Robotics 1

Industrial Robotics

Prof. Alessandro De Luca
What is a robot?

- **industrial definition (RIA = Robotic Institute of America)**
  
  re-programmable multi-functional manipulator
  designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response

- **ISO 8373 definition**
  
  an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications

- more general definition ("visionary")
  
  intelligent connection between perception and action
Robots!!

Comau H4 (1995)

Waseda WAM-8 (1984)

Spirit Rover (2002)
A bit of history

- **Robota** (= “work” in slavic languages) are artificial human-like creatures built for being inexpensive workers in the theater play *Rossum’s Universal Robots (R.U.R.*) written by Karel Capek in 1920

- **Laws of Robotics** by Isaac Asimov in *I, Robot* (1950)
  1. A robot may not injure a human being or, through inaction, allow a human being to come to harm
  2. A robot must obey orders given to it by human beings, except where such orders would conflict with the First Law
  3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law
Evolution toward industrial robots

- with respect to the ancestors
  - flexibility of use
  - adaptability to a priori unknown conditions
  - accuracy in positioning
  - repeatability of operation

1950
- computer numerically controlled machines (CNC)
- mechanical telemanipulators

1970
- robot manipulators
  - Unimation PUMA
The first industrial robot

US Patent

General Motor plant, 1961

G. Devol and J. Engelberger (Unimation)
Robot manipulators

ASEA IRB-6 (1973)
first robot
all-electric-drives

Cincinnati Milacron T3 (1974)
first micro-computer controlled robot

Hirata AR-300 (1978)
first SCARA robot

Unimation PUMA 560 (1979)
6R with human-like dexterity
robots – a 50-year journey
robotics research up to 2000

Video compiled for the IEEE ICRA 2000 conference, S. Francisco
World Robotics 2015

executive summary for 2015
yearly statistics by IFR
issued at end of September
(available on the course web site)

- robotics market value in 2014: $10.7 billion (+13% over 2013), robot systems: $32 billion
- total worldwide stock at end 2014: 1.5 million units of operational industrial robots (+11%)
- year 2014 was once more the highest in robot sales worldwide (230K, +29%)
- China expanded further as the largest market since last year, now with a 25% share
- 70% of sales goes to 5 countries: China (57K), Japan (29K), USA (26K), Korea (25K), and Germany (20K); Italy (6.2K) is the second market in Europe (7th worldwide)
- main industrial drivers: automotive (43% of new robots) and electrical/electronics (34%)
- research trends: industry 4.0 (energy efficiency, human-robot collaboration, VR, ease of use)
- service robotics (household, professional) is slowly catching up w.r.t. industrial robotics
  - 24K new robots for professional service sold in 2014 (+11.5%)
  - 4.7 million personal and domestic service robots sold in 2014 (+28%), for a total value of $2.2 billion
World Robotics 2014

executive summary for 2014
yearly statistics by IFR

- robotics market value: >$10 billion + software, peripherals, systems: >$30 billion
- year 2013 was the highest in robot sales worldwide (180K)
- China is the biggest (for the first time) and fastest growing market
- decreased life-cycle and increased variety of products ask for increasingly more robots and automation
- research trends: energy efficiency, new materials, human-robot/machine collaboration
- service robotics (household, professional) is slowly catching up w.r.t. industrial robotics
  - 21K new robots for professional service sold in 2013
Diffusion
Industrial robots in operation worldwide

(as reference: industrial robots in stock in 1983 = 66K)
length of robot service life is estimated in 12-15 years

from World Robotics 2012
Diffusion
Industrial robots in operation by world regions

from World Robotics 2013
Annual supply
New industrial robots worldwide

highest level ever
≈ 180K new units

* forecast

World Robotics 2014
Annual supply
New industrial robots by world regions

*forecast: annual average growth of 10% in 2014–2017
Annual supply
Largest markets of new industrial robots

70% of world supply goes to 5 markets

then, after Taiwan and Central/East Europe,

elaborated from World Robotics 2014
Annual supply
New robots by industrial sectors

Estimated worldwide annual supply of industrial robots at year-end by main industries 2010 - 2013

- Automotive
- Electrical/electronics
- Metal
- Rubber and plastics
- Food
- Pharmaceuticals and cosmetics

continued growth!

recovering from last year

World Robotics 2014

Robotics 1
Density of robots - 1

Number of multipurpose industrial robots (all types) per 10,000 employees in the manufacturing industry (ISIC rev.4: C) 2011

Degree of automation still relatively high

Number of robots per 10,000 employees in the manufacturing industry in 2011

Average robot density world: 58
Density of robots - 2

Number of multipurpose industrial robots (all types) per 10,000 employees in the automotive and in all other industries 2011

Number of robots per 10000 employees in the automotive and in all other industries in 2011
A long-range trend in robot prices

An articulated industrial robot with six degrees of freedom of medium/large size costs about 100 KEuro
Industrial robot and its auxiliary equipments

1. Comau SMART H robot
2. C3G Plus controller
3. Welding control box
4. Application software
5. Air/water supply
6. SWIM Board
7. Integrated cables
8. Welding gun
9. Auxiliary devices in the robotic cell (servo-controlled axes)

SWIM = Spot Welding Integrated Module
commercial video by ABB
Industrial applications

- manipulation (pick-and-place)
- assembly
- spray painting and coating
- arc welding
- spot welding with pneumatic or servo-controlled gun
- laser cutting and welding
- gluing and sealing
- mechanical finishing operations (deburring, grinding)
A day in the life of an industrial robot

- At BMW car production line with ABB robots

pick-and-place with end-effector to reorient part

pick-and-place with support to reorient part
A day in the life of an industrial robot

- pick-and-place heavy parts and human intervention
- metal cutting on a supporting machine with dofs

Robotics 1
A day in the life of an industrial robot

- Video
- Video

- Glue deposit (on fancy paths!)
- Cooperation of multiple robots for handling and sealing a car body
A day in the life of an industrial robot

coating parts for roast protection

spray painting
A day in the life of an industrial robot

- Hood deburring with a suspended tool
- Test measurements with assembly on a AGV
What a robot should do and what cannot do yet

- spray painting very unhealthy for human operators
- assembly of flexible or complex parts (here a car dashboard)

$\Rightarrow$ human-robot collaboration (co-bots or co-workers)
Plasma cutting

small KUKA robot used for plasma cutting of a stainless steel toilet
(courtesy of Engenious Solutions Pty)
Robotized workcells
3D simulation of robotic tasks

- analysis of operative cycle times
- off-line programming and optimization
- layout design and collision checking
- 3D graphic simulation
Welding - 1

- spot with servo-controlled gun
- stud welding
Welding - 2

- spot (discrete) or arc (continuous)
Two cooperating robots in welding

ABB video at Laxa, Sweden
Palletizing

pallet = a portable platform on which goods can be moved, stacked, and stored
Palletizing of cheese forms

using Kawasaki robots (courtesy of Effedue Engineering)
Folding

with loading of sheets under the press
Deburring

- Car windshields may have large manufacturing tolerances and a sharp contour profile.

- The robot follows a given predefined Cartesian path.

- The contact force between cutting blade and glass must be feedback controlled.

- Deburring robot head mounts a force load cell and is pneumatically actuated.
Deburring center

deburring center for steel parts
using Comau SMART NJ 110-3.0/foundry robot (courtesy of Adami srl)
Off-line robot workstation

articulated robot in metal surface finishing operation
Safety in robotic cells

commercial video from ABB
SafeMove cell monitoring system (no fences!)
Robot manipulator kinematics

- **Kuka 150_2** (series 2000)
  - open kinematic chain
  - (rigid bodies connected by joints)

- **Comau**
  - Smart H4
  - closed kinematic chain

- **Fanuc**
  - F-200iB
  - parallel kinematics
Other types of robots - 1

SCARA (Selective Compliant Arm for Robotic Assembly)

- 4 degrees of freedom (= joints): 3 revolute + 1 prismatic (vertical) axes
- compliant in horizontal plane for micro-assembly and pick-and-place
Adept Cobra i600

fastest SCARA robot for pick-and-place tasks!
Other types of robots - 2

Comau Mast gantry robot
(payload up to 560 kg)

ABB Flexpicker
(150 pick-and-place operations/minute)
Chocolate packaging with lightweight parallel robots

test video with ABB Flexpicker

video with Adept Quatro s650
Distribution by robot type

of kinematic configuration

for 59600 **articulated** robots installed in 2004
(90% of all robots installed in America, 74% in Europe, only 49% in Asia)
**Robot data sheet**

Fanuc  
R-2000i/165F

Here is a table with the specific technical specifications:

<table>
<thead>
<tr>
<th>Voce</th>
<th>R-2000i/165F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipo</td>
<td>Articolato</td>
</tr>
<tr>
<td>Assi controllati</td>
<td>6 assi (J1, J2, J3, J4, J5, J6)</td>
</tr>
<tr>
<td>Installazione</td>
<td>A pavimento</td>
</tr>
</tbody>
</table>
| Area di lavoro (Velocità massima) | Rotazione asse J1: 360° (105°/s)  
|                 | Rotazione asse J2: 135° (105°/s)  
|                 | Rotazione asse J3: 361,8° (105°/s)  
|                 | Rotazione asse J4: 720° (130°/s)  
|                 | Rotazione asse J5: 250° (130°/s)  
|                 | Rotazione asse J6: 720° (210°/s)             |
| Carico massimo al polso | 165 kg                                           |
| Momento di carico max. al polso (Nota 1) | Asse J4: 94kgf·m, 921Nm  
|                 | Asse J5: 94kgf·m, 921Nm  
|                 | Asse J6: 47kgf·m, 461Nm             |
| Momento di inerzia max. al polso | Asse J4: 800kgf·cm², 78,4kgm²  
|                 | Asse J5: 800kgf·cm², 78,4kgm²  
|                 | Asse J6: 410kgf·cm², 40,12kgm²       |
| Tipo di azionamento | Motori elettrici AC                            |
| Ripetibilità  | ± 0,3 mm                                         |
| Peso          | 1,210 kg                                         |
| Ambiente Installazione | Temperatura ambiente: 0-45°C  
|                 | Umidità ambiente:  
|                 | Normale: ≤ 75%                                   
|                 | Breve (in un mese): ≤ 95%                       
|                 | Vibrazioni: 0,5 G max.                          |
Workspace
Visualization of workspace and mobility

kinematic simulation of a 6-dof Comau robot (all revolute joints)
Visualization of workspace and mobility

**V-REP** simulation of the 7-dof KUKA LWR4+ robot (all revolute joints)
Robot end-effector sensors and tools
Calibration of robot kinematics
Man-machine interface

- teach-box pendant used as robot programming interface
- cabinet with power electronics for robot supervision and control
Programming and control environment

control modules and interfaces (Reis Robotics)
Motion programming and scaling

commercial video from ABB
TrueMove & QuickMove fast motion control performance
Mobile base robots in industry

- **AGV** (Automated Guidance Vehicles) for material and parts transfer on the factory floor: wire- or laser-driven along predefined paths
Lifting AGV for warehouses

video by Elettric80
company acquired for $775 million by Amazon (store automation)
Intelligent AGV in factories

commercial video of ADAM mobile robot (RMT Robotics)