Application Note

The Importance of Single Twisted-Pair Ethernet (SPE) for Robotics System Designs

ABSTRACT

Communication in robotics system designs is undergoing a transformation as it keeps pace with the fourth industrial revolution, or industry 4.0. In the status quo, robot communications must be robust, accurate, have excellent timing characteristics and neither hinder axis movement, nor be negatively impacted by it. Several important, but disparate, communication interfaces have evolved to meet the stringent requirements of robotics communications and have done so for many years. Increasing speed and bandwidth requirements from robots is starting to exceed the capabilities of these very effective interfaces.

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1 Introduction

Communication in robotics system designs is undergoing a transformation as it keeps pace with the fourth industrial revolution, or industry 4.0. In the status quo, robot communications must be robust, accurate, have excellent timing characteristics and neither hinder axis movement, nor be negatively impacted by it. Several important, but disparate, communication interfaces have evolved to meet the stringent requirements of robotics communications and have done so for many years. Increasing speed and bandwidth requirements from robots is starting to exceed the capabilities of these very effective interfaces.

As designers look for new ways to meet faster cycle time and higher throughput to meet big data requirements, and have these wider-bandwidth systems work at the highest efficiencies with minimal downtime, they may also wish to minimize impact on the upgrade by reusing existing cabling infrastructure. Most also employ advanced features like smarter diagnostics, higher safety specifications and faster and better real-time characteristics for motor control.

Robotic system architectures must meet communication interface requirements like bandwidth margin. As bandwidth requirements continue to increase, designers are incorporating both Ethernet and optical solutions that are faster than legacy interfaces like RS-485 and Controller Area Network (CAN). However, when moving to Ethernet, it's important to consider how to minimize latency in the real-time performance of the Ethernet protocol, either through industrial Ethernet protocols such as Ethernet/IP, EtherCAT, Profinet …, or by implementing a proprietary communication protocol.

This article discusses the benefits of single twisted-pair Ethernet (Base-T1) for robotics applications as well as key challenges when designing with compact, efficient, robust and low-noise communication interfaces for robotic systems. These challenges need to be understood to implement single twisted-pair ethernet in the robot systems and still achieve the needed performance to operate the robot efficiently.

Typically, two key design parameters are data rate and cable size/length. These two parameters are related which means that the cable length for some communication interfaces define the data rate which can be achieved. A second parameter is the physical amount of cables and connector pins which are needed to implement the interface.

Table 1 lists the standard data rates and cable lengths of PHY types typically used in robotic systems.

Table 1-1. Physical Communication Interface Features

COMMUNICATION INTERFACE	DATA RATE	CABLE LENGTH	TWISTED-PAIR WIRES
CAN	1 Mbps	40 m	1
CAN-Flexible Data Rate (FD) or CAN-Signal Improvement Capability	10 Mbps	10 m	1
RS-485	20 Mbps	40 m	1
100Base-TX	100 Mbps	100 m	2
1000Base-TX	1,000 Mbps	100 m	4
1000Base-SX	1,000 Mbps	1,000 m	Multimode fiber
1000Base-LX	1,000 Mbps	5,000 m	Single-mode fiber
Low-voltage differential signaling	360 Mbps	10 m	1
100Base-T1	100 Mbps	100 m	1
1000Base-T1	1,000 Mbps	40 m	1

When considering the data rate and cable lengths required for a particular robotic system, you should also consider the cable aging (highly affected by the movement of the robot), cost, diameter and weight of the cables to be used in the system. In a robotic arm it is typical to replace the cable tree of the manipulator every 2 to 3 years due to cable aging. This is performed as preventive maintenance, without testing the cable function. Now with this in mind, reducing the number of wires (which can age) and by introducing smart diagnostic features in the PHY (to understand the ongoing quality of the cable), there are fewer points of failure and cable and connector health indicate a need to change cabling, rather than arbitrarily doing so every couple of years, needed or not. Another benefit is that the mechanical construction of the arm gets smaller and more cost effective due to less space being needed to route the smaller sized cables.

There are specifications beyond data rate and cable selection which impact a robotic system's performance and so need to be understood. Below I have listed some system elements which influence robots' system performance and should be considered in a system's design.

- Deterministic real-time communication with minimum latency.
- Jitter between different packets.
- Electromagnetic compatibility of the Base-T1 interface.
- Hardware and software factors to achieve bandwidth and latency.
- Diagnostics for detecting cable defects.

2 Reference Schematics

Figure 2-1 shows latency and jitter affecting the real-time performance of a robotic system, which requires quantifying to ensure the necessary performance timings are possible.

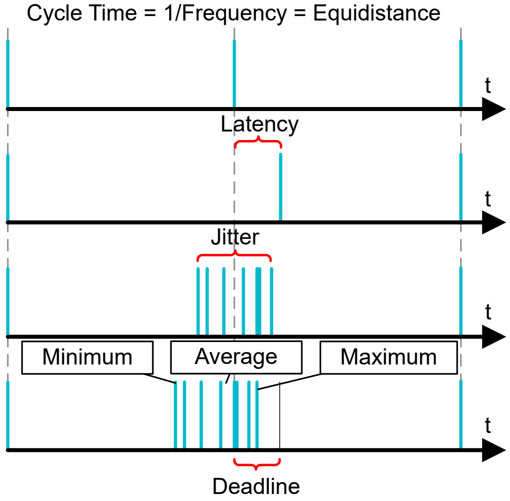

Figure 2-1. Key Points of Understanding Determinism

Quantifying jitter and latency performance will define the maximum acceleration and speed at which the robot will have controlled movements. Tests must be conducted on each physical layer (PHY) to determine their jitter and latency performance. The results of these tests allow us to understand the timing effects that a potential change of interface could have on system performance.

The quantification of determinism of the physical layer will also influence the industrial protocol chosen. To date, no common industrial protocol has been finalized for use over a SPE PHY layer. Instead, designers have to either develop proprietary systems, or use protocols that have not been standardized, adding time and risk to a product's development.

Complex systems like robots have several communication interfaces – and potentially a mix of different interfaces – to support because of different subsystem requirements. Figure 2 shows a decentralized robot system with several communication interface paths, each of which has a different specification.

Changing to SPE from these interfaces provide benefits for the overall system cost and mechanical dimensioning. However, it also creates the need to ensure that the necessary timing performance is possible.

The green lines in show the communication interface, which usually employs Figure 3-1 a real-time protocol that ensures deterministic communication with a high data rate for amount of data transferred. The blue lines show the encoder interface, which is typically accomplished with either a proprietary digital protocol based on RS-485, or an analog encoder interface.

The internal communication path of a robot operates in proximity to the location of switching phases of the motors. This implementation can reduce the number of cables and power levels in the robot, while also eliminating the need for cooling at the robot joint. Moving the placement of power electronics into the manipulator has the potential to cause continuous noise in the communication interface of the system. This in turn creates a new challenge of losing communicated data due to the poor noise performance of the chosen interface or design. In SPE, performance in noisy environments is highly dependent on the type of PHY termination selected. As previously described, another challenge is that the manipulator is constantly moving the cable around, damaging the cable over time.

Several standards help ensure that continuous noise does not cause the system to fail; one example is the International Electrotechnical Commission (IEC) 61000-4 tests for radiated and conducted noise types. The standard's accepted criterion level will show how well the system can perform when the system is subjected to noise. The IEC 61000-4-4 electrical fast transient (EFT) test, in particular, is a compliance test that simulates the switching phases of a motor.

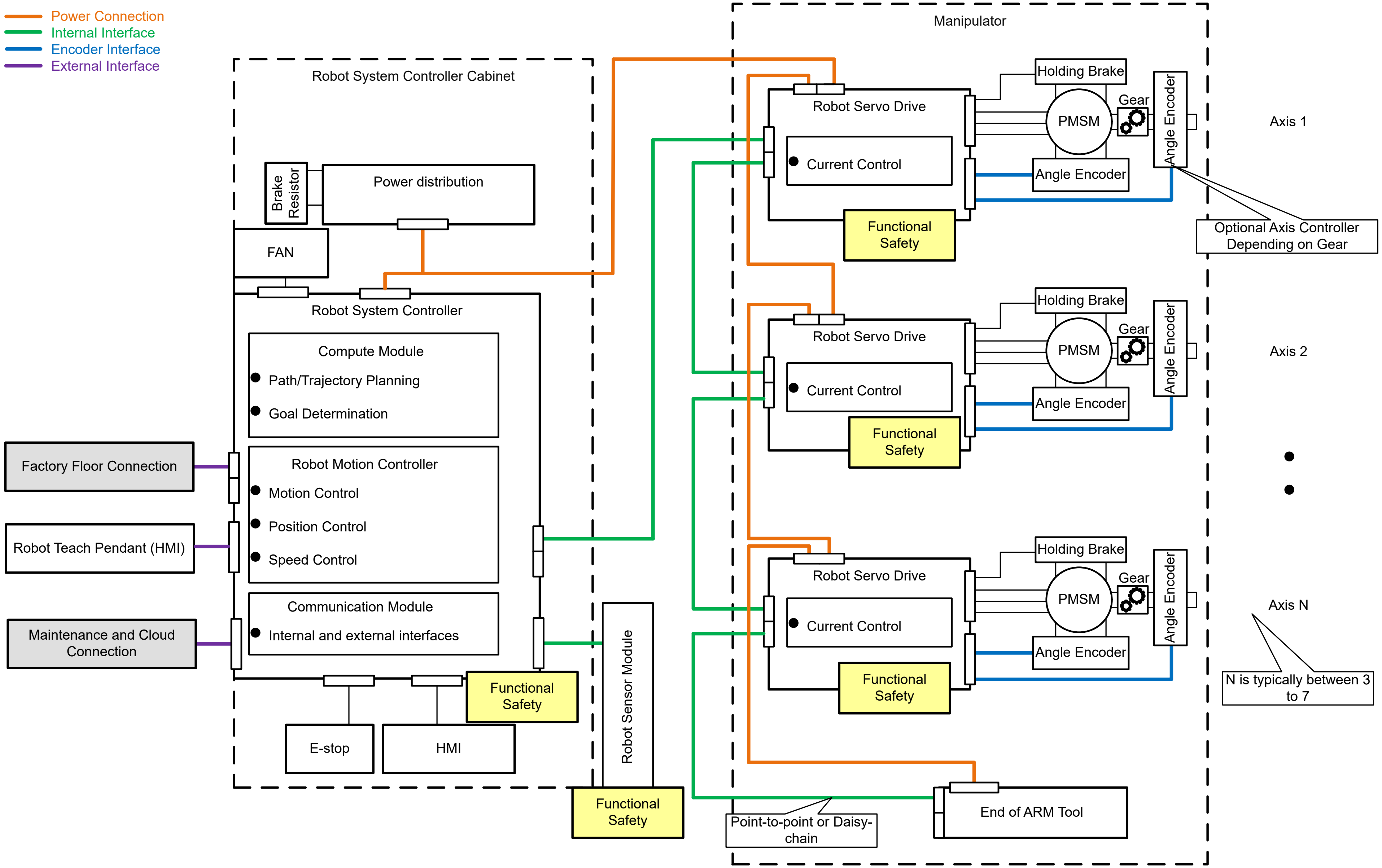

Figure 3-1. A Decentralized Robot Architecture Example

To pass the EFT test, it is important to optimize the termination of the communication interface to ensure its best performance. There are two ways to terminate a single-pair Ethernet interface: capacitive coupling or inductive coupling. Given the isolation requirements on the communication line in industrial systems, the rating of the capacitor must be as high as the isolation need. For example, you would use 1.5 kV if building a robot in accordance with the IEC 62368-1 standard.

Texas Instruments (TI) has conducted tests on capacitive and inductive decoupling indicating that:

- Inductive decoupling is less susceptible to noise.
- Inductive coupling has a better mode conversion and return loss performance response than capacitive decoupling.
- Inductor tolerances are more precise.

Future test plans include optimizing inductive coupling to achieve no bit errors.

A key benefit of some Base-T1 PHYs is the ability to conduct diagnostics of the interface during data communication. Using a diagnostic tool requires a media access control interface to provide full access to the serial management interface of the PHY.

These are the current integrated diagnostic features of the TI PHY’s:

- Signal quality indication.
- Time-domain reflectometry.
- Electrostatic discharge sensor.
- Voltage sensor.
- Temperature sensor.
- Pseudorandom binary sequence built-in self-test.

For more details, see TI’s DP83GT720S-Q1 1000Base-T1 PHY data sheet, Section 7.3.1.

Base-T1 Ethernet technology features, such as low cable count and high bandwidth, can enable real-time diagnostic capability, including cable diagnostics that can detect when a cable is damaged or degrading. This detection feature allows engineers to replace cables during normal maintenance instead of performing production-line stops. Another benefit specific to battery-driven robots is the ability to reduce the number of cables, which can also reduce weight and increase system efficiency.

3 Conclusion

Many of the benefits of the Base-T1 Ethernet are highly valuable to a robotic system and can be used to simplify and cost optimize the system functions. The additional diagnostic tools which have been added into the TI Base-T1 PHY's are enabling new possibilities to achieve predictive maintenance. While the Base-T1 Ethernet has the potential to be used in industrial systems, it requires further testing before it can be used in a finished product. Many companies are reviewing the initial hurdles of using the Base-T1 Ethernet interface in industrial applications to understand and improve the technology. The future for Base-T1 Ethernet can be compared with the CAN interface which was first introduced in automotive systems and has been successfully implemented in automotive markets; CAN has later also proven successful in industrial markets. Many of the benefits of Base-T1 ethernet is very valid for industrial markets however there are still work to be done verifying the feasibility on a system level.

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