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A Comprehensive Analysis on IO-Link Communication and Transceivers

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***Abstract*— The Industrial Internet of Things (IIoT) has led to an increase in the quantity and variety of sensors installed on factory floors. These sensors are looking for more efficient ways to exchange data and interact, frequently in real-time. IO-Link, which is regarded as the first worldwide standardized input/output (I/O) technology for communications with sensors and actuators, is increasingly filling that demand. IO-Link, which operates on a typical three- wire connection and offers bi-directional, point-to- point communications, has gained popularity in Europe over the past ten years and is now making inroads in the US. The IO-Link system market reached $11.2 billion in 2022 with expectations of a CAGR of 25.1% through 2028, according to a report from Mordor Intelligence.[1] This paper discusses about communication between master controllers and Sensors/Actuators. In industries various methods are used for communication between masters and slaves. These methods can be analog/digital communications using industrial standards like 0-10 V or 4-20 mA. The paper exhibits IO-Link communication protocol for industrial communication and non- industrial applications. For the scope of this paper, the pros and cons of IO-Link communications, IO- Link transceivers and their pros and cons, also various IO-Link transceivers, are all covered. A comparative analysis and study of the transceiver ICs and boards is displayed here, but this paper reflects on a limited set of transceiver ICs from the vast pool that exists. Considering that there are few IO-Link transceiver ICs and boards that were found during the research and their ICs which are instilled in many other transceiver ICs and boards.**

***Index Terms*— Interfacing and isolation, Serial Peripheral Interface -SPI, Universal Asynchronous Receiver/Transmitter -UART, IO-Link transceiver, Inter-integrated circuit -I2C, and networking.**

I. INTRODUCTION

In this modern world, all processes involve communications at their core. Each and every process uses communication in one way or the other. Communications can be measurements, process data, etc., beginning transmitted from a sensor or commands beginning sent to an actuator. There are many ways to transmit this data from master to slave or vice-versa, it may be using transducers and modifying output signal to voltage or current to further relay analog/digital voltage or current. This paper covers a similar transmitting method called IO- Link communication. IO-Link communication requires the sensors and actuators to be IO-Link communication capable. IO-Link communication is a communication standard using which we can transmit many different types of data from the master which may be a PLC (Programmable Logic Controller) to a slave which may be a sensor

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(Distance sen5sor like Laser distance sensor DT-50 from SICK) or any actuator compatible with IO- Link communication. IO-Link is point to point and bidirectional protocol for communication with an IO-Link compatible sensor/actuator.

II. IO-LINK

A communication protocol called IO-Link allows master controllers, such as PLCs (Programmable Logic Controllers), to interact with slaves, which might be IO- Link-compliant sensors or actuators. IO-Link Communication provides a number of advantages over other widely used communication protocols. The technology known as IO-Link is standardized (IEC 61131-9).

The following information can be sent to its master by a Sensor/Actuator which is suitable with IO-Link:

- Process Data: The master can receive current data/states of sensors/actuators (such as rotation speed from a motor or distance measurements from a distance sensor) cyclically at the microcontroller-set speed. In a single cycle, this mechanism can handle data as large as 32 bits.
- Status of Value: Provides information on the accuracy of the process data. Along with the process data, its value is periodically transmitted to the master from the slave IO-Link device.
- Device Info: A device's parameters or diagnostic data, as well as more sophisticated information like a serial number or version number, can be transmitted via an IO- Link slave. This data is delivered by the slave only in response to a request from the master controller, as opposed to cyclic process data, which is continuously given by the slave.
- Device data can be written to the device in addition to being read from it. For example, the master could simply accomplish the task of changing a certain sensor parameter by delivering the necessary instruction using IO-Link communication

The IO-Link consortium was founded in 2008 by 41 producers of sensors and actuators. The original intention was to standardize the data protocol for communication and the hardware (PHY layer) interface for IO-Link products. Currently, over 100 companies are part of this consortium including semiconductor vendors and software vendors like Analog Devices, Arrow, NXP semiconductors, etc. [3]

IO-Link communication is a 3-wire sensor and actuator connection without additional requirements regarding the cable material.

A. Hardware Requirement

IO-Link compatible Sensor or Actuator.

- IO-Link Communication Cable
- IO-Link Master
- Master Controller

A sensor or actuator that is an IO-Link compliant slave talks with the IO-Link master, which can be up to 20 meters away from the sensor. The data from IO-Link connection is transformed by this IO-Link master into fieldbus or industrial ethernet protocol before being sent to the microcontroller, which might be an HMI (Human Machine Interface) or PLC controller. Recently, some IO-Link masters have also included USB connections, which allow the sensor or actuator to be programmed or operated directly from a PC or server.

B. IO-Link Communication

Standard connections, typically M12, are used in IO- Link communication coupled with a 3- or 4-wire cable up to 20 meters in length. The power supply for IO-Link communication ranges from 0 to 24 V. There are two modes available for each IO-Link port in a master: 1) Standard I/O and 2) IO-Link mode.

- SIO mode: - This mode enables communication in the form of 1 or 0 (i.e., ON or OFF) with the sensor/actuator. This enables the sensor to give outputs like 1 or 0 depending on the logic of the sensor or enables the controller to give commands like ON or OFF.
- IO-Link mode: Slaves are designed to communicate on one of the three data rates supported by IO-Link communication mode, which are COM1 4800 baud, COM2 338400 baud, whereas COM3 operates at 230400 baud. The master is set up for communication at these rates. A master can only speak with one slave on a single IO-Link port. Various word length formats are feasible for communication; depending on the slave, it may be as large as 32 bits. These deal with the numbers 0 and 1, where logic 1 is represented by 0 V between the same lines and 0 is represented by 24 V between the CQ and L-lines. In general, 4-pin and 5-pin connectors are the two types of connections that are accessible. The fifth pin can be utilized in several ways depending on the slave.

C. Configuration

Installing and importing the sensor or actuator's IODD file is required when configuring an IO- Link Device with an IO-Link master. Every actuator and sensor has an IODD file. The term "IO Device Description File" (IODD) refers to a file that includes information on the identity, parameters, process, diagnostic, and communication features of a device. Together with graphical and PNG representations of the device, the IODD file also contains an engineering tools user interface. Furthermore, it includes various language files that permit users to set the device in their own preferred language.

D. Connecting the non-IO Link slave to the IO Linkmaster

Since the IO-Link Master's DI/DO mode allows for control over digital input and output (i.e., 1 and 0), it is possible to link a slave that does not support IO-Link communication to the master. This allows users to utilize IO-Link cable, which is high-quality, insulated, and helps reduce environmental noise to a manageable level, to standardize communication across the project and prevent noise.

E. Merits

- Simple Installation: Since all IO-Link slaves communicate with the IO-Link Master using standard insulated 3- or 4-wire wires, installing them is simple.
- Simple Integration: Because the IO Link masters support industrial communication protocols like Ethernet, Profibus, and other fieldbus protocols, they may be easily integrated with industry controllers and standards that were previously in use.
- Flexibility in speed communication: The IO Link communication has three data communication rates. Manufacturers incorporate one of these three data communication rates into slaves based on their specifications and standards. The Master can communicate on any of these three data rates, enabling it to communicate with various slaves at various rates.
- Greater Data Availability: In addition to sensor data, a slave can transmit Process Data, Communication Failure, Device Data (such as serial number, diagnostic data, etc.), and Failure Events (such as actuator overheating, sensor failure, short circuit, etc.) over the IO Link communication line. Making smarter judgments is possible with the use of this data.

F. Demerits

- Restricted Range: From slave to IO-Link Master, the greatest distance that IO-Link communication may typically go is 20 meters. In large industrial settings, this might not be the best option. When physical constraints make it inconvenient or impossible to deploy IO-Link masters near the slave (or within 20 meters of the slave).
- Not being able to interact using standard communication protocols: Because IO-Link master is intended for industrial use, it lacks SPI, I2C, USART, and UART connectivity, making it unable to interface with Arduino or other Arm-based microcontrollers.

III. IO-Link Transceiver

A. Introduction

To engage with the IO-Link device, a slave IO-Link device must primarily connect with an IO-Link master. It can now link to a controller, which might be a PLC controller or any other controller that has Ethernet, Profinet, and fieldbus protocols supported. However, using the IO-Link master to communicate with the IO-Link device is not practical if another microcontroller, such as an Arduino or an STM microcontroller, has to be reached that does not have Fieldbus protocols installed. Hence, a transceiver is needed. A transceiver is a piece of hardware that has the ability to function as an IO-Link master while also having communication between the IO- Link device and Fieldbus protocols is not feasible (via IO-Link master). For this reason, a transceiver is needed. A transceiver is a piece of hardware that may function as an IO- Link master and has ports for UART, USART, SPI, and I2C, which are frequently seen on microcontrollers such as Arduino. The term transceiver is a combination of the phrases transmitter and receiver. It can accept instructions from a microcontroller by UART, USART, SPI, or I2C, send them to an IO-Link device, receive data from the IO- Link device over IO-Link, and transmit the data to the microcontroller via UART, USART, SPI, or I2C.

B. Merits

- It transforms IO Link data into SPI, I2C, USART, or UART, and vice versa.

- Makes it feasible for industry to employ microcontrollers such as Arduino and other ARM-based microcontrollers.
- Over the IO-Link communication line a slave can communicate more than sensor data, it can also communicate Process Data, Communication Failure, Device Data (i.e., Serial no., diagnostics data, etc.), Failure Events (like overheating of actuators, Failure of sensors, Short Circuit, etc.)

C. Demerits

- A major challenge is the lack of IO-Link transceivers that can connect to many slaves at once.
- Expensive. As they include more expensive gear in the project, the cost might go up.

IV. COMMON COMMUNICATION PROTOCOLS

These are few of prominent communication protocols in which IO-Link Transceivers convert IO-Link data to: -
- UART
- SPI
- I2C

Fig. 1 provides a potentially holistic information, background and a comparative study with analysis

Features	UART	SPI	I^2C
	Universal Asynchronous Reception and Transmission	Serial Peripheral Interface	Inter integrated circuit
Pin Designations	TxD : For transmitting of data RxD : For receiving of data	SCLK : Serial Clock MOSI : Master Out, Slave In MISO : Master In, Slave Out SS : Slave Select	SDA : Serial Data SCL : Serial Clock
Data Rate	Supports speeds from 230kbps to 460kbps	Supports speeds from 10Mbps to 20Mbps	Supports speeds up to 3.4Mbps
Modes	Supports Simplex and Full duplex mode.	Supports Full duplex mode	Supports Half duplex mode
Range	Least	Maximum	Intermediate
Type of Communication	Asynchronous	Synchronous	Synchronous
No. of Masters	None	Multiple masters possible *	One or more than one
Clock	No common clock signal is used baudrate should be common	One common serial clock signal	One common serial clock signal
Software Addressing	N/A	'n' no. of slave select lines for 'n' slaves for a single master	Upto 127 slave devices **
Error Detection	Parity bit can be used	CRC can be used ***	Acknowledgement Bit is available for error check and to check if other device received data
Disadvantages of error Detection Methods	Old and can only detect if there is corruption of odd no of bits in data	The CRC data is also needed to be sent	Describes only if reciever has received data or not, no information about corruption of data
Communication and Device Networking	Communication is between 2 devices only.	No of slaves depends on GPIO pins available with master	Upto 127 slave devices possible **
Communicate to Milti-Ddevoces	Communication between multiple devices on same Tx and Rx line is not possible	Communication to multiple slaves on same MOSI-MISO line is possible	Communication with multiple slaves on the same SDA line is possible
Interfacing Strategies	Whole different UART peripheral is required for different devices	Slaves can be selected and switched using Chip select line	Address of slave is used for switching slaves and communicating to multiple slaves
Hardware Scalability in Multi Slave Systems	With the increase in no of devices, hardware becomes most complex	With the increase in no of slaves, hardware becomes comparatively less complex	No extra hardware/wiring is required with increase in no of slaves

Figure 1

V. IO-LINK TRANSCEIVER ICS

These are few of prominent companies providing IO-Link Transceiver solutions: -

- Analog Devices
- Texas Instruments
- STMicroelectronics
- HMT Microelectronics AG

Fig 2. is the result of comparative analysis of various available transceiver ICs [5] – [30].

Part Number	Company	COM Rates	Io-Link Version	Configure	Transmit	Voltage Levels	Supply Voltage Range	No of IO-Link Ports	Operating Temperature Range	Package Area (mm²)
MAX22515	Analog Devices	COM1, COM2, COM3	-	I^2C	UART	3.3V and 5V	9V to 36V	1	-40 to 125°C	16
MAX22514		COM1, COM2, COM3	-	SPI	UART	3.3V and 5V	8V to 36V	1	-40 to 125°C	20
MAX14828		-	-	SPI	UART	3.3V and 5V	9V to 65V	1	-40 to 125°C	16
MAX14826		COM1, COM2, COM3	v1.0 and v1.1	SPI	UART	2.5V to 5V	9V to 36V	1	-40 to 105°C	16
MAX14821		COM1, COM2, COM3	v1.0 and v1.1.2	SPI	UART	2.5V to 5V	9V to 36V	1	-40 to 85°C	16
MAX14829		-	-	UART	UART	3.3V and 5V	9V to 65V	1	-40 to 125°C	16
LT3669		COM1, COM2, COM3	v1.1	UART	UART	3.3V and 5V	7.5V to 40V	1	-40 to 150°C	20
MAX14827A		-	-	SPI	UART	3.3V and 5V	9V to 65V	1	-40 to 125°C	16
MAX22513		-	-	I^2C and SPI	UART	3.3V and 5V	9V to 36V	1	-40 to 125°C	19.25
MAX14820		COM1, COM2, COM3	v1.0 and v1.1	SPI	UART	3.3V and 5V	9V to 36V	1	-40 to 85°C	16
MAX14824		COM1, COM2, COM3	v1.0 and v1.1	SPI	UART	3.3V and 5V	9V to 36V	1	-40 to 105°C	16
MAX14819		COM1, COM2, COM3	v1.1.3.	SPI	UART	3.3V and 5V	9V to 65V	2	-40 to 125°C	50.41
MAX14819A		COM1, COM2, COM3	v1.1.3.	SPI	UART	3.3V and 5V	9V to 36V	2	-40 to 125°C	50.41
LTC2874		COM1, COM2, COM3	v1.1	SPI	UART	2.9V to 5.5V	8V to 34V	4	-40 to 85°C	35
TIOL112	Texas Instruments	COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	4.1659
TIOL1125		COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	9
TIOL1123		COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	4.1659
TIOL1113		COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	7.5
TIOL111		COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	7.5
TIOL1115		COM1, COM2, COM3	-	UART	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	7.5
SN65HVD101		COM3	-	UART	UART	3.3V and 5V	9 to 30	1	-40 to 105°C	14
SN65HVD102		COM3	-	UART	UART	3.3V and 5V	9 to 30	1	-40 to 105°C	14
L6360	STMicroelectronics	COM1, COM2, COM3	v1.1	I^2C	UART	3.3V and 5V	18 to 32.5	2	-55 to 150	17.5
L6362A		COM1, COM2, COM3	v1.1	Digital Inputs	UART	3.3V and 5V	7 to 36	1	-40 to 125°C	9
L6364		COM2, COM3	v1.1	SPI	UART	3.3V and 5V	5 to 35	2	-40 to 150°C	6.25
HMT7748	HMT ElectronicsAG	COM2, COM3	v1.1	SPI	UART	3.3V and 5V	5 to 35	1	-40 to 150°C	16

Figure 2

VI. CONCLUSION

This paper covered the pros and cons of a growing communication protocol in the industry which is booming with the inclusion of IOT. It is also discussed about the IO-Link transceivers which enable the user to use IO-Link compatible sensors to their maximum efficiency. This paper discussed commonly available IO-Link transceiver solutions in the market and created a comparative analysis of these solutions. Further, it is the code to use IO- Link transceivers using Arduino can be made there has been significant work in that direction also,open-source libraries for Arduino are created byusers. Further work can be done in that direction forthe development of further solutions in this field. It is envisioned that this paper helps readers to make an informed decision and motivates readers to develop various solutions.

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