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IEC 61499: primer course

Module 2: Ecosystem of Industrial Automation Systems

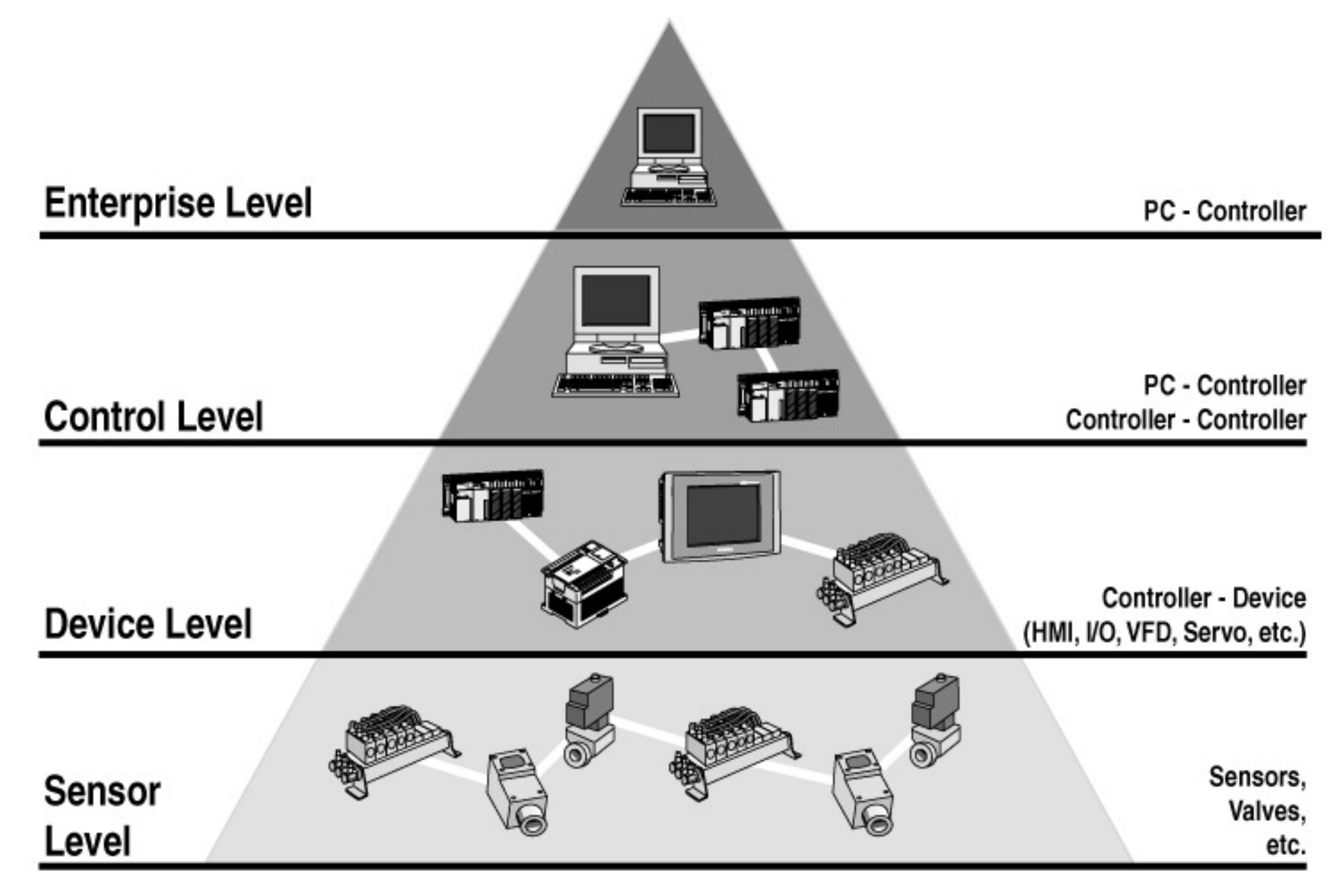
Valeriy Vyatkin

Luleå University of Technology and Aalto University

The key terms in the automation eco system

- PLC
- DCS (Distributed Control System)
- Motion control
- Robot control
- Computer numeric control
- SCADA (Supervisory Control and Data Acquisition)
- HMI (Human-Machine Interface)
- Field Devices
- Industrial Networks and Communication Protocols
- I/O Modules (Input/Output Modules)
- Control Algorithms
- MES (Manufacturing Execution System)
- ERP (Enterprise Resource Planning)
- Software Engineering

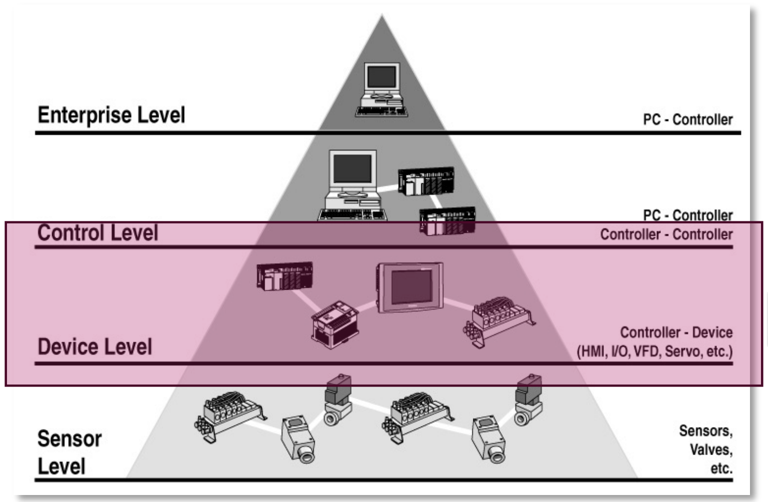
Automation ICT Pyramid



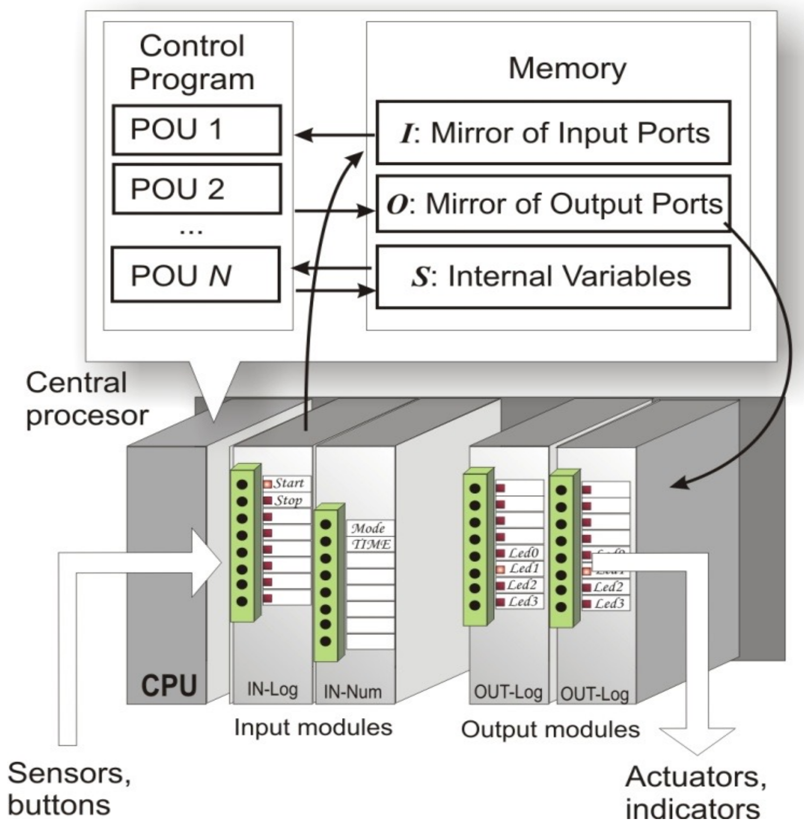
PLCs

What is a PLC?

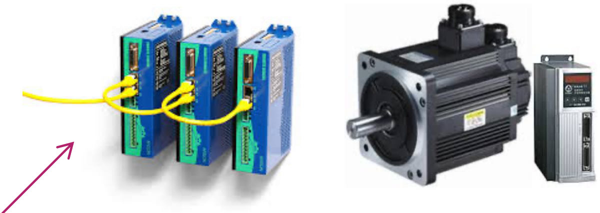
A PLC, or Programmable Logic Controller, is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, robotic devices, or any activity that requires high reliability, ease of programming, and process fault diagnosis.



PLC as an Integration Platform



Motion controllers (Drives)



Computer Numeric Controllers (CNC)

Industrial robot controllers

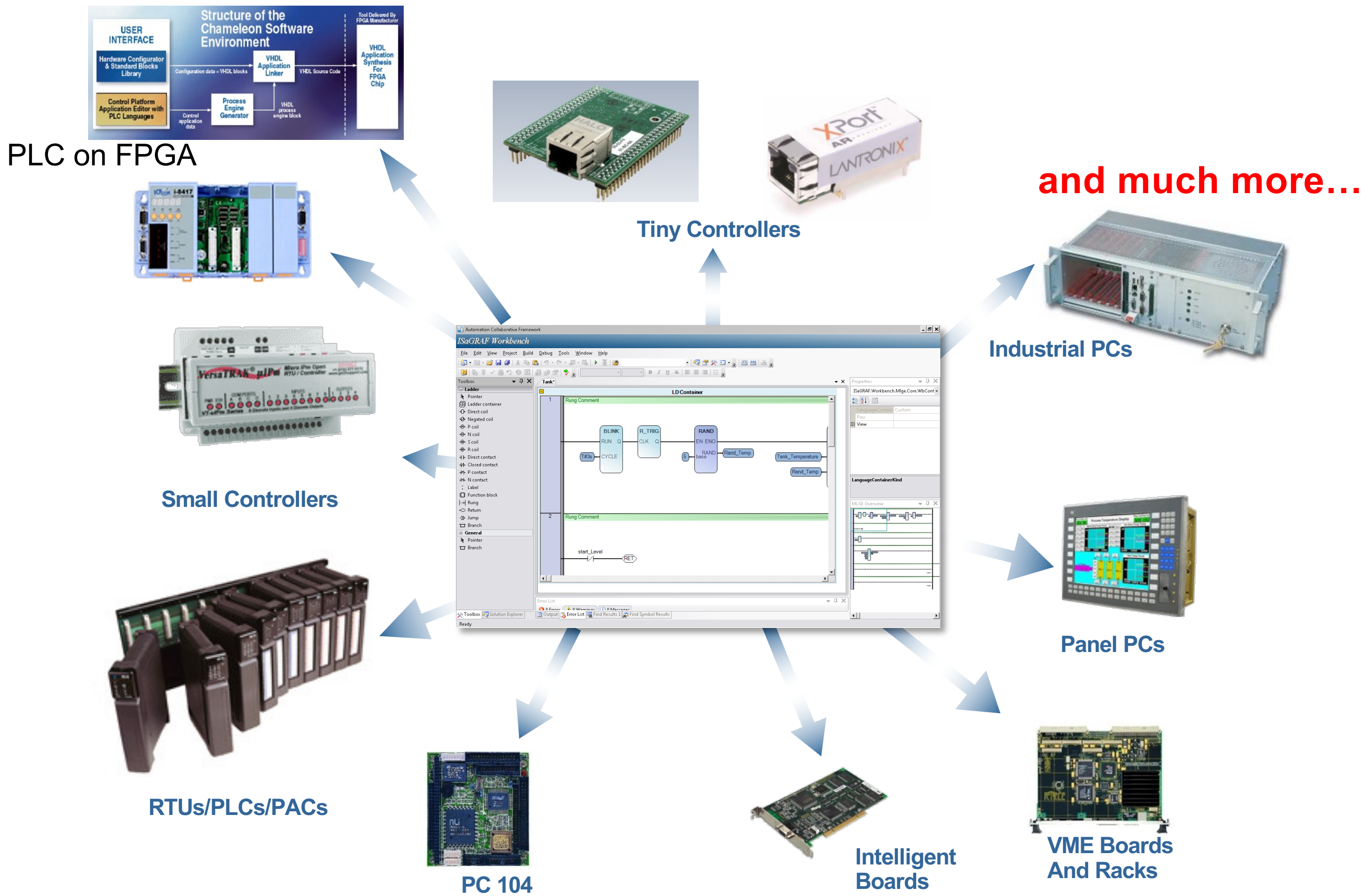
Key properties of PLCs

- Rugged and Adaptable: PLCs are designed to withstand harsh industrial environments. They are typically resistant to vibration, temperature, humidity, and noise, making them ideal for industrial settings.
- Programmable: A PLC can be programmed according to the needs of the operation. This programming is done using specialized languages, such as Ladder Logic, Functional Block Diagrams, Structured Text, and Sequential Function Charts.
- Control of Manufacturing Processes: PLCs are commonly used to control various processes in manufacturing, from simple lighting functions to complex control systems in chemical processing plants.
- High Reliability: Due to their critical role in industrial processes, PLCs are designed for high reliability and to operate continuously for years.

Key properties of PLCs

- Ease of Programming and Maintenance: PLCs are user-friendly in terms of programming and maintenance. They can be easily modified and updated as process requirements change.
- Process Fault Diagnosis: PLCs have diagnostic capabilities to detect and report faults in the processes they control. This helps in quick troubleshooting and reduces downtime in industrial processes.
- Modular and Scalable: Many PLCs are modular, allowing for expansion and customization. This means additional input/output (I/O) units, communication modules, and other functionalities can be added.
- Real-time Operation: PLCs operate in real-time, meaning they can process data and control outputs almost instantaneously, which is crucial for time-sensitive industrial processes.

Programmable Logic Controllers: Form Factors



DCS – Distributed Control Systems

What is it?

A Distributed Control System (DCS) is an integrated control system used in industrial environments, especially for continuous, complex processes in large-scale industries such as oil refining, power generation, chemicals manufacturing, and papermaking.

The core idea of a DCS is to distribute control functions across multiple interconnected subsystems, thus enhancing reliability, scalability, and flexibility.

Basic Concept and Architecture

Distributed Control: Unlike traditional centralized control systems, a DCS distributes control functions across several interconnected units. Each unit manages a specific portion of the plant process but is **coordinated by a central control system**.

Often the key function of a DCS node is to implement continuous regulation of a parameter (e.g., using PID control)

Modularity: The system is inherently modular, allowing for expansion or reconfiguration with minimal disruption to the overall system.

Components of a DCS

- **Controllers**: These are the hardware components that execute control functions. Each controller is responsible for a specific plant section and operates semi-independently.
- **Input/Output (I/O) Modules**: These connect the controllers to field devices like sensors and actuators. They convert sensor signals into digital data that the controller can process and convert controller commands into signals to control actuators.
- **Operator Interfaces**: Often referred to as Human-Machine Interfaces (HMIs), these provide graphical displays to operators for monitoring and controlling the process.
- **Communication Network**: DCS uses a high-speed communication network for data exchange between controllers, operator stations, and other system components.

Key Features

- **Redundancy**: To ensure high availability and reliability, DCS systems often incorporate redundancy in their controllers, networks, and power supplies, minimizing the impact of component failures.
- **Advanced Process Control (APC)**: DCS systems have sophisticated control algorithms, like PID control, to maintain process variables within desired limits.
- **Scalability**: The modular nature allows for easy expansion or modification, accommodating changes in process requirements.

Functionality

- **Process Control**: DCS systems manage complex, continuous processes and maintain stability and efficiency.
- **Data Acquisition and Monitoring**: They collect extensive process data for monitoring, analysis, and reporting.
- **Alarm Management**: DCS systems provide comprehensive alarm management capabilities, alerting operators to potential process deviations or equipment malfunctions.
- **Batch Control**: While primarily used for continuous processes, modern DCS systems can also handle batch processing operations.

Integration with Other Systems

- **SCADA Integration**: In some settings, DCS systems are integrated with SCADA systems for enhanced monitoring and control capabilities over geographically dispersed assets.
- **Enterprise Integration**: DCS can interface with higher-level systems like MES (Manufacturing Execution Systems) and ERP (Enterprise Resource Planning) for broader operational coordination.

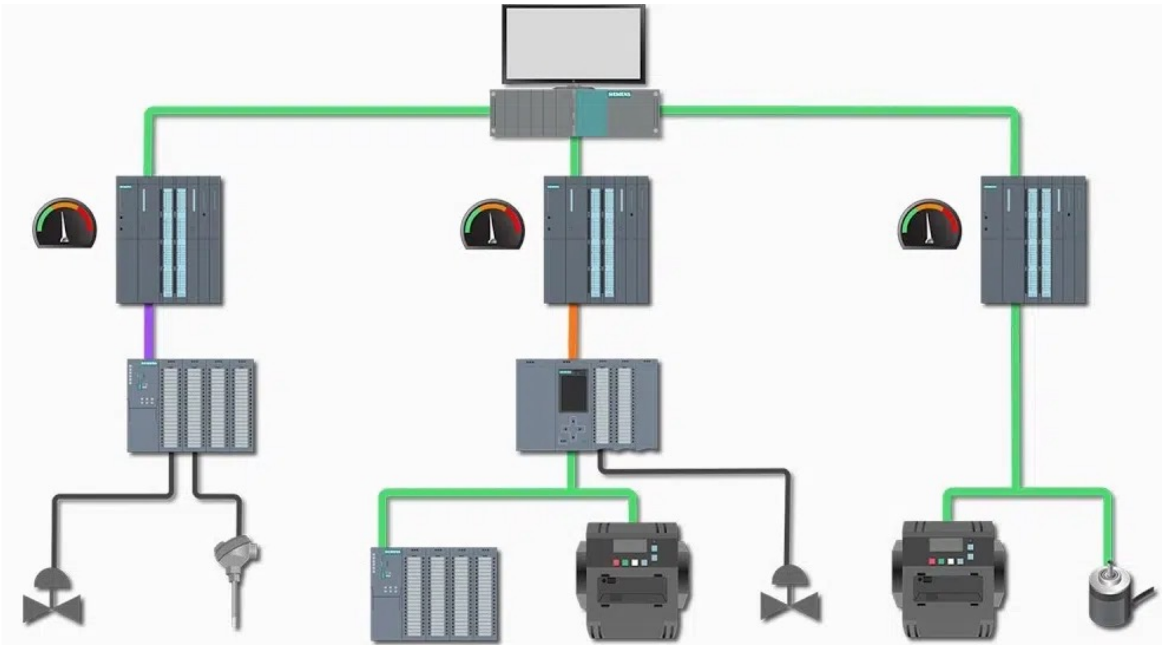
Applications of DCS

DCS are used across various industries for process control and automation:

1. Power Generation
2. Oil and Gas
3. Chemicals
4. Food and Beverage
5. Mining and Metals
6. Paper and Pulp
7. Pharmaceutical
8. Water and Wastewater Treatment

How is DCS programmed?

- There are some specific languages, e.g. CFC (Continuous Function Charts), and some common with the PLC programming (ST, FBD).
- Software tools help the developer to configure the entire system and orchestrate functions, available in the CPU and in functional modules, such as PID controllers
- A good deal of the programming process is configuring control loops



https://cciepc.com/three-examples-of-distributed-control-systems/

Advantages and Challenges

- **Advantages**: Enhanced reliability, improved process quality, scalability, and efficient handling of complex processes.
- **Challenges**: High initial cost, complexity in configuration and maintenance, and the need for specialized skills for operation and troubleshooting.

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SCADA (Supervisory Control and Data Acquisition)

What is it?

- SCADA (Supervisory Control and Data Acquisition) is a system used extensively in industrial, infrastructure, and facility-based processes.
- It is designed for high-level process supervisory management, data acquisition, and control.
- SCADA systems are crucial in industries where data monitoring and control over long distances are necessary.

https://industrialautomationco.com/blogs/news/what-is-dcs

Basic Concept and Architecture

- **High-Level Supervisory Control**: SCADA systems provide a top-level view and control of industrial processes, allowing operators to interact with devices like pumps, valves, and motors across various locations.
- **Centralized Monitoring**: They enable centralized monitoring of various industrial environments, from manufacturing plants to water treatment facilities.

Components of SCADA

- **Human-machine Interface (HMI)**: The interface through which operators interact with the SCADA system, providing visualization, management, and control of processes.
- **Controllers**: These include PLCs (Programmable Logic Controllers) and RTUs (Remote Terminal Units) that interface with field devices and execute control actions.
- **Communication Systems**: SCADA systems utilize communication protocols and networks to transmit data between field devices, controllers, and the central HMI.

Key Features

- **Real-Time Data Processing**: SCADA systems process data in real-time, providing up-to-date information on system performance and conditions.
- **Alarm Management**: They provide sophisticated alarm handling capabilities, notifying operators of critical events or system anomalies.
- **Historical Data Recording**: SCADA systems record detailed historical data, valid for trend analysis, optimization, and regulatory compliance.

Functionality

- **Monitoring and Visualization**: SCADA provides a comprehensive process view, displaying key data points and system statuses.
- **Control Functions**: While SCADA systems primarily focus on monitoring, they also offer control functions, such as starting or stopping pumps and adjusting setpoints.
- **Data Acquisition and Analysis**: They collect and analyze data from various parts of the process, aiding in decision-making and process improvement.
- **Reporting and Documentation**: Automatic generation of reports and logs for performance analysis, maintenance scheduling, and compliance.

Integration with Other Systems

- **DCS and PLC Integration**: SCADA systems often integrate with DCS and PLCs for enhanced control and monitoring capabilities.
- **Enterprise Systems**: Integration with business systems like ERP for aligning process operations with business strategies.

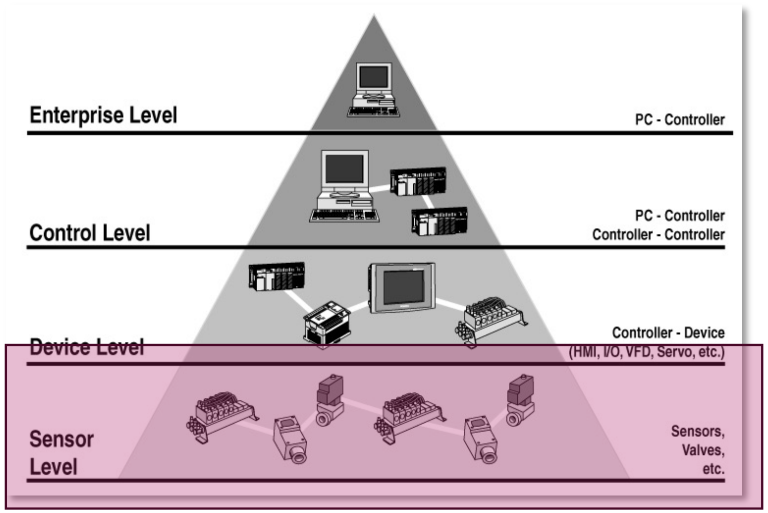
Advantages and Challenges

- **Advantages**: Real-time monitoring, remote control capabilities, improved efficiency, and effective response to system changes or failures.
- **Challenges**: Security vulnerabilities, especially with increased connectivity, complexity in system integration, and the need for specialized operators.

Field Devices

What are they?

- Field devices are fundamental components in industrial automation and process control systems, including PLC, DCS, and SCADA systems.
- They are directly involved in monitoring and manipulating the physical processes in various industrial environments.



Basic Concept and Architecture

- **Direct Interaction with Processes**: Field devices are the primary instruments that interact directly with the physical process in an industrial setting. They measure process variables (Sensors) or execute control actions (Actuators).
- **Variety and Specialization**: These devices come in many forms, each specialized for specific functions, environments, and industries.

Components of Field Devices

- **Sensors and Transducers**: Devices that measure physical quantities like temperature, pressure, flow rate, and level, converting them into electrical signals.
- **Actuators**: Devices that convert control signals from a control system into physical action, like opening a valve or starting a motor.
- **Positionners:** devices managing the position of actuators, such as control valves, dampers, or other mechanical components. It ensures that the actuator accurately reaches and maintains a specific position based on a control signal, which is usually an electrical or pneumatic input.
- **Transmitters**: They convert sensor signals into standardized signals suitable for transmission to control systems.
- **Switches and Relays**: Devices that open or close circuits mechanically or electronically.

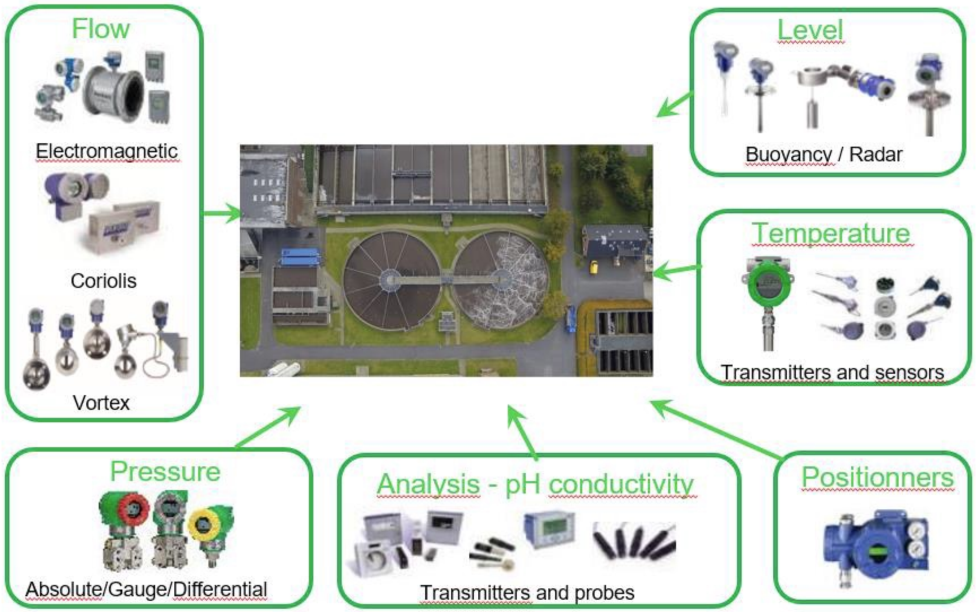


Figure courtesy Schneider Electric

Key Features

- **Accuracy and Reliability**: Precision in measurements and reliable operation under various conditions are crucial.
- **Robustness**: Field devices are often designed to withstand harsh industrial environments, including extreme temperatures, pressures, and corrosive conditions.
- **Compatibility**: These devices are made to be compatible with various communication protocols and control systems.

Functionality

- **Data Acquisition**: Sensors and transmitters provide critical data about the process conditions to control systems.
- **Process Control**: Actuators execute control actions to manipulate the physical process based on commands from control systems.
- **Safety and Monitoring**: Some field devices, like pressure relief valves and smoke detectors, are dedicated to ensuring process safety and integrity.

Integration with Control Systems

- **Connection to PLCs, DCS, and SCADA**: Field devices are integrated into broader control systems through wired or wireless communication networks.
- **Signal Conversion and Processing**: Many field devices have built-in capabilities to process and convert signals to be compatible with control systems.

Advantages and Challenges

- **Advantages**: Real-time process monitoring, enhanced control accuracy, and direct impact on process efficiency and safety.
- **Challenges**: Maintenance requirements, environmental susceptibility, the need for regular calibration, and technological obsolescence.

Industrial Networks and Communication Protocols

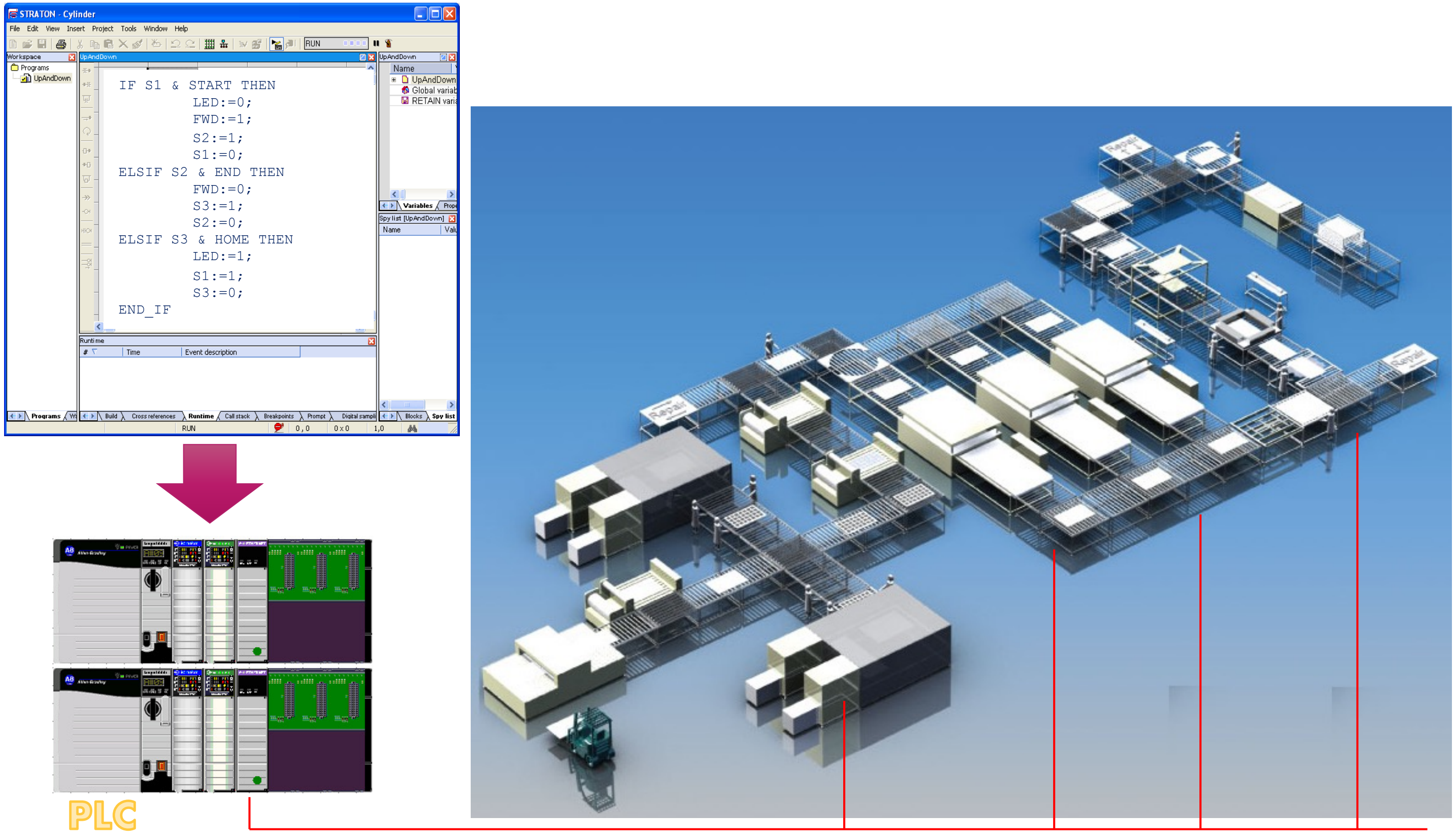
What are they?

Industrial networks and communication protocols are essential for connecting and communicating between field devices, PLCs, and systems within industrial environments, such as manufacturing plants, power generation facilities, and other automated operations.

Basic Concept and Architecture

- **Connectivity Between Devices**: Industrial networks enable the connection and communication between industrial devices like PLCs, sensors, computers, and other field devices.
- **Data Exchange Framework**: Communication protocols provide the rules and standards by which data is exchanged within the network, ensuring interoperability and reliable communication.

PLC connected to field devices with Industrial Networks



Components of Industrial Networks and Communication Protocols

- **Physical Media**: This includes wired connections such as Ethernet cables and wireless technologies like Wi-Fi or ZigBee.
- **Controllers and Switches**: Hardware that directs data traffic within the network.
- **End Devices**: Machines and networked sensors to send and receive data.
- **Gateways and Routers**: Devices that connect different networks and manage data traffic between them.

Key Features

- **Standardization**: Protocols are standardized to ensure devices from different manufacturers can communicate effectively.
- **Real-Time Communication**: Many industrial protocols are designed for real-time data transmission, which is critical for time-sensitive applications.
- **Robustness**: Networks and protocols in industrial settings are built to be robust and reliable, able to withstand harsh environments and interference.

Functionality

- **Data Transmission**: Moving data between devices, from simple sensor readings to complex control commands.
- **Network Management**: Tools and software to monitor network health, manage connections, and troubleshoot issues.
- **Security**: Protocols include security features to protect against unauthorized access and ensure data integrity.

Integration with Control Systems

- **PLC and DCS Systems**: Industrial networks integrate directly with control systems to enable device coordination and process control.
- **SCADA Systems**: Networks provide the communication infrastructure for SCADA systems to monitor and control distributed assets.

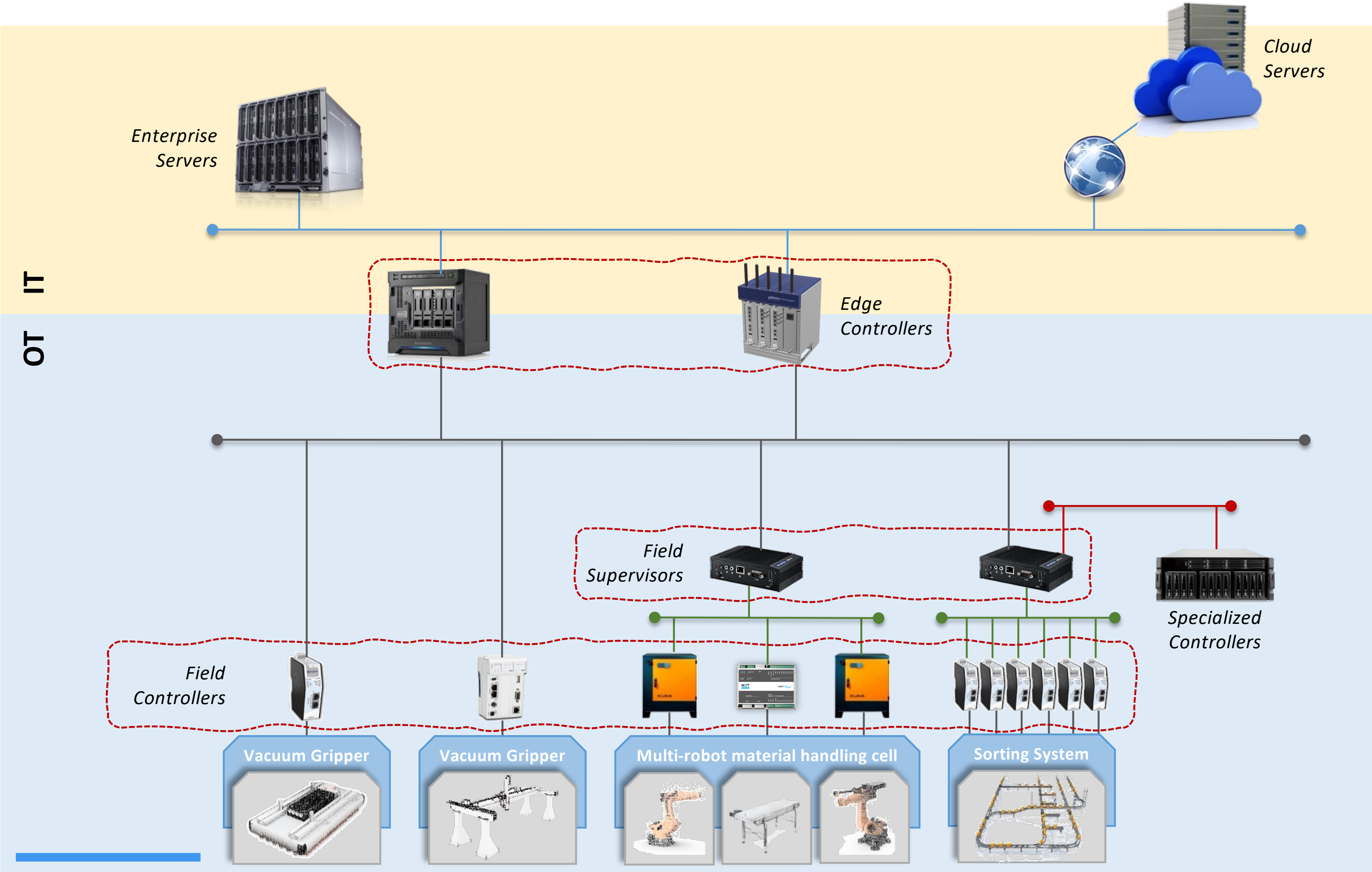
Advantages and Challenges

- **Advantages**: Enhanced interoperability, efficient and reliable communication, real-time data exchange, and centralized management.
- **Challenges**: Complexity in setup and management, cybersecurity risks, and the need for continuous updates to meet technological advancements.

Common Industrial Protocols

- **Modbus**: One of the earliest and still widely used for connecting industrial electronic devices.
- **PROFIBUS & PROFINET**: Widely used in Europe and in automation for both discrete and process markets.
- **EtherCAT**: Known for its high speed and efficiency, particularly suitable for real-time applications.
- **Ethernet/IP**: Uses standard Ethernet communication and is popular in North America.
- **CANopen**: Commonly used for embedded systems within vehicles and other automation applications.

OT-IT distinction: device-level

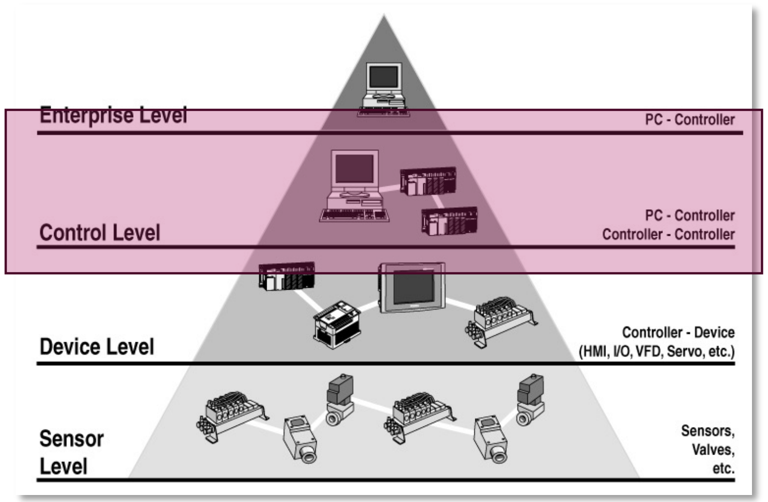


Slide courtesy Franco Antonio Cavadini CTO @ Synesis *franco.cavadini@synesis-consortium.eu*

MES (Manufacturing Execution System)

What is it?

A Manufacturing Execution System (MES) is a control system that manages, monitors, and synchronizes the execution of real-time, physical processes involved in transforming raw materials into finished goods. MES operates at the plant floor level to ensure that manufacturing operations are effectively executed to improve production output.



Basic Concept and Architecture

- **Real-time Operational Control**: MES provides real-time information that helps manage and optimize production activities from order launch to finished goods.
- **Intermediate Layer**: It acts as an intermediate layer between enterprise-level planning systems, like ERP (Enterprise Resource Planning), and the control systems like PLCs and SCADA that manage the actual machinery on the factory floor.

Components of MES

- **Data Collection/Acquisition**: This involves capturing real-time data from machines, devices, and operators on the production floor.
- **Production Monitoring**: Tools and dashboards for monitoring production processes and performance indicators.
- **Work Order Management**: Systems for managing and tracking work orders through production.
- **Quality Management**: Modules for monitoring and ensuring product quality throughout manufacturing.

Key Features

- **Process Control**: MES provides detailed control over the manufacturing processes, including the ability to respond quickly to changes or issues.
- **Traceability and Genealogy**: Tracking the history, application, and location of parts or products in manufacturing.
- **Performance Analysis**: Tools for analyzing production data to identify trends, inefficiencies, and opportunities for improvement.

Functionality

- **Document Control**: Handling of instructions, specifications, and recipes for production.
- **Labor Management**: Tracking and managing labor skills, certifications, and performance.
- **Maintenance Management**: Scheduling and tracking of equipment maintenance to prevent downtime.
- **Inventory Management**: Real-time tracking of material consumption, flow, and inventory levels.

Functionality

- **Scheduling**: Detailed production scheduling to maximize throughput and resource utilization.
- **Dispatching Production Units**: Assigning and sequencing production units to match the production schedule.
- **Product Tracking and Genealogy**: Full traceability of product manufacturing history.

Integration with Other Systems

- **ERP Integration**: MES integrates with ERP systems for order scheduling and resource allocation.
- **PLC/SCADA Integration**: It communicates with PLCs and SCADA systems to control and monitor the production equipment and processes.

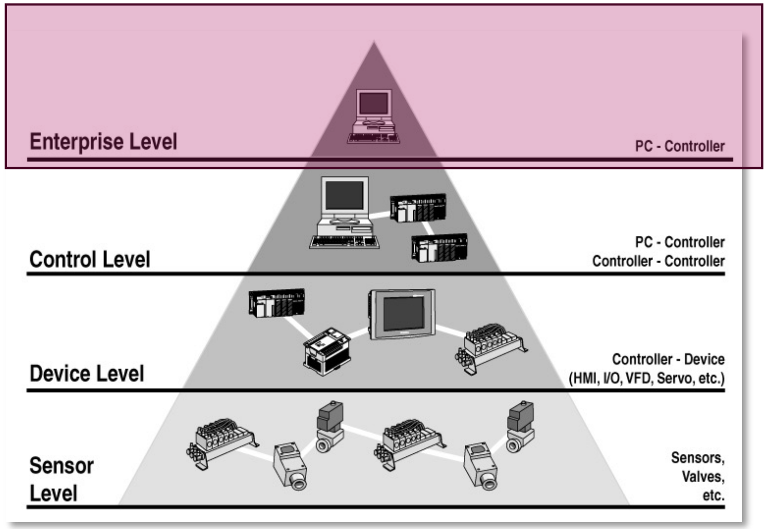
Advantages and Challenges

- **Advantages**: Increased production efficiency, improved product quality, reduced waste and rework, and enhanced responsiveness to demand changes.
- **Challenges**: Complexity in integrating with existing systems, managing the change in operational culture, and keeping up with the rapidly evolving technology landscape.

ERP (Enterprise Resource Planning)

What is it?

Enterprise Resource Planning (ERP) systems are comprehensive software platforms used by organizations to manage and integrate important parts of their businesses. An ERP system integrates areas such as planning, purchasing, inventory, sales, marketing, finance, human resources, and more.



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Basic Concept and Architecture

- **Centralized Business Management**: ERP is a central hub for data and processes across various business functions, facilitating information flow and management decisions.
- **Integration Across Departments**: It integrates disparate business processes into a unified system, enhancing department communication and coordination.

Components of ERP

- **Financial Management**: Modules for accounting, financial reporting, risk management, and compliance.
- **Supply Chain Management**: Tools for demand forecasting, procurement, inventory management, and logistics.
- **Human Resources**: Systems for managing employee information, payroll, recruitment, and performance.
- **Customer Relationship Management (CRM)**: Features for managing customer data, sales pipelines, and customer service.

Key Features

- **Process Automation**: Automates repetitive tasks to increase efficiency and reduce errors.
- **Reporting and Analytics**: Comprehensive reporting tools for strategic planning and operational insights.
- **Business Intelligence**: Some ERP systems include BI functionalities for advanced data analysis and visualization.

Functionality

- **Enterprise Performance Management (EPM)**: Tools for planning, budgeting, predicting, and reporting on an organization's financial results.
- **Order Processing**: Management of the order lifecycle from order creation and inventory sourcing to service delivery.
- **Procurement**: Facilitates direct and indirect procurement processes.

Integration with Other Systems

- **MES Integration**: ERP systems integrate with Manufacturing Execution Systems to align production planning with business operations.
- **SCADA/PLC Integration**: They can receive operational data from SCADA systems and PLCs for inventory and production tracking.

Advantages and Challenges

- **Advantages**: Streamlined processes, improved resource management, enhanced decision-making capabilities, and operational efficiency.
- **Challenges**: Maintaining an ERP system can be costly and time-consuming, with risks of disruption to business operations during transition and upgrade periods.

Summary

You should now be able to explain what happens for example, when you make a custom order for a car on a car dealer website, how different systems described in this section come into play.

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