Industrial Ethernet Designs with MCUs- a Hands on Introduction

Class 2: Industrial Ethernet

12/12/2017

Warren Miller

Presented by:

This Week's Agenda

12/11/17 An Overview of Ethernet

12/12/17 An Introduction to Industrial Ethernet

12/13/17 Industrial Ethernet Applications

12/14/17 Industrial Ethernet Implementations

12/15/17 Industrial Ethernet- an example

Course Description

- Industrial Ethernet is still a key communication technology for factory control.
- It is built on the long legacy of Ethernet, but adds significant capabilities for increasing robustness and reliability.
- This course will provide an overview of the key differences between our familiar Ethernet protocol and the Industrial version.
- A hands on example will use easily available software and development boards to dig into some of the key details of an actual Industrial Ethernet implementation. Students can optionally obtain the hardware and software to follow along with the implementation.

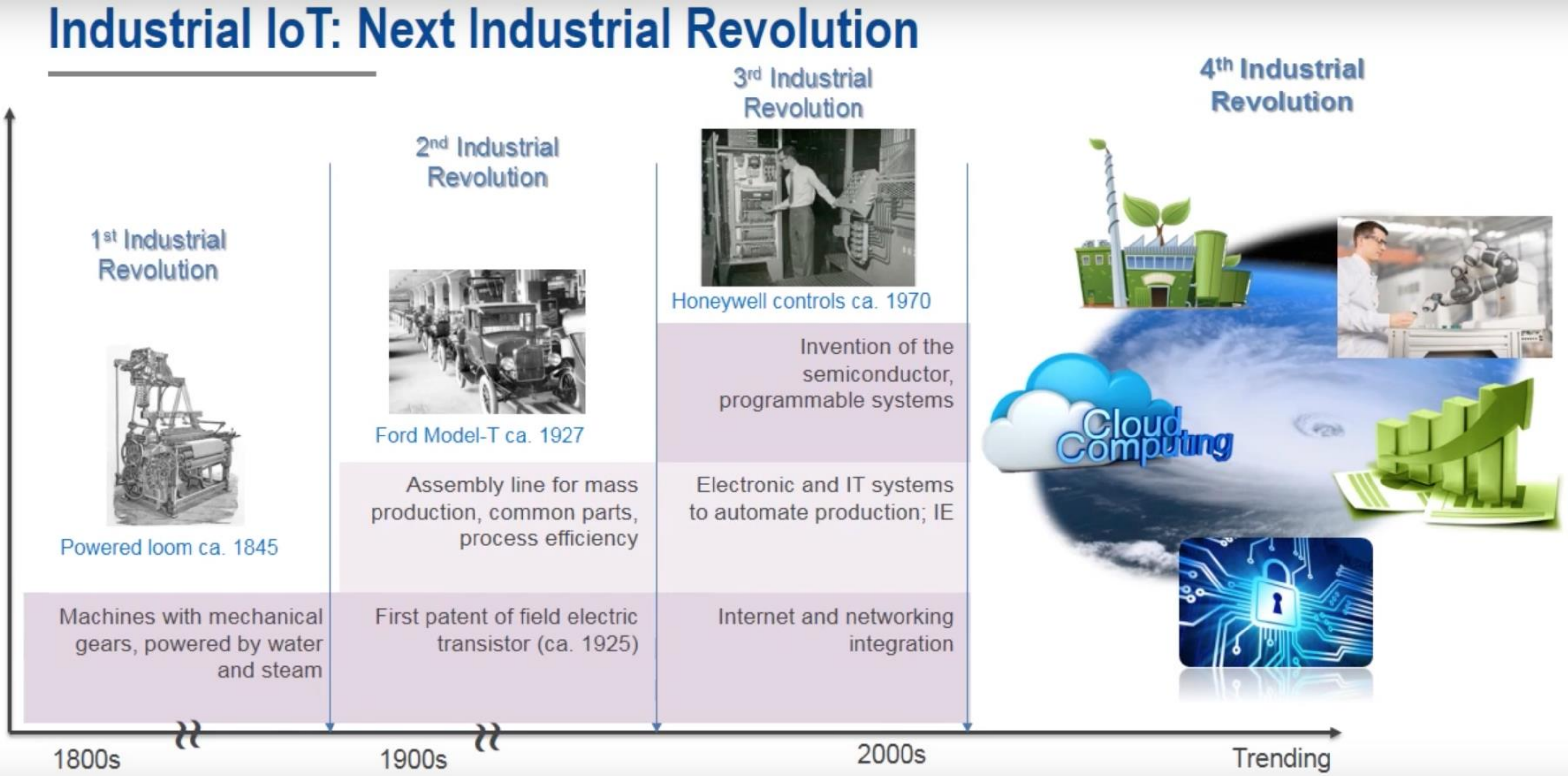
Today's Topics

Industrial Ethernet leverages the key elements of Ethernet and provides a robust solution for industrial applications. This class provides an introduction to the Industrial Ethernet standard.

- Modern factory communications and IoT
- Industrial Ethernet Variants
- IEEE- 1588

Industrial IoT Revolution

Industrial Ethernet is a key element of the wider Industrial IoT (Internet of Things) revolution.



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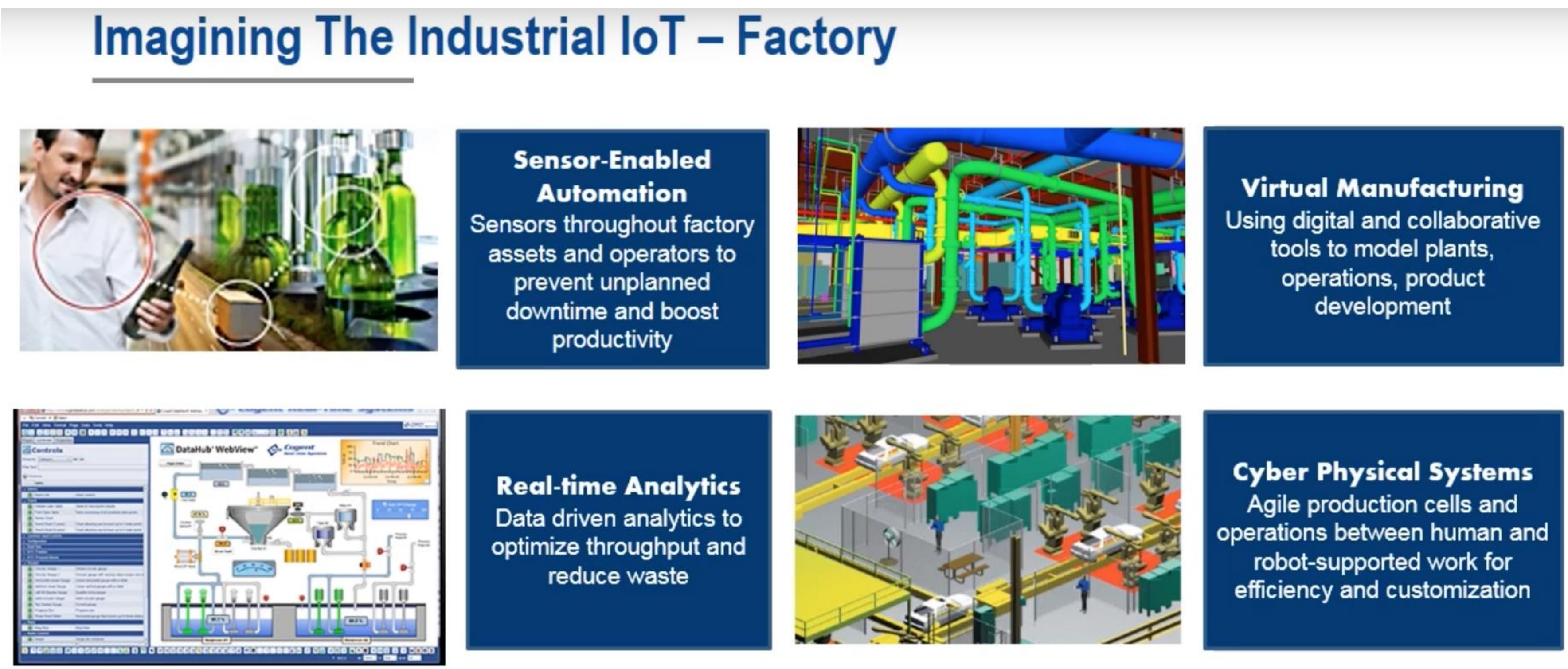
The Industrial IoT- an example

What significant changes does the I IoT bring?

A Factory Example

- What will be done differently in an IoT enabled factory?



Follow the Money

Where will new revenue streams come from in the I IoT world?

Industrial IoT

What are the key elements of I IoT solutions?

Main Components of Industrial IoT Solutions

Seamless Operation of People, Assets, & Process

- Technology-enhanced with sensors, feedback mechanisms
- Autonomous to the point of 'self-aware'
- Configurable, customizable

Connected

- Real time, non-real time domains
- Wired and Cloud components

Safe & Secure

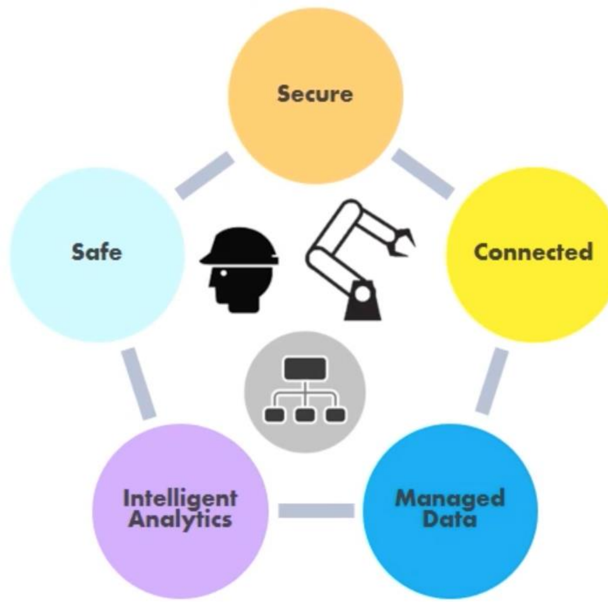
- Inherent safety
- User authenticated, context aware security

Intelligent Analytics

- Descriptive, Predictive and Prescriptive Analytics
- Conditioned at each plant level

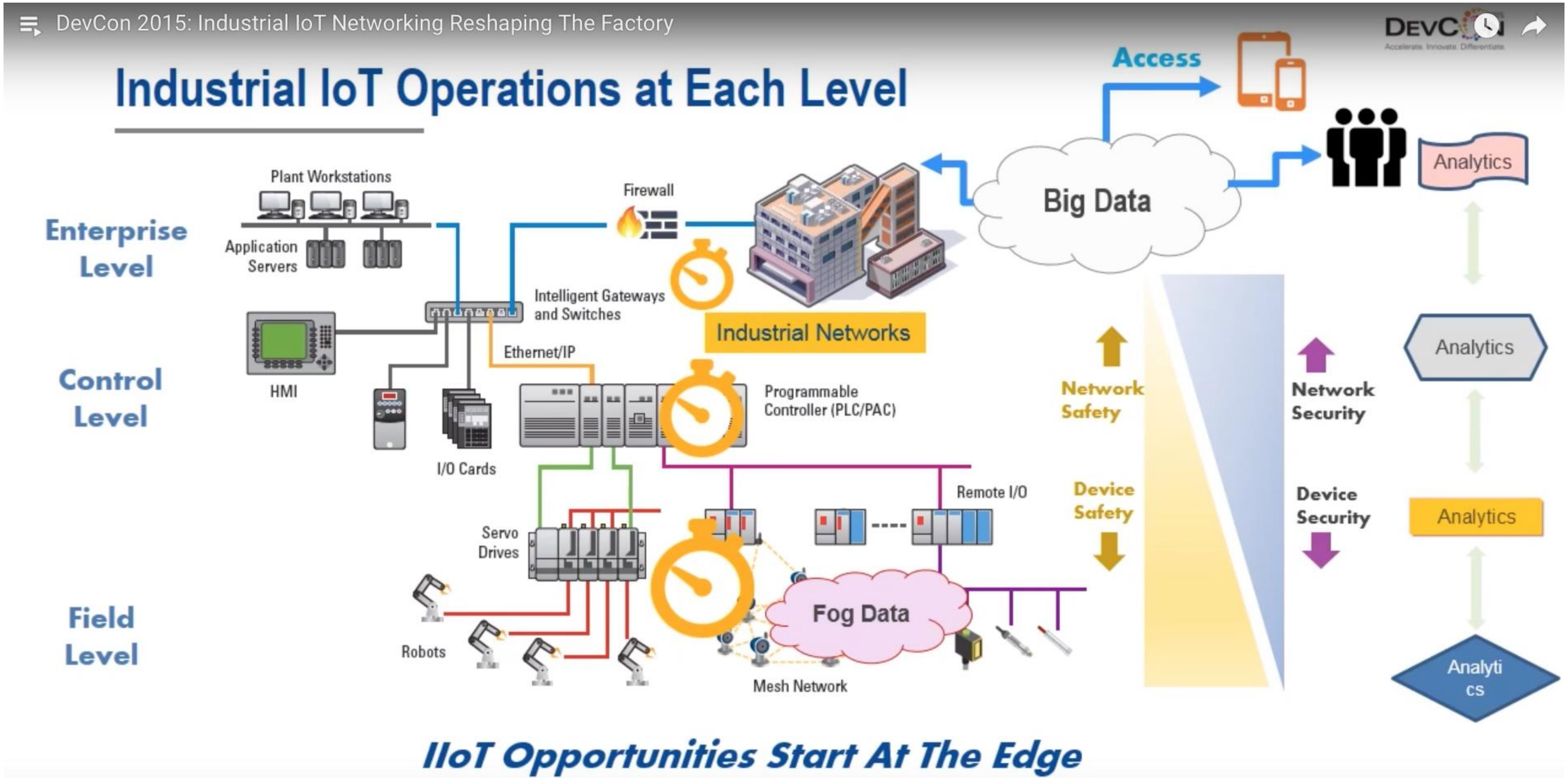
Managed Data

- Reusable, scalable data models
- "Intelligent Information" when and where people are

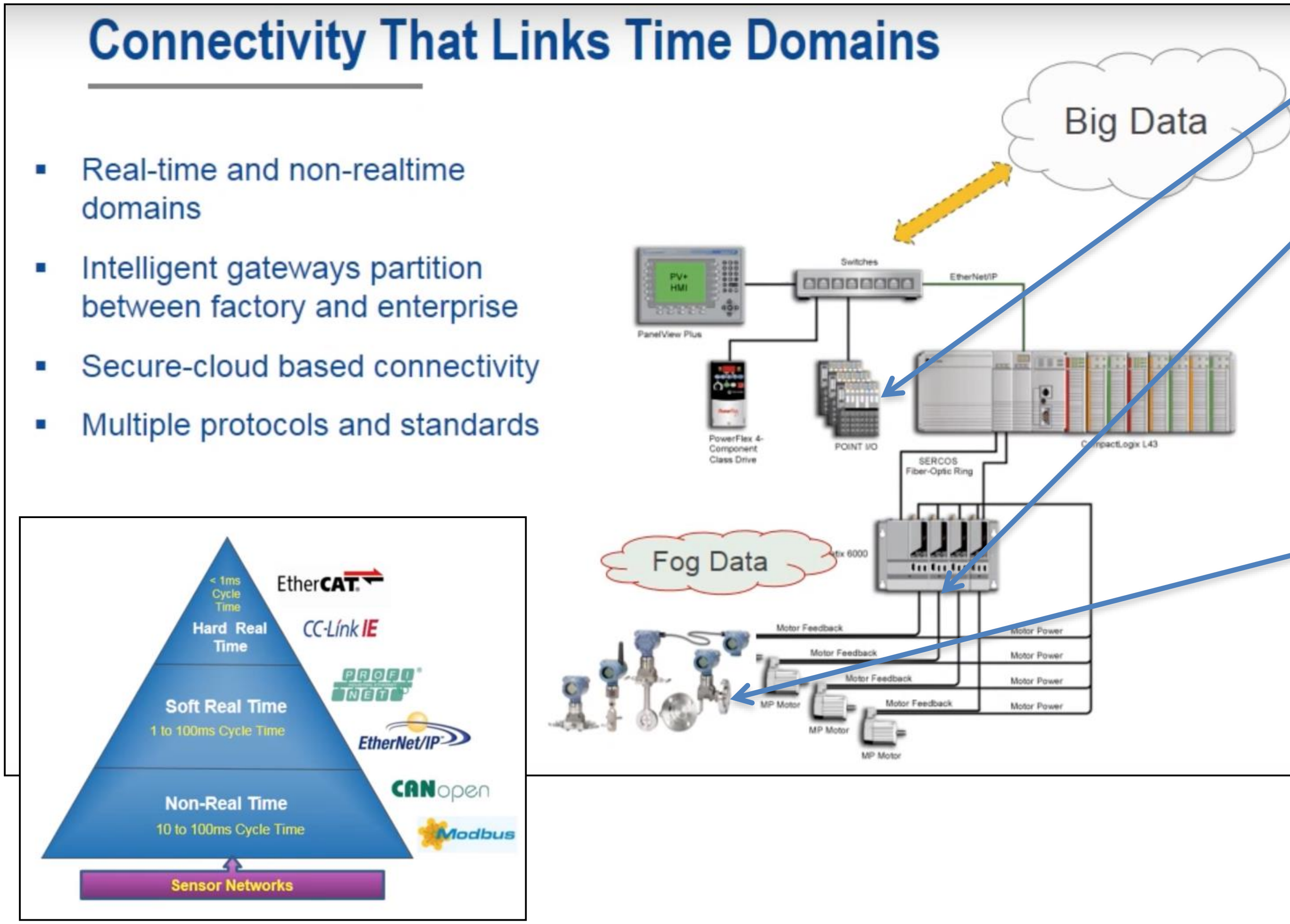


Operation Details

What does the operation of an IoT enabled factory look like?



Where does Industrial Ethernet Fit?

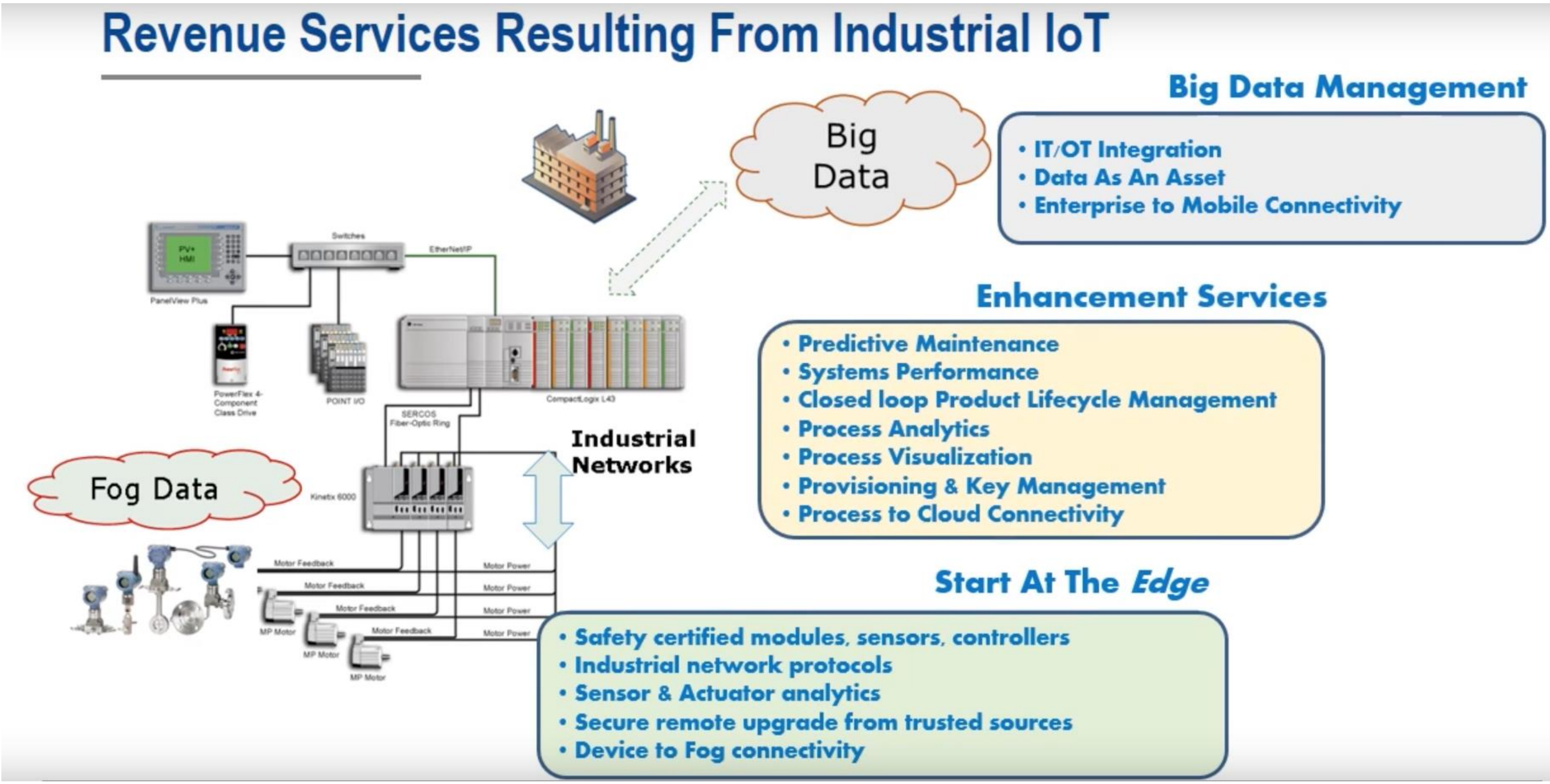


Process Control
(soft real time, <100ms)

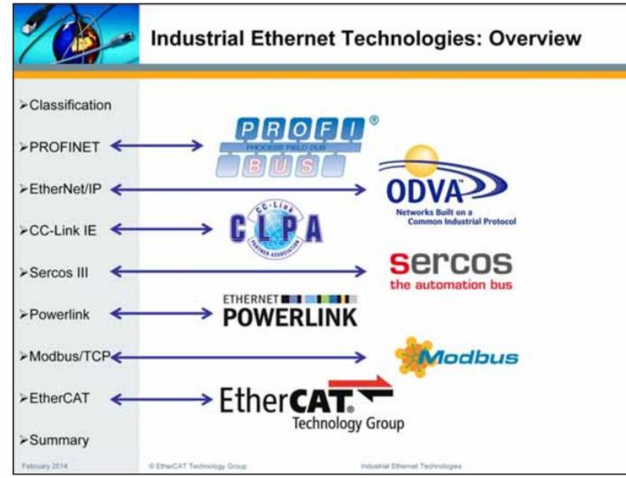
Industrial Ethernet
(<100us)

Fieldbus Protocols
(ms range)

New Revenue Reshapes Thinking



Industrial Ethernet



PROFINET is the Ethernet-based Profibus communication system.

EtherNet/IP is an industrial networking standard that takes advantage of commercial off-the-shelf Ethernet communications chips and physical media. The IP stands for ‘industrial protocol’.

EtherCAT (Ethernet for Control Automation Technology) is an open real-time Ethernet network that provides real-time performance, features twisted pair and fiber optic media and supports various topologies.

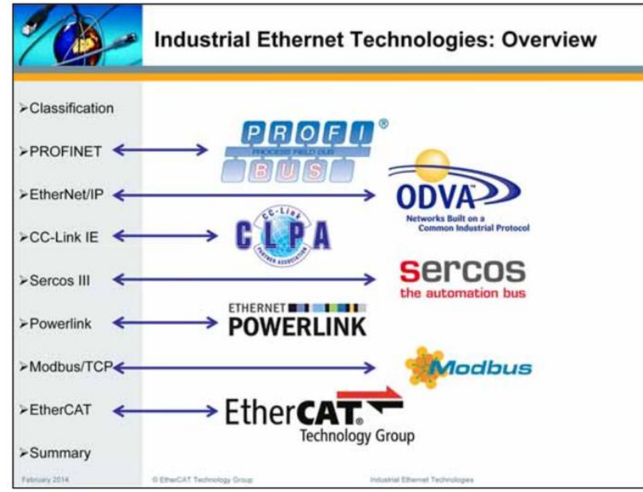
Ethernet Powerlink is a real-time Ethernet protocol that combines the CANopen concept with Ethernet technology.

Modbus-TCP, supported by Schneider Automation, allows the well-proven Modbus protocol to be carried over standard Ethernet networks on TCP/IP.

https://www.ethercat.org/download/documents/Industrial_Ethernet_Technologies.pdf

EtherCAT

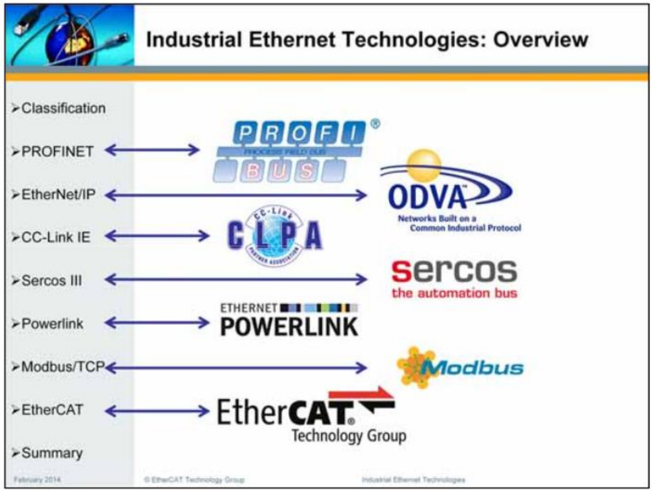
EtherCAT was originally developed by Beckhoff to enable on-the-fly packet processing and delivery of real-time Ethernet to automation applications with scalable connectivity for entire automation systems, from large PLCs all the way down to the I/O and sensors.



- EtherCAT uses standard IEEE 802.3 Ethernet Frames. Each slave node processes its datagram and inserts the new data into the frame while each frame is passing through.
- The process is handled in hardware so each node introduces minimum processing latency, enabling the fastest possible response time. EtherCAT is the MAC layer protocol and is transparent to any higher level Ethernet protocols such as TCP/IP, UDP, Web server, etc.
- EtherCAT can connect up to 65,535 nodes in a system, and EtherCAT master can be a standard Ethernet controller, thus simplifying the network configuration.
- Due to the low latency of each slave node, EtherCAT delivers flexible, low-cost and network-compatible industrial Ethernet solutions.

EtherNet/IP

EtherNet/IP is an industrial Ethernet protocol originally developed by Rockwell. Unlike EtherCAT, which is MAC-layer protocol, EtherNet/IP is application-layer protocol on top of TCP/IP. EtherNet/IP uses standard Ethernet physical, data link, network and transport layers, while using Common Industrial Protocol (CIP) over TCP/IP.

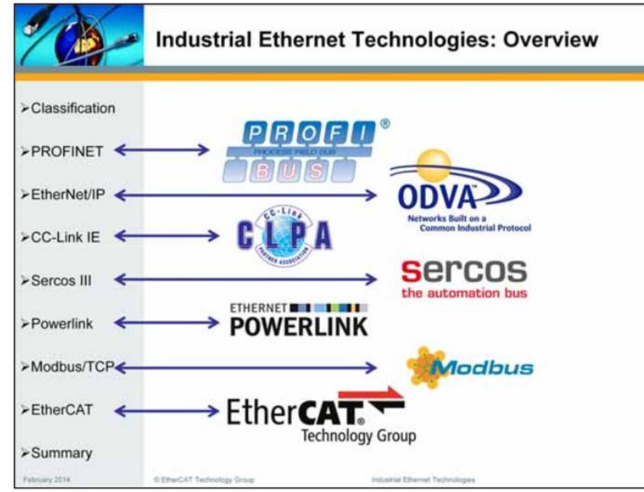


- CIP provides a common set of messages and services for industrial automation control systems, and it can be used in multiple physical media. For example, CIP over CAN bus is called DeviceNet, CIP over dedicated network is called ControlNet and CIP over Ethernet is called EtherNet/IP.

- EtherNet/IP establishes communication from one application node to another through CIP connections over a TCP connection, and multiple CIP connections can be established over one TCP connection.

- EtherNet/IP uses the standard Ethernet and switches, thus it can have an unlimited number of nodes in a system. This enables one network across many different end points in a factory floor. EtherNet/IP offers complete producer-consumer service and enables very efficient slave peer-to-peer communications. EtherNet/IP is compatible with many standard Internet and Ethernet protocols but has limited real-time and deterministic capabilities.

PROFINET



PROFINET is widely used industrial Ethernet by major industrial equipment manufacturers such as Siemens and GE. It has three different classes- Class A, B and RT.

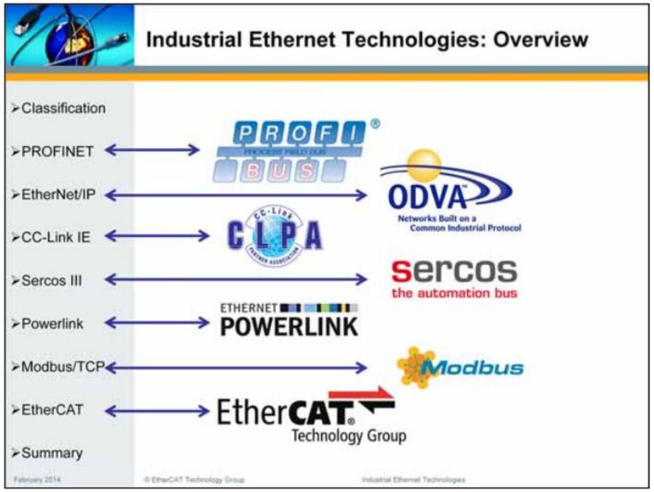
- PROFINET Class A provides access to a PROFIBUS network through proxy, bridging Ethernet and PROFIBUS with a remote procedure calling on TCP/IP. Its cycle time is around 100ms, and it is mostly used for parameter data and cyclic I/O. The typical application includes infrastructure and building automation.

- PROFINET Class B, also referred as PROFINET Real-Time (PROFINET RT), introduces a software-based real-time approach and has reduced the cycle time to around 10ms. Class B is typically used in factory automation and process automation. PROFINET Class C (PROFINET IRT), is Isochronous and Real-Time, requiring special hardware to reduce the cycle time to less than 1ms to deliver the suf cient performance on the real-time industrial Ethernet for motion control operations.

- PROFINET RT can be used in PLC-type applications, while PROFINET IRT is a good t for motion applications. Branch and Star are the common topology used for PROFINET. Careful topology planning is required for PROFINET networks to achieve the required performance of the system.

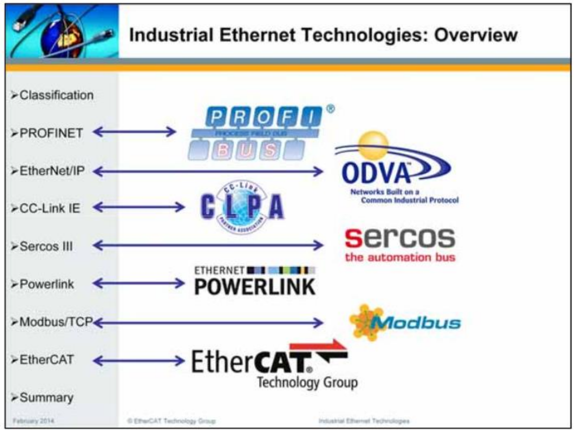
POWERLINK

POWERLINK was originally developed by B&R. Ethernet POWERLINK is implemented on top of IEEE 802.3 and, therefore, allows a free selection of network topology, cross connect and hot plug.



- POWERLINK uses a polling and time slicing mechanism for real-time data exchange.
- A POWERLINK master or “Managed Node” controls the time synchronization through packet jitter in the range of 10s of nanoseconds. Such a system is suitable for all kinds of automation systems ranging from PLC-to-PLC communication and visualization down to motion and I/O control.
- Barriers to implement POWERLINK are quite low due to the availability of open-source stack software.
- CANopen is part of the standard which allows for easy system upgrades from previous fieldbus protocols.

Sercos III and CC-Link IE



Sercos III is the third generation of Serial Real-time Communication System (Sercos). It combines on-the-fly packet processing for delivering real-time Ethernet and standard TCP/IP communication to deliver low latency industrial Ethernet.

- Much like EtherCAT, a Sercos III slave processes the packet by extracting and inserting data to the Ethernet frame on-the-fly to achieve low latency. Sercos III separates input and output data into two frames. With cycle times from 31.25 microseconds, it is as fast as EtherCAT and PROFINET IRT. Sercos III supports ring or line topology. Sercos III can have 511 slave nodes in one network and is most used in servo drive controls.

CC-Link IE is the industrial Ethernet technology of CC-Link, originally developed by Mitsubishi.

•CC-Link IE control is intended for controller-to-controller communications and can have 120 nodes per network. CC-Link IE Field intended for I/O communications and motion control, and it can have 254 nodes per network.

•CC-Link IE leverages the Ethernet data link layer, and its control frames are directly embedded in the Ethernet frame. Only ring topology is supported in CC-Link without switches. This can provide network redundancy, but a limited number of nodes can be supported in a network, and the cycle time is dependent on the number of the nodes in the network.

IEEE- 1588 Precision Time Protocol

Concerto IEEE-1588 Precision Time Protocol

What is an IEEE 1588 System?

- IEEE 1588 is "Precision Clock Synchronization Protocol for Network and Control Systems" – or Precision Time Protocol – or PTP
- IEEE 1588 allows the clocks in the system components to synchronize to a high degree of accuracy
- Microsecond accuracy is easily achievable using low cost, small footprint implementations such as Stellaris

How are the synchronized clocks used?

- The clocks in an IEEE 1588 system are typically used to coordinate the activities of the primary applications executing on the system
- If Sensor data is time stamped at a source, the time stamped data may be correlated in post-acquisition operations
- The clock is used to initiate actions in one or more components. An actuator can be change its value at time T while a sensor measures a value at time T+delta
- Since the clocks are synchronized, the resulting actions are coordinated in time

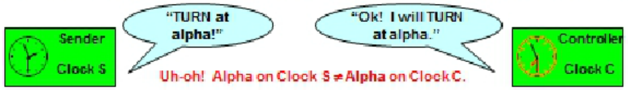
Visualizing the Benefits of IEEE-1588

Before IEEE 1588, Ethernet communication in control applications occurred without absolute determinism:

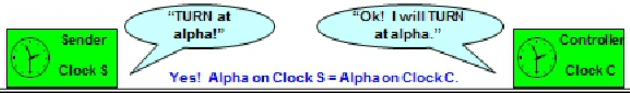
- Assume ***Sender*** sends a control instruction ***Turn*** to ***Controller***
- Assume also that ***Clock S*** and ***Clock C*** are not synchronized

If ***Sender*** asks ***Controller*** to ***Turn*** upon receipt of the instruction, then there is no telling when ***Controller*** wil receive ***Turn***

Even if ***Sender*** asks ***Controller*** to ***Turn*** at a given time ***alpha***, there is still the problem of unsynchronized clocks



But if ***Sender*** asks ***Controller*** to ***Turn*** at a given time ***alpha***, and the clocks are synchronized to a master, then determinism is achieved



Shown on this slide is an example of an application of IEEE-1588. Before IEEE-1588 was developed, Ethernet communication was absolute determinism. In this example the sender or host sends a control instruction to turn to a controller, and it is assumed that the sender clock, clock S, and the receiver or controller clock, clock C, are not synchronized. The sender asks the controller to turn upon receipt of the instruction; there is no telling when the controller will actually receive the command turn on, so maybe a couple milliseconds, maybe a few microseconds, maybe a few seconds, or maybe a few minutes later the controller actually turns. In the second example, the sender asks the controller to turn on at a given time, or alpha. Because the clocks are not linked or synchronized clocks, there is still a problem with the command. The sender alpha and controller alpha are not synched and the turn may happen at a random time. The bottom example shows the same command, with IEEE-1588. The clocks are synchronized to a master and there is now determinism in the system. When the sender asks the controller to turn on at alpha the controller turns at alpha and is ready for the next command.

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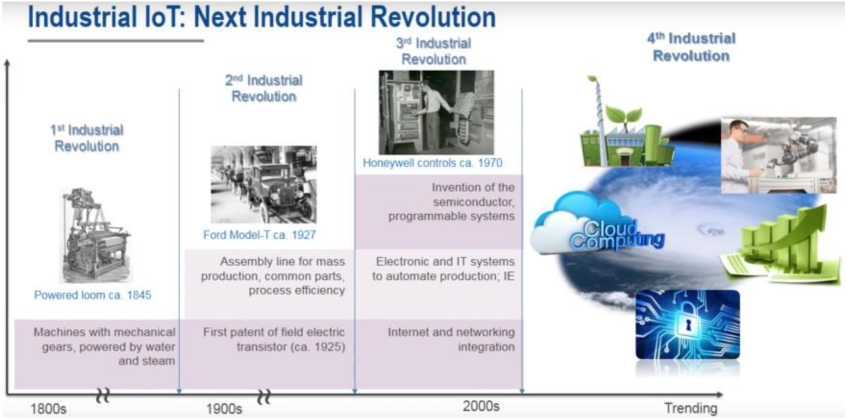
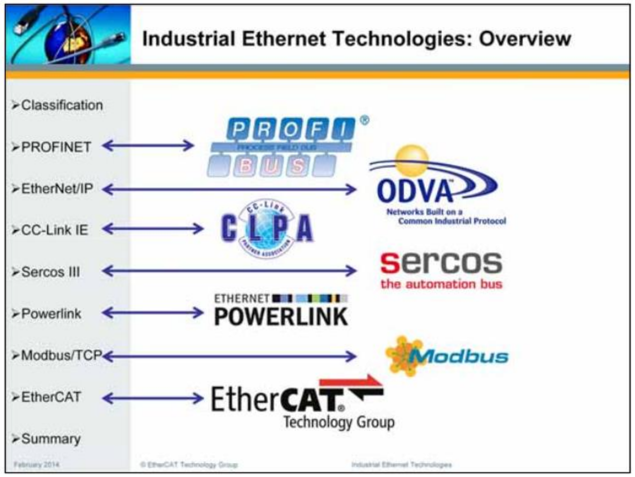
Conclusion

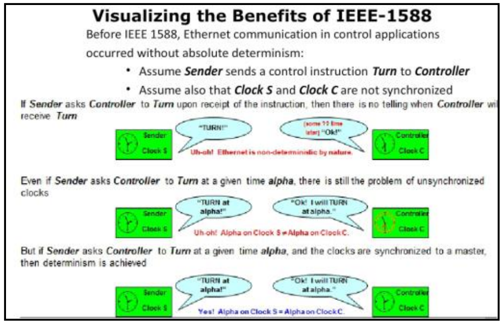
Industrial IoT is Changing the Factory Floor



Industrial Ethernet Variants



IEEE- 1588



Class Resources

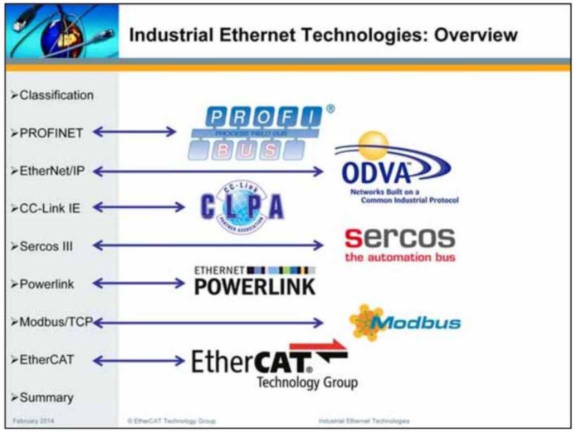
- Industrial Ethernet Overview- TI
- http://www.ti.com/lit/wp/spry254/spry254.pdf

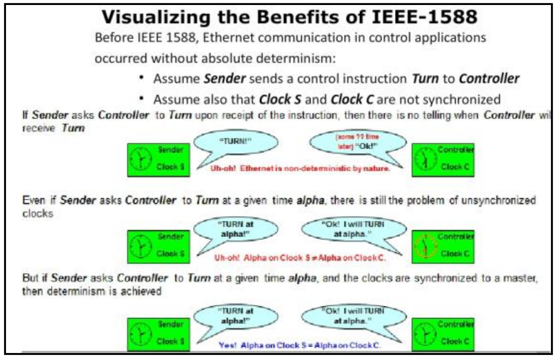
- Video of Industrial IoT Presentation- Renesas
- https://www.youtube.com/watch?v=gphJtw0pluo&list=PLgUXqPkOStPum60jqifNt7lDY9_0a0_rX&index=14

- Technology Overview- EtherCAT Org
- https://www.ethercat.org/download/documents/Industrial_Ethernet_Technologies.pdf

- Digi-Key Article EtherCAT
- https://www.digikey.com/en/articles/techzone/2015/aug/mcus-and-ethercat-gear-up-for-the-industrial-internet-of-things

- TI Connectivity MCUs
- https://dkc1.digikey.com/IE/en/TOD/Texas_Instruments/Connectivity-Control-Systems/Connectivity-Control-Systems.html





Course Resources

Industrial Ethernet Overview- TI

- http://www.ti.com/lit/wp/spry254/spry254.pdf

Industrial Communications Kit

- https://www.digikey.com/en/product-highlight/t/texas-instruments/industrial-communications-engine-using-tis-am3359

EtherCAT Article

- https://www.digikey.com/en/articles/techzone/2015/aug/mcus-and-ethercat-gear-up-for-the-industrial-internet-of-things

Connectivity and Control Systems- TI

- https://dkc1.digikey.com/IE/en/TOD/Texas_Instruments/Connectivity-Control-Systems/Connectivity-Control-Systems.html

Embedded Ethernet- MicroChip

- https://dkc1.digikey.com/IE/en/TOD/microchip/EmbeddedEthernet/EmbeddedEthernet.html
- https://dkc1.digikey.com/IE/en/TOD/Microchip/Ethernet_Controller_Solution/Ethernet_Controller_Solution.html

Introduction to Industrial Ethernet

- http://www.bb-elec.com/Learning-Center/All-White-Papers/Ethernet/Introduction-to-Industrial-Ethernet/AnIntroductionToIndustrialEthernet-WP12B-R1_1112.pdf

Additional Resources

- http://www.ti.com/lit/wp/spry254/spry254.pdf
- https://www.ethercat.org/download/documents/Industrial_Ethernet_Technologies.pdf
- https://www.youtube.com/watch?v=gphJtw0pluo&list=PLgUXqPkOStPum60jqifNt7lDY9_0a0_rX&index=14

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