DDC Basics

Sphere Systems Pty Ltd

Input / Output (I/O) Basics

Binary Inputs

A digital input typically consists of a switch with voltage free contacts. Depending on the switch's open/closed status, the sensing device detects a voltage or no voltage condition, which in turn generates a logical 0 or 1, on or off, alarm or normal or similarly defined state. For example, a digital input could be whether a chiller is operating or not, or if a fan was on or off.

Binary Outputs

A digital output typically consists of a relay or contactor that either opens or closes the circuit between two terminals depending on the binary state of the output. This is primarily used to turn items on and off such as relays or items of equipment.

Types of Binary Devices

The following sections outlines common switching devices currently used by the industry.

Switches

In the world of HVAC control, there is basically one type of device used to complete a digital input (BI) circuit. A switch, employed in various forms, is this device.

A switch is an electrical device used to enable or disable flow of electrical current in an electrical circuit. Switches may be actuated in a variety of ways, including movement of two conducting materials into direct contact (mechanical), or changing the properties of a semi-conducting material by the application of voltage (electronic).

Switches are typically rated in terms of voltage, voltage type (AC or DC), current carrying capacity, current interrupting capacity, configuration, and load characteristic (inductive or resistive). Also specified are applicable ranges of ambient conditions over which the ratings are valid. Current carrying capacity (or current rating) is the maximum current that may continuously flow through the closed switch contacts without exceeding the maximum permissible temperature.

Process medium property sensing switches are also rated by parameters such as adjustment range, accuracy or repeatability, and deadband or differential. The range of a control switch is specified by upper and lower process values between which the switch has been designed to operate. The accuracy or repeatability of a control switch is a value typically measured in process units or percent of range that represents the expected maximum deviation from setpoint at which the switch will operate under test conditions. The switch differential or deadband is the change in process value required to cause the state of the switch to change. For example, a pressure switch that makes at 100 Pa and breaks at 8 Pa has a 2 Pa differential.

Switch contacts are characterized in much the same way as relay contacts.

Hand Switches

Hand switches are used as digital input devices and in hardwired electrical control circuits associated with digital outputs. Hand switches come in numerous sizes, shapes, and configurations. Common switch types include rotary, selector type switches, toggle switches, and pushbuttons. Selector and toggle switches are almost always maintained contact type. Pushbuttons may be momentary or maintained contact type. Selector switches can have key operators to prevent tampering.

Temperature Switches

Temperature switches (also called thermostats depending on application) are commonly used in DDC control systems to provide a digital input when a process medium temperature rises or falls to a set temperature. Switches with a number of different operating principles are manufactured.

Humidity Switches

Humidity switches, or humidistats, are used in DDC control systems to provide a digital input when a process or space humidity level rises or falls to a set level. Common applications are high limit safety interlocks for humidifiers, space or process humidity alarms, and simple on-off humidity control.

Flow Switches

Flow switches are used to provide a digital input to DDC controls systems when a fluid flow rate has risen above or fallen below the set value. Common applications include safety air and water flow interlocks for electric heaters and humidifiers, chiller safety interlocks, and burner safety interlocks. Numerous technologies are available, but the most common types used in DDC systems for HVAC control are mechanical and differential pressure types.

Level Switches

Level switches are used in DDC control systems (for HVAC) to provide a digital input when the fluid level in a tank, vessel or sump has reached a predetermined height. Common applications include cooling tower sump level control and monitoring, steam condensate tank level, storm water and sewage sump level monitoring and control and thermal storage tank level monitoring.

Pressure Switches

Pressure switches are used in DDC systems to provide status indication for fans, filters and pumps, and to provide flow and level status indication by virtue of the predicable relationships between pressure and these values. Pressure switches may be mechanical or electronic.

Vibration Switches
Vibration switches are used to provide a signal when vibration levels in rotating machinery such as fans, reach unsafe levels. Vibration switches are commonly applied on large cooling tower and air handling unit fans.

Moisture Switches
Moisture detecting switches are commonly used to detect moisture under raised floors, in piping and tank containment areas and in the drain pans of air handling units to alert system operators before damage or flooding occurs.

Current Switches
Current sensing relays are used in DDC systems to monitor the status of electrical devices. The devices typically have one or more adjustable current set points. Common applications include fan and pump on/off status feedback. Current switches can detect broken fan belts if properly adjusted. Current relays can also be used for phase monitoring.

Analogue Inputs

An analogue input is a measurable electrical signal with a defined range that is generated by a sensor and received by a controller. The analogue input changes continuously in a definable manner in relation to the measured property.

Common Types

There are basically two types of analogue input signals that WebXL can support: voltage and current.

Voltage

Common voltage signals used in the controls industry are 2-10 V, 0-5 V and 0-10 V.

Current

The 4-20 mA signal has become the industry's standard current signal for use with analogue and digital controllers. With the WebXL unit, to convert 4-20mA to 0-10V, a 500 ohm resistor will be required. Some 4-20mA devices can only drive a 250 ohm resistor so this will convert the devices signal range to 0-5 volts only.

Analogue Outputs

An analogue output is a measurable electrical signal with a defined range that is generated by a controller and sent to a controlled device, such as a variable speed drive or actuator. Changes in the analogue output cause changes in the controlled device that result in changes in the controlled process.

Controller output digital to analogue circuitry is typically limited to a single range of voltage or current, such that output transducers are required to provide an output signal that is compatible with controlled devices using something other than the controller's standard signal.

Voltage

Common voltage signals used in the controls industry are 2-10 V, 0-5 V and 0-10 V.

Types of Analogue Devices

Temperature Measurements

One of the most common properties measured in the HVAC control world is temperature. Human comfort, computer room requirements, and a host of other considerations make temperature measurement necessary to HVAC control strategies.

Types of Temperature Measurement Devices

Several temperature measurement technologies exist for use with DDC control systems. These can be resistance temperature detectors (RTDs), thermistor based devices, thermocouples and IC based temperate sensors. Note that WebXL only supports IC based temperature sensors that produce a 0-10V DC output.

Installation

Temperature sensors are all small devices with similar mounting techniques used for all of the types. Sensors for pipe and duct mounting are commonly sheathed in a stainless steel or PVC sheath of 6mm diameter (larger and smaller diameters are available). Wiring may be exposed or contained in various types of enclosures. Sensors for liquid piping systems may be mounted with direct immersion into the fluid or installed in a tubular sheath called a thermowell or well to allow removal without draining the piping system and to reduce the likelihood of leaks. Sensors installed in wells should be installed with a heat transfer compound filling the space between the sensor and the well to insure good thermal contact between the measured fluid and the sensor.

In measuring the temperature of air in large ducts, it is often desirable to use an averaging element because the air temperature can vary significantly over the cross section of the duct. Averaging elements are commonly applied downstream of mixing dampers, and following large or multiple heating or cooling coils.

Sensors for outdoor air applications should be located in normally shaded areas to prevent the heating effects of solar radiation. In adverse or outdoor environments, it is sometimes desirable to enclose sensors in aspirated cabinets to prolong their life and reduce maintenance. Aspirated cabinets typically include a filtered air intake and an exhaust fan to provide positive airflow through the enclosure. Flush mount wall sensors, wire guards or locking guards are also used to protect sensors in areas subject to vandalism.

Humidity Measurements

Humidity is the presence of water vapor in air. The amount of water vapor present in air can affect human comfort and numerous material properties. It is a parameter that HVAC designs often must take into account and therefore can be a required measurement in HVAC control schemes. The amount of water vapor in air can be defined by one of several ratios, which include relative humidity, humidity ratio, specific humidity, and absolute humidity. By far the most common measurement of humidity in the HVAC industry is relative humidity (RH).

Relative humidity is the ratio of partial water vapor pressure in an air-water mixture, to the saturation vapor pressure of water at the same temperature. This is analogueous to the ratio of the number of water molecules per unit volume of the mixture to the number of water molecules that would exist in a saturated mixture at the same temperature.

Pressure Measurements

Pressure is measured in DDC controls systems for HVAC in order to control the operation and monitor the status of fans and pumps. Space pressure is sometimes measured and used for control. Pressure is also the basis of many flow and level measurements.

Types of Pressure Sensors

Diverse electrical principles are applied to pressure measurement. Those commonly used with DDC control systems include capacitance and variable resistance (piezoelectric and strain gage).

Flow Measurements

Flow measuring devices are widely used in DDC control systems for HVAC to monitor and control various air and liquid flows. Typically, airflow-measuring devices are used to monitor and control the output of fans, dampers, and associated equipment used to control outside airflow, VAV box airflow, and building and space pressures. Liquid flow is commonly measured to maintain required flows in boilers, chillers and heat exchangers, and to control and monitor energy production and use (requires temperature measurement also).

Liquid Level Measurements

Liquid level measurements are typically used in DDC control systems for HVAC applications to monitor and control levels in thermal storage tanks, cooling tower sumps, water system tanks, pressurized tanks, etc.

Electrical Measurements

Monitoring of electrical system attributes is performed by DDC control systems to protect system components, determine power and energy consumption of various components, and implement usage and demand control strategies to conserve energy. A variety of hardware and techniques are applied to these measurements.

Energy Measurements

The measurement of energy is a very important aspect of the DDC system. Savings due to operational procedures and equipment performance can be directly determined through this measurement. A variety of devices and methods are currently available.

Types of Energy Measurement Devices

The three most common energy measurements used for DDC systems are airside, waterside and electrical energy measurements. Airside energy measurements are typically calculated in the DDC system using air temperature and flow rate measurements. Waterside energy can be calculated in the DDC system or with energy measuring devices called kW or BTU meters. Electrical energy measurements can be calculated in the DDC system or with Power Monitoring Devices.

Power Monitoring Devices

Power monitoring devices can be used to monitor electrical energy usage. They can either directly measure the energy usage by providing pulses that represent kW per hour, or can provide an analogue signal that measures power which can be used in an energy calculation (over time) in the DDC system.

Function Basics

Continuous loops & Heating/Cooling Loops

These functions are used where proportional control is required. Heating/Cooling loops are just a pair of continuous loops which share the same input. They provide a convenient shortcut for doing both heating and cooling control. Everything discussed below applies to both heating/cooling loops and continuous loops.

What is a Continuous loop?

A continuous loop takes an analogue value as an input and compares it to a setpoint. The difference, or error value, is used to drive the output which then drives the controlling device in such a way as to minimise the error. The simplest form of loop just multiplies the error by a constant value. The value of the multiplier is called the proportional gain (Pg). The equation for this is:

Output = Error * Proportional gain

The disadvantage of this type of loop is that there must always be an error for the output to be nonzero. One can add a fixed value to the output to set the error to be zero at one value. This makes the loop become a Reset loop. The equation for this is:

Output = (Error * Pg) + Reset value

The reset value is normally set to the expected required output under normal conditions.

Integral gain

The error can be removed if we add an Integral gain (Pi) to the loop. Integral gain effectively sums the error over time and multiplies this sum by the integral gain and adds the result to the output. This has the effect of gradually driving the output higher or lower as time progresses which results in the error eventually reaching zero. The integral gain has to be kept fairly low otherwise the loop can become unstable and the output will switch between fully on to fully off. Integral gain is extremely useful in providing an adaptive control loop.

Differential gain

The problem with using integral gain is that it takes time for the loop to reach equilibrium. While this works perfectly well in normal building control it has problems with fast responding control such as steam control. We can add another type of control called Differential gain (Pd) to a control loop to handle this sort of control. Differential control looks at the rate of change of the input and multiplies this by the differential gain and adds the result to the output. Take the case of steam where the control valve opens a bit too far. You will get a very rapid increase in the output which will give a large differential error resulting in a very rapid loop response. Differential gains have to be kept fairly low to keep the loop stable.

PID loop gains

The use of the three types of gain gives what is called a PID loop. In a building the typical sort of proportional gain used is about 45. If integral gain is used a typical starting point is about one hundredth of the proportional gain. The differential gain is likely to be similar in value to the integral gain. Always start at a conservative value and only increase the gains slowly if required. If the loop becomes unstable dramatically reduce the gain values.

Deadband

To prevent actuator wear it is common practice to use a deadband in a continuous loop. The deadband is the amount the input can change without causing any change in the output. For example, if you have a setpoint of 21C with a deadband of 0.5C then the temperature can vary from the setpoint by 0.5C before the output will change.

Heat/Cool loops

Heating/Cooling loops use 2 loops to generate a heating and a cooling input. They share a common input and otherwise are identical to using 2 separate loops, one for heating and one for cooling. The advantage of using a Heating/Cooling loop compared to using 2 separate loops is that there is less data to enter when configuring the loop and the polarity for the heating and cooling outputs is automatically selected.

Let's take an example. Imagine a loop where the setpoint is fixed at say 20ºC, the loop gain is set to 1 and there is no integral or differential gain and the reset value is 0. The error is calculated as the setpoint minus the input so that for inputs above the setpoint the error is negative and hence the output of the loop is negative. You cannot set an output to less than 0V so it will be locked to zero. As the input falls below the setpoint the error becomes positive and the output of the loop is positive.

Positive outputs are allowed. This is a typical heating loop. When the input is above the setpoint the loop output is always 0. The loop output increases as the temperature falls further below the setpoint.

This is a typical heating loop. As the temperature falls you want to increase the heating. Now if we invert the error so that the error is the input minus the setpoint the behaviour of the loop changes. Now if the input is below the setpoint the error is negative and the loop output is 0. As the input rises further above the setpoint the error becomes larger and is positive so the loop output increases. This is a typical cooling loop.
In either case if you use a reset value then the reset value is added to the loop output so that when the input equals the setpoint the loop output is at the reset value.

Discrete loops

Discrete loops provide a discriminator type of function. They take an analogue value as an input and compare this to a setpoint. The output of the loop is a binary value.

Switch Functions

If the input is above the setpoint then the output will be ON, if the input is below the setpoint the output will be OFF. This is a basic Switch function. The output of the loop can be inverted which means that the ON becomes OFF while the OFF becomes ON.

Window Functions

A Window function uses an upper and a lower setpoint. If the input is between the 2 setpoints the output is ON otherwise it is OFF. Again the loop output can be inverted making the output ON when the input is less than the lower setpoint or higher then the upper setpoint.

If the input is not stable then one can get repeated transitions from ON to OFF and vice versa as the input oscillates around the setpoint value. To overcome this problem hysteresis can be added to the function. With hysteresis the output changes from OFF to ON when the input is above the setpoint PLUS the hysteresis. It turns OFF when the input falls below the setpoint MINUS the hysteresis. A similar operation applies to a window function at both the upper and lower trigger points. If the input now oscillates around the setpoint the output remains stable. The hysteresis value if chosen to accommodate expected small scale fluctuations in the input.

Arithmetic functions

The arithmetic functions in the WebXL system accept up to 16 inputs, which have to be analogue points or fixed values. The output of an arithmetic function is an analogue output or variable. A variety of arithmetic functions are implemented as detailed below. Note that all inputs to a function must use the same units and scale factor otherwise the output is probably meaningless. All calculations are done using the internal 12 bit value for a point. The outputs and calculations are protected from returning an invalid result so that numbers greater than 4095 are limited to 4095 and negative numbers are set to 0.

Maximum value

This functions looks at each input and returns the maximum value found.

Minimum value

This functions looks at each input and returns the minimum value found.

Average value

This functions looks at each input and returns the average value of all the values.

Median value

This functions looks at each input and returns the median value of the inputs. The median is the midpoint between the minimum and the maximum.

Sum

This function returns the sum of all the inputs. Note that this can result in a value which is greater than the internal 12 bit representation. The result is limited at the maximum internal value.

Enthalpy

This function takes a temperature as the first entry and the humidity as the second entry and returns the enthalpy. The calculations are based on a temperature range of 0-100°C and a humidity between 0 and100%. The resulting scale is 0 – 135 kJ kg.

Difference

This function only uses 2 inputs and computes the difference between the first and the second entries as:

Output = first input - second input.

If the result is less than zero the result is set to 0.

Multiply

This function multiplies the first entry by the second entry and divides the result by the scale factor. The scale factor can be 1, 10 or 100. The result is limited to 4095 which is the maximum value permitted in 12 bit arithmetic.

Output = (first input - second input) / scale factor

Divide

This function multiplies the first entry by the scale factor and then divides the result by the second entry. The result is limited to 4095.

Output = (first input * scale factor) / second input

Slope and Offset

This function implements the function:

Output = ((first input * second input) / scale factor) + third input

Which represents the standard line equation: y = ax + b where a is the slope of the line and b is the offset.

Reverse Slope and Offset

This function implements the function:

Output = third input - ((first input * second input) / scale factor)

Which represents the equation: y = b - ax where a is the slope of the line and b is the offset.

Logic functions

Logic functions are implemented as an array of AND/OR functions. Each function takes up to 8 inputs and combines these as a set of 8 AND functions which are all OR'd together. If one AND function is TRUE then the output of the function is TRUE. The output of the function can also be inverted if required. The inputs must be binary inputs, variables or outputs and the output can be a binary variable or output.

To define a function you have to select the inputs for the function. There can be any number of inputs from 1 to 8. The AND functions are defined in 8 columns where an input can be selected as True, False or not used.

This defines a logic function of the form:

Output = (A & B & /D) OR (/B & C & D & E) OR /A

Where & represents the logical AND and /X represents the complement value of X Entries with white backgrounds are ignored. You only have to assign physical points to inputs which are used.

Logic functions can be cascaded and are evaluated from 1 to 32 so that if you feed back an output from function 27 to function 25 any changes in the output of LF25 due to change in the output of LF27 will not be processed until the next iteration. Logic functions are evaluated once/second. In general feeding an output from a later function to an earlier one will introduce a delay while feeding forward won't. There could be cases where this introduced delay is desirable.

Lead/Lag functions

A Lead/Lag function uses a number of inputs and drives a number of outputs. It is used to cycle the operation of plant such as chillers. Each device in the list has a control input, a fault input and an output. The algorithm is designed for use with multi-stage heating or cooling. Inputs MUST turn on in order for the algorithm to work. If the Fault input is true then that piece of plant is assumed to be unavailable and is taken out of the algorithm.

The various assigned outputs are put into a list in the order entered into the list of points. When an input is turned ON the algorithm turns ON the first output in the list. When the next input is turned ON the algorithm will turn ON the next output in the list. Note that there is no correlation between which input is turned ON and which output is turned ON.

WebXL Delay functions

Delay functions are used when you need something to happen for a longer, or possibly shorter, time than a binary input is present for. An example of this is when a light should remain on for a few seconds after the switch controlling it is turned off. This is used in modern vehicles to allow the cabin light to remain on while the person is locking the car.

A DDC system should allow the generation of a number of commonly used types of delay. In addition, a delay where the time delay can be controlled by an analogue point is very useful in implementing energy saving optimised start/stop operation of plant.

Retriggerable fixed width delay

This form of delay drives the output ON whenever the input turns ON. The output stays on for a fixed time irrespective of how long the input is ON for. If the input turns OFF and then ON the delay gets restarted (re-triggered) so that the output will be ON for the delay time after the last input transition from OFF to ON.

Non-retriggerable fixed width delay

This form of delay drives the output ON whenever the input turns ON. After that time the input is ignored until the delay finishes. Thus this form of function ignores anything on the input while the delay time is active.

Input lengthened by delay time

This delay type is used to delay the turn on of the output. The output stays OFF after the input turns ON and stays OFF until the delay time after which the output follows the input. Multiple transitions of the input while the delay is active reset the delay.

Reverse operation

Triggering of the delay can be either on the OFF to ON (rising) edge of an input or on the ON to OFF transition (falling edge). The diagrams indicate what happens on the rising edge. Reverse operation inverts the Input.

Variable delay

Variable delay uses a number of other analogue parameters which control the delay time of the function. The delay time varies as a function of the source, setpoint, low and high limits at the time the input to the function becomes true (ON for normal operation or OFF for reverse action). If the source is below the setpoint then the delay is:

Delay = delay time * (1 - ((setpoint - source) / (setpoint - low limit)))

While if the source is above the setpoint the delay becomes:

Delay = delay time * (1 - ((source - setpoint) / (high limit - setpoint)))

Reverse action on the Variable delay changes these formulae to:
Source < setpoint:

Delay = delay time * (setpoint - source) / (setpoint - low limit)

Source > setpoint:
Delay = delay time * (source - setpoint) / (high limit - setpoint)

Normal operation of a variable delay sets the delay to 0 when the source equals the appropriate limit and the delay is equal to the set delay when the source is at the setpoint. The output of a variable delay turns ON when the delay time has expired after the input turns ON. Reverse operation on the input allows the selection of whether the rising or the falling edge on the input is used as a trigger.

Alarms

Alarms send notifications by email, system messages, SMS or even paging to alarm the user that something has gone wrong. This allows the consolidation of viewing alarms at a system wide level. In addition, an alarm can also be configured to drive a binary output or binary variable. This could be useful for providing a local user alert or for establishing fault-tolerant control. Each alarm has an "input" which if it is a binary value can be set to trigger an alarm either when the "input" becomes true or false. Analogue points generate an alarm by comparing the value of the point with that of another point or fixed value.

Hysteresis can be added to eliminate spurious alarm states when the 2 analogue values are similar. A binary point can also be used to Inhibit an alarm. For example, you could generate an alarm if the temperature in a room gets too cold but then inhibit the alarm from occurring based on a time schedule so that it doesn't fire at night or on weekends when the plant is turned off.

An alarm state has to persist for a user programmable time before an actual alarm is raised. If during this delay time the alarm goes away then the delay is reset. This can be used to prevent transitory conditions from causing an alarm.

Time and holiday control

Time and holiday schedules drive internal binary variables. This means that they can be used just like any other binary point. The great advantage of this becomes obvious when trying to do some otherwise difficult operations such as running plant over the midnight boundary.

All you need do is set a time schedule to turn on at the desired timer. Drive the output of the time schedule into a delay function which is set as a fixed delay corresponding to the time the plant should turn on. You then use the output of the delay function to control the plant.

Time schedules

A typical time schedule contains a start time and a stop time plus the days of the week when the schedule should be active. The times are set in 24 hour time mode. Public holidays and other date driven controls use the Public Holiday day.
Binary Variables 33 – 48.

Time group schedules

These allow a number of schedules to be grouped together to provide a more complex set of On and Off times during a day.
Binary Variables 49 -56.

Holiday schedules

Holiday schedules drive the Public Holiday day of the week in a time schedule as well as setting their own binary variable. A public holiday is a single day starting at midnight and ending at midnight.
Binary Variables 57 – 72.

Holiday From-To schedules

These schedules provide a range of holiday dates and times. They can be set to start at a particular time on a particular day and operate until a particular time and date. There a number of variations which can be employed for further flexibility. Besides being set for a range of dates they can be set to start immediately and end on a particular time and day or they can be set to start on a particular day and then run indefinitely.