analog signals in parallel (however, the sampling frequency will be divided by the number of parallel channels).

2.3.1.2 Resolution

Precision of the analog input signal converted into digital format is dependent upon the number of bits the ADC uses. The resolution of the converted signal is a function of the number of bits the ADC uses to represents the digital data. The higher the resolution, the higher the number of divisions the voltage range is broken into, and therefore, the smaller the detectable voltage changes. An 8 bit ADC gives 256 levels (2^8) compared to a 12 bit ADC that has 4096 levels (2^12). Hence, 12 bit ADC will be able to detect smaller increments of the input signals then an 8 bit ADC. All DAQ boards in the EE Undergraduate lab have a resolution of 12 bits. LSB or least significant bit is defined as the minimum increment of the voltage that a ADC can convert. Hence, LSB varies with the operating input voltage range of the ADC. Figure 4 illustrates the resolution for a 3 bit ADC. FS stands for full scale and LSB is the least significant bit. If the full scale of the input signal is 10V than the LSB for a 3-bit ADC corresponds to 10/2^3=1.25V. That is not very good! However, for a 12 bit ADC the least significant bit will be 10/2^12=10/4096=2.44mV. If one needs to detect smaller changes, one has to use a higher resolution ADC. Clearly, the resolution is an important characteristic of the DAQ board.

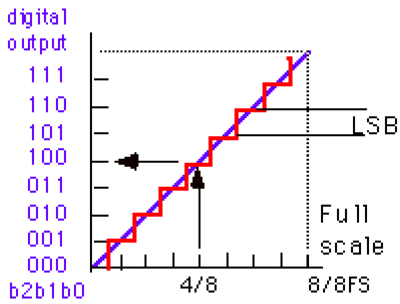

Figure 5: Resolution of ADC, X-AXIS IS ANALOG Input

2.3.1.3 Non-Linearity

Ideally if the voltage applied to the input of an ADC is increased linearly, we would expect the digital codes to increment linearly.

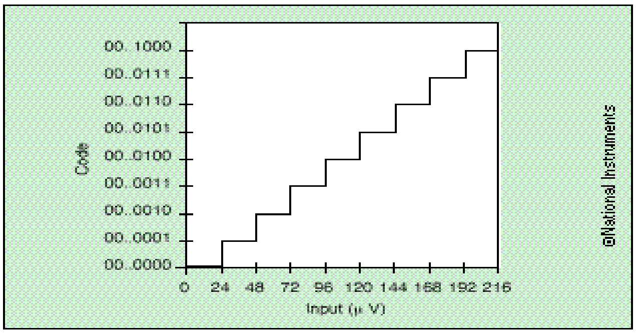

Figure 6: Transfer Characteristic of an Ideal ADC

A perfect DAQ board will have no non-linearity but most commercially available boards display some non-linearity. This specification is clearly stated as differential non-linearity. Following figure shows the result of non-linearity.

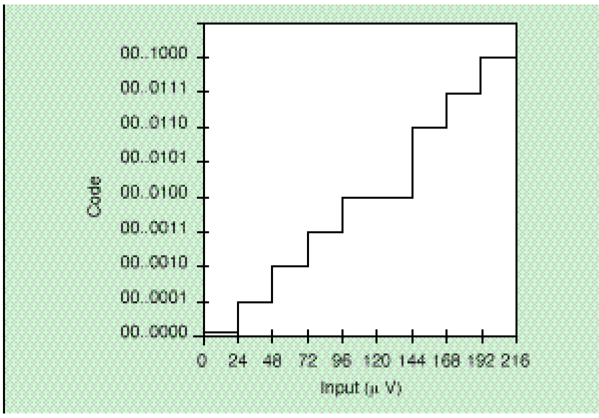

Figure 7: Differential Non- Linearity ADC

2.3.1.4 Data Transfer to the Computer

Typically, DAQ boards are installed in a PC with high speed data bus like PCI. Depending on the speed of the motherboard of the PC, the maximum data transfers can occur between microprocessor and memory at 20 MHz to 40 MHz. To improve the data transfers, bus mastering (allowing DAQ board to transfer data directly) is implemented as shown in the figure.

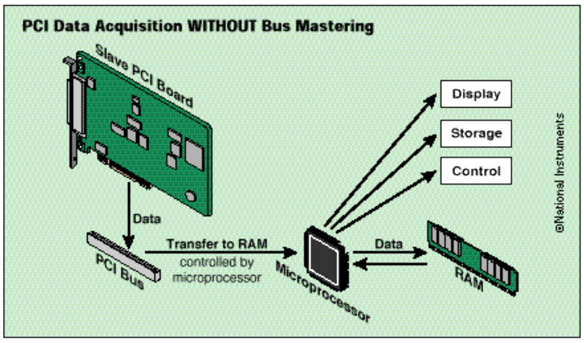

Figure 8: Data Transfer without Bus Mastering (Conventional)

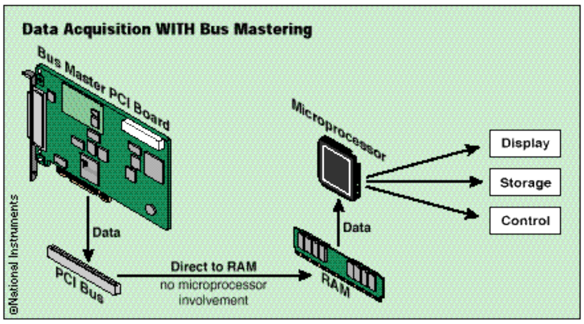

Figure 9: Data Transfer with Bus Mastering (used In Expensive DAQ Boards)

As you may now conclude, that sampling frequency and resolution are very important factors in determining the performance of a DAQ card. But, in addition to the sampling speed, there are other factors that can affect the functionality of a DAQ system.

2.4 Computer Bus

DAQ device connect to a computer through a slot or port. The computer bus serves as the communication interface between the DAQ device and computer for passing instructions and measured data.

2.5 Computer and Software

A computer with programmable software controls the operation of the DAQ device and is used for processing, visualizing and storing measurement data.

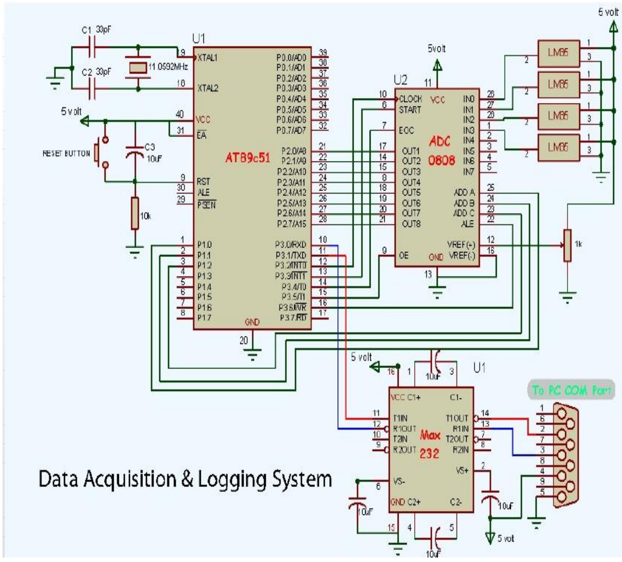

Figure 9: Circuit Diagram of Data Acquisition System

DATA ACQUISTION SYSTEM USING AT89c51

Figure 10: At89c51

AT89C51 is an 8-bit microcontroller and belongs to Atmel's 8051 family. ATMEL 89C51 has 4KB of Flash programmable and erasable read only memory (PEROM) and 128 bytes of RAM. It can be erased and program to a maximum of 1000 times.

In 40 pin AT89C51, there are four ports designated as P_1, P_2, P_3 and P_0. All these ports are 8-bit bi-directional ports, *i.e.*, they can be used as both input and output ports. Except P_0 which needs external pull-ups, rest of the ports have internal pull-ups. When 1s are written to these port pins, they are pulled high by the internal pull-ups and can be used as inputs. These ports are also bit addressable and so their bits can also be accessed individually.

Port P_0 and P_2 are also used to provide low byte and high byte addresses, respectively, when connected to an external memory. Port 3 has multiplexed pins for special functions like serial communication, hardware interrupts, timer inputs and read/write operation from external memory. AT89C51 has an inbuilt UART for serial communication. It can be programmed to operate at different baud rates. Including two timers & hardware interrupts, it has a total of six interrupts.

The following are the important features of AT89c51-

- This is an 8-bit microcontroller.
- It has 4kB masked ROM.
- It has 128 bytes of internal data memory.
- There are 32 input output lines.
- It has internal UART (Universal Asynchronous Receiver Transmitter)
- There are 5 Interrupts including 2 external interrupts
- It supports additional 60kB external program memory & 64kB external data memory

ADC 0808

ADC0808 is an 8 bit analog to digital converterwith eight input analog channels, *i.e.*, it can take eight different analog inputs. The input which is to be converted to digital form can be selected by using three address lines. The voltage reference can be set using the Vref+ and Vref- pins. The step size is decided based on set reference value. Step size is the change in analog input to cause a unit change in the output of ADC. The default step size is 19.53mV corresponding to 5V reference voltage. ADC0808 needs an external clock to operate unlike ADC0804 which has an internal clock. The ADC needs some specific control signals for its operations like start conversion and bring data to output pins. When the conversion iscomplete the EOC pins goes low to indicate the end of conversion and data ready to be picked up.

In lot of embedded systems microcontrollers needs to take analog input. Most of the sensors and transducers such as temperature, humidity, pressure are analog. For interfacing these sensors to microcontrollers we require to convert the analog output of these sensors to digital so that the controller can read it. Some micro controllers have built in Analog to Digital Converter (ADC) so there is no need of external ADC. For controllers that don't have internal ADC external ADC is used. One of the most commonly used ADC is ADC0808. ADC 0808 is a Successive approximation type with 8 channels i.e. it can directly access 8 single ended analog signals.

MAX 232

The MAX232 is an integrated circuit that converts signals from an RS-232 serial port to signals suitable for use in TTL compatible digital logic circuits. The MAX232 is a dual driver/receiver and typically converts the RX, TX, CTS and RTS signals.

RS232 is a serial interfacing device. For this reason to connect any RS232 to a microcontroller system we must use voltage converters such MAX232 to convert TTL logic levels to the RS232 voltage levels and vice versa. MAX232 IC chips are commonly referred to as line drivers. This chip uses a +5volts power which is same as source voltage of 8051. So with single +5volt power supply we can power both the 8051 and MAX232. In this there are two sets of transferring and receiving data that is T1, T2, R1, R2. But for many applications only one set is used.

Data Acquisition Characteristics

1. PC-Connected Data Acquisition

Dependent upon a PC to acquire data, PC-connected instruments usually share these common traits:

- Faster sampling speeds
- Provided with software that delivers PC-based storage and a real time display of acquire data.
- Sometimes powered directly from the PC, or supplied with an external power supply

2. Stand Alone Data Acquisition

Beyond their ability to operate independently, stand-alone data acquisition products usually share a number of common traits:

- The ability to support removable memory devices like SD memory cards
- Often, but not always slower sampling rates than PC-connected data acquisition products
- Often DC-powered devices for deployment flexibility

Interfaces

Figure 11: PC-Connected Data Acquisition Interface

Data acquisition products that need a PC to acquire data must connect to them in some manner. This is done through standard interfaces, which are found on all PCs. The most common are:

- USB
- Ethernet

Stand Alone Data Acquisition Interface

Even though they operate without a connected PC, stand-alone data acquisition products need to be programmed to define how data is logged. Common ways to connect are the same as PC-connected products:

- USB
- Ethernet

Memory

Figure 12: PC-Connected Data Acquisition Memory

By definition, pc-connected data acquisition products use a PC’s memory for data storage. Software supplied or purchased with the data acquisition system determines how the PC’s memory is used:

- Stored to PC's RAM
- Streamed to a PC's hard disc drive
- Virtually unlimited storage

Stand Alone Data Acquisition Memory

Memory options for stand-alone data acquisition products come in many shapes and sizes, but the most common forms are:

- SD memory

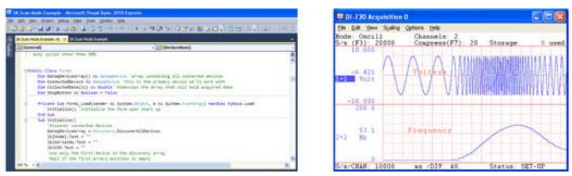

Figure 13: Software

All data acquisition products offer PC software solutions that can adapt to the demands of any application. These assume three forms that address the broad base of software approaches:

- Ready-to-run data acquisition software offers a no-programming environment to acquire, display, record, analyze and export data to other applications.
- Software that supports programming languages like VB, and Dot Net under a Windows operating system environment.
- Protocol-level support that allows root access to a given device's command set from any programming language or operating system.

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