Robotics
Manipulation and control

University of Strasbourg

Telecom Physique Strasbourg, ISAV option

Master IRIV, AR track

Introduction

Outline of the lecture

- Introduction : Overview
- 1. Theoretical background
  - 1.1. Rigid motions
  - 1.2. Kinematics
  - 1.3. Velocity Kinematics
- 2. Modeling kinematics
  - 2.1. Denavit-Hartenberg convention
  - 2.2. Forward kinematic model
  - 2.3. Inverse kinematic model

Outline of the lecture

- 3. Modeling velocity kinematics
  - 3.1. The Jacobian
  - 3.2. Inverting the Jacobian
  - 3.3. Static force computation
- 4. Modeling dynamics
  - 4.1. Euler-Lagrange equations
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Outline of the lecture

- 5. Control
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Outline of the introduction

- 1. History and definitions
- 2. Categories of robots
- 3. Specific vocabulary
- 4. Robot main characteristics
- 5. Different kinds of manipulators
- 6. Robot usage
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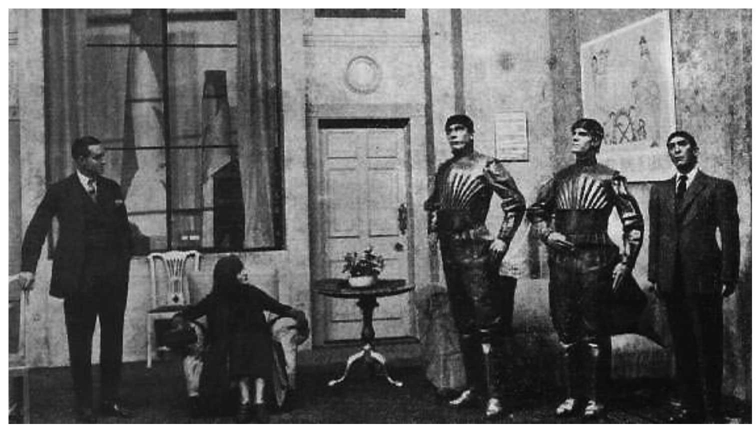
1. History and definitions

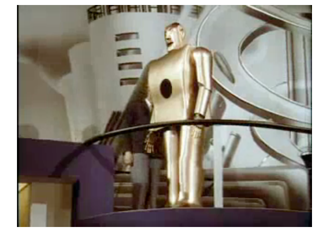
- **Etymology** :"*Rossumovi Univerzální Roboti*" is a science fiction play in the Czech language created in 1920 by Karel Čapek. It was translated in English as "Rossum's Universal Robots". This is the first known occurrence of the word "Robot".

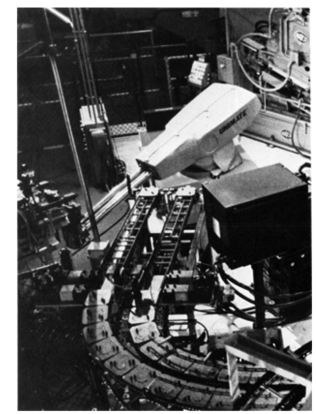


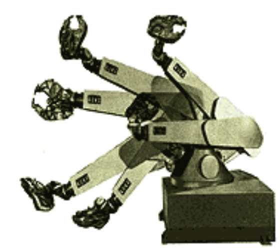
One scene from the play "RUR" showing 3 robots

1. History and definitions

- **Short history**
  - **1939** : "*Elektro*", humanoid robot presented at the world fair in New-York from the Westinghouse Electric Corporation.
  - **1956** : "*Unimate*", first commercial industrial manipulator from the Unimation Company. It was first installed in 1961 in a General Motors plant.
  - **1973** : "*Famulus*", first 6 axis industrial robot from KUKA robotics.





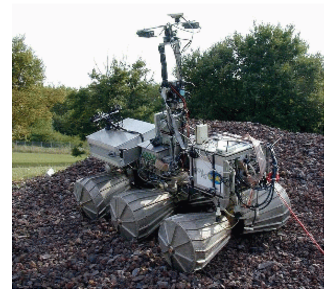


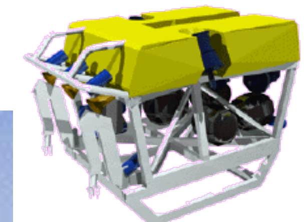
1. History and definitions

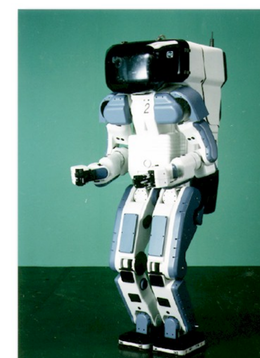
- **Definition**
  - *A robot is a mechanical articulated and actuated system controlled by a computer.*

2. Categories of robots

- Mobile robots
- Unmanned Aerial Vehicles (UAV)
- Underwater robots
- Humanoid robots
- Industrial robots : topic of this lecture



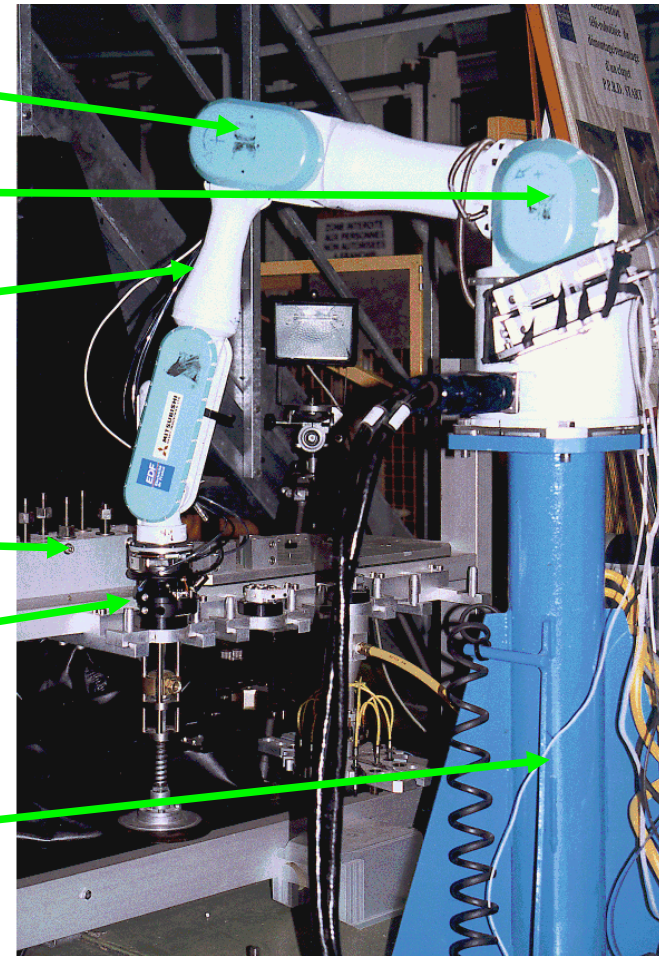




Other categories : biologically inspired robots, medical robots, space robots, cable-driven parallel robots, agricultural robots, rescue robots, military robots, nano robots, …

3. Specific vocabulary

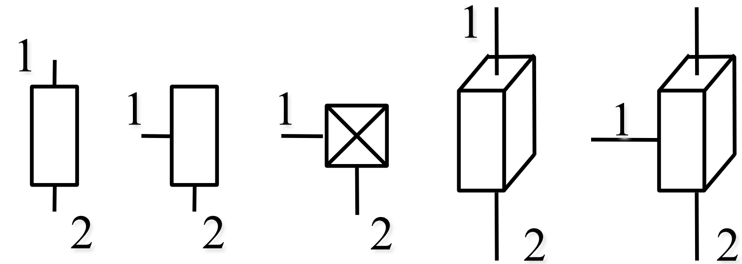
- Actuator = motor
- Joint = axis
- Link
- End-effector
- Tool
- Base



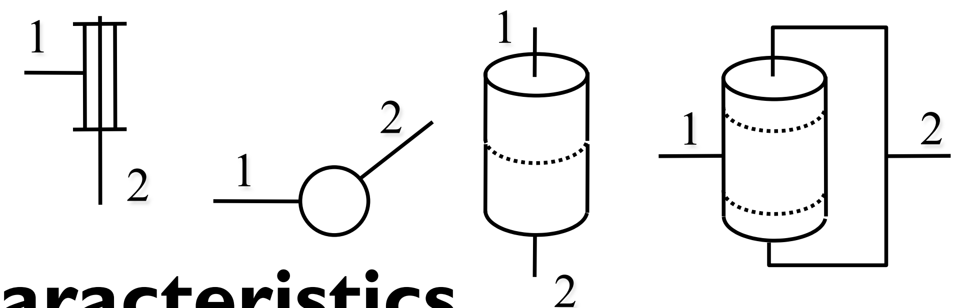
4. Robot main characteristics

4.1 Geometry

- **Two types of joint**
  - Translational / prismatic :



  - Rotational :



- **Geometric characteristics**
  - Number of joints
  - Architecture (serial or parallel)
  - Joint sequence
  - Number of degrees of freedom

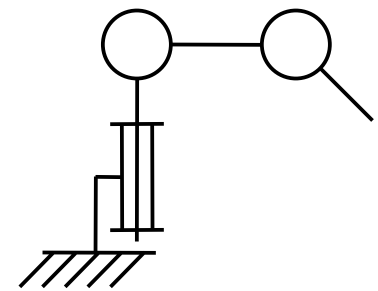
4. Robot main characteristics

4.1 Geometry

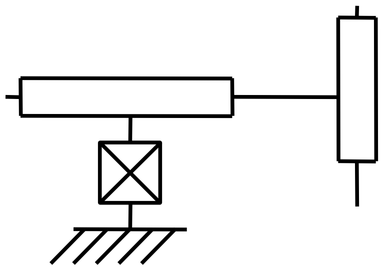
- **Definitions**
  - The configuration of a manipulator is the description of the position of every point of the manipulator.
  - A robot is said to have n degrees of freedom if its configuration can be defined by a minimum of n parameters.
  - On a parallel robot, the end-effector is linked to the ground by several independent kinematic chains.
  - On a serial robot, the end-effector is linked to the ground by only one kinematic chain.

4. Robot main characteristics
4.1 Geometry

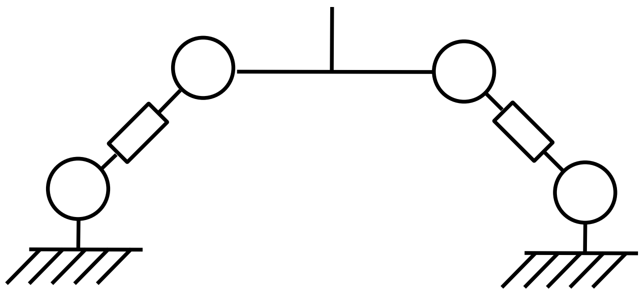
- **Examples**
  - 3 joints, serial, RRR, 3DoF



  - 3 joints, serial, PPP, 3DoF



  - 4 joints, parallel, RP+RP, 3DoF



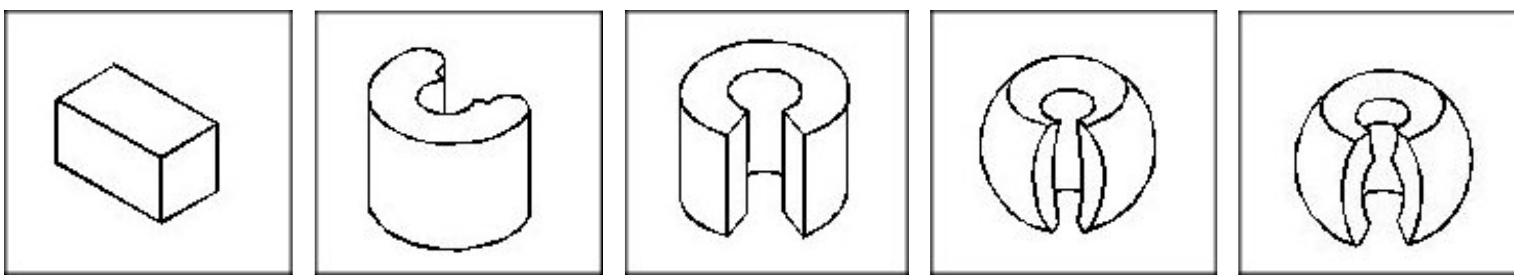
4. Robot main characteristics

4.2 Workspace

- **Definitions**
  - *Reachable workspace* : whole set of points reachable by a point on the end-effector, usually the tool center point.
  - *Dexterous workspace* : whole set of points that a point on the end-effector can reach without limitation in its orientation.

4. Robot main characteristics
4.2 Workspace

- The workspace depends mainly on :
  - The geometry of the robot (see 4.1)
  - The dimensions of the links
  - Limitations on articular motion
- Examples of workspaces :



NB : usually, exact dimensions of these volumes are given by the manufacturer.

4. Robot main characteristics

4.3 Accuracy / Repeatability

- **Definitions**
  - *Accuracy* : how closely the robot can reach a reference position in its workspace.
  - *Repeatability* : how closely a robot can return to a previously learned position in its workspace.
- **Notes**
  - The repeatability of a robot is usually far better than its accuracy.
  - The vast majority of installed robots is used to cyclically repeat a programmed sequence of positions.
  - The norm ISO 9283 specifies the conditions of assessment of the repeatability. It should be measured at maximal payload.

4. Robot main characteristics

4.4 Dynamic performances

- **Maximal velocity**
  - Given for each joint and also sometimes for the end-effector in the most favourable case.
- **Maximal acceleration**
  - Given for each joint in the most unfavourable case (*i.e.* in the maximal inertia configuration).
  - Usually, an industrial robot is in an acceleration/deceleration state most of the time. The joints have rarely the time to reach their maximum velocity.

4. Robot main characteristics
4.5 Payload

- **Payload or carrying capacity**
  - Maximum weight the robot can handle with its end-effector without hindering its repeatability and dynamic performances.
- **Note**
  - The payload is usually much smaller than the maximum weight the robot can lift when the actuators are fed with the maximum current.

4. Robot main characteristics

4.6 Example : the KUKA KR30

- 6R anthropomorphic industrial robot :

Products | Industrial Robots | Medium Payloads | **KR 30-3**

KR 30-3

The KR 30-3 is a masterful mover with a fist-shaped work envelope, and is ideal for the implementation of cost-effective, space-saving system concepts.

Loads

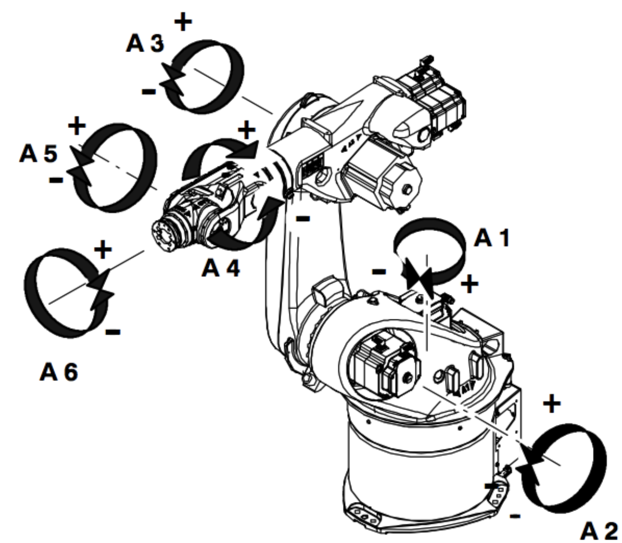
Payload	30 kg
Supplementary payload	35 kg

Working envelope

Max. reach	2033 mm

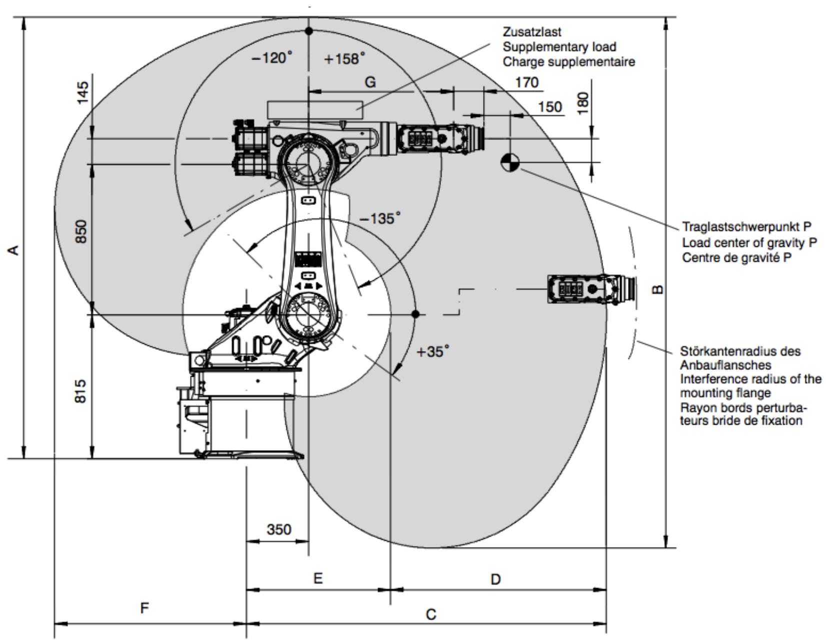
Other data and variants

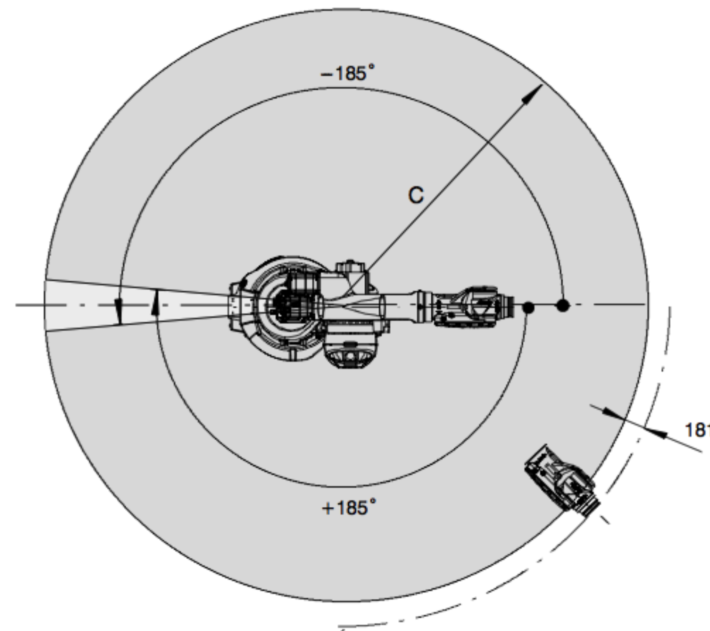
Number of axes	6
Repeatability	<±0,06 mm
Weight	665 kg
Mounting positions	Floor, ceiling
Controller	KR C2



4. Robot main characteristics
4.6 Example : the KUKA KR30

- Workspace :





4. Robot main characteristics
4.6 Example : the KUKA KR30

- Other characteristics :

3 TECHNICAL DATA

Types	KR 30-3, KR 30 L16, KR 60-3, KR 60 L45-3, KR 60 L30-3
Variants	KR 30 L16 EX, KR 30-3 CR, KR 60-3 CR, KR 60 L45-3 CR, KR 60 L30-3 CR
Number of axes	6 (Fig. 1-3)

Repeat-ability (ISO 9283)	KR 30-3	±0.06 mm
	KR 30 L16	±0.07 mm
	KR 30 L16 EX	±0.07 mm
	KR 60-3	±0.06 mm
	KR 60 L45-3	±0.06 mm
	KR 60 L30-3	±0.06 mm

KR 30-3

In-line wrist, rated payload 30 kg

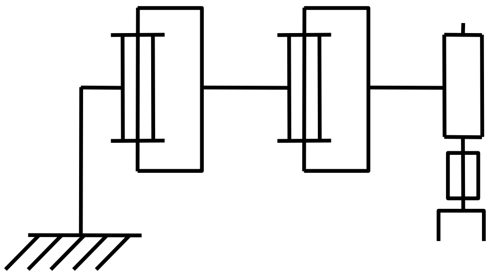
Axis	Range of motion software-limited	Speed
1	±185°	140 °/s
2	+35° to -135°	126 °/s
3	+158° to -120°	140 °/s
4	±350°	260 °/s
5	±119°	245 °/s
6	±350°	322 °/s

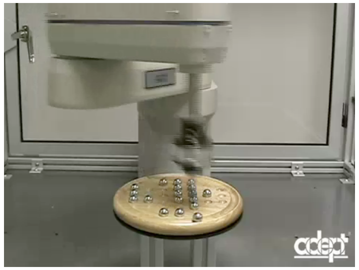
Drive system	Electromechanical, with transistor-controlled AC servomotors	
Installed motor capacity	approx. 14.9 kW	
Principal dimensions	see Fig. 3-9 and Fig. 3-10	
Weight	KR 30-3	approx. 665 kg
	KR 60-3	approx. 665 kg
	KR 60 L45-3	approx. 671 kg
	KR 60 L30-3	approx. 679 kg
	KR 30 L16	approx. 700 kg
	KR 30 L16 EX	approx. 700 kg

NB : for this robot, the maximal acceleration is not given although it is a critical information.

5. Different kinds of robots
5.1 SCARA robots

- **SCARA**
  - **S**elective **C**ompliance **A**rticulated **R**obot for **A**ssembly
- **Characteristics**
  - 4 joints, serial, RRPR, 4 DoFs
  - Cylindrical workspace
  - Accurate
  - Very fast
- **Examples**
  - Mitsubishi RH-3SDHR
  - Adept Cobra i600

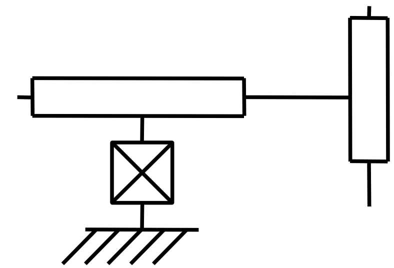




5. Different kinds of robots

5.2 Cartesian robots

- **Characteristics**
  - 3 perpendicular prismatic joints
  - Very good accuracy
  - Easy to control
  - Slow



- **Example**
  - Epson XM3000

5. Different kinds of robots

5.3 Parallel robots (out of the lecture scope)

- **Characteristics**
  - Limited workspace
  - High stiffness
  - High dynamic performances
- **Example**
  - Adept Quattro s650H

This is real time footage of the Adept Quattro robot playing the mobile-device game "1to50" The point of the game is to press the buttons for the numbers 1 through 50 in succession. Quattro now tops the leader boards.

5. Different kinds of robots

5.4 Anthropomorphic robots

- **Characteristics**
  - Inspired by the human arm
  - 6 DoFs
  - Highly polyvalent
  - The most common structure
- **Examples**
  - Stäubli RX170HSM
  - Robocoaster G3 (Kuka robot)

5. Different kinds of robots

5.4 Anthropomorphic robots

- Various sizes :

KR 6 R900 SIXX (KR AGILUS)

The KR 6 R900 sixx has a payload capacity of 6 kg and a reach of approx. 901 mm. The KR AGILUS is consistently rated for particularly high working speeds.

Loads

Payload	6 kg

Working envelope

Max. reach	901 mm

Other data and variants

Number of axes	6
Weight	52 kg
Mounting positions	Floor
Controller	KR C4 compact
Protection class	IP 54

KR 1000 TITAN

The KR 1000 TITAN is the strongest and biggest 6-axis robot available on the market. With a payload of up to 1000 kg, it is used primarily in the glass, foundry, building materials and automotive industries.

Loads

Payload	1000 kg
Supplementary payload	50 kg

Working envelope

Max. reach	3202 mm

Other data and variants

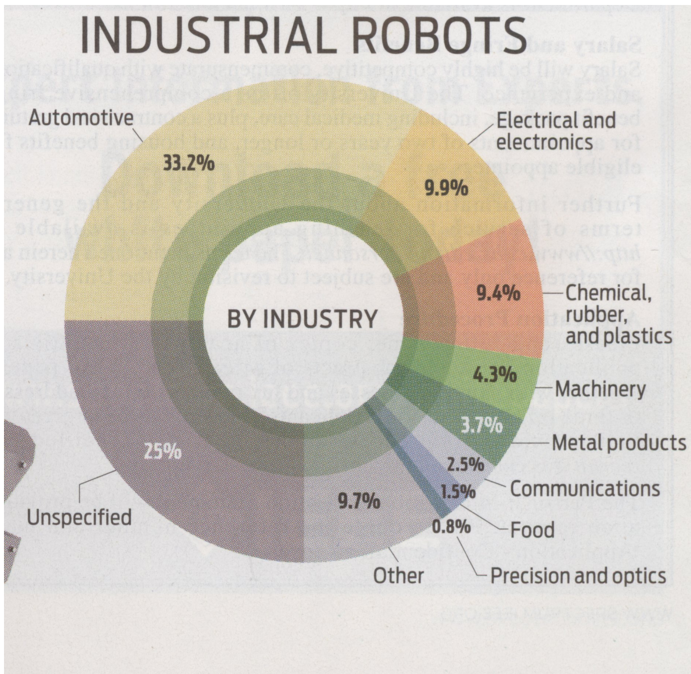
Number of axes	6
Repeatability	<±0,1 mm
Weight	4950 kg
Mounting positions	Floor
Controller	KR C2

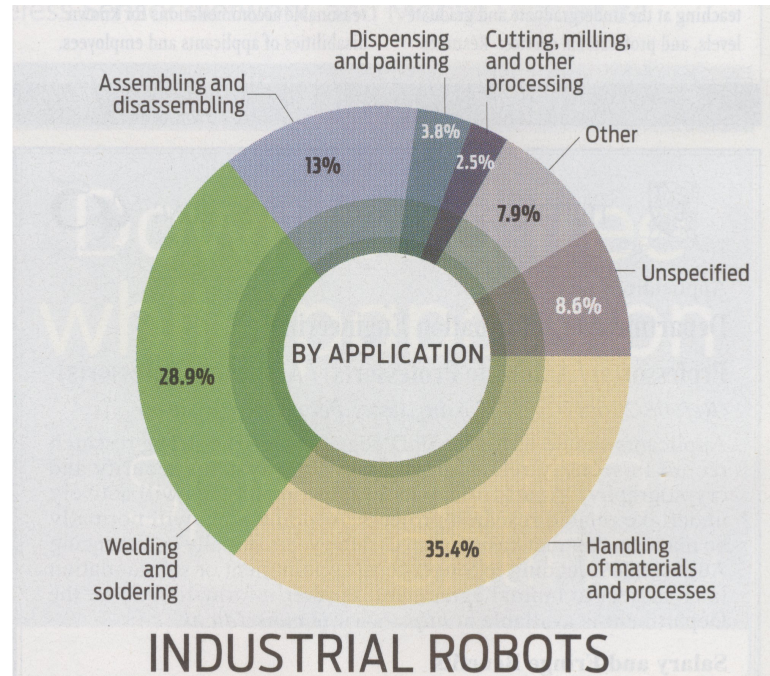
6. Robot usage

6.1 Overview

- The vast majority of industrial robots is used for simple tasks :
  - Repeat accurately a learned sequence of motion. The teaching/learning phase is manual and can be very time consuming.
  - The object must be accurately positioned wrt the robot.
- Criterions for robotising a task :
  - Simple, repetitive, laborious, hazardous.

6. Robot usage
6.1 Overview

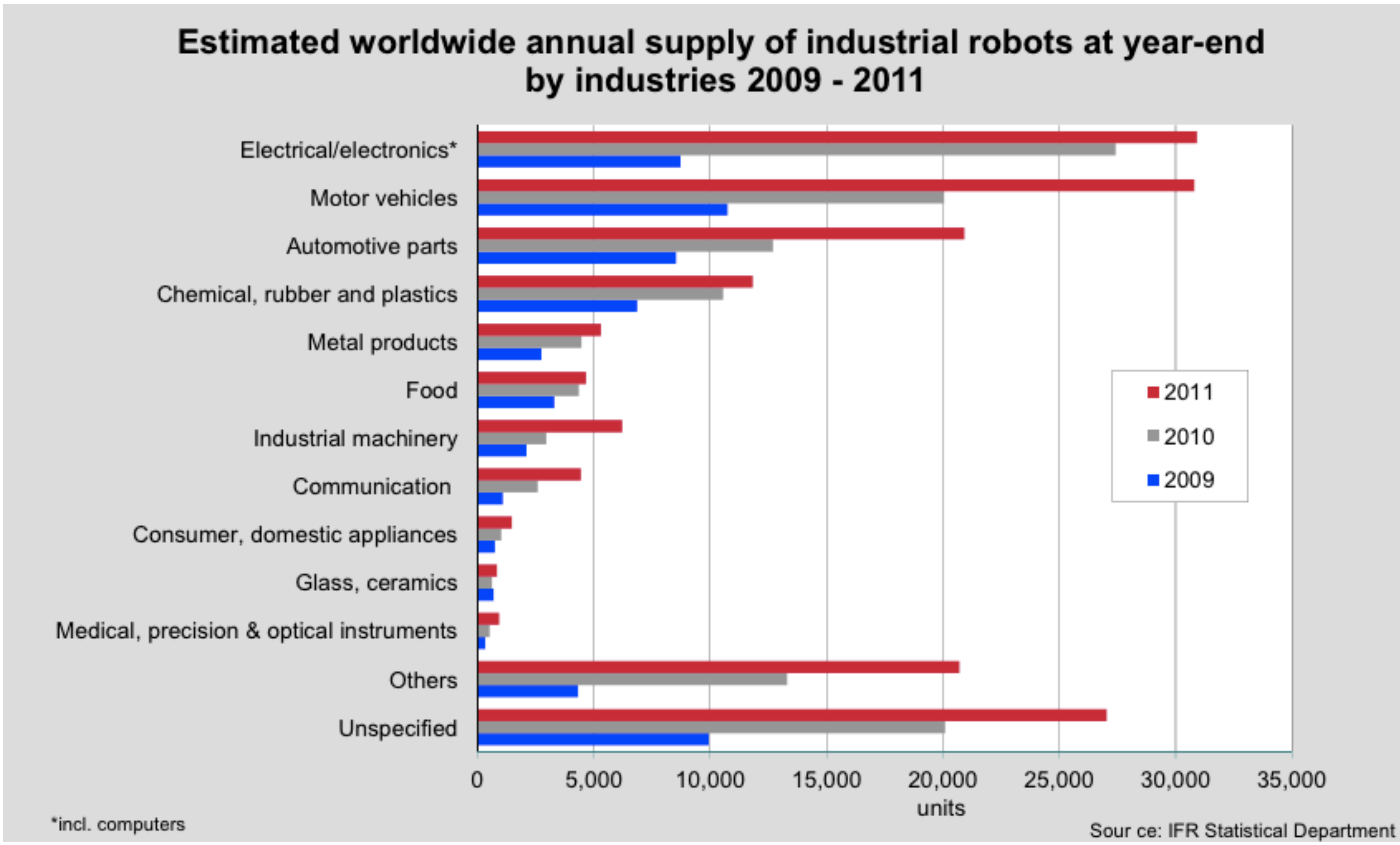




Source : IEEE Spectrum, December 2008

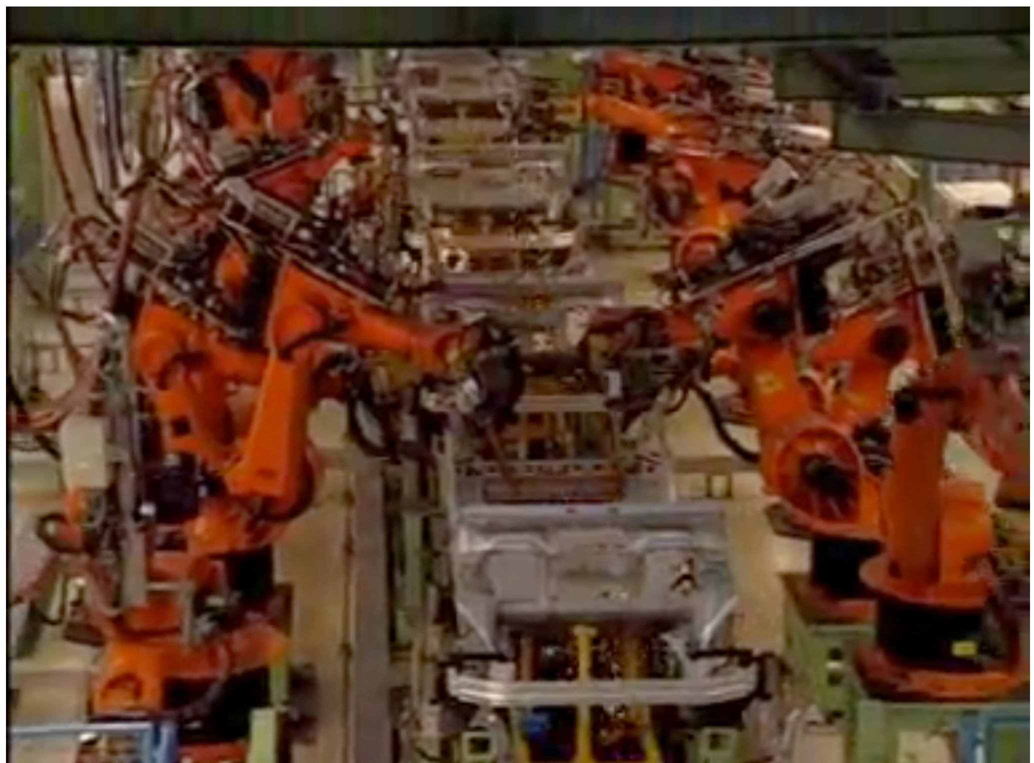
6. Robot usage

6.1 Overview



6. Robot usage
6.2 Automotive industry

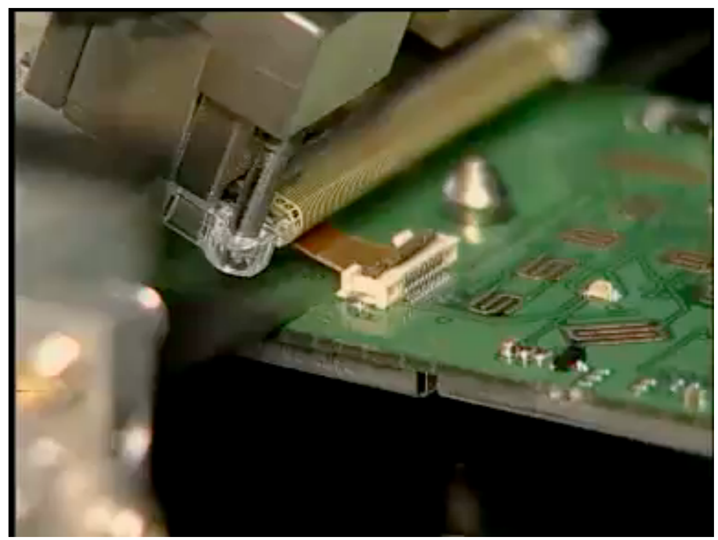
- ~30% of all installed robots.
- Tasks : welding, milling, gluing, assembling.



6. Robot usage

6.3 Electrical and electronics industry

- ~10% of all installed robots.
- Tasks : assembling, gluing, soldering, connecting.
- Example : mobile phone assembly.

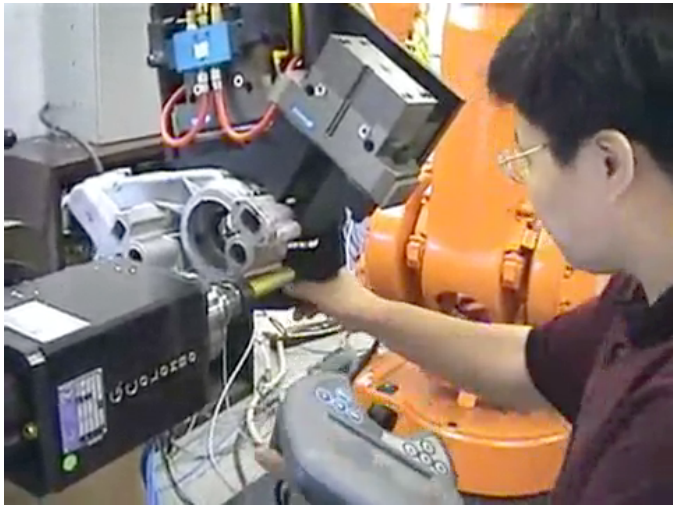


6. Robot usage
6.4 Plastic industry

- ~9% of all installed robots.
- Tasks : handling, assembling, milling.
- Example : Plastic moulding machine servicing.

6. Robot usage
6.5 Metal industry

- ~4% of all installed robots.
- Tasks : machining, milling, deburring, polishing.
- Example : deburring.

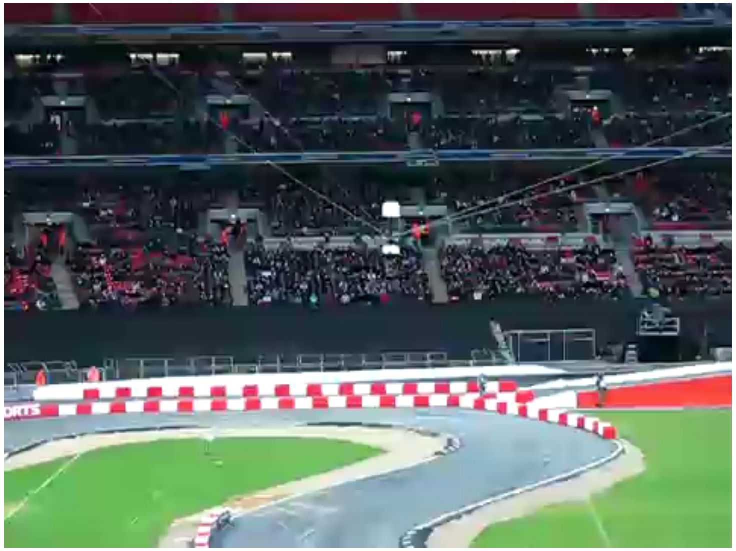


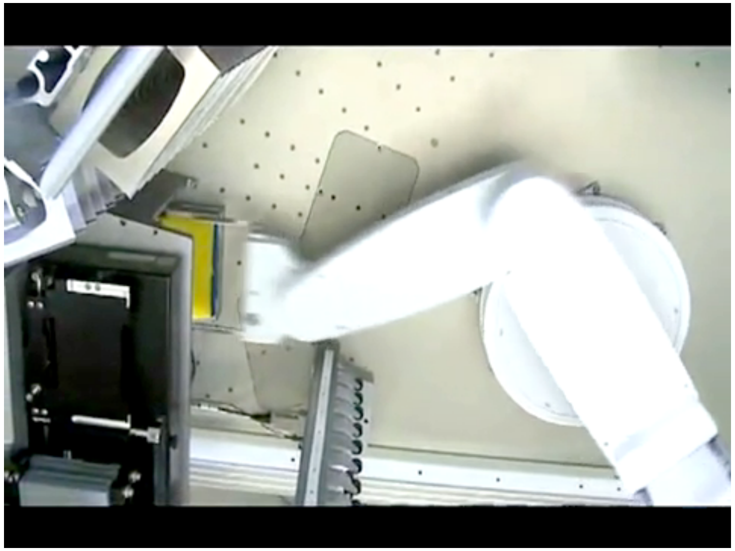
6. Robot usage
6.6 Food and beverage industry

- ~2% of all installed robots.
- Tasks : handling, filling, packaging.
- Example : pancake stacking.

6. Robot usage
6.6 Emerging applications

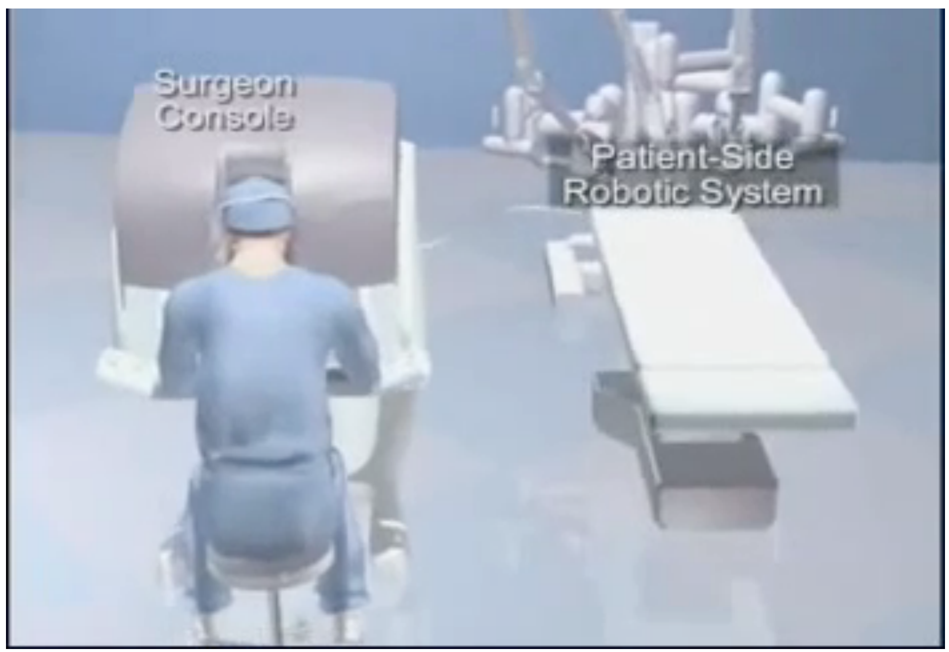
- Entertainment : Skycam, Robocoaster.
- Wood industry : sawing, milling, boring, handling.
- Drug industry : handling.





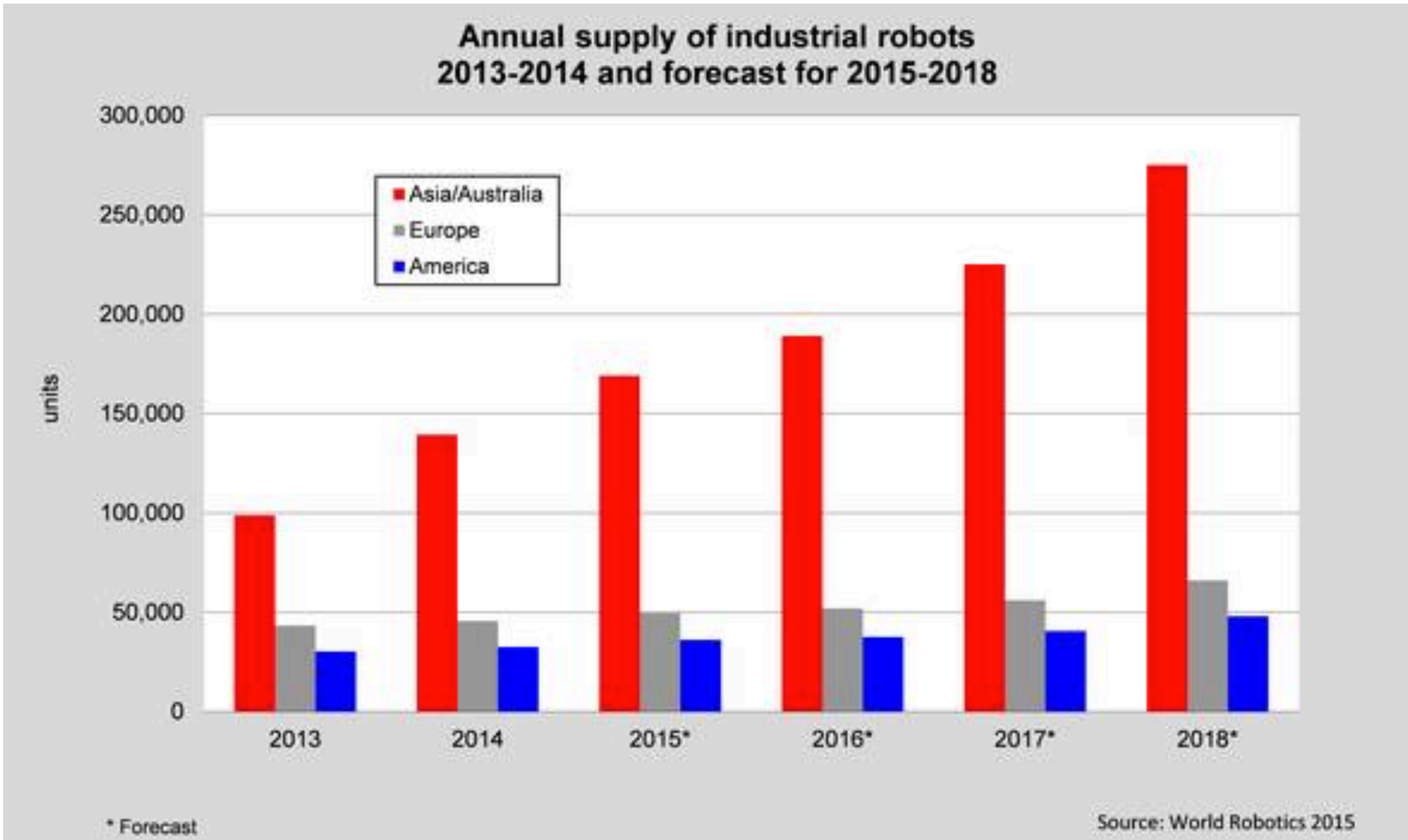
6. Robot usage
6.6 Emerging applications

- Medical robotics : telemanipulation, insertion, milling, cutting, positioning, handling.



7. Stats

7.1. Robots worldwide



Statistiques courantes : http://www.ifr.org/industrial-robots/statistics/

7. Stats

7.2. Robots by countries

Estimated yearly shipments of multipurpose industrial robots in selected countries. Number of units

Country	2013	2014	2015*	2018*
America	**30,317**	**32,616**	**36,200**	**48,000**
Brazil	1,398	1,266	1,000	3,000
North America (Canada, Mexico, USA)	28,668	31,029	35,000	44,000
Other America	251	321	200	1,000
Asia/Australia	**98,807**	**139,344**	**169,000**	**275,000**
China	36,560	57,096	75,000	150,000
India	1,917	2,126	2,600	6,000
Japan	25,110	29,297	33,000	40,000
Republic of Korea	21,307	24,721	29,000	40,000
Taiwan	5,457	6,912	8,500	12,000
Thailand	3,221	3,657	4,200	7,500
other Asia/Australia	5,235	15,535	16,700	19,500
Europe	**43,284**	**45,559**	**49,500**	**66,000**
Czech Rep.	1,337	1,533	1,900	3,500
France	2,161	2,944	3,200	3,700
Germany	18,297	20,051	21,000	25,000
Italy	4,701	6,215	6,600	8,000
Spain	2,764	2,312	2,700	3,200
United Kingdom	2,486	2,094	2,400	3,500
other Europe	11,538	10,410	11,700	19,100
Africa	**733**	**428**	**650**	**1,000**
not specified by countries**	4,991	11,314	8,650	10,000
Total	**178,132**	**229,261**	**264,000**	**400,000**

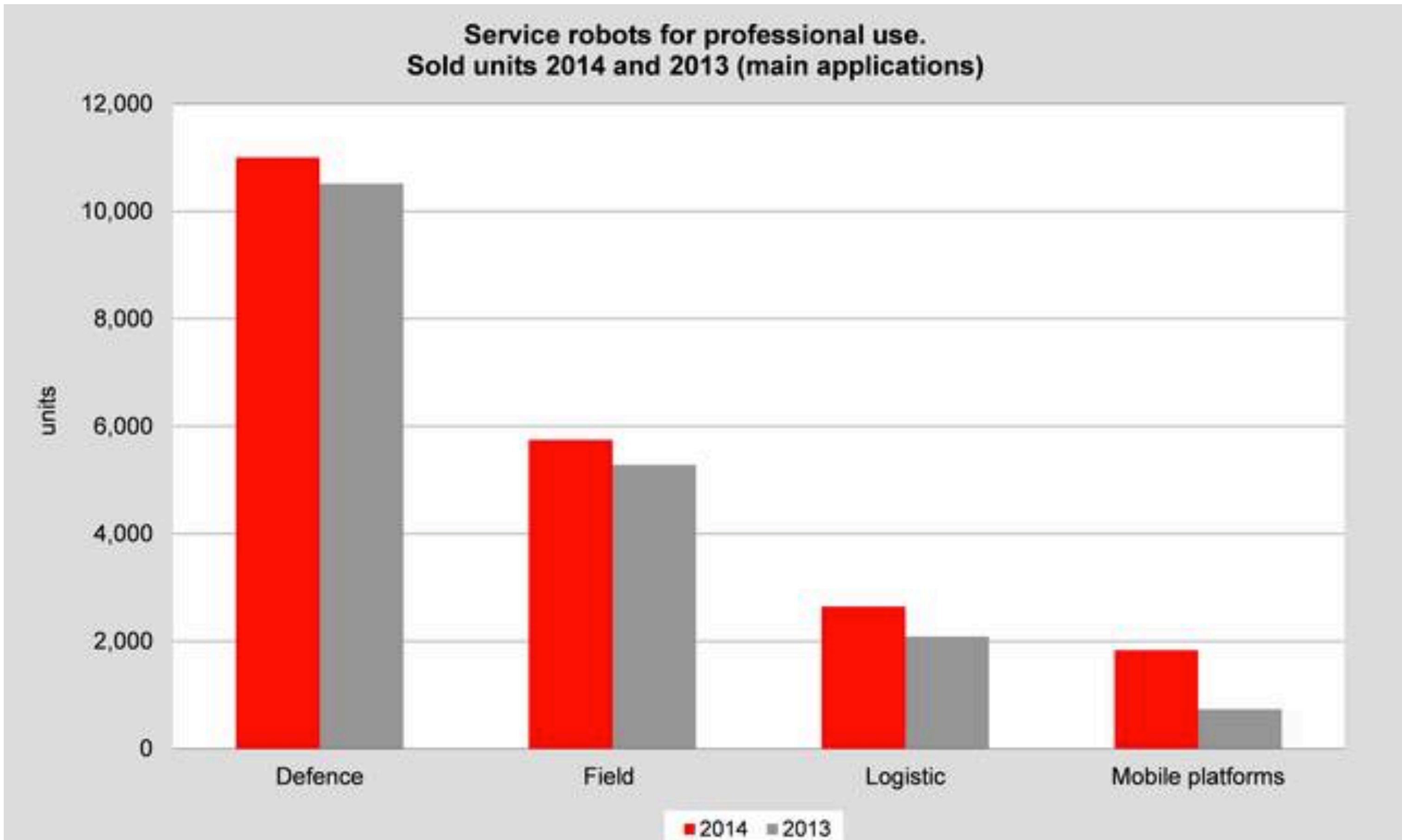
Sources: IFR, national robot associations.

*forecast

** reported and estimated sales which could not be specified by countries

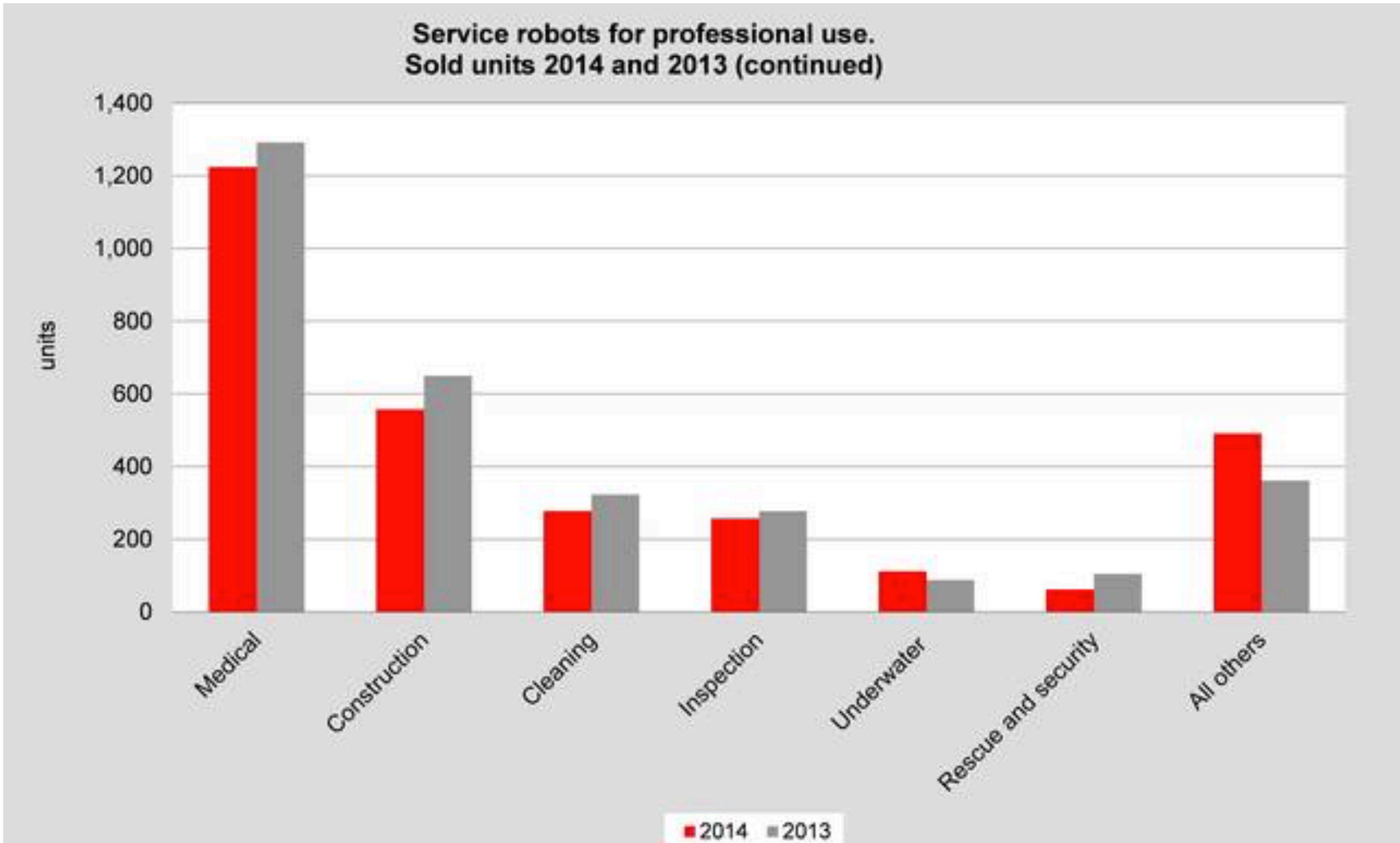
7. Stats

7.3. Service robotics



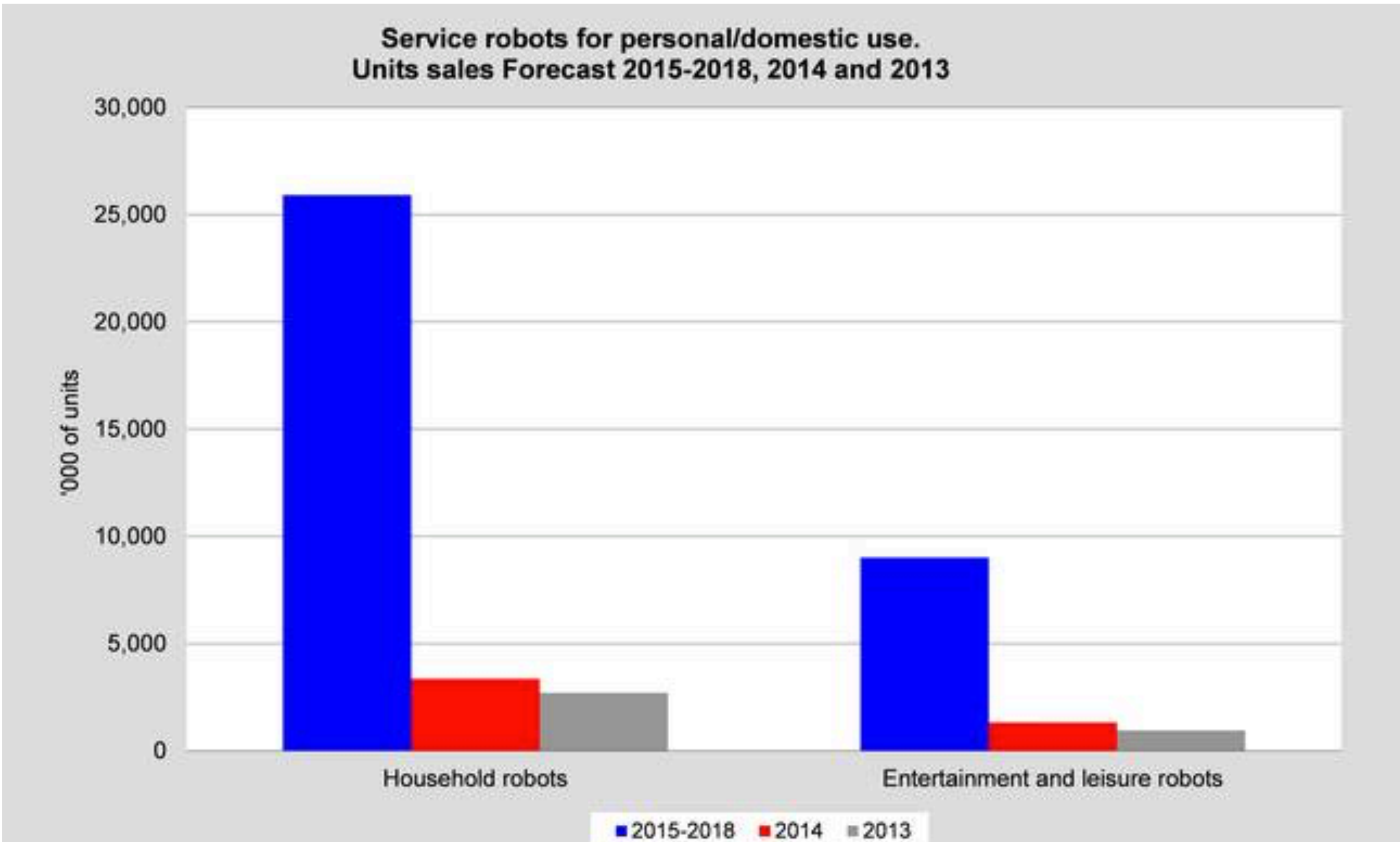
7. Stats

7.3. Service robotics



7. Stats

7.3. Service robotics



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- **J. J. Craig**, *Introduction to Robotics: Mechanics and Control (3rd Edition)*, Prentice Hall, 2004.
- **W. Khalil and E. Dombre**, *Modeling, Identification & Control Of Robots*, Hermes Penton, 2004.
- IEEE transactions on robotics : http://ieeexplore.ieee.org/
- International Journal of Robotics Research : www.ijrr.org/

Quizz

- https://goo.gl/T7qo8y