Application Note

How Ethernet Addresses Humanoid Robotics Communication Challenges

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ABSTRACT

Texas Instruments Ethernet portfolio addresses communication challenges in humanoid robotics by enabling higher bandwidth for increased data throughput, minimized latency for real-time deterministic communication, and reduced cabling for space and weight optimization. This application note is intended for engineers and system architects who are evaluating and selecting technology for communication in humanoid robotics. Communication applications in a humanoid include motor control, perception sensing, tactile sensing, battery management, battery charging, and controller to controller communication. Various types of Ethernet standards defined by IEEE support a variety of communication requirements for different data rate, latency, and cabling requirements. Ethernet addresses diverse challenges and therefore is emerging as the leading technology standard for communication in humanoid robots.

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1 Introduction

The development of humanoid robots is rapidly progressing. Whether used to perform manufacturing, logistics, customer service, dangerous tasks, or household chores, humanoid robots have the potential to benefit society by increasing efficiency and protecting human life. As the development of humanoid robots continues to exponentially increase, engineers are identifying technical challenges and critical design decisions for the communication system in a humanoid robot. Three technical challenges include the need for higher data throughput, lower latency, and thinner and lighter weight cables. Ethernet comprehensively addresses the challenges of data communication in humanoid robotics today, and therefore designers are continuing to adopt Ethernet as the backbone of communication in robotics.

2 Detailed Description

Today designers are running out of bandwidth to facilitate data communication in humanoid robots. What does it take for a humanoid to move and respond to its environment like a human? The short, perhaps oversimplified answer is faster movement of data. To perceive and respond to the world around it, a humanoid must facilitate high data communication between the main controller and the perception sensors, tactile sensors, actuators, encoders, and torque sensors. Bandwidth for perception sensors communicating radar, lidar, or camera data is increasing from Kbps to 10Mbps or in some cases 1000Mbps. Bandwidth for motor control is increasing from Kbps to 10Mbps or in some cases 100Mbps. Therefore, there is an emerging need for higher data throughput to enable humanoid robots to move as well as process and respond.

Humanoid robot designers are continuing to identify the need to minimize system latency. Latency impacts a humanoid's ability to respond quickly and reliably. For example, minimal latency is required for a humanoid to perform tasks such as carry fragile objects or lift a heavy object. These tasks require the robot to calibrate pressure, force, and torque immediately to respond quickly.

Small and lightweight designs for humanoid design have emerged as a top priority. Electrical components and high cable count cause congestion particularly in the limbs of humanoid robots. Greater number of cables also increases the overall weight and drains battery life. Therefore, the need for both small and lightweight cabling designs is prominent.

While 4/20mA, HART, CAN, and RS485 have been reliable communication protocols for industrial applications for over 40 years, their bandwidth does not meet the communication needs of robotics today. Table 2-1 lists the standard data rates and cable lengths of PHY types typically used in robotic systems.

Table 2-1. Physical Communication Interface Features

	Communication Interface	Data Rate	Cable Length	Twisted-Pair Wires
Legacy Industrial Communication Standards	4mA to 20mA I/O	0.01Mbps(1)	3000m	1
	HART	0.0012Mbps	3000m	1
	CAN	1Mbps	40m	1
	CAN-Flexible Data Rate (FD) or CAN-Signal Improvement Capability	10Mbps	10m	1
	RS-485	20Mbps	40m	1
	Low-voltage differential signaling	360Mbps	10m	1
Standard Ethernet	100BASE-TX	100Mbps	100m	2
	1000BASE -TX	1,000Mbps	100m	4
	1000BASE -SX	1,000Mbps	1,000m	Multimode fiber
	1000BASE -LX	1,000Mbps	5,000m	Single-mode fiber
Single-Pair Ethernet	100BASE-T1	100Mbps	50m (UTP) 100m (STP)	1
	1000BASE-T1	1,000Mbps	15m (UTP) 40m (STP)	1
	10BASE-T1L	10Mbps	1000m	1
	10BASE-T1S	10Mbps	25m	1

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Both Standard Ethernet which uses between 2-4 wire pairs and Single-Pair Ethernet which uses 1 wire pair support 1000Mbps and provide higher throughput for humanoid communication.

Figure 2-1 shows the characteristics of the IEEE Ethernet standards.

IEEE802.3 | Key Types of Ethernet PHYs

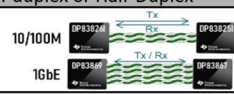
	Standard ENET			Single Twisted Pair ENET			
Cable type	2+ twisted pairs / 4+ wires			1 twisted pair / 2 wires			
IEEE Standard	**802.3i**	**802.3u**	**802.3ab**	**IEEE802.3cg**	**IEEE802.3cg**	**IEEE802.3bw**	**IEEE802.3bp**
Description	10BASE-T	100BASE-TX	1000BASE-T	10BASE-T1S	10BASE-T1L	100BASE-T1	1000BASE-T1
Maximum Bandwidth (Mb/s)	10	100	1000	10	10	100	1000
Standard Cable Reach (m/link)	100			25	1000	50	15/40
Point-to-point, Line, Ring, Star, Extended Star	✓			✓	✓	✓	✓
Multidrop				✓			
Data Transfer	Full-duplex or Half-Duplex			Half-Duplex	Full-duplex		
Wire Count							
Cable / Connectors	 Cat 7, Cat 6, Cat 5e, RJ-45			 Rosenberger	 Type A/ Type B Automotive Cables	Leoni Dacar547/647	Rosenberger, MATEnet
Sample Applications	Harsh environments, diagnostics Firmware/Software Upgrades End of line programming Ethernet fieldbuses			Diagnostics Automation Robotics Avionics	PoDL Field transmitters	Harsh environments Domain to domain connections Robotics ADAS/Infotainment Body Control Module	

Figure 2-1. IEEE Ethernet Standards

When communicating high-precision motor control in a humanoid, 100Mbps bandwidth may be required. Using 100Mbps Standard Ethernet PHY, like DP83826A satisfies high-bandwidth motor control requirements and supports EtherCAT, a common industrial communication protocol designed for real-time deterministic motor control. For space-contained areas, designers must minimize cabling without compromising reliable communication to the actuators, encoders, and torque sensors as well as perception sensors. An emerging design minimizes cabling and maximizes data throughput by running Time Sensitive Networking over 1000Mbps Single Pair Ethernet. Using a 1000Mbps Single Pair Ethernet PHY like DP83TG721-Q1 provides sufficient bandwidth and TSN support (802.1AS) to optimize latency.

In addition to the benefits of high bandwidth, Ethernet is also being adopted as the primary communication protocol in humanoids to minimize latency for real-time performance of the Ethernet protocol, either through industrial Ethernet protocols such as EtherCAT, Profinet, and so forth, or by implementing a proprietary communication protocol which may utilize TSN standards. Using a robust 100Mbps EtherCAT PHY, for example TI's DP83826A, enables fast, real-time automation control. When a designer needs to reduce cabling and use Single-Pair Ethernet, TSN can be used to enable real-time deterministic communication over Ethernet. Texas Instrument's Single-Pair Ethernet PHYs with integrated 802.1AS functionality, for example DP83TC815-Q1 for 100Mbps applications and DP83TG721-Q1 for 1000Mbps applications, reduce cabling and offer local timestamping and synchronization to reduce system latency.

While industrial Ethernet based on Standard Ethernet PHYs has historically been used for deterministic, real-time applications, Single-Pair Ethernet is becoming increasingly attractive as an alternative to reduce the size and weight of cable inside the humanoid by up to 75%. As seen Table 1-2, while Standard Ethernet requires two wire pairs for 100Mbps and four wire pairs for GbE, Single-Pair Ethernet requires only one pair for both 100Mbps and Gigabit Ethernet communication. Reducing size and weight is an essential factor in humanoid robots, where lower weight enhances mobility, energy efficiency, and balance. Using Single-Pair Ethernet, for example TI's DP83TC81x for 100Mbps, DP83TC72x for 1000Mbps, or DP83TD5x5 for 10Mbps multidrop applications minimize cable count and weight accomplishing communication with a single wire pair. Along with the weight and

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size reductions that come with Single-Pair Ethernet, designers can further optimize space with TI's smallest size Ethernet PHY, DP83TC813.

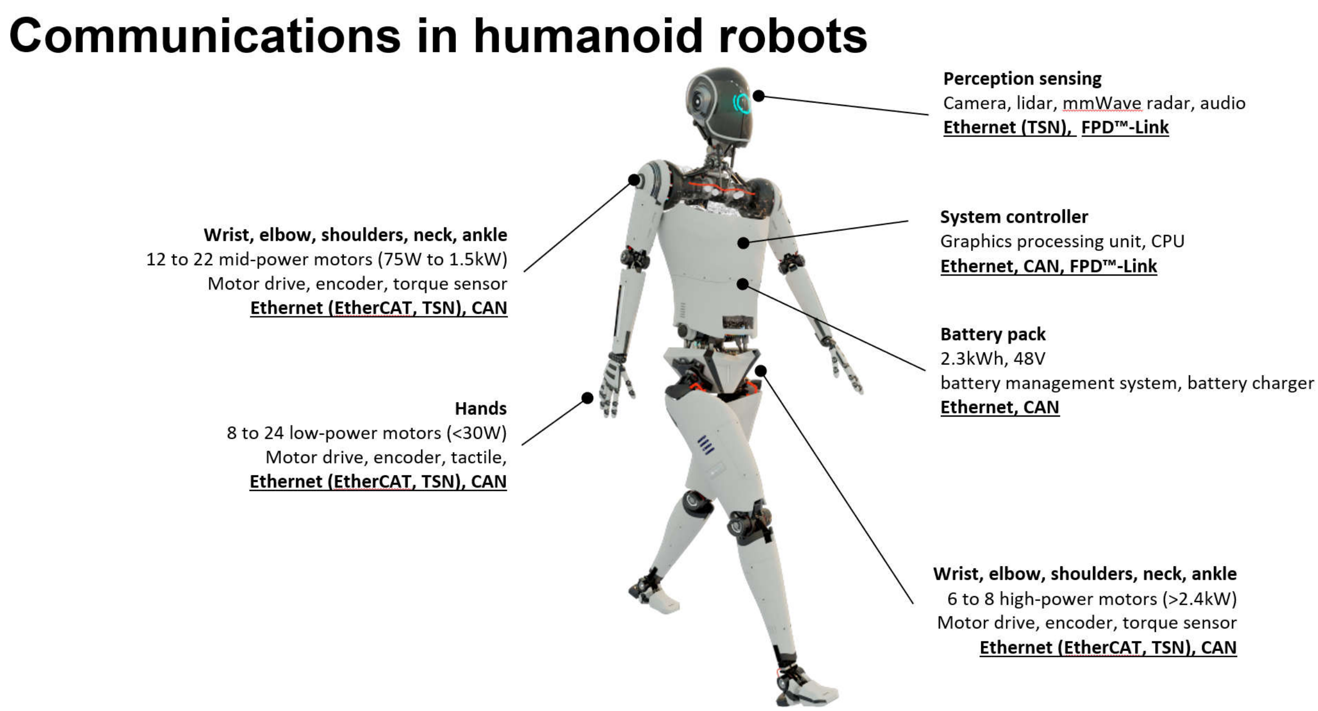

Figure 2-2. Communications in Humanoid Robots

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3 Summary

Ethernet comprehensively addresses the challenges of data communication in humanoid robotics today and therefore designers are continuing to adopt Ethernet as the backbone of communication in robotics. Ethernet addresses the need for higher data throughput, lower latency, and smaller and lighter weight cables.

4 References

1. Texas Instruments, *Advancing Humanoid Robotics with Single Pair Ethernet*, application brief.
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