5ELEN018W - Robotic Principles
Lecture 2: Introduction to Robotics - Configuration Space

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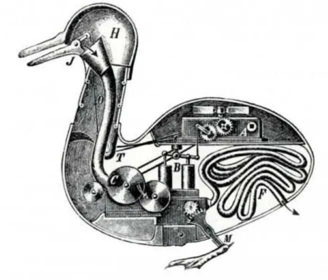
Before Robots

Fascination for mechanical devices such as automata. Complex enough (for that time) to demonstrate some kind of `life-like` behaviour.

Example: Vaucanson's Digesting Duck (1739)

- Flap its wings, eat grain and defecate.



History and Terminology

The word *robot* comes from the word `Robota` in Slav languages, first introduced by the Czech playwright Karel Capek in his play *Rossum's Universal Robots* (RUR) in 1920.

The original word meaning was *worker*.
Free audiobook:
`https://archive.org/details/rossums_universal_robots_1409_librivox`

History and Terminology (cont'd)

Robots in many:

- Science fiction books
- Movies

In the mid twentieth century (1950s), the term `cybernetics` was used for an exciting science field to understand life and create intelligent machines.

The 3 Laws of Robotics — Isaac Asimov

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 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.

Videos on the history of Robots

- Robots - A 50 year journey video
- Robots - The journey continues video

Robots Today

Robotic automation mostly used in Manufacturing (millions of arm-type robots), e.g.:

- Welding
- Painting
- Machine loading/unloading
- Electronic assembly
- Packaging

Categorising Robots and Definition

Many different ways to classify robots, e.g.

- Fixed in place.
- Mobile (legs, wheels, wings, etc)

or according to the operation they perform:

- Manufacturing
- Service robots (cleaning, personal care, medical)
- Field robots (agriculture, mining, construction)
- Humanoid robots having the form of a human being and perform more than one tasks

A robot can be defined as (according to Peter Corke):
A goal oriented machine that can sense, plan and act.

Characteristics of Robots

- Consistent
- Accurate
- Reliable

Do things that people

- can't do
  - → space, deep sea
- won't do
  - → dull, boring tasks
- shouldn't do
  - → dangerous, unhealthy, risky

Rigid Bodies and Robotic Manipulators

The most common form of an industrial robot is a **mechanical manipulator**.

- A mechanical manipulator consists of rigid bodies (called *links*) connected by *joints*.
- The joints are moved by actuators (e.g. electric motors).
- An *end-effector* (gripper or hand) is usually attached to a specific link.

A *rigid body* is a solid body which cannot be deformed (or deformations are so small that can be neglected). The distance between any 2 points in a rigid body remains constant even if forces are applied.

A Modern Robotic Manipulator

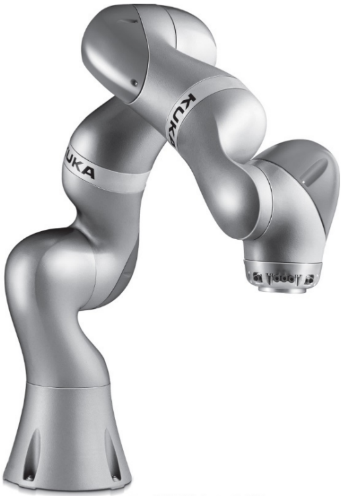
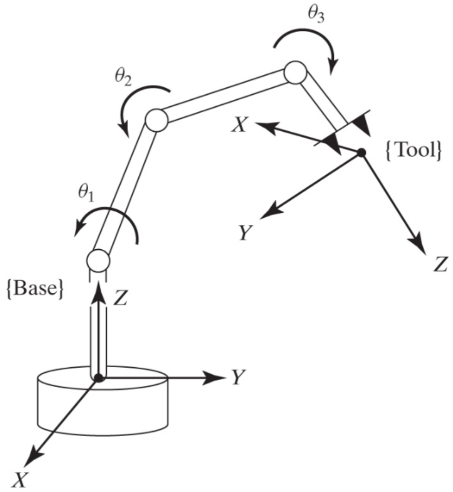


Image courtesy KUKA Roboter GmbH.

- The above has 7 degrees of freedom as explained a bit later.

Robotic Manipulators and Configuration Space



- How can we specify the exact position of a Robot (Manipulator)?

Configuration Space

The answer to *How can we specify the exact position of a Robot* is:

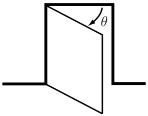
- **Robot Configuration**: a specification of the positions of ALL points of a robot.

Robot links are rigid: therefore only a few numbers are required to represent its configuration (position).

Configuration Examples

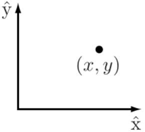
- *How can the configuration of a door be represented?*

  $\rightarrow$ angle θ about its hinge.



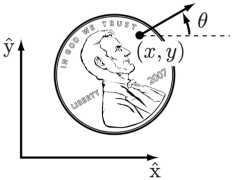
- *How can the configuration of a point on a plane be described?*

  $\rightarrow$ 2 coordinates (x, y)



Configuration Examples (cont'd)

- *How can the configuration of a coin lying on a table be represented?*
  - $\rightarrow$ 2 coordinates (x, y) to specify the position of a fixed point on the coin (e.g. centre) and one coordinate θ to specify the coin's orientation.



Degrees of Freedom of a Body (Robot)

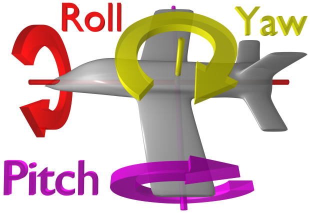
The number of **degrees of freedom (DOF)** of a body (e.g. robot) is the smallest number of real-valued variables needed to represent its configuration.

- **C-space (Configuration space)**: the n-dimensional space of all possible configurations of a robot
- Degrees of freedom n is the dimension of the *C-space*

Degrees of Freedom of a Spatial Rigid Body

A rigid body in a 3-dimensional space (*spatial rigid body*) has 6 degrees of freedom.

- (x, y, z) coordinates for specifying the position of the centre of mass.
- 3 angles (θ, ϕ, ψ) specifying the orientation (attitude) of the body.

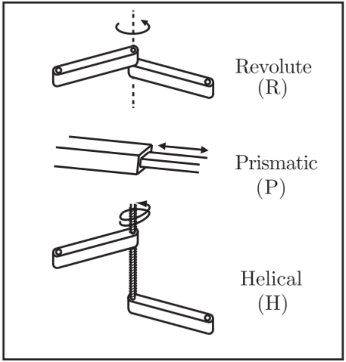


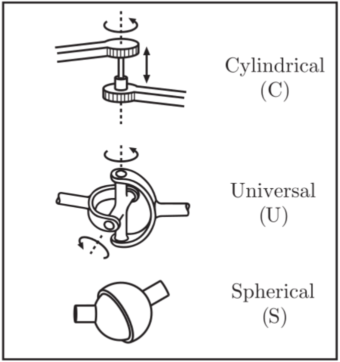
https://compsci290-s2016.github.io/CoursePage/Materials/EulerAnglesViz/

Degrees of Freedom for Robots

$$\text{degrees of freedom} = (\text{sum of freedoms of the bodies}) - (\text{number of independent constraints}) \quad (1)$$

Types of Robot Joints





Robot Joints: Degrees of Freedom and Constraints

- A joint provides freedoms to allow one rigid body to move relative to another
- *Equivalently*: a joint provides constraints on the possible motions of 2 rigid bodies it connects.

Joint type	dof f	Constraints c between two planar rigid bodies	Constraints c between two spatial rigid bodies
Revolute (R)	1	2	5
Prismatic (P)	1	2	5
Helical (H)	1	N/A	5
Cylindrical (C)	2	N/A	4
Universal (U)	2	N/A	4
Spherical (S)	3	N/A	3

- *The number of degrees of freedom of a rigid body (3 for planar bodies, 6 for spatial bodies) minus the number of constraints provided by a joint, must equal the number of freedoms provided by that joint.*

Grübler's Formula

The number of degrees of freedom of a mechanism (robot) with links and joints can be calculated using *Grübler's formula* which is another expression of equation (1).

Consider a mechanism (robot) with:

- N links (ground is also considered a link)
- J joints
- m is the degrees of freedom of a rigid body ($m = 3$ for planar mechanisms, $m = 6$ for spatial mechanisms)
- f_i the number of freedoms provided by joint i
- c_i the number of constraints provided by joint i, where $f_i + c_i = m$ for all joints i.

assumes all joints constraints are independent.

Then:

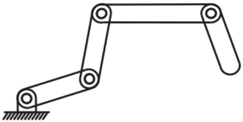
$$\text{dof} = m \cdot (N - 1 - J) + \sum_{i=1}^{J} f_i \tag{2}$$

Derivation of Grübler's Formula

$$\begin{aligned} \text{dof} &= \underbrace{m \cdot (N-1)}_{\text{rigid body freedoms}} - \underbrace{\sum_{i=1}^{J} c_i}_{\text{joint constraints}} \\ &= m \cdot (N-1) - \sum_{i=1}^{J} (m - f_i) \\ &= m \cdot (N-1) - \sum_{i=1}^{J} m + \sum_{i=1}^{J} f_i \\ &= m \cdot (N-1-J) + \sum_{i=1}^{J} f_i \end{aligned} \qquad (3)$$

Example of Grübler's Formula - Open Chain

3R Serial (3 revolute)

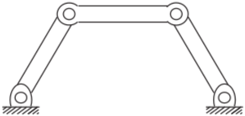


- $m = 3$ (planar)
- $J = 4$
- $N = 5$ (including the ground)
- $f_i = 1$

$$\text{dof} = 3(5 - 1 - 4) + 4 = 4 \tag{4}$$

Example of Grübler's Formula - Closed Chain mechanism

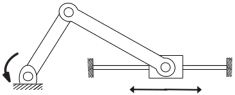
Four-Bar Linkage



- $m = 3$ (planar)
- $J = 4$
- $N = 4$ (including the ground)
- $f_i = 1$

$$\text{dof} = 3(4 - 1 - 4) + 4 = 1 \tag{5}$$

Example of Grübler's Formula - Slider-crank mechanism



3 revolute joints and 1 prismatic joint.

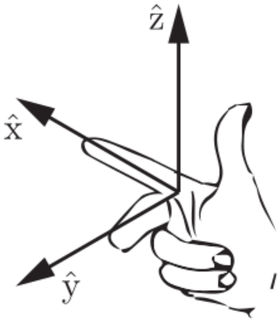
- $m = 3$ (planar)
- $J = 4$
- $N = 4$ (including the ground)
- $f_i = 1$

$$\text{dof} = 3(4 - 1 - 4) + 4 = 1 \tag{6}$$

Coordinate Reference Frames

- Fixed to the body of the robot (moving)
- Fixed somewhere in space (stationary)

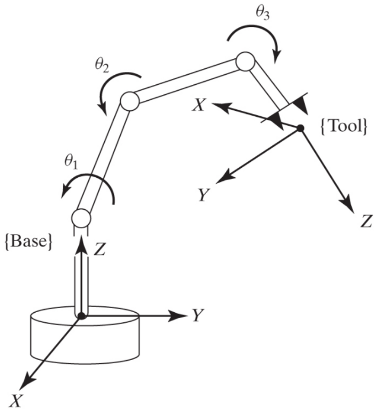
In robotics, the x, y, z axes are aligned according to the right hand rule:



Kinematics

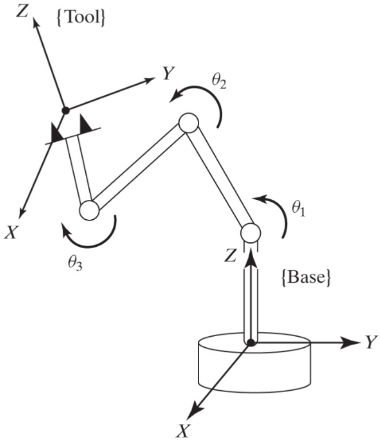
The science of motion that treats motion without considering the forces which cause it.

- *Forward Kinematics*: Given the angles for the joints, calculate (compute) the position and orientation of the end-effector of a robot manipulator.



Kinematics (cont'd)

- *Inverse Kinematics*: Given the position and orientation of the end-effector, compute all possible sets of joint angles that can be used to achieve this position and orientation.



Robots: Social Issues and Ethics

Social Issues:

- Workers losing their jobs and income
- Economic consequences
- Legal rights of robots (as they become more advanced and intelligent)

Ethical Issues:

- Self driving cars:
  - → Choosing to save the driver over pedestrians or other drivers, etc?
  - → Who is to blame, the robot, the software developer, the manufacturer or the owner of the car?
- Robotic healthcare: who to blame (surgery failure, etc.)?
- Robots looking after elderly people: is this right as their quality of life is affected by removing human contact?
- Robots looking after children?
- Using robots in armies to kill human beings?