Chapter 1
Introduction to Instrumentation and Process Control Systems
1. Introduction
2. Process Control System
3. Integrated System
4. System Architecture
5. Industrial Internet of Things (IIoT)
Requisite subjects

- Industrial Process Measurement
- Feedback Control Systems
- Instrumentation Drawing
- Process Control Systems
- Advanced Process Control Systems
1. Introduction: Discrete versus Continuous

discrete system  continuous system

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
1. Introduction: Discrete versus Continuous

- Automotive Manufacturing
- Electronics
- Machinery
- Textiles
- Pharmaceuticals
- Fine Chemical
- Food & Beverage
- Metals & Mining
- Water & Waste
- Pulp & Paper
- Vehicles
- Petrochemicals
- Oil & Gas
- Electrical Power

Source: EPFL / ABB Research Center, Baden, Switzerland

Prof. Dr. H. Kirrmann
industry distinguishes the following categories of applications:

"process control": continuous processes, associated with fluids, for instance sewage water treatment, petrochemical process, cement…

"batch control": semi-continuous processes, associated with individual products, for instance chemical, pharmaceutical, brewery…

"manufacturing": discrete processes, associated with transformation of parts, e.g. automobile industry, bottle-filling, packaging

Note. Batch production is a method of manufacturing where the products are made as specified groups or amounts, within a time frame. A batch can go through a series of steps in a large manufacturing process to make the final desired product.
Why automation?

- Safety
- Quality
- Controllability
- Cost saving (Long term)
1. Introduction: Open-loop versus Closed-loop control

open-loop control / command

keywords: sequential / combinatorial, binary variables, discrete processes, "batch control", "manufacturing"

closed-loop control / regulation

keywords: feedback, analog variables, continuous processes, "process control"

Set-Point (solicited)

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
1. Introduction: Large control system hierarchy

- Process pictures
- Process Data Base
- Logging

- PLC nodes (multi-processors)
- Operator panel Mimic board
- Station
- Disk

- plant (Werk, usine)
- valve
- thermo-couple
- position
- motor

- Sensor bus
- Fieldbus station bus
- Open network: TCP/IP, ...

- Workstation bus
- Instrument bus (mimic board)

- Pool
- Station bus
- Control stations

- Directly coupled input/output

- Process bus (500m .. 3 km)

- Node bus

- Transducers (0.5..30 m)
1. Introduction: Large control system hierarchy

Management

Plant

Field

Process Control
Batch
Manufacturing

ERP
MES
SCADA DCS Large PLC

ERP=Enterprise Resource Planning
MES=Manufacturing Execution System
1. Introduction: Large control system hierarchy

5. Planning, Statistics, Finances
4. Production planning, orders, purchase
3. Workflow, order tracking, resources
2. Supervisory
   - Group control
   - Unit control
   - Field
      - Sensors & actors
0. Primary technology

SCADA = Supervisory Control And Data Acquisition

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
1. Introduction: Large control system hierarchy

Functional levels of a manufacturing control operation

Source: https://en.wikipedia.org/wiki/Distributed_control_system
<table>
<thead>
<tr>
<th><strong>Administration</strong></th>
<th>Finances, human resources, documentation, long-term planning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enterprise</strong></td>
<td>Set production goals, plans enterprise and resources, coordinate different sites, manage orders</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td>Manages execution, resources, workflow, quality supervision, production scheduling, maintenance.</td>
</tr>
<tr>
<td><strong>Supervision</strong></td>
<td>Supervise the production and site, optimize, execute operations visualize plants, store process data, log operations, history (open loop)</td>
</tr>
</tbody>
</table>
| **Group (Area)**    | Controls a well-defined part of the plant  
(.closed loop, except for intervention of an operator)  
- Coordinate individual subgroups  
- Adjust set-points and parameters  
- Command several units as a whole |
| **Unit (Cell)**     | Control (regulation, monitoring and protection) part of a group (closed loop except for maintenance)  
- Measure: Sampling, scaling, processing, calibration.  
- Control: regulation, set-points and parameters  
- Command: sequencing, protection and interlocking |
| **Field**           | data acquisition (Sensors & Actors*), data transmission  
no processing except measurement correction and built-in protection. |
Field level

the field level is in direct interaction with the plant's hardware (Primary technology, *Primärtechnik*)
1. Introduction: Large control system hierarchy

**Group level**

the group level coordinates the activities of several unit controls

the group control is often hierarchical, can be also be peer-to-peer (from group control to group control = distributed control system)

Note: "**Distributed Control Systems** (DCS) commonly refers to a hardware and software infrastructure to perform Process Automation"

*Source: EPFL / ABB Research Center, Baden, Switzerland*

*Prof. Dr. H. Kirrmann*
1. Introduction: Large control system hierarchy

Local human interface at group level

sometimes, the group level has its own man-machine interface or HMI (Human Machine Interface) for local operation control
(here: cement packaging)

also for maintenance: console / emergency panel

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
1. Introduction: Large control system hierarchy

Supervisory level: Man-machine interface

formerly, all instruments were directly wired to the control room

control room (mimic wall) 1970s...

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
Supervisory level: SCADA

- displays the current state of the process (visualization)
- display the alarms and events (alarm log, logbook)
- display the trends (historians) and analyse them
- display handbooks, data sheets, inventory, expert system (documentation)
- allows communication and data synchronization with other centres

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
2. Process Control Systems
Example of process control
2. Process Control Systems

Heat exchanger.

$T_i(t)$  Process fluid

$T(t)$  Process variable

$T(t)$  Disturbance

$F_s(t)$  Manipulated variable

$T_i(t)$  Disturbance

$T(t)$  Process variable
2. Process Control Systems

Figure 1-1.2 Heat exchanger control loop.

Temperature Regulation

RTD

Resistance

Transmitter

Standard signal
2. Process Control Systems

**Figure 1-1.2** Heat exchanger control loop.
2. Process Control Systems

Figure 1-1.2 Heat exchanger control loop.

SP: Standard signal
CO: Standard signal
TO: Standard signal
2. Process Control Systems

Components in Control Loop
- Process
- Sensor/Transmitter
- Controller
- Final Control Element

Figure 1-1.2 Heat exchanger control loop.

\[ T_{sp}(t) \rightarrow \text{Controller} \rightarrow \text{Control Valve} \rightarrow \text{Process} \rightarrow T(t) \]

\[ F_s(t) \]

\[ T_i(t) \rightarrow \text{Transmitter} \rightarrow \text{Controller} \rightarrow \text{Steam} \]

\[ T(t) \rightarrow \text{Sensor} \rightarrow \text{Controller} \rightarrow \text{Final control element} \rightarrow \text{Controller} \rightarrow \text{SP} \]

\[ T_i(t) \rightarrow \text{Process fluid} \rightarrow T(t) \rightarrow \text{Condensate return} \]
Components in Control Loop
- Process
- Sensor/Transmitter
- Controller
- Final Control Element

Figure 1-1.2 Heat exchanger control loop.
Example (1)

- From the process given in the figure below, what are PV=________, and MV=________. Draw the block diagram of process control system, and also explain the functions of this process.
Example(2)

- From the process given in a figure below, What are PV=_______, and MV=_______ . Draw the block diagram of process control system, and also explain the functions of this process.
2. Process Control Systems

Central Control Room for all plants

Fiber Optics

Outstation #1
System Cabinets
H1 Fieldbus HART

Outstation #7
System Cabinets

Outstation #14
System Cabinets
H1 Fieldbus HART

I
Examples of sequence control and Programmable Logic Controller
An example of PLC control panel
3. Integrated system: MES & ERP

- **ERP**
  - Enterprise Resource Planning

- **MES**
  - Manufacturing Execution System

- **OCS**
  - Open Control System

**Corporate Level**
- Decision support System

**Plant Level**
- Operational Planning and Decision Making

**Unit Process Level**
- Operational Monitoring and Control System
3. Integrated system: MES & ERP

Make a batch of QR6

The Schedule

The Equipment

The Recipe

Execution

The Report

The Batch
3. Integrated system: MES & ERP

Enterprise – Site – Area

Recipe Management
Production Planning and Scheduling
Production Information Management

Process Management
Unit Supervision

Process Control

Safety Protection

Information Domain

MES

Automation System

Controllers

Instructions (make a batch)

Data (Batch Record)
Significance of Integrating ERP with OCS in the Real World
3. Integrated system: MES (Production capability)

- **People**
- **Equipment**
- **Materials**
- **Segments**

**What is available**
- Current
- Future
- Per resource, usually a limited resource
- Per segment

<table>
<thead>
<tr>
<th>Product</th>
<th>Time</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
3. Integrated system : MES (Production schedule)

- People
- Equipment
- Materials
- Segments

Product Definitions

Production Schedule

- What to make
  - Priority and/or dates
  - What materials to use
  - What equipment to use
  - What personnel to use
  - Production parameters (e.g. Color, Options, ...)
  - Per Segment

Per location (Site, Area, ...)
Per week, day, shift, order, ...
3. Integrated system: MES (Production performance)

- What was made
  - What material was actually produced
  - What materials were actually consumed
  - Equipment used
  - Personnel used
  - Production data (e.g. Purity, density, ...)
  - Per Segment

- Per location (Site, Area, ...)
- Per shift, hour, end of batch, ...

People
Equipment
Materials
Segments
Production Schedule
Production Performance
3. Integrated system: Response time and hierarchical level

Planning Level

Execution Level

Supervisory Level

Control Level

ERP
(Enterprise Resource Planning)

MES
(Manufacturing Execution System)

SCADA
(Supervisory Control and Data Acquisition)

DCS
(Distributed Control System)

PLC
(Programmable Logic Controller)

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
3. Integrated system: Data Quantity & Quality

Higher Levels

When ascending the control hierarchy, data are reduced: higher level data are created (e.g. summary information). Processing and decisions become more complicated (requires using models). Timing requirements are slackened. Historical data are stored.

SCADA level

Presentation of complex data to the human operator, aid to decisions (expert system) and maintenance. Requires a knowledge database in addition to the plant's database.

Lower Levels

Lowest levels (closest to the plant) are most demanding in response time. Quantity of raw data is very large. Processing is trivial (was formerly realized in hardware). These levels are today under computer control, except in emergency situations, for maintenance or commissioning.

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
3. Integrated system: Complexity and Hierarchical level

Complexity

Command level

- ERP
- MES
- Supervision
- Group Control
- Individual Control
- Field
- Site

Reaction Speed
- months
- days
- minutes
- seconds
- 0.1s
- 0.1s

Source: EPFL / ABB Research Center, Baden, Switzerland
Prof. Dr. H. Kirrmann
3. Integrated system: MES & ERP

ERP (Enterprise Resource Planning)
- Production Planning

MES (Manufacturing Execution System)
- Scheduling
- Simulation
- Optimization
- Advanced Control

Control Execution

Modeling

Control Domain

Business Domain

Asset Management

Maintenance Management

Operation Assistance

Safety Management

Field Communication

Sensors, Actuators, Analyzers, ...

Subsystems
1. Centralized Control Architecture (classical)

Classical, hierarchical, centralized architecture.
The central computer only monitors and forwards commands to the PLCs.
Sometimes it may be called as “Direct Digital Control” (DDC).
all controllers can communicate as peers (without going through a central master), restricted only by throughput and modularity considerations.
Mostly controller functions are run in field level instruments, the field information can be communicated via the fieldbus interface module.
4. System Architecture: DDC, DCS and FCS

A third major trend is in the accelerating pace of the application of new technologies aimed towards completely digital systems with functionality distributed to the field reducing system complexity and cost. Fieldbus is the logical step improving on the familiar DCS - even more distributed and even more digital. It is a Field Control System (FCS).
4. System Architecture: DDC, DCS and FCS

- Lower Initial Cost
- Flexibility
- Interoperability
- Improved Information Availability and Integrity
- Lower Maintenance Cost
- Increased Product Quality

- Lower Cost of Expansion and Change
- Easier Operation
- Simplified Engineering
- Quicker and Easier to Learn
- Increased safety
### Task Distribution

<table>
<thead>
<tr>
<th>Field</th>
<th>Controllers</th>
<th>Workstation</th>
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<tbody>
<tr>
<td>Measurement</td>
<td>Control</td>
<td>Display</td>
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<tr>
<td>Actuation</td>
<td>Logic</td>
<td>operation</td>
</tr>
<tr>
<td>Control</td>
<td>Sequence</td>
<td>Process Flow Mimic</td>
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<tr>
<td>Computation</td>
<td>Computation</td>
<td>Trend</td>
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<td>Selection</td>
<td>Selection</td>
<td>Alarm</td>
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<td>Alarm</td>
<td>Reports</td>
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<td>Supervisory</td>
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<td>SQC</td>
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<td>Optimization</td>
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<td></td>
<td></td>
<td>Resource</td>
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<td></td>
<td></td>
<td>Planning</td>
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</tbody>
</table>
4. System Architecture: Examples of integrated system

ABB System 800xA

System Servers

Remote Clients

Workplaces

Control Network

Variable Speed Drives

MCC

Fieldbus High Speed Linking Devices (FF HSE/HI, FB DP/PA)

Process Automation

Process Automation and Safety

S900 I/O

S900 I/O (Ex)

Fieldbus Foundation

PROFIBUS

HART

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4. System Architecture: Examples of integrated system

- EtherNet / IP
- ControlNet
- DeviceNet

- Programmable Device Support PC
- Desktop PC with excel
- Controller and Bridge
- Servo
- Linking Device
- Drive
- Bridge or Linking Device
- HMI

- Modular I/O
- Micro PLC
- Sensor
- Block I/O

- NetLinx

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Modern systems (2010 onwards)
The latest developments in DCS include the following new technologies:

1. Wireless systems and protocols
2. Remote transmission, logging and data historian
3. Mobile interfaces and controls
4. Embedded web-servers

Increasingly, and ironically, DCS are becoming centralised at plant level, with the ability to log into the remote equipment. This enables operator to control both at enterprise level (macro) and at the equipment level (micro) both within and outside the plant as physical location due to interconnectivity primarily due to wireless and remote access has shrunk.

As wireless protocols are developed and refined, DCS increasingly includes wireless communication. DCS controllers are now often equipped with embedded servers and provide on-the-go web access. Whether DCS will lead IIOT or borrow key elements from remains to be established.

Many vendors provide the option of a mobile HMI, ready for both Android and iOS. With these interfaces, the threat of security breaches and possible damage to plant and process are now very real.

https://en.wikipedia.org/wiki/Distributed_control_system#Modern_systems_(2010_onwards)
The IIoT is part of a larger concept known as the Internet of Things (IoT). The IoT is a network of intelligent computers, devices, and objects that collect and share huge amounts of data. The collected data is sent to a central Cloud-based service where it is aggregated with other data and then shared with end users in a helpful way. The IoT will increase automation in homes, schools, stores, and in many industries.

The application of the IoT to the manufacturing industry is called the IIoT (or Industrial Internet or Industry 4.0). The IIoT will revolutionize manufacturing by enabling the acquisition and accessibility of far greater amounts of data, at far greater speeds, and far more efficiently than before. A number of innovative companies have started to implement the IIoT by leveraging intelligent, connected devices in their factories.

"IIoT connects devices such as industrial equipment on to the network, enabling information gathering and management of these devices via software to increase efficiency, enable new services (factory automation, robotics, supply chain efficiency)…"
What are the Benefits of IIoT?

The IIoT can greatly improve connectivity, efficiency, scalability, time savings, and cost savings for industrial organizations. Companies are already benefitting from the IIoT through cost savings due to predictive maintenance, improved safety, and other operational efficiencies. IIoT networks of intelligent devices allow industrial organizations to break open data silos and connect all of their people, data, and processes from the factory floor to the executive offices. Business leaders can use IIoT data to get a full and accurate view of how their enterprise is doing, which will help them make better decisions.

References: https://inductiveautomation.com/what-is-iiot
IoT starts at the sensor level where pressure, level, flow, temperature, vibration, acoustic, position, analytical and other sensors collect data and send this collected information to control and monitoring systems via wired and wireless networks. The advent of sensors that are wireless, self-powered, non-intrusive, calibration free and maintenance free, production processes can now cost-effectively send information from thousands more sensors to the control and monitoring systems. These sensors help create the IoT for the facility and gives its operating and maintenance personnel a better understanding of overall plant operations. Sensing devices provide ways to automatically improve performance, safety, reliability and energy efficiency in production facilities. These improvements occur as a result of:

- **Collecting** data from sensors (things), much more cost effectively than ever before because they are battery powered and wireless
- **Interpreting** this data strategically, using subject matter expertise to effectively analyze the data, either locally or remotely
- **Presenting** actionable information, built on task-oriented human centered design principles (HCD) principles, to the right person—either plant personnel or supplier-provided experts.
- **Leading** to results in performance improvements, when personnel take corrective action

**References:**
- [http://www2.emersonprocess.com](http://www2.emersonprocess.com)
SUMMARY AND QUESTIONS

SUMMARY AND QUESTIONS