Industrial Automation
(Automação de Processos Industriais)

http://users.isr.ist.utl.pt/~jag/courses/api1213/api1213.html

Slides 2010/2011 Prof. Paulo Jorge Oliveira
Rev. 2011-2014 Prof. José Gaspar
A steam engine built according to James Watt's patent in 1848 at Freiberg in Germany [wikipedia]
Industrial Revolution 1760/80 – 1820/40 (historians E. Hobsbawm, T. S. Ashton)

Steam engine and detail of the governor, James Watt's [wikipedia].
A jewel: Maillardet's Automaton, 18th century, the largest known mechanical memory

http://www.fi.edu/learn/sci-tech/automaton
Maillardet's Automaton, 18th century: the largest known mechanical memory

Four drawings and three poems

http://www.fi.edu/learn/sci-tech/automaton
Many options for controlling real world devices! Why PLCs?
Robustness
is not an Option

a brand of
Schneider
Electric

Telemecanique
Objectives of the course:

• *Analysis* of systems for industrial automation.

• Methodologies for the *implementation* of solutions in industrial automation.

• Programming *languages* of PLCs (*Programmable Logic Controllers*).

• CAD/CAM and Computerized Numerical Controlled machines.

• *Discrete Event Systems* Modeling.

• *Supervision* of Processes in Industrial Automation.
Program at a glance:

1. Introduction to Automation [1 week]
   Introduction to components and methodologies.

2. Introduction to PLCs [2 weeks]
   Components of Programmable Logic Controllers (PLCs). Architecture, functional structure, IO.

3. PLCs Programming Languages [2w]
   Standard languages (IEC-1131-3): Ladder Diagram; Instruction List and Structured Text.

4. GRAFCET (Sequential Function Chart) [1 week]
   Norm, elements of the language, modelling.

5. CAD/CAM and CNC Machines [1 week]
   Types of Computerized Numerical Controlled machines. Interpolation of trajectories. Flexible fabrication cells.

6. Discrete Event Systems [1 week]

7. Analysis of DESs [2 weeks]
   Properties of DESs. Methodologies for the analysis: reachability graph and matricial equation.

8. DESs and Industrial Automation [1 week]
   Relations GRAFCET / Petri networks. Analysis of industrial automation solutions as DESs.

9. Supervision of Industrial Processes [2w]
   Methodologies for supervision. SCADA. Synthesis based on invariants. Examples of application.
Assessment and grading:

• 2 Preliminary laboratory assignments - training purposes (0% of the final grade).

• 2 Laboratory assignments (20%+20% of the final grade). Groups of 3 or 4 students.

• 1 Seminar (20% of the final grade). Topics to be selected with each group.

• 1 Exam (40% of the final grade).

  Upon student choice, the second exam can be oral.

• Minimum grade: 9.0/20.0 val. in each component.

One extra value for students attending more than 70% of recitations and do short summaries of the classes.
Assessment and grading:

Short summaries of the classes

<table>
<thead>
<tr>
<th>Week</th>
<th>Monday</th>
<th>Notes</th>
<th>Friday</th>
<th>Notes</th>
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<td>27-Set-13</td>
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<td>07-Out-13</td>
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Download this XLS file from the webpage of the course.

**Industrial Automation 2013/4 - Self-taken links to bibliography**

Name: João Silva

Number: 12345

Bibliography:

- [slides12] API Slides 2012/2013, P. Oliveira, J. Gaspar, IST
- [Jack08] "Automating Manufacturing Systems with PLCs", Hugh Jack (online version 2008)
## Schedule (laboratories & exam):

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
<th>Date</th>
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<tr>
<td>Lab. registration(^1)</td>
<td>First week</td>
<td>16-20/09/2013</td>
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<tr>
<td>1(^{st}) preliminary lab.</td>
<td>1 week</td>
<td>30/9-4/10/2013</td>
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<tr>
<td>2(^{nd}) preliminary lab.</td>
<td>1 week</td>
<td>7/10-11/10/2013</td>
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<tr>
<td>1(^{st}) lab. assignment</td>
<td>3 weeks</td>
<td>14/10-01/11/2013</td>
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<tr>
<td>2(^{nd}) lab. assignment</td>
<td>3 weeks</td>
<td>11/11-29/11/2013</td>
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<tr>
<td>3(^{rd}) lab. assignment</td>
<td>0.5h seminar</td>
<td>One date &gt;= week 8</td>
</tr>
<tr>
<td>Exams</td>
<td>3h</td>
<td>16Jan, 1Fev 2013</td>
</tr>
</tbody>
</table>

\(^1\) Important: define the students’ representative
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</tr>
<tr>
<td>Exams</td>
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</tr>
</tbody>
</table>

\(^1\) *Important: define the students’ representative*
Schedule (according to IST-GOP):

• Recitation classes

  Monday         11.00 h – 12.30h  Ea5
  Friday         11.00 h – 12.30h  Ea4

• Lab. Classes (once per week)

  Monday         09.30h – 11.00h  L1  LSDC4 (room 5.21)
  Friday         09.30h – 11.00h  L2  LSDC4 (room 5.21)

• Groups registration for the Laboratory
Bibliography:

• Automating Manufacturing Systems with PLCs, Hugh Jack (online version available).


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Industrial Automation
(Automação de Processos Industriais)

Introduction to Automation

http://www.isr.ist.utl.pt/~jag/aulas/api1314/api1314.html

Slides 2010/2011, Prof. Paulo Jorge Oliveira
Rev. 2011-2014, Prof. José Gaspar
Industrial Process:

Making Cement

[Outão / Setúbal / Portugal]
Industrial Process:

Tetra Pak /
Parmalat

Complexity handled with modularity
Robot + Robot + Robot + ... + Global Controller = Automated Industrial Process

Other courses as e.g. Control

The subject of this course
Ch. 1 – Introduction to Automation [1 week]

Introduction to components in industrial automation.

Cabled logic versus programmed logic versus networked logic.

Introduction to methodologies for problem modeling. Methodologies of work.
Components used in industrial automation

The production of increasing amounts of goods requires the storage and handling of large quantities of resources.

The use of specialized, automatic tools are mandatory.

Consistent trend in the last three centuries (since the Industrial Revolution).

Automation was also fostered by the invention of computers,
Robotic Manipulators
Robotic Manipulators

Riding an ABB IRB 6600 Robot 1 [Youtube]

API Note: please understand the power, and do not do this; keep always the safety!
Robotic Manipulators - End Effectors
Robotic Manipulators

Major characteristics:

• Number of degrees of freedom
• Types of joints (prismatic/revolution)
• Programming tools and environments (high level languages, teach pendent, ...)
• Workspace
• Accuracy, reliability
• Payload and robustness
Robotic Manipulators

Workspace:

Examples

Fig. 15-23
Robot work envelope.

(a) Cylindrical

(b) Articulated

(a) Gripper

(b) Grinder

(c) Gas welding torch

End-of-arm tooling devices.
Robotic Manipulators

Central problems to address and solve:

• Direct / Inverse kinematics
• Trajectory generation
• Coordinate frames where tasks are specified
• Level of abstraction of the programming languages
Robotic Manipulators

Use in Flexible Cells of Fabrication:

It is required that the manipulators have correct interfaces for the synchronization and inputs for external commands.
Computerized Numerical Controlled Machines

Major characteristics:

- Number of degrees of freedom
- Interpolation methods
- Load/unload automation, and also in tool change
- Programming (high level languages, teach pendant, ...)
- Workspace
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

Examples:
Milling, Lathes, ...

MITSUI SEIKI Machining Center
Computerized Numerical Controlled Machines

Compact CNC plasma cutting machine
Effective cutting : 1.5 m X 3 m
Plasma torch cutting capacity up to 5cm (mild steel), Gas torch option allows up to 10cm.
Solutions for Handling materials

For transport...

Major characteristics:

• Load/unload automation
• Accuracy, reliability
• Payload and robustness
• Interface
• Synchronization with exterior
AGVs (Automatic Guided Vehicles)

Major characteristics:

• Load/unload automation

• Accuracy, reliability

• Payload and robustness

• Interface

• Synchronization with exterior
AGVs (Automatic Guided Vehicles)

Example of fleet operating in industry
AGVs (Automatic Guided Vehicles)

Kiva Systems Inc
- warehouse automation
- used by Staples, Toys R Us, ...
- 2012 bought by Amazon ($775 million)
Specific Components

Factory example: production of aluminum packs
Cabled Logic versus ...

(a) Typical hard-wired controller panel. (b) Typical hardwired diagram. (Courtesy of Allen-Bradley Company, Inc.)
... versus Programmed Logic ...
Cabled Logic versus ...

... versus Programmed Logic ...
... versus Networked Logic
Introduction to methodologies
for problem modeling in
Industrial Automation
Actuators
  Motors
  Solenoide valve
  Command relay
  Pneumatic cylinder
  Electro pneumatic

Sensors
  Pressure switch
  Temperature sensors
  Proximity sensors

Relay diagram / Ladder diagram

Actuation

Motors

Major characteristics:

• Type of start
• Type of control
• Accuracy, reliability
• Payload and robustness
• Interface with exterior
• Synchronization
Exemple of AC motor, with driver
Solenoide Valve

(a) Operation

(b) Solenoid valve installation

Valve must be installed with direction of flow in accordance with markings.
Chap. 1 – Introduction to Automation

Command Relay

Fig. 6-1
Electromagnetic control relay operation.

Fig. 6-2
Control relay. (Courtesy of Allen-Bradley Company, Inc.)
Cylinders (Pneumatics)

For Force:

\[ P = \frac{F}{A} \quad F = PA \]

where,

\( P \) = the pressure of the hydraulic fluid
\( A \) = the area of the piston
\( F \) = the force available from the piston rod
Valves (Electro-pneumatics)

The solenoid has two positions and when actuated will change the direction that fluid flows to the device. The symbols shown here are commonly used to represent this type of valve.
Sensors

Push buttons

- Normally open (NO) pushbutton
- Normally closed (NC) pushbutton
- Break-make pushbutton

*Note:* The abbreviations NO and NC represent the electrical state of the switch contacts when the switch is not actuated.

(a) Pushbutton switches

(b) Control circuit using a combination break-make pushbutton
Selector with three positions

(a) Selector switch operator

(b) Three-position selector switch and truth table

(c) Selector switch used in conjunction with a reversing motor starter to select forward or reverse operation of the motor.

Fig. 6-11
Selector switch.
Sensors

Pressure Switch

Fig. 6-15 (continued)
Pressure switch.
### Temperature Sensors

**Thermocouple**
- Self-powered
- Simple
- Rugged
- Inexpensive
- Wide variety
- Wide temperature range

**RTD**
- Most stable
- Most accurate
- More linear than thermocouple

**Thermistor**
- High output
- Fast
- Two-wire ohms measurement

**IC Sensor**
- Most linear
- Highest output
- Inexpensive

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>• Self-powered</td>
<td>• Nonlinear</td>
</tr>
<tr>
<td>• Simple</td>
<td>• Low voltage</td>
</tr>
<tr>
<td>• Rugged</td>
<td>• Reference required</td>
</tr>
<tr>
<td>• Inexpensive</td>
<td>• Least stable</td>
</tr>
<tr>
<td>• Wide variety</td>
<td>• Least sensitive</td>
</tr>
<tr>
<td>• Wide temperature range</td>
<td></td>
</tr>
</tbody>
</table>

**Common temperature sensors.**

- Fig. 6-38
Chap. 1 – Introduction to Automation

Thermocouple

Proximity detector

**Fig. 2-12**
Typical thermocouple connection to an analog input module.

**Fig. 6-20**
Inductive proximity sensor.
Magnetic detector

**Fig. 6-42**
Magnetic pickup sensor.

Magnetic switch

**Fig. 6-25**
Magnetic switch (reed switch).
Symbols associated to all components

Standards

Fig. 6-43
Symbols for output control devices.
Methodologies for the implementation of solutions in industrial automation

Device: Relay

Contact Diagram or Ladder Diagram

Fig. 6-3
Relay circuit—switch open.
Ladder Diagram

Or

Contact Diagram

Fig. 6-3
Relay circuit—switch open.
Methodologies for the implementation of solutions in industrial automation

Contacts diagram

Example

Fig. 6-4
Relay circuit—switch closed.
Example:

Fig. 1-13
Relay ladder diagram for modified process.

Fig. 1-14
PLC ladder logic diagram for modified process.
Chap. 1 – Introduction to Automation

**Logic Functions**

**AND**

\[
\begin{array}{c|cc|c}
&A & B & X \\
\hline
&0 & 0 & 0 \\
&0 & 1 & 0 \\
&1 & 0 & 0 \\
&1 & 1 & 1 \\
\end{array}
\]

\[X = A \cdot B\]

**OR**

\[
\begin{array}{c|cc|c}
&A & B & X \\
\hline
&0 & 0 & 0 \\
&0 & 1 & 1 \\
&1 & 0 & 1 \\
&1 & 1 & 1 \\
\end{array}
\]

\[X = A + B\]

**NOT**

\[
\begin{array}{c|c}
&A & X \\
\hline
&0 & 1 \\
&1 & 0 \\
\end{array}
\]

\[X = \overline{A}\]

**NAND**

\[
\begin{array}{c|cc|c}
&A & B & X \\
\hline
&0 & 0 & 1 \\
&0 & 1 & 1 \\
&1 & 0 & 1 \\
&1 & 1 & 0 \\
\end{array}
\]

\[X = \overline{A} \cdot B\]

**NOR**

\[
\begin{array}{c|cc|c}
&A & B & X \\
\hline
&0 & 0 & 1 \\
&0 & 1 & 0 \\
&1 & 0 & 0 \\
&1 & 1 & 0 \\
\end{array}
\]

\[X = \overline{A} + B\]

**EOR**

\[
\begin{array}{c|cc|c}
&A & B & X \\
\hline
&0 & 0 & 0 \\
&0 & 1 & 1 \\
&1 & 0 & 1 \\
&1 & 1 & 0 \\
\end{array}
\]

\[X = A \oplus B\]
Example 4-9

A motor control circuit with two stop buttons. When the start button is depressed, the motor runs. By sealing, it continues to run when the start button is released. The stop buttons stop the motor when they are depressed.
To exploit the advantages of Programmed Logic