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IO-Link (Single-Drop Digital Communication System) for Sensors and Actuators

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5.1 Motivation and Objectives for a New Technology

Th increased use of microcontrollers embedded in low-cost sensors and actuators has provided opportunities for adding diagnosis and configuration data to support increasing application requirements.

Th driving force for a new technology called IO-Link™* has been the need of these low-cost sensors and actuators to exchange the diagnosis and configuration data with a controller (PC or PLC) using a low-cost digital communication technology while maintaining backward compatibility with the current digital input and digital output (DI/DO) signals.

Another driving force is cost reduction and substitution of error-prone analog transmission such as 0–10 V. Using IO-Link avoids digital/analog conversion on the sensor side and analog/digital conversion on the controller side.

In fieldbus concepts, the IO-Link defines a generic interface for connecting sensors and actuators to a Master† unit, which may be combined with gateway capabilities to become a fieldbus remote I/O node.

Any IO-Link-compliant Device‡ can be attached to any available interface port of the Master. Devices perform physical-to-digital conversion in the Device and then communicate the result directly in a standard format using *coded switching* of the 24 V I/O signaling line, thus removing the need for diffe ent DI, DO, AI, AO modules, and a variety of cables.

* IO-Link™ is a trade name of the "IO-Link Community." Use of the registered logos for IO-Link™ requires permission of the "IO-Link Community."

† "Master" (with upper case M) means the IO-Link-compliant counterpart to "Device."

‡ "Device" (with upper case D) means IO-Link-compliant sensor or actuator in this document.

Physical.topology.is.point-to-point.from.each.Device.to.the.Master.using.three.wires.over.distances. up.to.20.m..The.IO-Link.physical.interface.is.backward.compatible.with.the.24.V.I/O.signaling.specified. in.IEC.61131-2..Transmission.rates.of.4.8,.38.4,.and.230.4.kbit/s.are.supported.

Th .Master.of.the.IO-Link.interface.detects,.identifi s,.and.manages.Devices.plugged.into.its.ports.

Tools.allow.the.association.of.Devices.with.their.corresponding.electronic.I/O.Device.descriptions. (IODDs).and.their.subsequent.configuration.to.match.the.application.requirements.

Th . IO-Link. technology. specifi s. three. diffe ent. levels. of. diagnostic. capabilities:. for. immediate. response. by. automated. needs. during. the. production. phase,. for. medium-term. response. by. operator. intervention,.or.for.longer-term.commissioning.and.maintenance.via.extended.diagnosis.information.

5.2 IO-Link Technology

5.2.1 Purpose of Technology

Figure.5.1.shows.the.basic.concept.of.IO-Link.

The.single-drop.digital.communication.interface.technology.for.small.sensors.and.actuators.IO-Link. (also.known.as.SDCI.in.IEC.61131-9).defines.a.migration.path.from.the.existing.DI/DO.interfaces.for. switching.24.V.Devices,.as.defined.in.IEC.61131-2,.toward.a.point-to-point.communication.link..Thus,. for. example,. digital. I/O. modules. in. existing. fieldbus. peripherals. can. be. replaced. by. IO-Link. Master. modules. providing. both. classic. DI/DO. interfaces. and. IO-Link.. Analog. transmission. technology. can. be. replaced. by. IO-Link. combining. its. robustness,. parameterization,. and. diagnostic. features. with. the. saving.of.digital/analog.and.analog/digital.conversion.efforts.

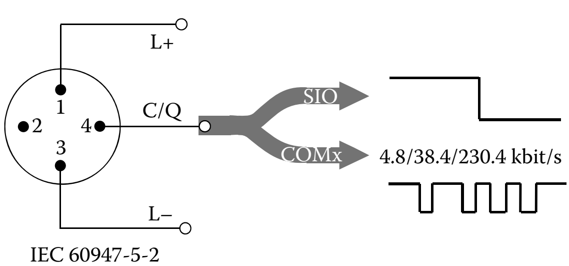
5.2.2 Positioning within the Automation Hierarchy

Figure.5.2.shows.the.domain.of.the.IO-Link.technology.within.the.automation.hierarchy.

The.IO-Link.technology.defines.a.generic.interface.for.connecting.sensors.and.actuators.to.a.Master. unit,.which.may.be.combined.with.gateway.capabilities.to.become.a.fieldbus.remote.I/O.node.or.via.an. adapter.to.personal.computers.or.drives.

Starting.point.for.the.design.of.IO-Link.is.the.classic.24.V.DI.defined.in.IEC.61131-2.and.output.inter-face.(DO).specified.in.[1]..Thus,.IO-Link.offe s.connectivity.of.classic.24.V.sensors.(*switching signals)*. as.a.default.operational.mode..Additional.connectivity.is.provided.for.actuators.when.a.port.has.been. configured.into.single-drop.communication.mode.(*coded switching*).

Many.sensors.and.actuators.nowadays.are.already.equipped.with.microcontrollers.offe ing.a.univer-sal.asynchronous.receiver.transmitter.interface.that.can.be.extended.by.the.addition.of.a.few.hardware. components.and.protocol.software.to.support.IO-Link.communication..This.second.operational.mode. uses.*coded switching*.of.the.24.V.I/O.signaling.line..Once.activated,.the.IO-Link.mode.supports.param-eterization,. cyclic. data. exchange,. diagnosis. reporting,. identification. and. maintenance. information,.



Pin	Signal	Definition	Standard
1	L+	24 V	IEC 61131-2
2	I/Q	Not connected, DI, or DO	IEC 61131-2
3	L−	0 V	IEC 61131-2
4	Q	"Switching signal" DI (SIO)	IEC 61131-2
	C	"Coded switching" (COM1, COM2, COM3)	IO-Link (IEC 61131-9)

FIGURE 5.1 IO-Link.compatibility.with.IEC.61131-2.

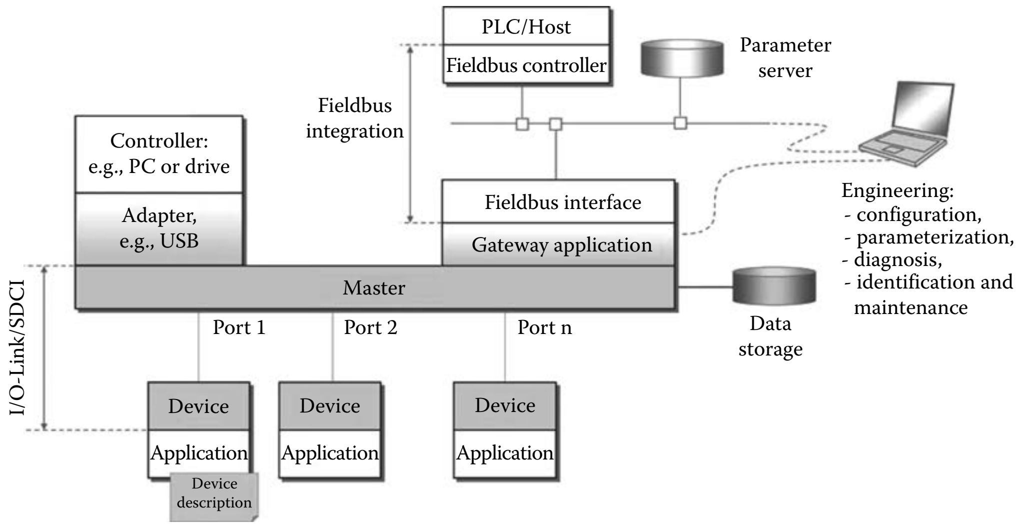


FIGURE 5.2 Domain of the IO-Link technology within the automation hierarchy.

and external parameter storage for Device backup and fast reload of replacement devices. To improve start-up performance, these Devices usually provide nonvolatile storage for parameters.

Configuration and parameterization of Devices are supported through an XML-based device description similar to fieldbus electronic device descriptions (see [2]).

5.2.3 Wiring, Connectors, and Power

The default connection (port class A) comprises four pins (see Figure 5.1). The default wiring for port class A complies with IEC 60947-5-2 and uses only three wires for 24, 0 V, and a signal line. The fourth wire may be used as an additional signal line complying with IEC 61131-2.

Five-pin connections (port class B*) are specified for Devices requiring additional power from an independent 24 V power supply.

Maximum length of cables is 20 m, and shielding is not required.

5.2.4 Communication Features of IO-Link

The generic Device model is shown in Figure 5.3 and explained in the following paragraphs.

A Device may receive process data (PD; out) to control a discrete or continuous automation process or send PD (in) representing its current state or measurement values. The Device usually provides parameters enabling the user to configure its functions to satisfy particular needs. To support this case, a large parameter space is defined with access via an index (0–65,535; with a predefined organization) and a subindex (0–255).

The first two index entries 0 and 1 are reserved for the direct parameter pages 1 and 2 with a maximum of 16 octets each. Parameter page 1 is mainly dedicated to Master commands such as Device start-up and fallback, retrieval of Device-specific operational and identification information. Parameter page 2 allows for a maximum of 16 octets of Device-specific parameters.

The other indices (2–65,535) allow access to one record having a maximum size of 232 octets. Subindex 0 specifies transmission of the complete record addressed by the index; other subindices specify transfer of selected data items within the record.

* A port class A Device using the fourth wire is not compatible with a port class B Master.

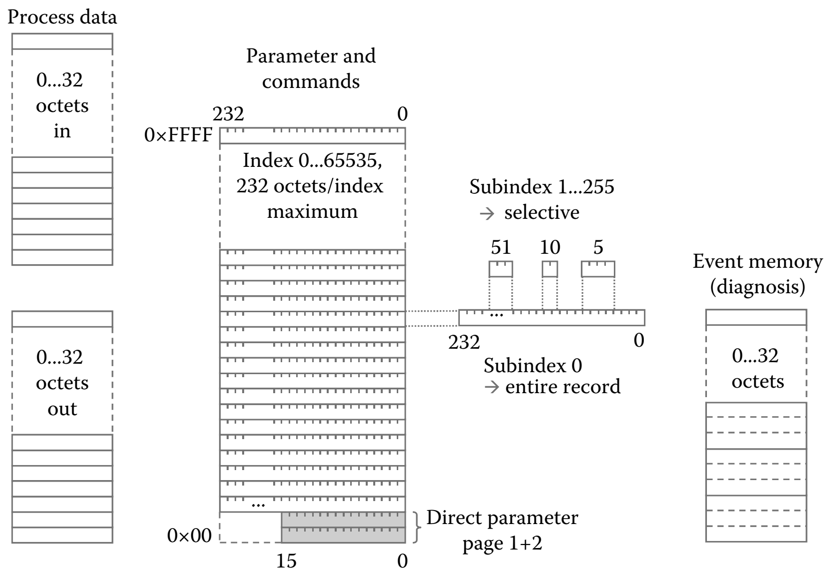


FIGURE 5.3 Generic Device model for IO-Link (Master's view).

Within a record, individual data items may start on any bit offset, and their length may range from 1 bit to 232 octets, but the total number of data items in the record cannot exceed 255. The organization of data items within a record is specified in the IODD (see [2]).

All changes of Device condition that require reporting or intervention are stored within an event memory before transmission. An event flag is then set in the cyclic data exchange to indicate the existence of an event.

Communication between a Master and a Device is point to point and is based on the principle of the Master first sending a request message and then a Device sending a response message (see Figure 5.4).

Both messages together are called an M-sequence. Several M-sequence types are defined to support user requirements for data transmission (see [1]). The first byte of a Master message controls the data transfer direction (read/write). It is followed by the M-sequence type of communication channel and data integrity checking code, and optional bytes with either *PD* and/or *on-request data* (OD).

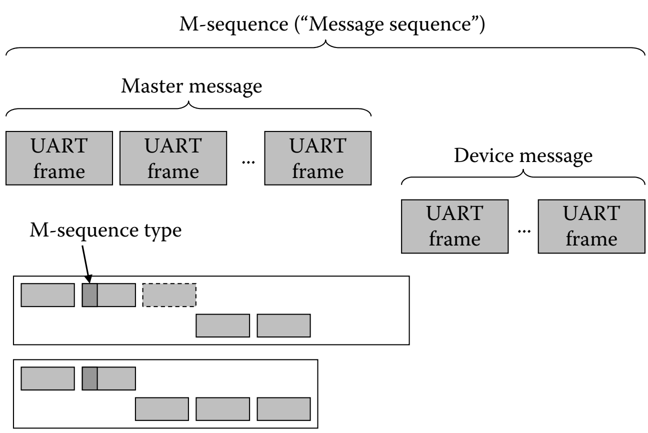


FIGURE 5.4 Principle of message sequences between Master and Device.

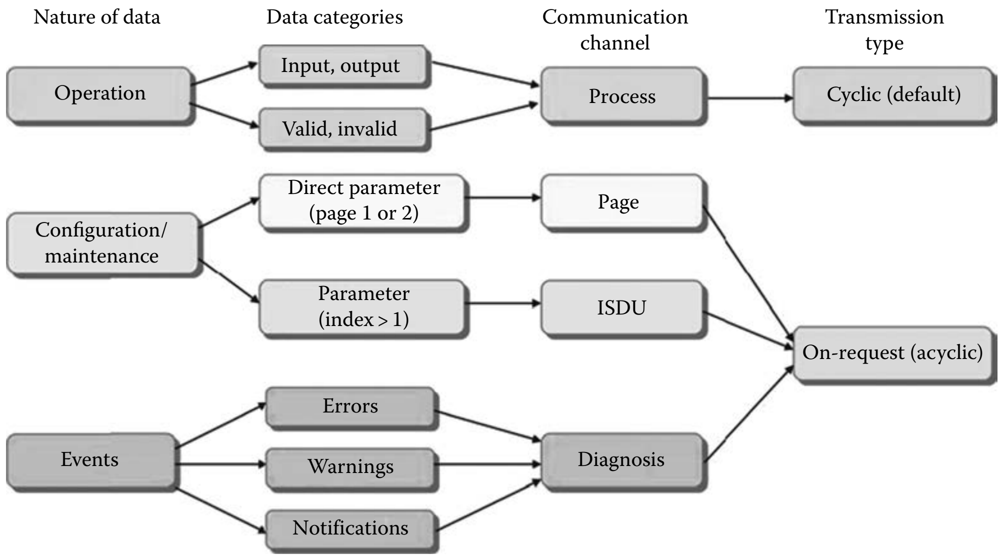


FIGURE 5.5 Relationship between nature of data and transmission types.

Data of various categories are transmitted through separate communication channels within the data link layer (DL), as shown in Figure 5.5.

- Operational data such as Device inputs and outputs are transmitted through a process channel using cyclic transfer. Operational data may also be associated with qualifie s such as valid/invalid.
- Configuration and maintenance parameters are transmitted using acyclic transfers. A page channel is provided for direct access to parameter pages 1 and 2, and an indexed service data unit channel is used for accessing additional parameters and commands via indices.
- Device events are transmitted using acyclic transfers through a diagnostic channel. Device events are reported using three severity levels: error, warning, and notification.

Figure 5.6 shows that each port of a Master has its own DL that interfaces to a common master application layer (AL). Within the AL, the services of the DL are translated into actions on *PD* objects (input/output), *OD* objects (read/write), and events. Master applications include a configuration manager, data storage mechanism, diagnosis unit (DU), OD exchange (ODE), and a PD exchange (PDE).

System management checks identification of the connected Devices and adjusts ports and Devices to match the chosen configuration and the properties of the connected Devices. It controls the state machines in the AL and DL, for example, at start-up.

5.2.5 Role of a Master

A Master accommodates 1 to *n* ports and their associated DLs. During start-up, it changes the ports to the user-selected port modes, which can be INACTIVE, DI, DO, FIXEDMODE, or SCANMODE. If communication is requested, the Master uses a special wake-up current pulse to initiate communication with the Device. The Master then auto-adjusts the transmission rate to COM1, COM2, or COM3 (see [1]) and checks the *personality* of the connected Device, that is, its vendor identification, Device identification, and communication properties.

If there is a mismatch between the Device parameters and the stored parameter set within the Master, the parameters in the Device are overwritten or the stored parameters within the Master are updated depending on configuration.

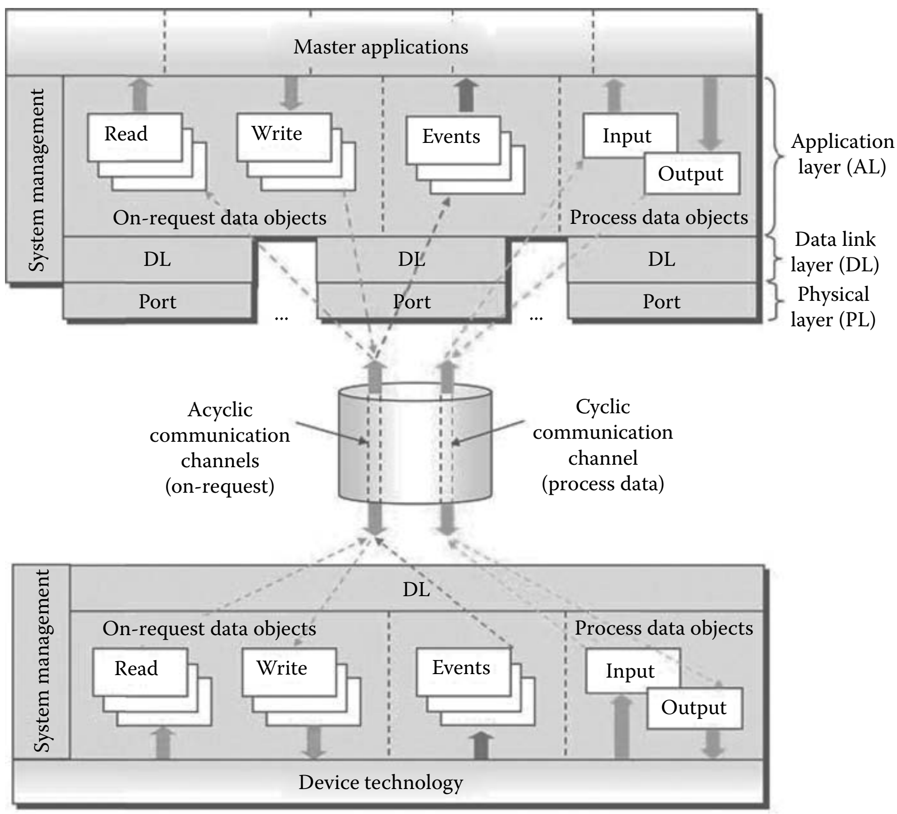


FIGURE 5.6 Object transfer at the application layer (AL) level.

It is also possible to start a device in DI mode, switch to IO-Link communication for configuration and parameterization, and then use a fallback command to switch back to DI mode for normal operation (see Figure 5.7).

Coordination of the ports is also a task of the Master, which the user can configure through the selection of port cycle modes. In *FreeRunning* mode, each port defines its own cycle based on the properties of the connected Device. In *MessageSync* mode, messages sent on the connected ports start at the same time or in a defined staggered manner. In *FixedValue* mode, each port uses a user-defined fixed cycle time (see [1]).

The Master is responsible for the assembling and disassembling of all data from or to the Devices.

The Master provides a data storage area of at least 2048 octets per Device for backup of Device data. The Master may combine these Device data together with all other relevant data for its own operation and make these data available for higher-level applications for Master backup purpose or recipe control.

5.2.6 IO-Link Configuration

Engineering support for a Master is usually provided by a Port and Device Configuration Tool (PDCT) connected directly or indirectly via fieldbus to the Master. The PDCT configures both port properties and Device properties (see parameters shown in Figure 5.3). It combines both an interpreter of the IODD and a configurator (see Figure 5.2). The IODD provides all the necessary properties to establish communication and the necessary parameters and their boundaries to establish the desired function of a sensor or actuator. The PDCT also supports the compilation of the PD for propagation on the fieldbus and vice versa.

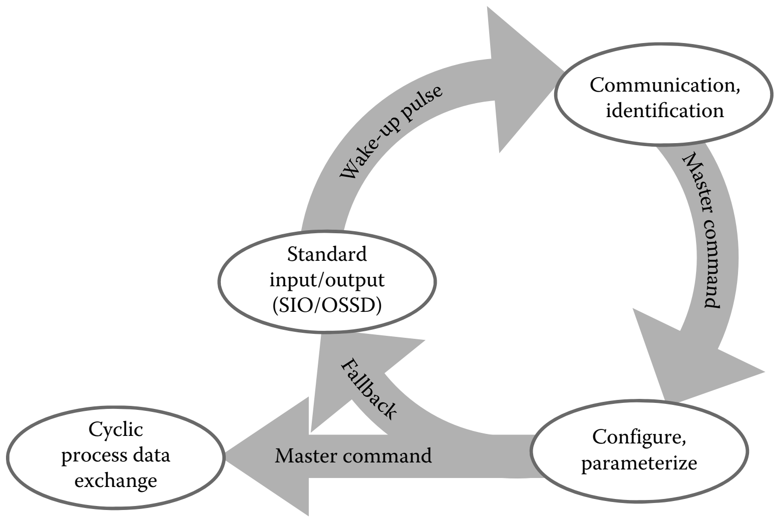


FIGURE 5.7 IO-Link.communication.states.

5.2.7 Mapping to Fieldbuses and System Integration

Integration.of.a.Master.within.a.fieldbus.system,.that.is,.the.defi ition.of.gateway.functions.for.exchanging. data. with. higher-level. entities. on. a. fieldbus,. is. out. of. the. scope. of. the. IO-Link. specification. [1].. Examples.of.these.functions.include.mapping.of.the.PDE,.realization.of.program-controlled.parameterization.or.a.remote.parameter.server,.or.the.propagation.of.diagnosis.information.

Th .integration.of.a.PDCT.into.engineering.tools.of.a.particular.fieldbus.is.also.out.of.the.scope.of.the. IO-Link.specification.[1].

However,. IO-Link. integrations. (gateways/Master). exist. for. the. most. important. fieldbuses. such. as. PROFIBUS,. PROFINET,. DeviceNet,. Ethernet/IP,. EtherCAT,. Powerlink,. CC-Link,. and. ASi.. It. is. the. responsibility.of.the.fieldbus.organizations.to.provide.corresponding.specifications.

5.2.8 Implementation and Engineering Support

A.number.of.application-specific.integrated.circuits.and.software.stacks.facilitate.the.design.and.implementation.of.Masters.and.Devices..Information.can.be.retrieved.from.www.io-link.com.

5.2.9 Test and Certification

A. comprehensive. specification. for. the. test. of. Masters. and. Devices. exist. (see. [3]),. and. corresponding. test. tools. can. be. acquired. for. both.. A. manufacturer. declaration. based. on. the. positive. results. of. the. Device.tester.is.required.for.the.usage.of.the.IO-Link.word.and.picture.mark..Certification.of.Devices.is. not.required..Similar.rules.exist.for.Masters..The.fieldbus.organizations.are.responsible.for.the.quality. assurance.of.the.combination.of.fieldbus.gateway.and.Master.

5.2.10 Profiles

An. IO-Link. profile. specification. exists. for. sensors. (see. [4]).. It. describes. the. common. part. of. a. sensor. model. that. should. be. valid. for. future. Device. profiles. and. a. more. specifi . part. for. the. so-called. Smart. Sensors. comprising. recommended. PD. structures,. identification. objects,. binary. switching. thresholds. and. hysteresis,. best. practice. handling. of. quantity. measurements. with. or. without. associated. units,. diagnosis.objects,.and.teaching.commonalities.

5.2.11 Functional Safety

Many fieldbuses provide additional profiles for functional safety communication (see [5]). For IO-Link, two possibilities exist in principle:

1. Tunneling of an existing fieldbus functional safety communication across IO-Link
2. A specifi slim IO-Link functional safety communication profile with a functional safety gateway

Th IO-Link community does not prohibit the tunneling solution, which is the responsibility of the corresponding fieldbus organization. In general, for sensor and actuator manufacturers, the second possibility is in favor due to less development and support efforts. A corresponding specification is going to be developed.

5.2.12 Standardization

Th IO-Link technology is internationally standardized within IEC 61131-9 (see [6]).

Abbreviations

AI	Analog input
AL	Application layer
AO	Analog output
ASIC	Application-specific integrated circuit
CM	Configuration manager
COM1	IO-Link transmission rates of 4.8 kbit/s
COM2	IO-Link transmission rates of 38.4 kbit/s
COM3	IO-Link transmission rates of 230.4 kbit/s
DI	Digital input
DL	Data link layer
DO	Digital output
DS	Data storage
DU	Diagnosis unit
IEC	International Electrotechnical Commission
I/O	Input/output
IODD	I/O device description
ISDU	Indexed service data unit
OD	On-request data
ODE	On-request data exchange
PC	Personal computer
PD	Process data
PDCT	Port and device configuration
PDE	Process data exchange
PLC	Programmable logic controller
SDCI	Single-drop digital communication interface for small sensors and actuators
SIO	Standard I/O mode according IEC 61131-2
UART	Universal asynchronous receiver transmitter
XML	Extensible mark-up language

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