Choosing the Best Type of Encoder For Your Application

For Some Applications The Best Solution May Surprise You

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Choosing the Best Encoder Type For Your Application

Overview

This white paper describes the advantages and disadvantages of different types and configurations of encoders with a focus on devices using an Ethernet/IP interface.

Different application situations are reviewed for size, cost and performance considerations and with respect to which encoder types fit best.

The industrial sensor market's selection of sensor interfaces can be broken down into over a dozen digital output interface types. These include ProfiNET, CANopen, Ethernet/IP, Modbus, Profibus and others. According to some studies, Ethernet/IP has the largest market share out of all of them by a few percent (at about 15%) and is the fastest growing segment. Based on this information, this white paper will focus on applications requiring an Ethernet/IP interface.

Application Example

A specific application is considered, followed by general considerations to apply to any application where an encoder is being considered.

Manufacturers use manual tool manipulators to reduce worker fatigue and prevent injury. Using encoders on the axes of a manipulator to monitor tool position provides additional advantages. See Figure 1 which shows a manipulator with two axes of rotation (need generic manipulator image).

With position feedback the location of the tool at the end of the arm can be known with precision. The assembly operation can be controlled, ensuring that all operations are performed, they are performed in the correct sequence, and in the correct location. Tool operation can be enabled/disabled based on the position information, improving error avoidance and traceability. As Industrial Ethernet becomes more prominent, manufacturers are increasingly demanding encoders with Ethernet/IP capability. There is often not sufficient space on a manipulator for large encoders with integrated bus connectivity. Using an encoder with a smaller form factor, along with a separate bus gateway, is one possible solution to this engineering problem.

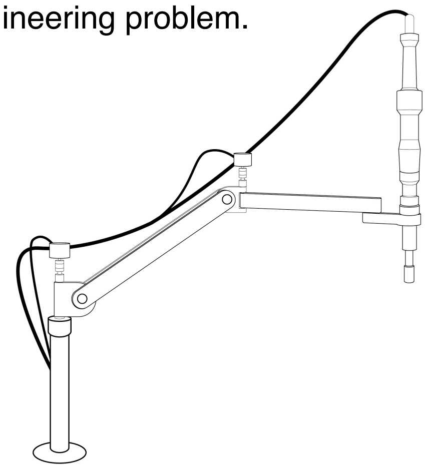

Figure 1. Tool Manipulator Arm

Rotary Encoder Output Interfaces

Rotary encoders interface options vary to some degree by manufacturer. The list of types of output interfaces includes, analog, EtherCAT, Profinet, binary, gray code, SSI, BiSS, Profibus, DeviceNet, Interbus, CANOpen, Modbus, Powerlink, and Modbus-RTU.

As Ethernet has become a leading and important device output interface, this paper focuses on that type.

Ethernet/IP is an industrial Ethernet protocol managed by the ODVA (Open DeviceNet Vendors Association), and championed by Rockwell Automation and others. Absolute

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rotary encoders with Ethernet/IP are available on the market from a number of vendors. They tend to be large in size (60 mm housing diameter) and very expensive A recent search found this type of product listed for sale in the range of $750 - $1200.

Part of the expense is the Ethernet/IP electronics, part is the housing and a large portion of the total cost can be attributed to high accuracy/performance. This includes finer resolution, higher speed capability, and low non-linearity which is designed into most, if not all, encoders produced. The degree of performance found in most encoders may not be needed in many applications.

The advantage of devices with Ethernet interfaces is that they can connect directly to the growing Ethernet-based industrial control and reporting infrastructure found in many factories. A disadvantage is that the challenge for OEMs and users who need Ethernet/IP but don't need high performance, or who don't have the space to install larger encoders.

Achieving Cost Savings By Selecting Devices With An Indirect Ethernet Interface

Lower cost single turn absolute encoders, especially ones with smaller form factors, are not readily available with an Ethernet/IP interface. Long-life magnetic encoders with external magnets paired with a sensor that has no shaft/bearing system are virtually unavailable with an Ethernet/IP interface.

One example of this type of sensor is Novotechnik's RFC-4800 series. This magnetic encoder is available with voltage or current analog interfaces as well as an option of various digital interfaces. These include SSI, IO-Link and SPI. By using a gateway, these and other non-Ethernet sensors can be connected to an Ethernet, even an Ethernet/IP network.

Gateways are data translation devices that enable users to apply a digital output from a device and "translate" that bus connections and protocol to a different one the user needs to connect the device to, than the one the device provides.

Ethernet/IP gateways were developed specifically to allow non-Ethernet/IP devices to be incorporated into Ethernet/IP networks. These gateways generally are designed to accept input from one or multiple, 4, 8, etc, sensors without an non-Ethernet/IP interface and make them available to the network.

Some gateways send process information from the multiple sensors to the network in a single Ethernet/IP message, while others allow each sensor's information to be sent in its own message.

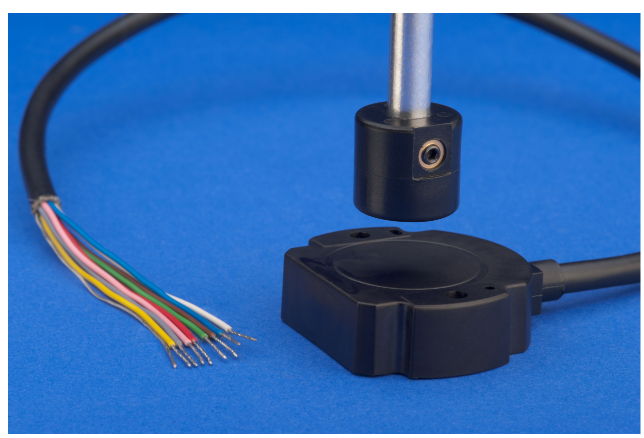

Fig. 2. Novotechnik RFC-4800 rotary position sensor

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Advantages of using standard encoders with gateways

The use of a 'stand-alone' ('standard') magnetic encoder plus an Ethernet/IP gateway includes the following potential advantages:

- Lower total system cost. Using standard encoders and gateways may be more economical than using encoders with an integral Ethernet/IP interface. This sensor + separate gateway product solution typically gets even lower cost when more encoders are needed.

- Smaller encoders can be used. Larger encoders require more space to install. An encoder with a much smaller form factor can be selected if the Ethernet/IP hardware is moved from the sensor to a gateway.

- Shorter run lengths of Ethernet/IP cables. With standard encoders installed on the axis being controlled, the Ethernet/IP gateway can be installed wherever it is convenient. They do not have to be near the encoder. The length of network cable from the gateway to the bus can be reduced by mounting the gateway closer to a trunk line.

• Reduced costs from increased quantity of standard encoders. One type of encoder can be used for a wide range of applications. Most OEMs build machines for a number of different customers, using different enterprise-level communication standards.

Some applications call for analog encoders and others need Ethernet/IP. The use of a standard encoder and a separate gateway allows the OEM to use the same base encoder for more customers. This reduces per-piece cost for those standard encoders by ordering a larger quantity of the same part.

• Potential for improved network efficiency. Some gateways can carry data for several sensors in a single frame. Four Ethernet/IP encoders each with a 12-bit single-turn resolution require (4) Ethernet frames to send process data to the network. Some 4-sensor gateways can send the process data for all 4 sensors in one frame. As a result, the overall bus load can often be decreased using a gateway instead of individual sensors.

Special considerations of using standard encoders with gateways

- Communication time from sensor to network. As rotary position changes, new position information requires a finite amount of time to become available on the network. The main components that affect this time are: internal update rate of the encoder, the time to communicate the new position to the gateway, the frequency with which the gateway can accept position information from the encoder, and the frequency with which the gateway can make the data available to the network. Ethernet/IP encoders are limited by the internal update rate, and the frequency with which they can make the data available to the network. See figures 5 and 6 below.

It is possible that an encoder plus gateway can make process data available to the network more frequently than Ethernet/IP encoders. Both the frequency of the communication and the age of the data should be considered.

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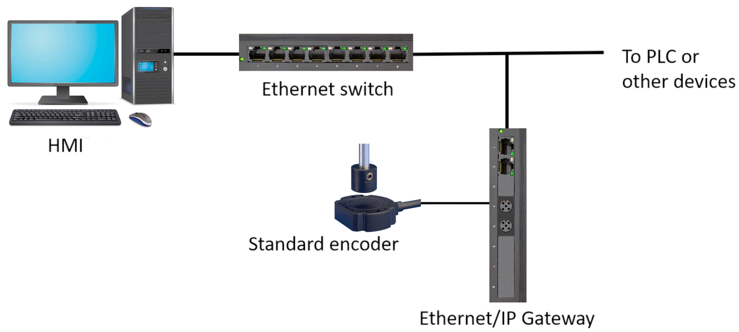

Figure 3. - The new position of an Ethernet/IP encoder is available directly to the network

The new position of a standard encoder is sent to the gateway before it is available to the Ethernet/IP network

• Installing two devices vs one device. An Ethernet/IP encoder can be connected directly to the bus. A standard encoder must first be connected to the gateway, and the gateway is then connected to the bus. Connecting a gateway to the network is similar complexity to connecting an Ethernet/IP encoder to the network.

• Device Profile (0 x 22 for Ethernet/IP encoders). Standard sensors used with gateways will not follow CIP (Common Industrial Protocol) profile 0 x 22 for encoders. The device profile for the gateway, if applicable, will be controlling. The data protocol provided from the encoder to the gateway needs to be known, and the location of the data in the Ethernet frame from the gateway to the bus must also be known. This enables the data in the frame to be mapped in the controller.

• Encoder and gateway system responsibility. If the encoder and gateway are purchased separately, compatibility of the encoder and gateway selected should be determined up front. An encoder manufacturer can suggest gateways that are compatible with their products.

Comparing encoders + Ethernet/IP gateways with Ethernet/IP encoders

A comparison of standard encoders plus Ethernet/IP gateways with Ethernet/IP encoders includes a discussion of update rates (how often new position data is available to the network), how old the data is when it becomes available, and cost.

Implicit messaging is used for real-time communication between the controller and an Ethernet/IP encoder. With implicit messaging, a connection is established between the encoder and controller. The controller specifies what information to be sent (e.g. position, velocity, etc.), along with how often that information is to be sent.

This time between process messages from the encoder to the controller is the Requested Package Interval (RPI), and is specified in milliseconds (ms). A typical minimum RPI for industrial Ethernet/IP encoders in the market is ~5 ms (0.005 seconds).
There are four timing elements that must be considered when using standard encoders with gateways:

- encoder's internal update rate (how often it forms a new position value),
- how often the gateway can accept a new input from the encoder,
- transmission speed of the position from the encoder to the gateway and
- how often the gateway can make that information available to the network—referred to as gateway RPI.

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The longest of these times determines how often the encoder position is available to the network. The combination of internal update rate, frequency of communication between encoder and gateway, and transmission time to the gateway determine the age of the position data that is being sent to the network.

Cost savings and throughput

Researching costs of pairing several popular gateways with Novotechnik's own RFC-4800 magnetic rotary encoders using IO-Link output, we have found the cost of encoder combined with a gateway to run from about $200 to $495 per encoder-gateway pair. The higher end is for applications only needing one encoder and the lowest for applications using four encoders with one four-channel gateway. See table 1.

For magnetic encoders with SSI output, multiple encoders cannot be used with one gateway, so the cost for each encoder-gateway pair is about $740 each.

Magnetic encoders with analog outputs can be combined with an Ethernet/IP gateway product with built in signal acquisition, A/D components and associated circuitry. While the cost is going to be higher due to the additional circuitry needed, the cost range is still less than $500 per encoder-gateway when four channels are used and about $1,600 for one channel.

Given these costs, you can compare costs for encoders with an Ethernet/IP interface. Should your findings match ours, you will see cost savings ranging from about $300 to $900 when an encoder-gateway pair is selected over an encoder with an integral Ethernet/IP interface.

The exception is analog output encoders in an application only needing one or two channels are less costly with an integrated Ethernet solution rather than an encoder-gateway pair solution.

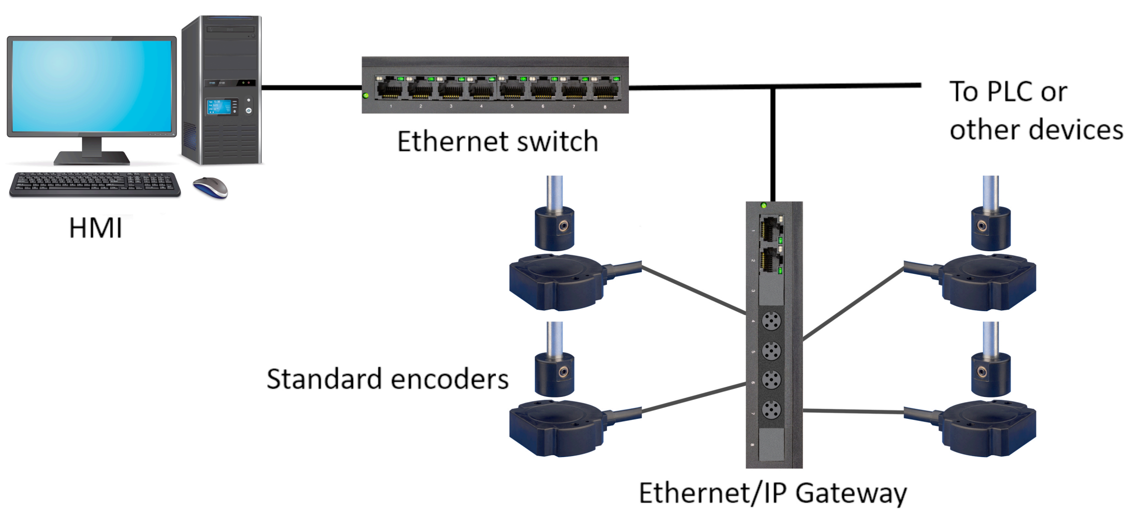

Figure 4 - Multiple encoders connected through a gateway to the network.

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Encoder Output	**Encoder**	**Gateway**	**Encoder+Gateway Update time** (maximum)	**Gateway RPI** (minimum)	**Encoder+Gateway Cost per ch.** ($s)
IO-Link	RFC-4800	Company/model A	~2.56 ms	1 ms	$ 495 @ 1 ch. used
					308 @ 2 ch. used
					245 @ 3 ch. used
					214 @ 4 ch. used
SSI	RFC-4800	Company/model B	0.042 ms	1 ms	740 @ 1 ch. used
					740 @ 2 ch. used
					740 @ 3 ch. used
					740 @ 4 ch. used
Analog	RFC-4800	Company/model C	~2.3 ms	1 ms	1,610 @ 1 ch. used
					865 @ 2 ch. used
					617 @ 3 ch. used
					493 @ 4 ch. used

Table 1 - Encoder + Gateway Cost and Throughput Summary

The total cost will depend on how many encoders are needed in the application, and how many encoder inputs a gateway has. Also, single-piece prices for encoders and gateways are used in this comparison.

Our review of integrated Ethernet/IP encoders revealed that all of the models from several manufacturers specified an encoder update rate + RPI minimum of 4 ms. As you can see in table 1, the RFC 4800 stand-alone encoder + gateway update rate +RPI minimum was comparable or less.

By adding the update time (encoder +gateway) to the gateway's minimum RPI, you get the total throughput time that it takes new data presented to the encoder to be available to a connected Ethernet/IP device.

As you can tell from table 1, IO-Link and analog are somewhat faster than a typical integrated encoder with Ethernet/IP output while SSI is almost four times as fast.

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Specifications of RFC-4800

IO-Link: Novotechnik's RFC-4800 with the IO-Link interface has the following specifications:

- 14-bit resolution over 360 degrees
- internal update rate of 1 kHz
- A transfer time of <0.5 ms from the hall sensor to the IO-Link output buffer
- IO-Link cycle time of 1 ms (how often it can communicate process data over IO-Link)
- IO-Link transmission speed of 230 kB/s (kilobaud/second).

SSI: RFC-4800 with SSI interface has the following characteristics: has the following specifications:

- 12-bit resolution over 360 degrees with13-bit SSI bus
- internal update rate of 2,000 kHz (2 MHz)
- SSI transmission speed of up to 1 MHz + 16 µs pause between transmissions.

Analog: RFC-4800 with analog (4-20mA or 0-10V) interface has the following specifications:

- 12-bit resolution over 360 degrees
- internal update rate of 3.4 kHz
- almost immediate availability of the signal at the gateway.

Conclusion

Standard encoders having an SSI interface, when used with Ethernet/IP gateways, offer potential advantages over Ethernet/IP encoders including smaller form factor and lower system cost. These advantages come with almost no penalty in age of the position data. Also, the position data can be made available more frequently with the right gateway.

Standard sensors with different interfaces such as IO-Link and analog provide older data, but this is not an issue for many applications. They still have smaller form factors and lower system cost.

On the other hand Ethernet/IP encoders require installation of only one device, and provide standardization of data types and formats using the Ethernet/IP encoder profile. The correct choice depends on how dynamic the application is, space restrictions, system cost considerations, and familiarity with standard encoder interfaces.

Rotary absolute encoders currently with on-board bus electronics tend to be fairly large form factor, engineered for high-end applications (e.g. high resolution, fast update rates, etc.), and can be quite expensive with our research finding units could easily cost more than $750 each.

For applications that don't required high resolution or high speed, or need smaller form factors, it may be more efficient and economical to use standard analog or digital interfaces in combination with gateways to make process data from these encoders available on the network. In general, the use of gateways also makes standard sensors from almost every manufacturer applicable to any industrial bus. This creates potential advantages for both device manufacturers and device users.