United Electronic Industries

Shaping the Future of Computer-Based I/O™

Everything You Ever Wanted to Know about Data Acquisition

— Part Two —

Other Types of DAQ I/O

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Abstract of Article

This article is comprised of two parts. Chapter 1, the first of the series, already published and currently available as a free download from our website, www.ueidaq.com, was designed to introduce the key aspects of computer-based data acquisition and control to new users. It can also serve as a useful reference document for existing DAQ customers. Chapter 1, which is titled “Analog Inputs”, covers a myriad of topics related to making measurements with a computer.

The second part of the series, Chapter 2, describes the “Other” types of DAQ I/O, — devices such as Motion I/O, Synchro/Resolvers, LVDT/RVDTs, String Pots, Quadrature Encoders, and Piezoelectric Crystal Controllers. It also includes a discussion of Analog Outputs, Digital Inputs, Digital Outputs, Counter/Timers, and Special DAQ functions, covering such topics as communications interfaces, timing, and synchronization functions. Chapter 2 will also be available soon as a free download from www.ueidaq.com.

Chapter 2 is about measurement types and system requirements other than the standard A/D, D/A, and DIO. Though most channels are included in the “big three”, most systems also have a few channels of “other, less common” types. Whether you call them “special” or “oddball” or “less common”, the reality of addressing these channels is often the most difficult and challenging part of building the DAQ system. For successful system implementation, these special channels must be addressed — since a ninety five percent solution is not an option.

The vast majority of data acquisition and control I/O channels are fairly standard types: Analog Inputs (a.k.a. A/D), Analog Outputs (a.k.a. D/A), and parallel Digital I/O. System requirements vary greatly regarding sample rates, accuracy /resolution requirements, output capabilities, and the like. These considerations are far from trivial, and much has already been written about them.

The non-mainstream I/O channels include such hardware devices as: Synchro/Resolver inputs, LVDT/RVDT inputs, Quadrature Encoders, and Pulse Width Modulated outputs. Communications interfaces to such common buses as RS-232, RS-485, CAN, ARINC 429, MIL-STD-1553, plus timing/synchronization considerations are discussed in Chapter 2. The article provides an introduction to many of these interfaces, explains how they work, and describes the factors/features you should either demand or not allow in your design.

Although most data acquisition and control I/O channels are fairly common types, system requirements vary greatly. The old 80-20 rule, however, holds as well in the DAQ arena as anywhere. Eighty percent of the I/O channels are typically addressed by twenty percent of the available I/O products. Since nobody wants an eighty percent solution, however, the remaining twenty percent of the I/O channels must also be addressed. Chapter 2 of this article, therefore, provides a brief introduction to the “other, less common” I/O types and also offers some things to look for (and watch out for) while specifying these products.

Author Biography

Bob Judd has been involved in the PC-based DAQ market for over 20 years. Currently Director of Sales and Marketing at United Electronic Industries (UEI), he has served as GM, VP of Marketing and VP of Hardware Engineering at Measurement Computing. Bob was also VP of Marketing at industry pioneer MetraByte. He holds a Bachelors degree in Engineering from Brown University and a Masters degree in Management from MIT.

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1.1. Preamble

This is the first of a series of articles designed to introduce the key aspects of computer-based data acquisition and control to new users. It should also serve as a useful reference document for existing DAQ customers. The presentation is provided in multiple parts.

Chapter 1 — Analog Inputs (with A/D conversion) covers the myriad of topics related to making measurements with a computer. (Chapter 1 is now available as a free download from our website, www.ueidaq.com.)

Chapter 2 “Other” types of DAQ I/O Hardware

The second part of the series describes the “other common” types of DAQ I/O — devices such as Analog Outputs, Digital Inputs, Digital Inputs, Counter/Timers, and Special DAQ functions, which covers such devices as Motion I/O, Synchro/Resolvers, LVDT/RVDTs, String Pots, Quadrature Encoders, and ICP/IEPE Piezoelectric Crystal Controllers. It also covers such topics as communications interfaces, timing, and synchronization functions. (Chapter 2 will soon be available as a free download from our website, www. ueidaq.com.)

2.1 Analog Outputs

Analog or D/A outputs are used for a variety of purposes in data acquisition and control systems. To properly match the D/A device to your application, it is necessary to consider a variety of specifications, which are listed and explained below.

2.11. Number of Channels

As it’s a fairly obvious requirement, we won’t spend much time on it. Make sure you have enough outputs to get the job done. If it’s possible that your application may be expanded or modified in the future, you may wish to specify a system with a few “spare” outputs. At the very least, be sure you can add outputs to the system down the road without major difficulty.

2.1.2 Resolution

As with A/D channels, the resolution of a D/A output is a key specification. The resolution describes the number or range of different possible output states (typically voltages or currents) the system is capable of providing. This specification is almost universally provided in terms of “bits”, where the resolution is defined as $2^{(\# \text{ of bits})}$. For example, 8-bit resolution corresponds to a resolution of one part in 2^8 or 256. Similarly, 16-bit resolution corresponds to one part in 2^{16} or 65, 536. When combined with the output range, the resolution determines how small a change in the output may be commanded. To determine the resolution, simply divide the full scale range of the output by its resolution. A 16-bit output with a 0-10 Volt full scale output provides 10 V/2^{16} or 152.6 microvolts resolution. A 12-bit output with a 4-20 mA full scale provides 16 mA/2^{12} or 3.906 uA resolution.

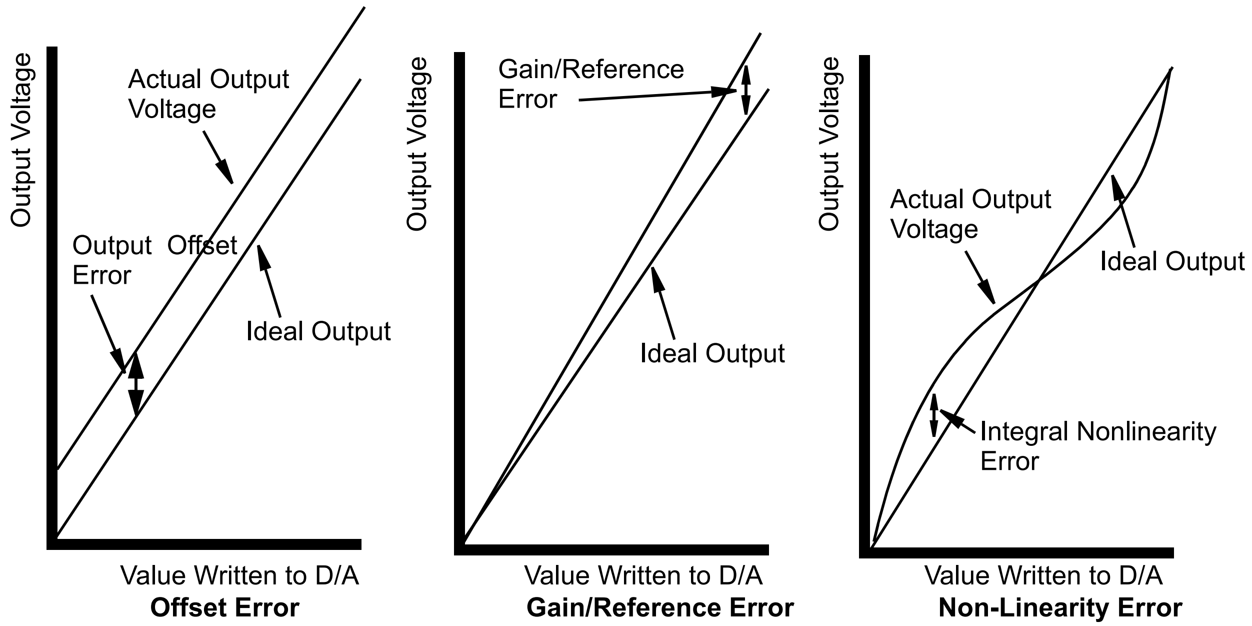

Figure 1. Error Factors.

The standard resolution of most DAQ analog output interfaces is 16-bit and you will also see some devices with 12-bit resolution. Though it is now common to see analog inputs with 20 or 24-bit resolution, requiring resolutions of greater than 16-bits is fairly rare in applications where DC accuracy is important, but is common in AC applications such as in the audio output ”world”.

2.1.3 Accuracy

Though accuracy is often equated to resolution, they are not the same. An analog output with a one microvolt resolution does not does not necessarily (or even typically) mean the output is accurate to one microvolt resolution. Outside of audio outputs, D/A system accuracy is typically on the order of a few LSBs. However, it is important to check this specification as not all analog output systems are created equal. The most significant and common error contributions in analog output systems are Offset, Gain/Reference, and Linearity errors. These are depicted graphically above in **Figure 1 – Error Factors.**

The primary contributors of a D/A output are Output Offset, Gain Error, Reference Error, and Non-Linearity. Note that both Gain and Reference are shown on a single graph as they both contribute to an undesired change of slope in the output diagram. More detailed descriptions of each of these errors is provided in a variety of articles, both published and on the web. A detailed description of each of these factors can be readily retrieved by simply typing the phrase into your favorite search engine. The important thing to remember is that these errors are additive, and to determine the overall system accuracy, you must account for the contributions from all error sources. There are additional contributing error factors that must be taken into account that are more application-specific than product-specific. Errors may be generated by the D/A channel output impedance as well as "IR" errors induced in the field wiring (as neither the current flowing in the field wiring nor the resistance of the wiring is zero.

Both output impedance and IR errors manifest themselves when the D/A channel is required to drive a significant output current. Ohm's law (V=IR) dictates that the error generated will be the product of the channel output impedance, plus the resistance in the field wiring, divided by the current flowing. The equation for this error is shown below:

Resistance error = (D/A output impedance + field wiring resistance)/current flow

In many applications, the device the output is driving is high impedance and the current is so low this error is negligible. However, many analog outputs are capable of driving five or ten milliamps, or even more. If your application requires output drive in the milliamp range or higher, be sure to check this error. D/A output impedances are typically on the order of 0.1 ohm. A 10 mA signal flowing through 0.1 ohm generates a 1 mV error signal. The resolution of a ±10 Volt, 16-bit, analog output channel is 305 uV, so that 1 mV error actually represents an error of over 3 LSBs.

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Table-1: Resistance and IR drop of Copper Wire Cable

		IR Voltage Drop 1 mA Current		**IR Voltage Drop 10 mA Current**	
Wire Size	**Ohms per 100 feet**	**10' Cable**	**100' Cable**	**10' Cable**	**100' Cable**
16ga	0.41	0.041mV	0.41mV	0.41mV	4.1 mV
20ga	1.04	0.104	1.04	1.04	10.04
22ga	1.65	0.165	1.65	1.65	16.5
2.62	0.262	0.262	2.62	2.62	26.2
26ga	4.16	0.416	4.16	4.16	41.6
30ga	10.5	1.05	10.5	10.5	105

Notes: All voltage errors are in millivolts (mV). Cable length is total length, including both output and return cables.

The table above shows the resistance per foot of a number of common solid copper sizes as well as the IR induced error at 1 mA and 10 mA with connection wire lengths of 10 and 100 feet. Note that 1 LSB of a 16-bit analog output with a ±10 Volt full scale output is 0.305 mV. The IR losses are often significant.

More insidious than the channel output impedance is the IR drop of the field wiring. While many people simply assume the resistance is low enough to have no impact, this is often not the case. Note that 26 and 30 gauge, single conductor, copper wire has resistance of about 0.026 ohm per foot and 0.105 ohm per foot, respectively. If your output is driving 5 mA, and is connected by 50 feet of 30 gauge wire, you'll see an IR drop in the field wiring of about 53 mV (don't forget the IR drop occurs in both directions). Table 1 above shows the IR error in a number of different combinations of wire size, output current, and cable length.

There are really three options for reducing this IR drop error. First. you can minimize the distance between the analog output and the device it is driving. Second, you can increase the size of the wire to reduce the series resistance. However, it is not always possible to do either of these, which leads to option three, use a board with "Sense" leads or connections. The Sense capability is designed to automatically compensate for IR losses in the system. Basically, the sense leads are connected in parallel with the "main" analog output leads, but do not conduct any current. This allows the D/A converter to adjust its output so the voltage at the device or load is at the desired level, and not the output at the D/A converts itself. Many analog output devices, and in particular, those designed to drive higher currents (>5 or 20 mA), will have sense leads that may be used.

2.1.4 Monotonicity

Though it's common sense to assume that if you command your output to go to a higher voltage, it will, regardless of the overall accuracy. However, this is not necessarily the case. D/A converters exhibit an error called differential non-linearity (DNL).

In essence, DNL error represents the variation in output "step size" between adjacent codes. Ideally, commanding the output to increase by 1LSB,would cause the output to change by an amount equal to the overall output resolution. However, D/A converters are not perfect and increasing the digital code written to a D/A by one may cause the output to change .5 LSB, 1.3 LSB, or any other arbitrary number.

A D/A/channel is said to be monotonic if every time you increase the digital code written to the D/A converter, the output voltage does indeed increase. If the D/A converter DNL is less than ±1 bit, the converter will be monotonic. If not, commanding a higher output voltage could in fact cause the output to drop. In control applications, this can be very problematic as it becomes theoretically possible for the system to "lock" onto a false set point, distant from the one desired.

2.1.5 Output Type

Unlike analog inputs, which come in a myriad of sensor-specific input configurations, analog outputs typically come in two flavors, voltage output and current output. Be sure to specify the right type for your system. Some devices offer a mixture of voltage and current outputs, though most offer only a single type. If your system requires both, you may want to consider a current output module, as the current outputs can often be converted to a suitable voltage output with the simple installation of a shunt resistor. Note the accuracy of the shunt resistor-created voltage output is very dependent on the accuracy of the resistor used. Also note, the shunt resistor used will be in parallel with any load or device connected to it. Be sure the input impedance of the device driven is high enough not to affect the shunt function.

2.1.6 Output Drive

Be sure to investigate how much current is required by whatever device you are attempting to drive with the analog output channel. Most D/A channels are limited to less than ±5 mA or ±10 mA max. Some vendors offer higher output currents in standard output modules (e.g., UEI's DNA-AO-308-350 which will drive ±50 mA). For higher output still, it is often possible to add an external buffer amplifier. Note that if you are driving more than 10 mA, you will likely need to specify a system with sense leads if you need to maintain high system accuracy.

2.1.7 Output Range

Another fairly obvious consideration, the output range must be matched to your application requirement. Like their analog input sibling, it is possible for a D/A channel to drive a smaller range than its max, though there is a reduction of effective resolution. Most analog output modules are designed to drive ±10 V, though some, like UEI's DNA-AO-308-350, will directly drive outputs up to ±40V. Higher voltages may be accommodated with external buffer devices. Of course, at voltages greater than ±40V, safety becomes an important factor. Be careful — and if in doubt, contact an expert who will help ensure your system is safe. A final note regarding increasing the output range of a D/A channel is that if the device being driven is either isolated from the analog output systems, or if it uses differential inputs, it may be possible to double the effective output range by using two channels that drive their outputs in opposite directions.

2.1.8 Output Update Rate

Though many DAQ systems "set and forget" the analog output, many more require that they respond to periodic updates. In control systems, loop stability or a requirement for control "smoothness" will often dictate that outputs be updated a certain number of times per second. Also, applications where the D/A's provide a system excitation, a certain number of updates per second may be required. Verify that the system you are considering is capable of providing the update rate required by your application. It is also a good idea to build a little buffer into this spec in case you find down the road you need to "spin" the outputs a little faster.

2.1.9 Output Slew Rate

The second part of the output "speed" specification, the slew rate, determines how quickly the output voltage changes once the D/A converter has been commanded to a new value. Typically specified in volts per microsecond, if your system requires the outputs to change and stabilize quickly, you will want to check your D/A output slew rate.

2.1.10 Output Glitch Energy

As the output switches from one level to the next, a "glitch" is created. Basically, the glitch is an overshoot that subsequently disappears via dampened oscillation. In DC applications, the glitch is seldom problematic, but if you are looking to create a waveform with the analog output, the glitch can be a major issue as it may generate substantial noise on any excitation derived. Most D/A devices are designed to minimize glitch, and it is possible to virtually eliminate it in the D/A system, but it also virtually guarantees that the output slew rate will be diminished.

2.2 Digital Inputs

Specifying the appropriate digital input for a system is often pretty straightforward, but there are a number of considerations that must be taken into account. It is surprising how many people take the DIO part of their system for granted, only to be later pressed into panic mode as they realize the DIO specified is not the right match for the application.

2.2.1 Input Type

Digital inputs are available in a wide variety of configurations. Some monitor voltage while others monitor current. Some monitor DC signals, while others can sense AC and/or DC signals. Still other inputs monitor the status of an electrical contact (e.g., open or closed). Be sure to identify and categorize all of the digital inputs required by your system early on. It is surprising how many people specify and buy a DAQ system with a cavalier “It’s only digital I/O” attitude, only to be bitten down the road.

2.2.2 Input Impedance/Required Drive Current

Input impedance, or input drive required, is an often forgotten and problematic specification. Some inputs, such as most opto-coupler inputs, often require a substantial drive current. Many outputs are only capable of providing a very small output drive. Be careful that each of your inputs will be provided with an appropriate drive capability.

2.2.3. Input Range

A fairly obvious, but sometimes forgotten, specification is — don’t try to monitor your 24 VAC signal with a logic level input. You won’t like the results, though your DAQ vendor may, as you will almost certainly be facing a repair or replacement charge.

2.2.4 Sample or Update Rate

Like every other element of a DAQ system, timing is often a critical component. Be sure your input system is fast enough to respond to signals provided within the timing required by your system.

2.2.5 Special Considerations

Another thing to consider is hysteresis.Hysteresis is basically a dead zone in the switching behavior where a low to high transition occurs at a higher voltage than a high to low transition. This hysteresis zone reduces the input’s susceptibility to noise

Another common capability is input “debouncing”. When the actual contact in a switch or relay closes, it will typically “bounce” up and down one or more times before it finally settles into a fully closed position. The bounce cycle is often as long a 100 mS. A debounce circuit slows the response of the digital inputs such that it only appears as closed once the contact has stabilized. The chatter is sometimes only a minor inconvenience in a static digital input, but can create large errors in applications where the digital input is used as a counter.

Additional diagnostic capability is also provided on some inputs. The price of A/D converters has come down to the point where some manufacturers are monitoring their digital inputs in the analog world. A/D-based boards like UEI's DNA-DIO-448 provide the same digital information as a standard board, but also offer a diagnostic voltage measurement mode. In diagnostic mode, the actual DI input voltage is read. This information is extremely useful in identifying broken wires, short circuits, and/or damaged output devices.

2.3. Digital Outputs

Digital Outputs require the same scrutiny and many of the same considerations as digital inputs. These include careful consideration of: output voltage range, maximum update rate, and maximum drive current required. However, the outputs also have a number of specific considerations, as described below.

2.3.1 Relay vs. Semiconductor Outputs

Relays have the advantage of very high off impedance, very low off leakage, very low on resistance, ambivalence between AC and DC signals, and built-in isolation. However, they are mechanical devices and thus provide lower reliability and typically slower response rates. Semiconductor outputs typically have an advantage in speed and reliability. Semiconductor switches also tend to be smaller than their mechanical equivalents, so a semiconductor-based digital output device will typically provide more outputs per unit volume.

When using DC semiconductor devices, be careful to consider whether your system requires the output to sink or source current. To satisfy differing requirements, UEI offers DIO boards such as the DIO-432 and DIO-433. The 432 offers 32 channels of digital output (600 mA current sinking), the 433 offers 32 channels of digital output (600 mA current sourcing).

2.3.2 Current Limiting / Fusing

Most outputs, and particularly those used to switch high currents (100 mA or so), offer some sort of output protection. There are three types most commonly available. The first is a simple fuse. Inexpensive and reliable, the main problem with fuses, is they cannot be reset and must be replaced when blown.The second type of current limiting is provided by a resettable fuse. Typically, these devices are variable resistors. Once the current reaches a certain threshold, their resistance begins to rise quickly, ultimately limiting the current and shutting the current off.Once the offending connection is removed, the resettable fuse reverts to its original low impedance state. The third type of limiter is an actual current monitor that turns the output off if and when an overcurrent is detected. This "controller" limiter has the advantages of not requiring replacement following an overcurrent event. Many implementations of the controller configuration also allow the overcurrent trip to be set on a channel by channel basis, even with a single output board.

2.3.3 Output Confirmation / Readback

For critical controls, it is often desirable or even required to be able to read back the status of a digital output. Of course, this can be done by connecting a digital input to the output and monitoring it, but that doubles the number of DIO channels required. Many digital output devices provide a way to automatically read-back the state of the output. Be a bit careful with how the readback is implemented. In some products, the readback is simply the status of the latch or buffer that is controlling the output and not the output itself. This allows the application to confirm that the correct data has been written to the device, but it does not confirm that the output has actually gone into the desired state. The more secure systems actually monitor the actual output voltage and current, providing not only confirmation of the output state, but also a powerful diagnostic capability capable of detecting short/open circuits as well as other suspect conditions or behavior. Many other vendors also provide some type of output confirmation or read-back capability.

2.3.4 PWM and Soft-Start Functions

The UEI DNA-DIO-432 and 433 boards offer a “Soft Start/Stop” feature for PWM outputs that greatly increases the reliability of devices like incandescent bulbs where thermal shock reduces life expectancy. This feature applies a gradually increasing PWM sequence to the output or input that gradually turns it on, minimizing the thermal shock applied to the device

2.3.5 Counter / Timer Functions

Counter/Timers are used for such functions as measuring frequency, pulse width, or pulse duration, counting events, and generating periodic or PWM outputs. A thorough article of counter/timer applications could easily run longer than this entire piece. However, we will touch on a variety of the specifications that are most commonly of concern.

2.3.6 Up Counter

Counters can typically be configured as “up” counters, “down” counters, or “up-down” counters, Up counters are the most commonly used of the configurations and, as the name implies, simply start at zero and count up. These counters are used for counting events, measuring frequency, measuring pulse width, etc.

2.3.7 Down Counters

Down counters are most commonly used as timers or alarm generators (e.g., watch dog timers).Typically, a preset value is loaded into counter register and on each “event” (e.g., rising or falling edge) the counter decrements by one. When the counter reaches zero, it typically generates an interrupt or reset pulse, so the application knows the specific number of input events has been obtained.

2.3.8 Up/Down Counters

Up-down counters are commonly used when the difference in the number of “events” between two inputs is important, while the absolute number of events is not. Up-down counters are commonly used in devices such as quadrature encoder inputs or balancing applications.

“Special Function” I/O Hardware

2.4 Motion I/O

Much of the “other” common I/O is related to monitoring -- and sometimes control of -- motion. The following section provides an introduction to the types of motion I/O you’re likely to see.

2.5 Synchros and Resolvers

Synchros and Resolvers have been used to measure and control shaft angles in various applications for over 50 years. Though they predate WWII, these units became extremely popular during WWII in fire/gun control applications, as indicators/controllers for aircraft control surfaces and even for synchronizing the sound and video in early motion picture systems. In the past, these units were also called Selsyns (for Self-Synchronous.)

At a first glance, Synchros and Resolvers don’t look too different from electric motors. They share the same rotor, stator, and shaft components. The primary difference between a synchro and a resolver is a synchro has three stator windings installed at 120 degree offsets while the resolver has two stator windings installed at 90 degree angles.

To monitor rotation with a synchro or resolver, the data acquisition system needs to provide an AC excitation signal and an analog input capable of digitizing the corresponding AC output. Though it is possible to create such a system using standard analog input and output devices, it is a fairly complicated process to do so, and most people opt for a dedicated synchro/resolver interface. These DAQ products not only provide appropriate signal conditioning, they also typically take care of most of the “math” required to turn the analog input into rotational information. It always a good idea to check the software support of any synchro/resolver interface to ensure that it does provide results in a format you can use.

Most synchro/resolvers require an excitation of roughly 26 Vrms at frequencies of either 60 or 400 Hz. It is important to check the requirements of the actual device you are using. Some units require 120 Vrms (and provide correspondingly large outputs…be careful.) Also, some synchro/resolver devices, and in particular those used in applications where rotational speed is high, require higher excitation frequencies, though you will seldom see a system requiring anything higher than a few kilohertz.

Finally, some synchro/resolver interfaces such as UEI’s DNx-AI-255 provide the ability to use the excitation outputs as simulated synchro/resolver signals. This capability is very helpful in developing aircraft or ground vehicle simulators as well as for providing a way to test and calibrate synchro/resolver interfaces without requiring installation of an actual hardware.

Note: In some applications the synchro/resolver excitation is provided by the DUT itself. In such cases, it is important to make sure that your DAQ interface is capable of synchronizing to the external excitation. This is typically accomplished by using an additional analog input channel.

2.6 LVDT and RVDT

LVDT and RVDT (Linear/Rotary Variable Differential Transformer) devices are similar to synchro/resolvers in that they use transformer coils to sense motion. However, in an RVDT/LVDT, the coils are fixed in location and the desired signal is induced by movement of the ferromagnetic “core” relative to the coils. (Of course, a primary difference of the LVDT and synchro/resolvers is that the LVDT is used to measure linear motion, not rotation.)

Another difference between RVDTs and synchro/resolvers is the RVDT has a limited angular measurement range, while the synchro/resolver can be used for multi-turn rotational measurement with rated accuracy for the entire 0-360 degree spectrum.

When connecting an RVDT/LVDT to your DAQ system, most of the concerns are similar to those of the synchros. First, you may build an RVDT/LVDT interface out of generic A/D and D/A interfaces, but it’s not a trivial exercise. Most people opt for a special purpose interface designed specifically for the task. In addition to eliminating the need for complex signal conditioning, the specifically designed interface will usually convert the various signals into either rotation (in degrees or percent of scale) or in the case of the LVDT, into percentage of full scale.

The LVDT/RVDT interface will also provide the necessary excitation, which is typically in the 2-7 Vrms range at frequencies of 100 Hz to 5 kHz. Some systems may provide their own excitation, and in such a case, be sure the LVDT/RVDT interface you choose has a means to synchronize to it.

Finally, like the synchro/resolver, LVDT/RVDT interfaces such as UEI’s DNx-AI-254 provide the ability to use the excitation outputs as a simulated LVDT/RVDT signals. This capability is very helpful in developing aircraft or ground vehicle simulators, as well as for providing a way to test and calibrate RVDT/LVDT interfaces without requiring installation of the actual hardware.

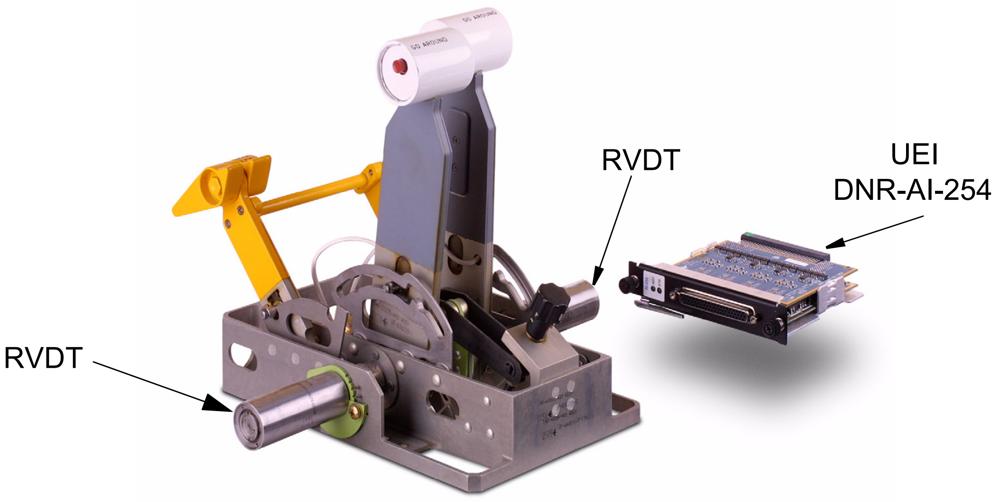

Figure 3.3. Interfacing to RVDT devices such as this jet throttle control is made easy using a dedicated RVDT/LVDT Interface such as UEI’s DNR-AI-254, shown at right of photo.

2.7 String Pots

String pots are designed to measure linear displacement. They are typically lower cost than LVDTs and can offer much longer measurement distances.

As their name implies, the basis for string pot is a string or cable, and a potentiometer. Basically, a string and a spring are attached to the wiper screw of the potentiometer and as the string is pulled, the potentiometer resistance changes. The string pot provides a calibration factor that describes what displacement is represented by a percentage of resistance change.

As a simple variable resistance device, with a linear output, most string pots are interfaced to standard A/D boards. The most common connection configuration connects a voltage reference to the one side of the string pot with the other side connected to ground. The “wiper” is then connected to an A/D input channel. With the string completely retracted, the measured voltage will be equal to either reference voltage or zero. With the string completely extended, the voltage measured will be the opposite (either zero or the reference voltage). At any intermediate string extension, the voltage measured will be proportional to the percentage of string “out”.

Be sure your voltage reference has the output current capacity to drive the string pot resistance. Your measurement will be in error by the same percentage as any voltage reference error. In some cases, it may be beneficial to drive the string pot with a higher capacity, lower accuracy voltage source. Should you need higher accuracy than the voltage source provides, you may always dedicate an A/D channel to measure the voltage source. This makes the system virtually immune to errors in the voltage source.

Another note is that string pots are single ended, isolated devices. When connecting a string pot to a differential input, be sure to connect the string pot/reference ground and the A/D channel’s low or “-“ input. Failing to make this connection in some way will likely cause unreliable and even “odd” behavior as the input “-“ terminal floats in and out of the input amplifier’s common mode range.

2.8 Quadrature Encoders

Quadrature encoders are also used to measure angular displacement and rotation. Unlike the other devices we have described in this article, these products provide a digital output. There are two primary digital outputs which are in the form of 90 degree out-of-phase digital pulse trains. The frequency of the pulses determine the angular velocity, while the relative phase between the two (+90°or -90°) describes the direction of rotation.

These pulse trains can be monitored by many generic DAQ counter systems with one of the outputs being connected to a counter clock while the other is connected to an up/down pin. However, the Quadrature encoder is such a common part of many DAQ systems that many vendors provide an interface specifically developed for quadrature measurements.

One thing that cannot be determined from the pulse counts alone is the absolute position of the shaft. For this reason, most Quadrature encoder systems also provide an “Index” output. This index signal generates a pulse at a known angular position. Once a known position is identified, the absolute position can be determined by adding (or subtracting) the relative rotation to the known index position.

Many encoders provide differential outputs, but differential noise immunity is seldom required unless the electrical environment is very harsh (e.g., local arc-welding stations) or the runs from the encoder to the DAQ system are very long (100s of feet or more).

Dedicated Quadrature Encoders are available from many vendors in a variety of configurations.

2.9 ICP/IEPE Piezoelectric Crystal Sensors

When considering piezoelectric crystal devices for use in a DAQ system, most people think about vibration and accelerometer sensors as these crystals are the basis for the ubiquitous ICP/IEPE sensors. It is generally understood that when you exert a force on a piezoelectric crystal it causes the crystal to deform slightly and that this deformation induces a measurable voltage across the crystal.

Another feature of these crystals is that a voltage placed across an unstressed piezoelectric crystal causes the crystal to "deform". This deformation is actually very small, but also very well behaved and predictable. Piezoelectric crystals have become a very common motion control device in systems that require very small deflections. In particular, they are used in a wide variety of laser control systems as well as a host of other optical control applications. In such applications, a mirror is attached to the crystal, and as the voltage applied to the crystal is changed, the mirror moves. Though the movement is typically not detectable by the human eye, at the wavelength of light, the movement is substantial.

Driving these piezoelectric devices presents two interesting challenges. First, achieving the desired movement from a piezoelectric crystal often requires large voltages, though mercifully at low DC currents. Second, though the crystals have high DC impedances they also have very high capacitance, and driving them at high rates is not a trivial task. Special drivers such as UEI's PD-AO-AMP-115 are often required as the typical analog output board does not offer the output voltage or capacitive drive capability required.

2.10 Communication Interfaces

Communications is an "oft forgotten" part of many data acquisition and control systems. Note that we're not talking about the communications interface between the I/O device and the host computer. We're referring to various devices to/and from which we either need to acquire data or issue control commands. Examples of this type of device might be the CAN-bus in an automobile or the ARINC-429 interface in either a commercial aircraft or ship.

2.11 ARINC-429

ARINC-429 is the avionics interface used by almost all commercial aircraft (though 429 is not the primary interface on the Boeing 777 and 787 and the Airbus A-380). It is used for everything from communicating between various complex systems such as flight directors and autopilots as well as for monitoring more simplistic devices such as airspeed sensors or flap position indicators.

In test systems, it's often critical to coordinate data from ARINC-429 devices with more typical DAQ devices such as pressure sensors and strain gauges. When studying stress placed on a wing spar, you'd certainly like to be able to coordinate the stress results with such parameters as airspeed, altitude, and any turn or climb/descent induced g-forces.

While the ARINC-429 bus is well defined, computer based interfaces for the 429 bus are very different. The 429 bus defines functionality in terms of labels, with each label representing a different parameter. It's important for the data acquisition system to be able to differentiate between the labels. If your system is only interested in airspeed, you want to ignore other parameters. Note that some ARINC-429 interfaces allow you to make these selections in interface hardware, while others place the burden of effort on the software.

Many ARINC-429 devices run on a definitive schedule. For example, the magnetic heading may be transmitted every 200 mS. Some ARINC interfaces count on software-based scheduling while others build the scheduling into an FPGA in the hardware. The more factors and parameters a given ARINC interface builds into hardware the better, as you may be counting on those precious host CPU cycles for other things.

2.12 MIL-STD-1553

MIL-STD-1553 is the military's equivalent to ARINC-429, though structurally it is VERY different. The first and most obvious difference is that most 1553 links are designed with dual, redundant channels. Though commercial aircraft don't typically get wires cut by bullets or flak, military aircraft are typically designed such that a single cut wire or wiring harness won't cause a loss of system control. If you are looking to "hook" to a MIL-1553 device, be sure your interface has both channels.

Also, a MIL-1553 device can serve as Bus Controller, Bus Monitor, or Remote Terminal. Not all interfaces support all three functions. Be sure the interface you select has the capability you require.

As with the ARINC-429 bus, when operating as a bus controller, the unit must be capable of detailed transmission scheduling (including major and minor frame timing) and this is best performed in hardware rather than via software timing.

2.13 CAN

The CAN (Controller Area Network) bus is the standard communications interface for automotive and truck systems. Gone are the days when your car was controlled by mechanical linkages, gears, and high current switches. Your transmission now shifts gears based on CAN commands sent from a computer. Even such things as raising/lowering the windows and adjusting the outside rearview mirror are frequently no longer done via simple switches, but are now done via CAN sensors and actuators. Vehicle speed, engine RPM, transmission gear selection, even internal temperature are all available on the CAN bus.

As with the ARINC-429 aircraft example, when running tests in a car or truck, it's very useful to be able to coordinate the data available on the various CAN networks with any more conventional DAQ measurement you may be making. If you are measuring internal vibration, you'll want to coordinate it with Engine RPM and speed (among other things).

Like any data acquisition system, one of the first things you need to be aware of when specifying a CAN interface system is how many CAN ports you will need. There are sometimes 50 or more different CAN networks in a given vehicle. Be sure your system has enough channels to grab all the data you still need. The CAN specification supports data rates up to 1 megabaud. Be sure the system you specify is capable of matching the speed of the network you wish to monitor.

2.14 RS-232/422/423/485

People first began predicting the demise of RS-232 in the 1980s. Of course, RS-232 is still around and kicking. If Mark Twain were still alive, I'm sure he'd write something on the order of "The reports of the death of RS-232 have been greatly exaggerated". The RS-series ports remain extremely common in the data acquisition and control arena.

RS-232 is older, and slower than its 422/423/485 family mates, but usage of both is still very common. As a fairly simple interface, there is not too much to consider when specifying an RS-series interface, but a few words may be in order. First, not all serial devices operate at the same speed. Be sure to specify a device that will handle the baud rate of your device. Second, for stable and consistent operation, especially at higher speeds, be sure to select a device with a substantial FIFO.

Note that RS-232 ports, and in particular those on older devices, use hardware handshaking signals such as “Ready to Send”, “Clear to Send”. Many newer RS-232 interfaces do not support these handshaking signals, so be sure to check that your serial interface supports what you need.

Another common series of questions arise when considering the differences between RS-422, 423 and 485. RS-422 uses a two-wire, fully differential signal interface. RS-423 uses the same signal levels, but uses only one of the two wires. RS-422 and RS-485 are almost identical. The difference is that an RS-485 is networkable and can be connected to multiple serial devices. An RS-485 interface will almost always be perfectly suitable for talking to an RS-422 device.

2.15 Timing and Synchronization

One final aspect of “non-standard” data acquisition and control systems is how larger systems are synchronized. Often, it is critical that you know not only “what” happened, but also “when” it happened. In small systems, this is usually easy to accomplish as the analog inputs and even the output excitation, are on the same board. However, systems with high channel counts and, in particular, applications spread over large areas require careful attention to timing. An in-depth discussion of this topic is well beyond the scope of this article, but the following brief section may help the reader start off in the right direction immediately.

2.16 Synchronization

2.17 Simple Wiring of Clock/Trigger

Simple Wiring of clock and trigger signals is often the quickest, easiest and most accurate way to synchronize events in different places. Most DAQ devices have one or more trigger/clock inputs and it is frequently possible to simply synchronize systems by connecting these signals. Note that the propagation of an electronic signal in a wire is very close to the speed of light. A thousand feet of wire would typically only introduce about a microsecond of delay.

Most people think of GPS (Global Positioning System) as an inexpensive way to find the nearest gas station or pizza parlor. However, GPS is also an excellent technology for providing very precise time information. In fact, the entire basis for the GPS system is extremely accurate clocks (as well as satellites at known locations). Even a relatively inexpensive GPS can provide absolute timing accuracy better than 1 microsecond. Though the GPS on your boat or car may not have a time output signal, many inexpensive GPS devices provide a 1 or 5 Pulse per Second signal accurate to within 1 uS of absolute UTC. Using these simple and inexpensive devices, it becomes straightforward to synchronize data samples anywhere in the world.

Figure 2. Typical UEI Garmin GPS System

Low cost GPS interfaces such as the Garmin unit shown in **Figure 2** with a UEI data acquisition and control "Cube" can provide world-wide timing and synchronization accuracy of approximately 1 microsecond.

2.18 IRIG

IRIG (Inter-Range Instrumentation Group) is not so much a timing technology as it is a timing protocol. However, most of the high accuracy timing and synchronization systems available today have standardized on one of the IRIG protocols. These high performance timing devices are generically referred to as IRIG interfaces. The underlying timing of an IRIG device can be based upon many things such as GPS, WWV synchronization, or a highly stable and accurate on-board clock. The key to using an IRIG device is simply to look at the device's rated timing accuracy and verify that this will provide the synchronization accuracy your system requires.

Summary

As you can see, there is often much more to specifying a data acquisition and control system than simply selecting the appropriate A/D, D/A, and digital I/O devices. Hopefully, this article has provided a useful introduction to some of the more common “second tier” interfaces. Should you need further information on any of these items, it should be readily available a few key-clicks away on your favorite web-based search engine.