Robotics

Erwin M. Bakker| LIACS Media Lab

11-2 2020

Universiteit Leiden

Organization and Overview

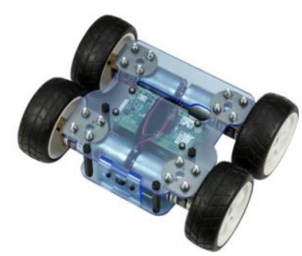
Period: February 4th – April 28th 2020
Time: Tuesday 14.15 – 16.00
Place: LIACS, Room 407-409 (Workshops Room 302-304)
Lecturer: Dr Erwin M. Bakker (erwin@liacs.nl)
Assistant: Laduona Dai

NB E-mail your name and student number to erwin@liacs.nl

Schedule:

4-2	Introduction and Overview
11-2	Locomotion and Inverse Kinematics
18-2	***SLAM Workshop I*** *and Yetiborg Introduction*
25-2	*Robotics Sensors and Image Processing*
3-3	***Project Proposals*** *(presentation by students)*
10-3	**Yetiborg Qualification Challenge**
17-3	Robotics Image Processing and Understanding
24-3	***Yetiborg Race***
31-3	**Project Progress Report** (by students)
7-4	Robotics Reinforcement Learning
14-4	**Robotics Reinforcement Learning Workshop II**
21-4	TBA
28-4	***Project Demos*** *(by students)*

Website: http://liacs.leidenuniv.nl/~bakkerem2/robotics/



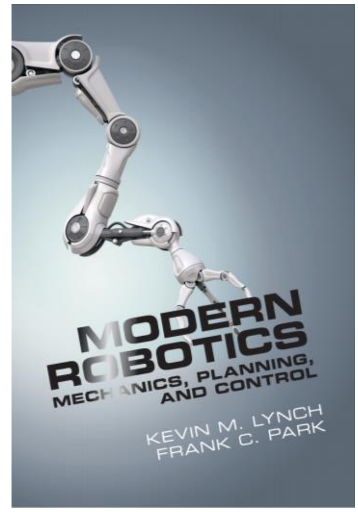
Grading (6 ECTS):

- Presentations and Robotics Project (60% of grade).
- Class discussions, attendance, workshops and assignments (40% of grade).
- It is necessary to be at every class and to complete every workshop.

Overview

- Robotic Actuators
- Configuration Space
- Rigid Body Motion
- Forward Kinematics
- Inverse Kinematics

- Link: http://modernrobotics.org



K.M. Lynch, F.C. Park, Modern Robotics: Mechanics, Planning and Control, Cambridge University Press, 2017

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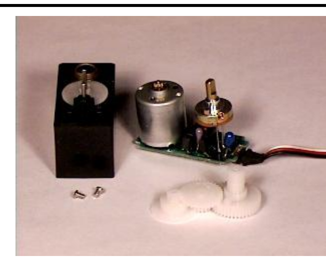
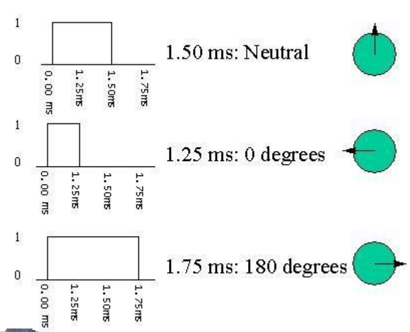
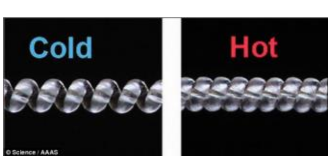
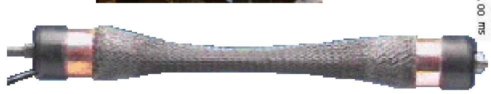
Robotics Actuators

- Electro motors
- Servo's
- Stepper Motors
- Brushless motors
- Solenoids
- Hydraulic, pneumatic actuator's
- Magnetic actuators
- Artificial Muscles
- Etc.









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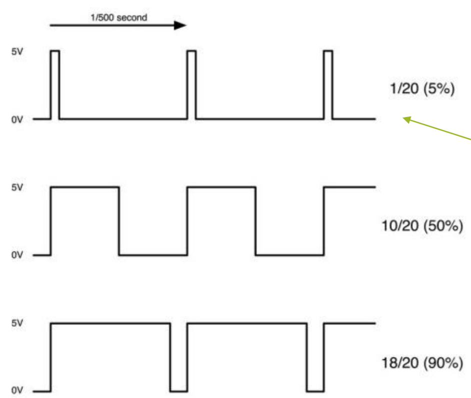
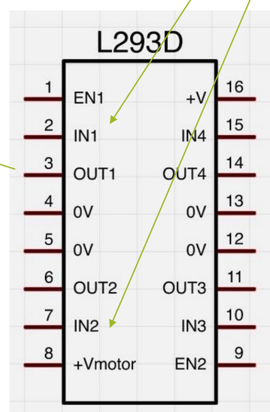
Robotics Actuators:

- Electro motors






```
import RPi.GPIO as io
io.setmode(io.BCM)

in1_pin = 4
in2_pin = 17

io.setup(in1_pin, io.OUT)
io.setup(in2_pin, io.OUT)

def set(property, value):
    try:
        f = open("/sys/class/rpi-pwm/pwm0/" + property, 'w')
        f.write(value)
        f.close()
    except:
        print("Error writing to: " + property + " value: " + value)

set("delayed", "0")
set("mode", "pwm")
set("frequency", "500")
set("active", "1")

def clockwise():
    io.output(in1_pin, True)
    io.output(in2_pin, False)

def counter_clockwise():
    io.output(in1_pin, False)
    io.output(in2_pin, True)

clockwise()

while True:
    cmd = raw_input("Command, f/r 0..9, E.g. f5 :")
    direction = cmd[0]
    if direction == "f":
        clockwise()
    else:
        counter_clockwise()
    speed = int(cmd[1]) * 11
    set("duty", str(speed))
```

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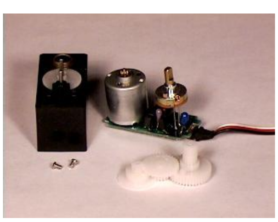
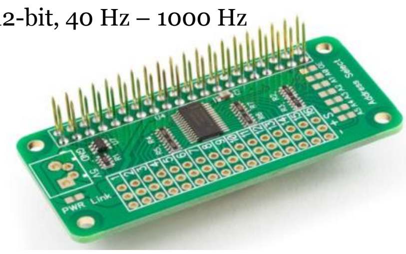
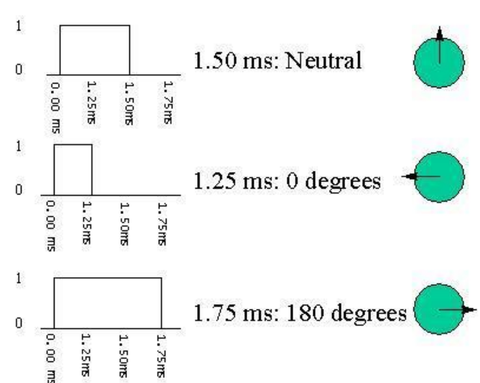
Servo's



16-ch, 12-bit, 40 Hz – 1000 Hz





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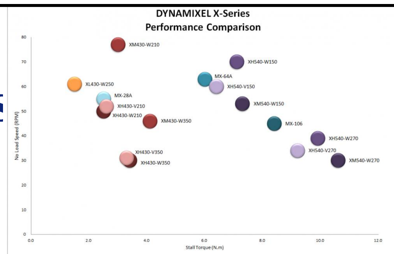
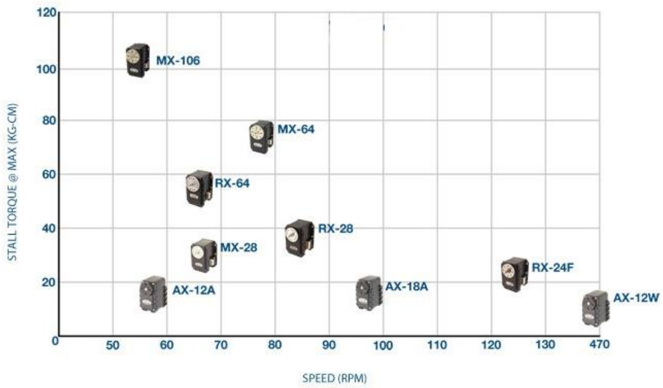
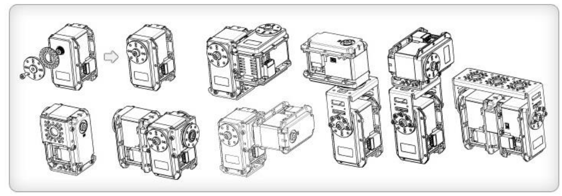
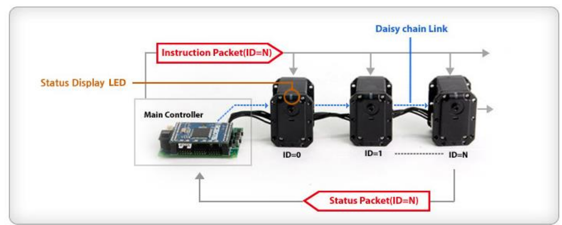
Servo's





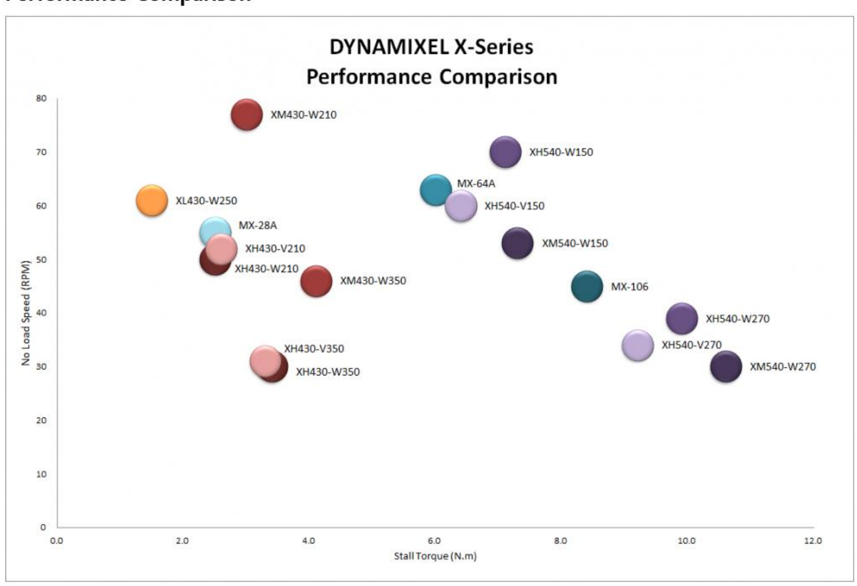
Flexible Construction and Modular Structures





Servo's

Performance Comparison



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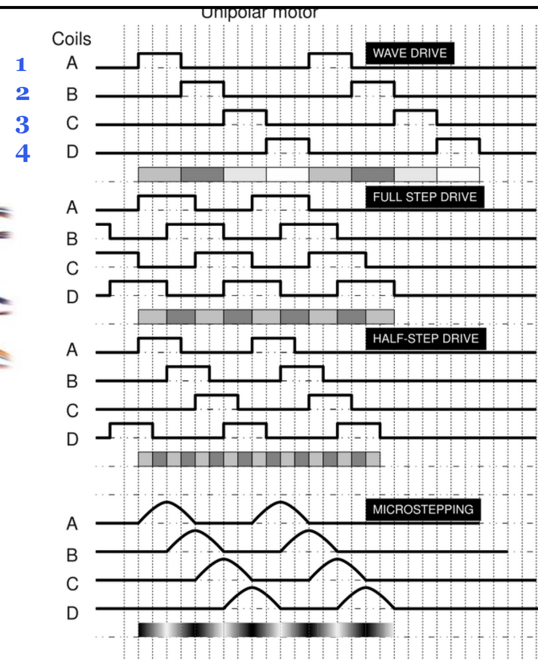
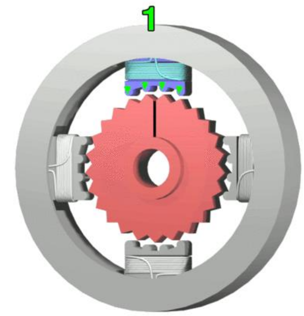
Robotics Actuators

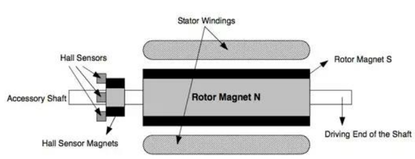
- Stepper motors
- Drivers: low-level, high level

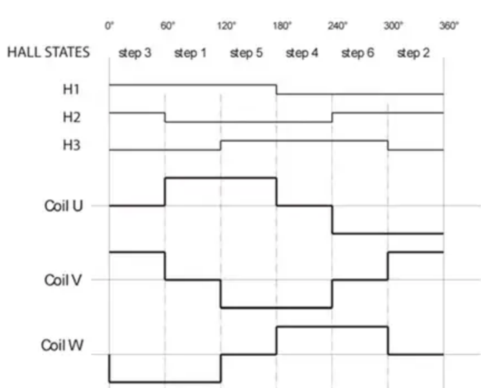


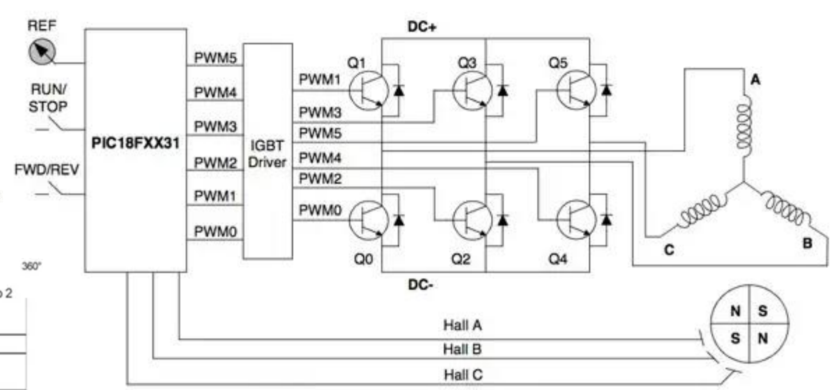


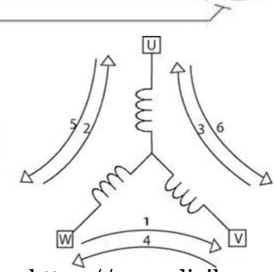
By Wapcaplet; Teravolt. (Wikipedia)

Brushless Motors



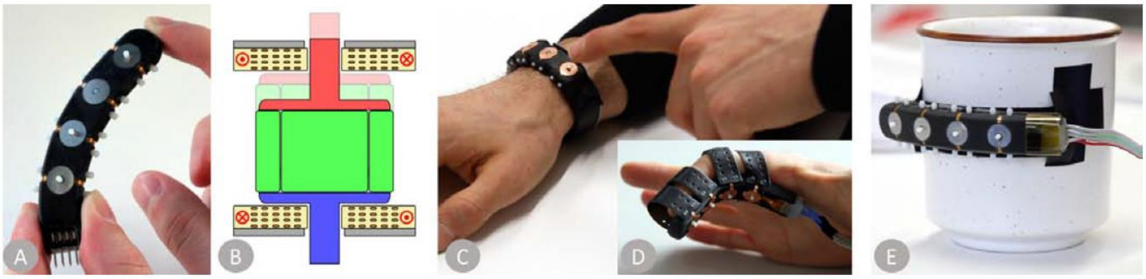


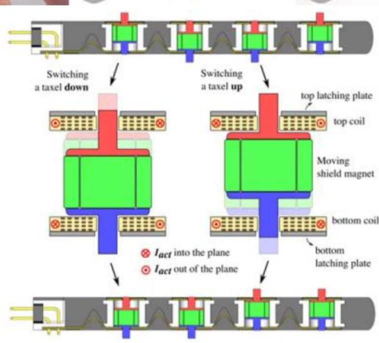




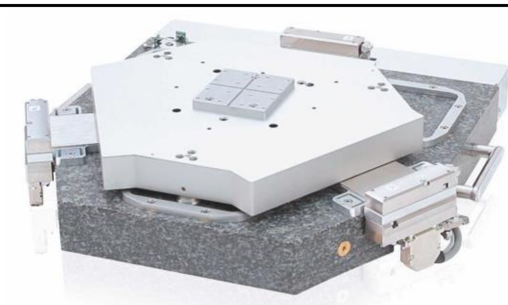
https://www.digikey.com

Flexible Magnetic Actuators



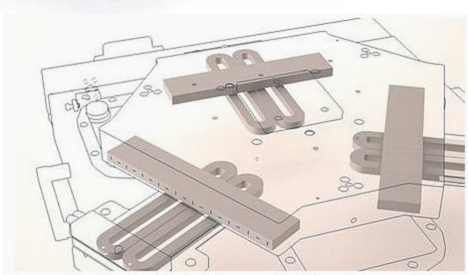


F. Pece et al., MagTics: Flexible and Thin Form Factor Magnetic Actuators for Dynamic and Wearable Haptic Feedback, UIST 2017, Oct. 22–25, 2017, Québec City, Canada

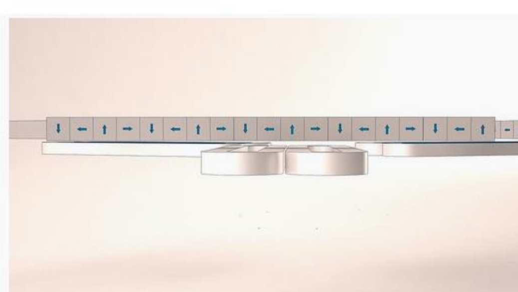


Robotics Actuators

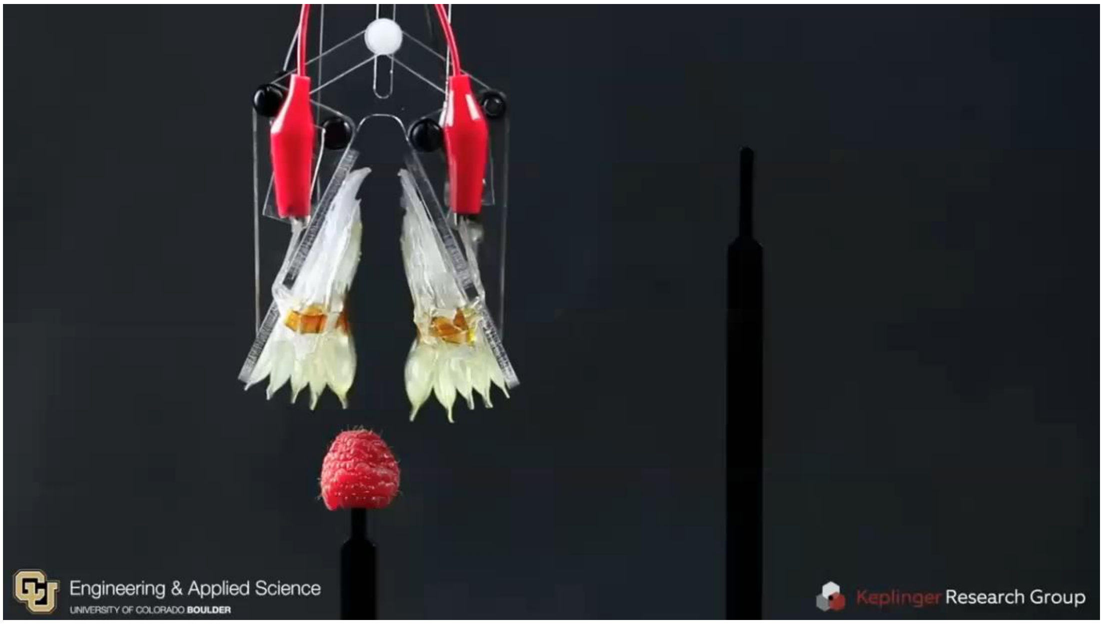
- 6D Magnetic Control
- https://www.pi-usa.us
- pimag-6d-magnetic-levitation



Simple structure: The platform levitates on a magnetic field generated by only six planar coils in the stator



The Halbach arrangement of the magnets makes it possible, to minimize the energy required by the active coils in the stator for carrying the platform, to increase the load carrying capacity and to reduce thermal load



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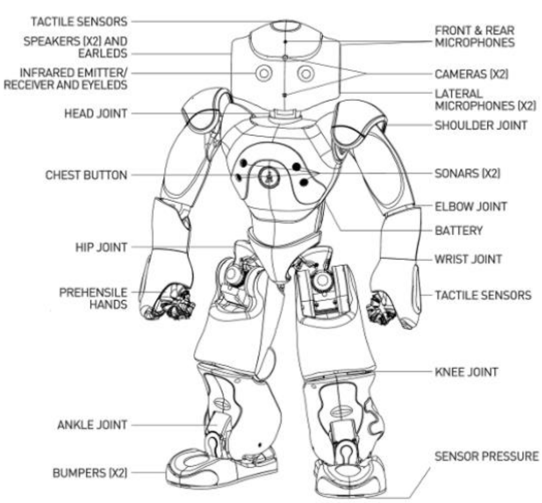
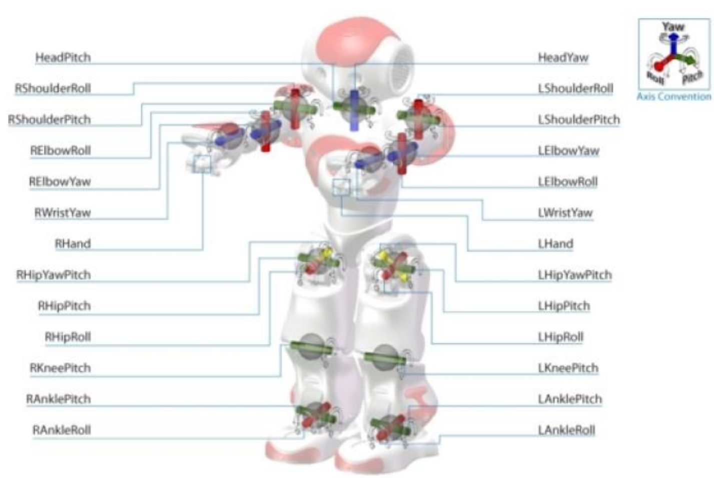
NAO





http://doc.aldebaran.com/2-1/family/nao_dcm/actuator_sensor_names.html

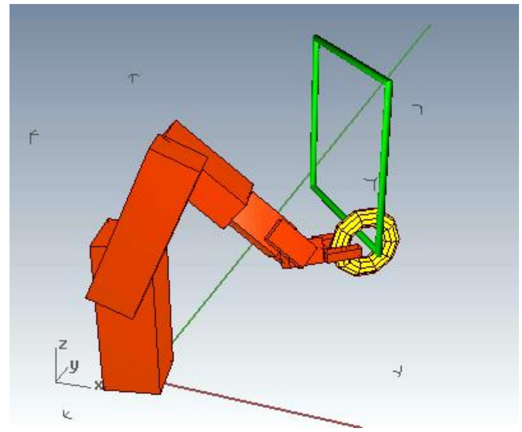
How to move to a goal?

Problem: How to move to a goal?

- Grasp, Walk, Stand, Dance, Follow, etc.

Solution:

1. *Program step by step*
   - *Computer Numerical Control (CNC), Automation.*
2. *Inverse kinematics*:
   - take end-points and move them to designated points.
3. *Tracing movements*
   - by specialist, human, etc.
4. ***Learn the right movements***
   - **Reinforcement Learning**, give a reward when the movement resembles the designated movement.



https://pybullet.org/wordpress/

Configuration Space

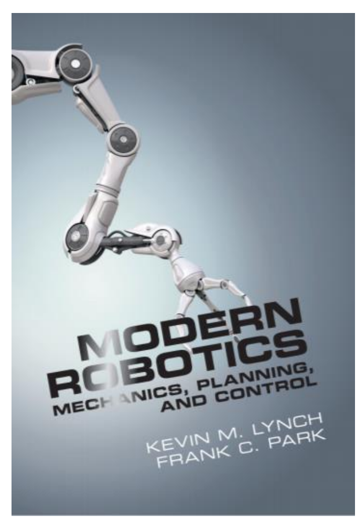
Robot Question: Where am I?

Answer:

The robot's configuration: a specification of the positions of all points of a robot.

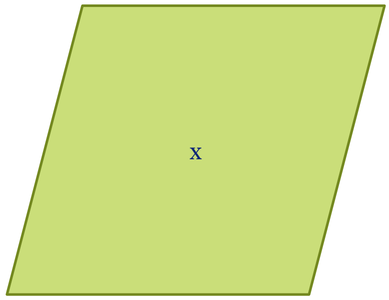
Here we assume:

Robot links and bodies are rigid and of known shape => only a few variables needed to describe it's configuration.



K.M. Lynch, F.C. Park, Modern Robotics: Mechanics, Planning and Control, Cambridge University Press, 2017

Configuration Space



- Degrees of Freedom of a Rigid Body: the smallest number of real-valued coordinates needed to represent its configuration

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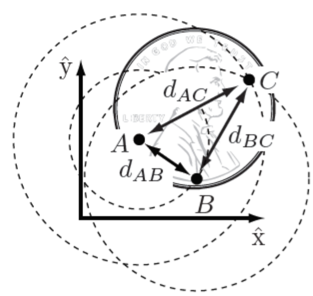
Configuration Space



Assume we have a coin with 3 points A, B, C on it.

In the plane A,B,C have 6 degrees of freedom:
(x_A,y_A) , (x_B,y_B) , (x_C,y_C)
A coin is rigid => 3 extra constraints on distances: ***d_{AB}, d_{AC}, d_{BC}***
are fixed, wherever the location of the coin would be.

1. The coin and hence A can be placed everywhere => (x_A,y_A) free to choose.
2. B can only be placed under the constraint that its distance to A would be equal to d_{AB}. =>
   freedom to turn the coin around A with angle φ_{AB} => (x_A, y_A, φ_{AB}) are free to choose.
3. C should be placed at distance d_{AC}, d_{BC} from A and B, respectively => only 1 possibility, hence no degree of freedom added.

Degrees of Freedom (DOF) of a Coin
= sum of freedoms of the points – number of independent constraints
= number of variables – number of independent equations = 6 – 3 = 3

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Configuration Space

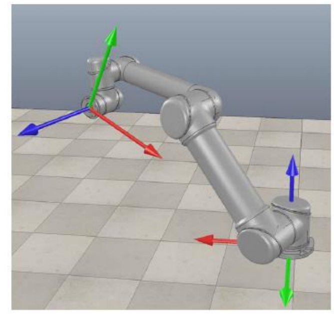
[1] Definition 2.1.

The **configuration** of a robot is a complete specification of the position of every point of the robot.

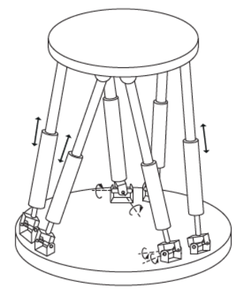
The minimum number n of real-valued coordinates needed to represent the configuration is the number of **degrees of freedom (dof)** of the robot.

The n-dimensional space containing all possible configurations of the robot is called the **Configuration Space (C-space)**.

The configuration of a robot is represented by a point in its C-space.



Open-chain robot: Manipulator (in V-REP). [1]



Closed-chain robot: Stewart-Gough platform. [1]

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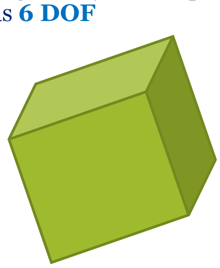
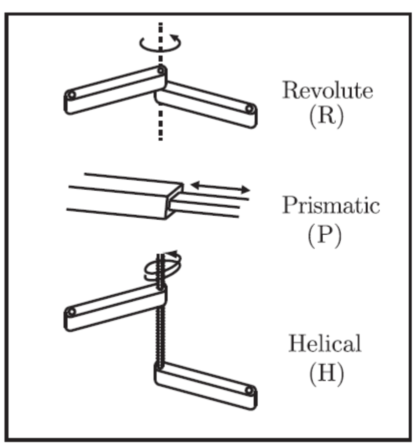
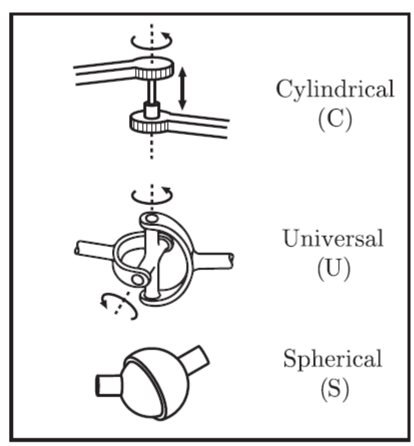
Degrees of Freedom of a Robot

- A rigid body in 3D Space has **6 DOF**



- A joint can be seen to put constraints on the rigid bodies it connects
- It also allows freedom to move relative to the body it is attached to.





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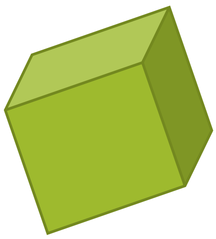
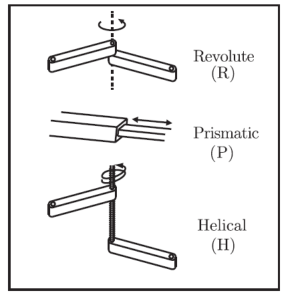
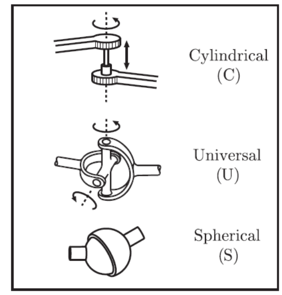
Degrees of Freedom of a Robot

- A **rigid body** in 3D Space has 6 DOF



- A **joint** can be seen to put constraints on the rigid bodies it connects
- It also allows freedom to move relative to the body it is attached to.





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

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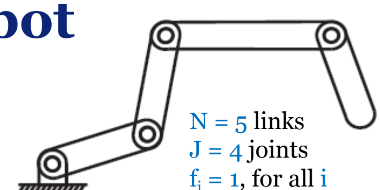
Degrees of Freedom of a Robot

Planar Mechanism DOF = 4



N = 5 links
J = 4 joints
f_i = 1, for all i
c_i=2, for all i

Proposition (Grübler's formula)

Consider a mechanism consisting of

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

Then *Grübler's formula* for the number of degrees of freedom of the robot is

$$dof = m(N-1) - \sum_{i=1}^{J} c_i = m(N-1-J) + \sum_{i=1}^{J} f_i$$

This formula holds only if all joint constraints are independent. If they are not independent then the formula provides a lower bound on the number of degrees of freedom.

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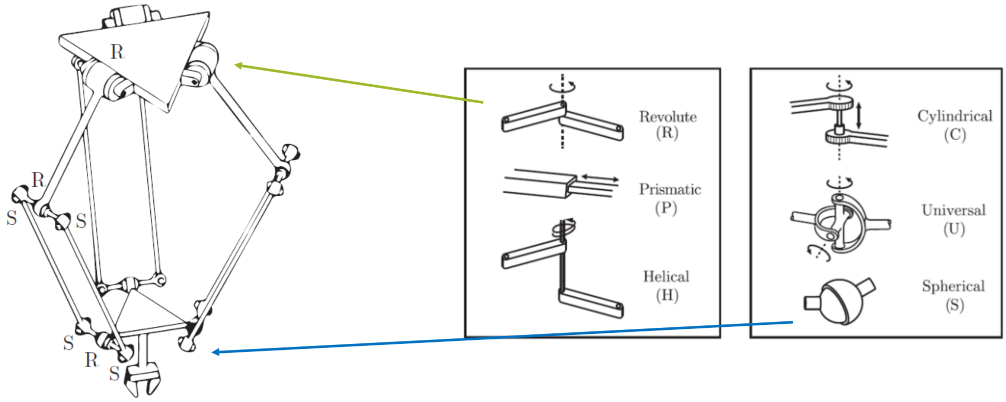

Figure 2.8: The Delta robot.

Example 2.7 (Delta robot). The Delta robot of Figure 2.8 consists of two platforms – the lower one mobile, the upper one stationary – connected by three legs. Each leg contains a parallelogram closed chain and consists of three revolute joints, four spherical joints, and five links. Adding the two platforms, there are $N = 17$ links and $J = 21$ joints (nine revolute and 12 spherical). By Grübler's formula,

$$\text{dof} = 6(17 - 1 - 21) + 9(1) + 12(3) = 15.$$

- Links: 1 + 3 + 3 + 6 + 3 + 1 = 17
- Joints: 21: 9x R(1 dof) and 12 x S(3 dof)
- m= 6

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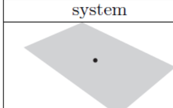
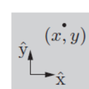
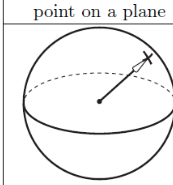
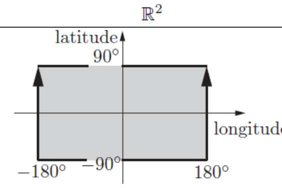
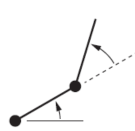
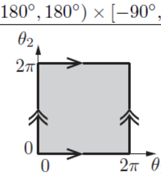
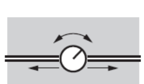
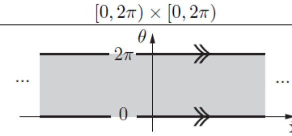
Topologies

Note: $S^1 \times S^1 = T^2$ (not S^2)

Coordinates

Explicit Coordinates
- Euclidean (x,y)
- Polar (r,φ)
- Combined (x,y) x (r, φ)

Implicit Coordinates
- { (x,y,z) | $x^2+y^2+z^2=1$ }

system	topology	sample representation
 point on a plane	 $\mathbb{E}^2$	 $\mathbb{R}^2$
 spherical pendulum	 S^2	 $[-180°, 180°) \times [-90°, 90°]$
 2R robot arm	 $T^2 = S^1 \times S^1$	 $[0, 2\pi) \times [0, 2\pi)$
 rotating sliding knob	 $\mathbb{E}^1 \times S^1$	 $\mathbb{R}^1 \times [0, 2\pi)$

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C-Space (Configuration Space)

How to describe a rigid body's position and orientation in C-Space?

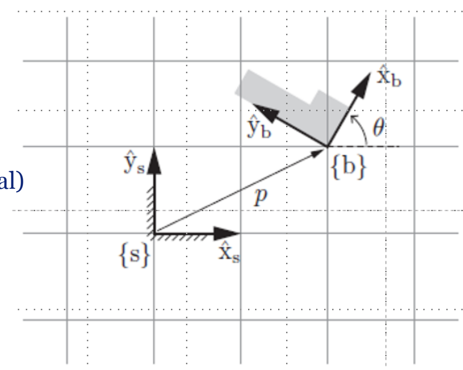
Fixed reference frame {s}

Reference fame attached to body {b}

Described by 4x4 matrix with 10 constraints (unit-length, orthogonal)

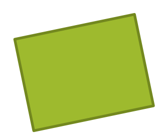
Matrix can be used to:

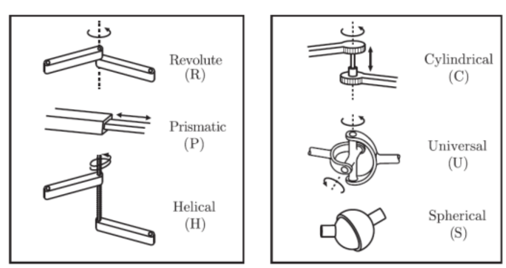
1. Translate or rotate a vector or a frame
2. Change the representation of a vector or a frame
   - for example from relative to {s} to relative to {b}

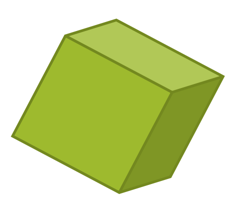


C-Spaces

- The C-space of a rigid body in the plane can be written as $\mathbb{R}^2 \times S^1$, since the configuration can be represented as the concatenation of the coordinates (x, y) representing $\mathbb{R}^2$ and an angle θ representing S^1.
- The C-space of a PR robot arm can be written $\mathbb{R}^1 \times S^1$. (We will occasionally ignore joint limits, i.e., bounds on the travel of the joints, when expressing the topology of the C-space; with joint limits, the C-space is the Cartesian product of two closed intervals of the line.)
- The C-space of a 2R robot arm can be written $S^1 \times S^1 = T^2$, where T^n is the n-dimensional surface of a torus in an $(n+1)$-dimensional space. (See Table 2.2.) Note that $S^1 \times S^1 \times \cdots \times S^1$ (n copies of S^1) is equal to T^n, not S^n; for example, a sphere S^2 is not topologically equivalent to a torus T^2.
- The C-space of a planar rigid body (e.g., the chassis of a mobile robot) with a 2R robot arm can be written as $\mathbb{R}^2 \times S^1 \times T^2 = \mathbb{R}^2 \times T^3$.
- As we saw in Section 2.1 when we counted the degrees of freedom of a rigid body in three dimensions, the configuration of a rigid body can be described by a point in $\mathbb{R}^3$, plus a point on a two-dimensional sphere S^2, plus a point on a one-dimensional circle S^1, giving a total C-space of $\mathbb{R}^3 \times S^2 \times S^1$.







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Task Space and Work Space

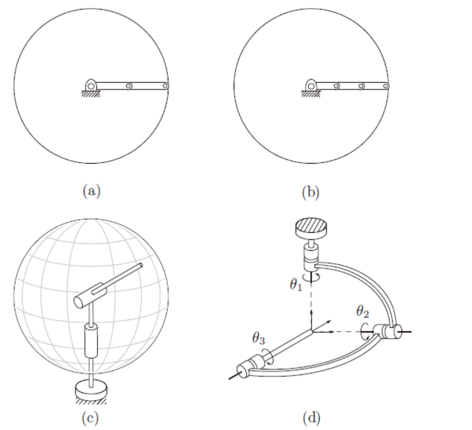
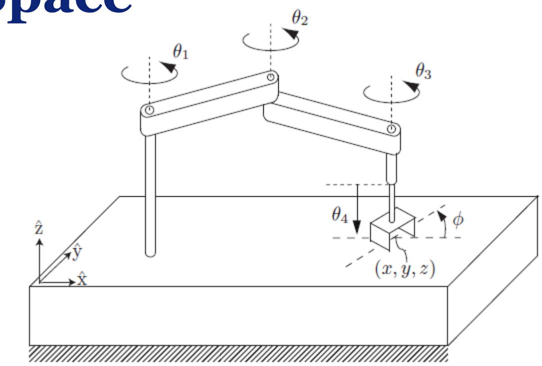


Figure 2.12: Examples of workspaces for various robots: (a) a planar 2R open chain; (b) a planar 3R open chain; (c) a spherical 2R open chain; (d) a 3R orienting mechanism.

The **workspace** is a specification of the configurations that the end-effector of the robot can reach.



The SCARA robot is an RRRP open chain that is widely used for tabletop pick-and-place tasks. The end-effector configuration is completely described by (x, y, z, φ)

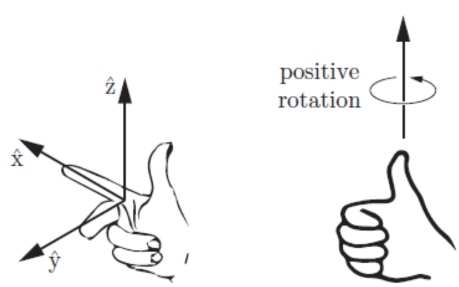
⇒ **task space** $R^3 \times S^1$ and

⇒ **workspace** as the reachable points in (x, y, z), since all orientations φ can be achieved at all reachable points.

Rigid Body Motion

Rigid-body position and orientation (x, y, z, φ, θ, ψ)

- Can also be described by 4x4 matrix with 10 constraints.
- In general 4x4 matrices can be used for
  - Location
  - Translation + rotation of a vector or frame
  - Transformation of coordinates between frames

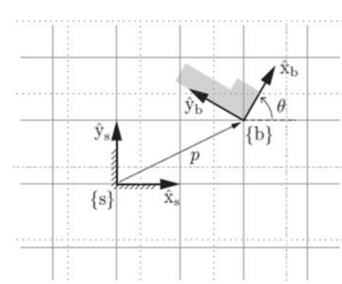


- Velocity of a rigid body: $(\partial x/\partial t,\ \partial y/\partial t,\ \partial z/\partial t,\ \partial \phi/\partial t,\ \partial \theta/\partial t,\ \partial \psi/\partial t)$

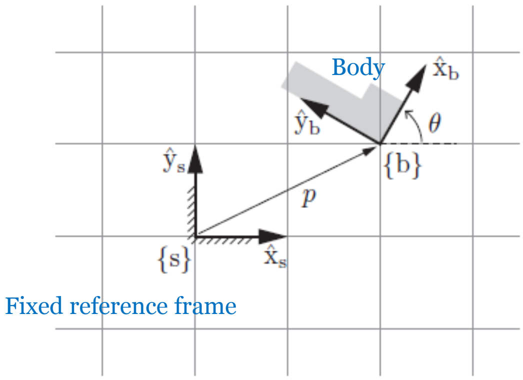
Exponential coordinates:

Every rigid-body configuration can be achieved by:

- Starting in the fixed home frame and integrating a constant twist for a specified time.
- Direction of a screw axis and scalar to indicate how far the screw axis must be followed



Rigid Body Motions in the Plane



$$p = p_x \hat{x}_s + p_y \hat{y}_s.$$

$$\hat{x}_b = \cos\theta\, \hat{x}_s + \sin\theta\, \hat{y}_s,$$
$$\hat{y}_b = -\sin\theta\, \hat{x}_s + \cos\theta\, \hat{y}_s.$$

Figure 3.3: The body frame {b} is expressed in the fixed-frame coordinates {s} by the vector p and the directions of the unit axes $\hat{x}_b$ and $\hat{y}_b$. In this example, $p = (2, 1)$ and $\theta = 60°$, so $\hat{x}_b = (\cos\theta, \sin\theta) = (0.5, 1/\sqrt{2})$ and $\hat{y}_b = (-\sin\theta, \cos\theta) = (-1/\sqrt{2}, 0.5)$.

Rigid Body Motions in the Plane

Previously:

$$p = p_x \hat{x}_s + p_y \hat{y}_s.$$

$$\hat{x}_b = \cos\theta\, \hat{x}_s + \sin\theta\, \hat{y}_s,$$
$$\hat{y}_b = -\sin\theta\, \hat{x}_s + \cos\theta\, \hat{y}_s.$$

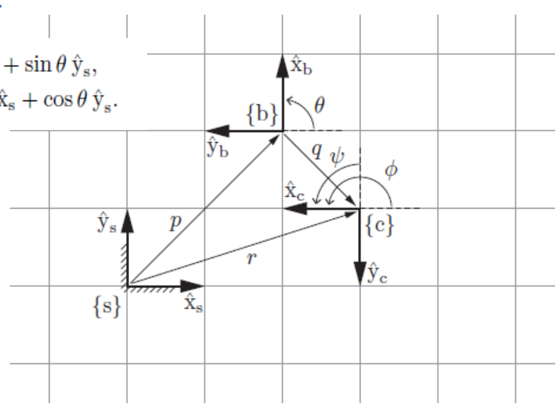


Figure 3.4: The frame {b} in {s} is given by (P, p), and the frame {c} in {b} is given by (Q, q). From these we can derive the frame {c} in {s}, described by (R, r). The numerical values of the vectors p, q, and r and the coordinate-axis directions of the three frames are evident from the grid of unit squares.

{b} relative to {s}

$$p = \begin{bmatrix} p_x \\ p_y \end{bmatrix}$$

$$P = [\hat{x}_b\ \ \hat{y}_b] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

{c} relative to {s}

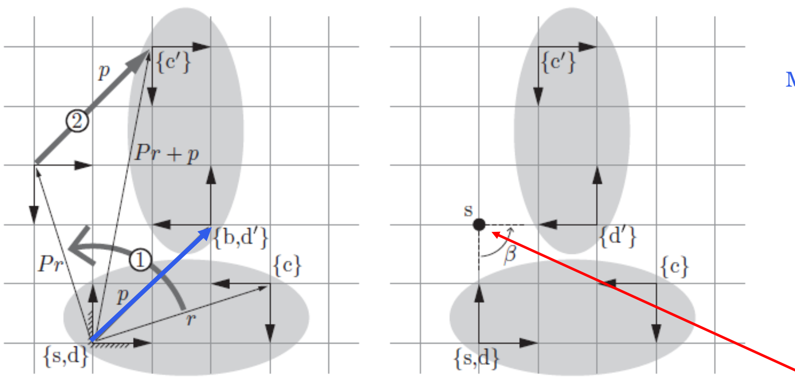
$$r = \begin{bmatrix} r_x \\ r_y \end{bmatrix}, \qquad R = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix}$$

{c} relative to {b}

$$q = \begin{bmatrix} q_x \\ q_y \end{bmatrix}, \qquad Q = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix}$$

Note and verify: R = PQ, and r = Pq+p

Rigid Body Motions in the Plane



(a) (b)

{c} described by (R,r)

$$r = \begin{bmatrix} r_x \\ r_y \end{bmatrix}, \qquad R = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix}$$

Move rigid body such that {d} coincides with {d'}.

$$p = \begin{bmatrix} p_x \\ p_y \end{bmatrix} \qquad P = [\hat{x}_b \ \ \hat{y}_b] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

Then {c'} described by (R',r'):

$$R' = PR,$$
$$r' = Pr + p,$$

(P, p) can be used to

1. Represent a configuration of a rigid body in {s}
2. Change the reference frame for vector representation.
3. **Displace a vector or a frame.**

Note: SCREW MOTION
The above rotation followed by a translation can also be expressed as a rotation of the rigid-body about a fixed point s by an angle β

Rigid Body Motions in the Plane

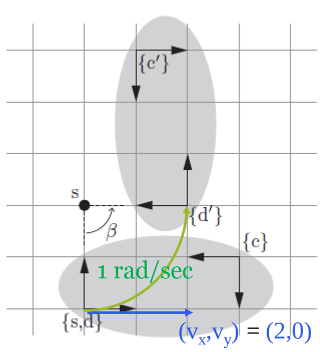
Note: SCREW MOTION
The above rotation followed by a translation can also be expressed as a rotation of the rigid-body about a fixed point s by an angle β

(β, s_x, s_y) , where $(s_x, s_y) = (0, 2)$

In the {s}-frame rotate 1 rad/sec with speed $(v_x, v_y) = (2, 0)$ is denoted as:
$S = (\omega, v_x, v_y) = (1, 2, 0)$

Following the screw-axis for an angle $\theta = \pi/2$ gives the displacement we want:
$S\theta = (\pi/2, \pi, 0)$

These are called the **exponential coordinates** for the planar rigid-body displacement.



{c} described by (R,r)

$$r = \begin{bmatrix} r_x \\ r_y \end{bmatrix}, \qquad R = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix}$$

Move rigid body such that {d} coincides with {d'}.

$$p = \begin{bmatrix} p_x \\ p_y \end{bmatrix} \qquad P = [\hat{x}_b \ \ \hat{y}_b] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

Then {c'} described by (R',r'):

$$R' = PR,$$
$$r' = Pr + p,$$

Note:
- distance = vt
- distance along quarter circle with radius 2 equals π.

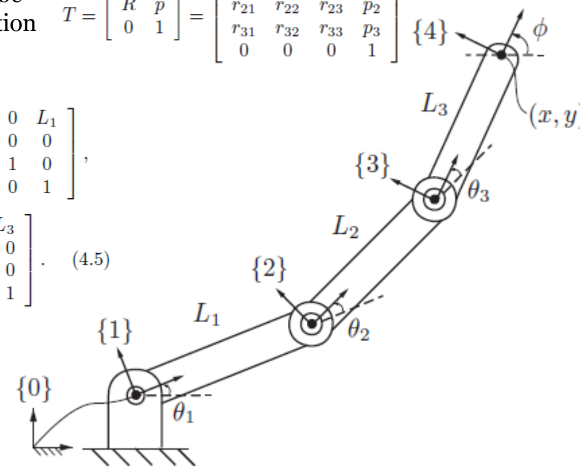
Forward Kinematics

The forward kinematics of 3R Planar Open Chain can be written as a product of four homogeneous transformation matrices: $T_{04} = T_{01}T_{12}T_{23}T_{34}$, where

$$T = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_1 \\ r_{21} & r_{22} & r_{23} & p_2 \\ r_{31} & r_{32} & r_{33} & p_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{01} = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad T_{12} = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & L_1 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$T_{23} = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & L_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad T_{34} = \begin{bmatrix} 1 & 0 & 0 & L_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (4.5)$$



Home position M:

$$M = \begin{bmatrix} 1 & 0 & 0 & L_1 + L_2 + L_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Forward Kinematics: Product of Exponentials

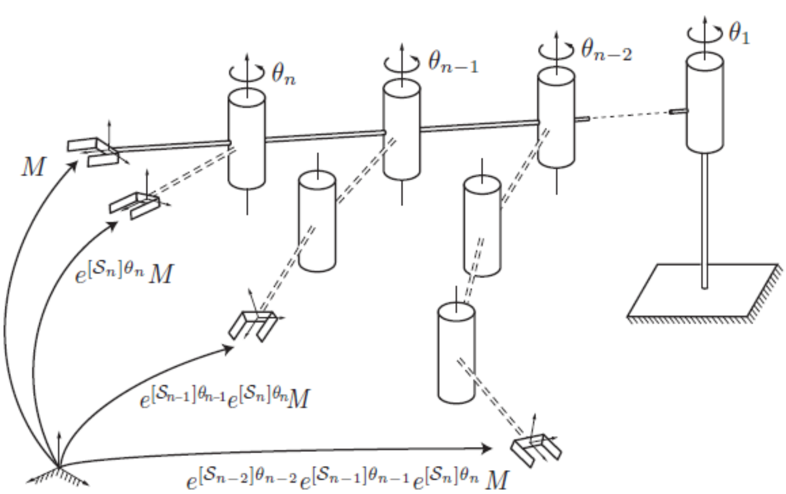


Figure 4.2: Illustration of the PoE formula for an n-link spatial open chain.

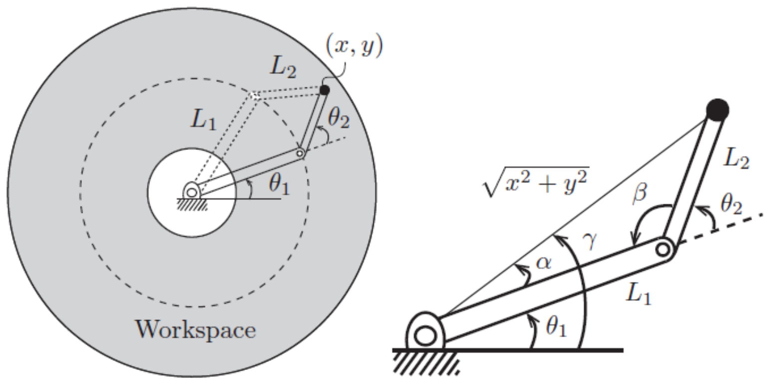
PoE parameters also known as Euler-Rodrigues parameters.

There are many other representations:
- for example Denavit-Hartenberg (1955) representation is very popular, but can be cumbersome

In velocity kinematics Jacobians are used.

Inverse Kinematics

Which angles θ_1, and θ_1 will lead to location (x,y)?



(a) A workspace, and lefty and righty configurations.

(b) Geometric solution.

Figure 6.1: Inverse kinematics of a 2R planar open chain.

Law of cosines gives:

$$L_1^2 + L_2^2 - 2L_1L_2\cos\beta = x^2 + y^2$$

, hence

$$\beta = \cos^{-1}\left(\frac{L_1^2 + L_2^2 - x^2 - y^2}{2L_1L_2}\right)$$

,and similarly

$$\alpha = \cos^{-1}\left(\frac{x^2 + y^2 + L_1^2 - L_2^2}{2L_1\sqrt{x^2+y^2}}\right)$$

γ= atan2(y,x)

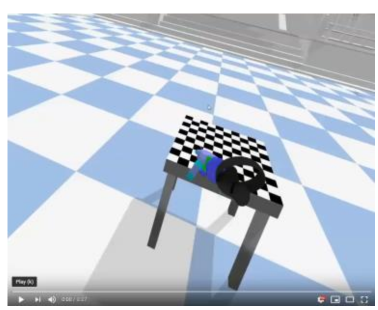
Answer:

$$\theta_1 = \gamma - \alpha, \qquad \theta_2 = \pi - \beta$$

In general: IK-Solvers

Real Time Physics Modelling

https://pybullet.org/wordpress/



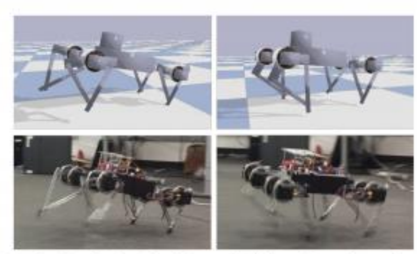
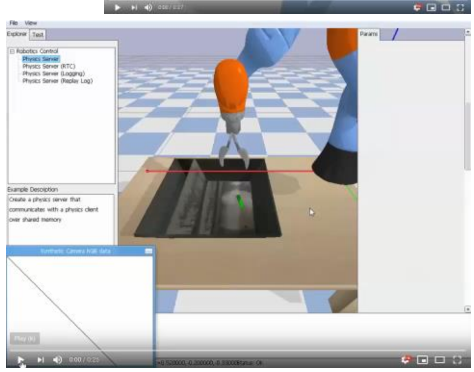
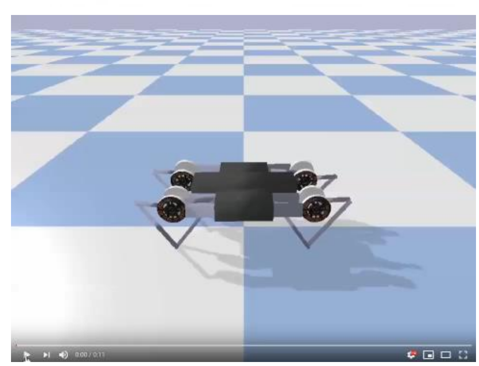


Fig. 1: The simulated and the real Minitaurs learned to gallop using deep reinforcement learning.

pybullet KUKA grasp training

Using Tensorflow
OpenAI gym
Baselines
DeepQNetworks (DQNs)





Robotics Homework I

Assignment:

Give a link to the coolest, strangest, most impressive, most novel, or technologically inspirational robot you could find.

Due: Monday 10-2 at 14.00 PM.

Email your link to erwin@liacs.nl with subject 'Robotics'.

Robotics Homework II

Assignment:

Visit http://modernrobotics.org and obtain the pdf of the book.

Read Chapters 1 and 2 and answer the following exercises:

- 2.7
- 2.9 for Figures 1.18 d, e, and f
- 2.17 a) and b).

Due: Thursday 28-2 at 14.00 PM.

Email your answers to erwin@liacs.nl with subject 'Robotics HW2'.

Robotics Preparations

1) Form YetiBorg Racing Teams of 3 to 4 people
Appoint one person who will be responsible for the robot.

Email your teams to erwin@liacs.nl with subject 'Robotics YetiBorg Racing Team'.
Due: Thursday 7-3 at 14.00 PM.

2) **Project Proposal Title and Abstract**
Give the title and abstract of the project proposal you will present on March 15th.
Also mention the number of people that will cooperate on the project (1-4).

Email your proposal to erwin@liacs.nl with subject 'Robotics Project Proposal'.
Due: Thursday 7-3 at 14.00 PM.

References

1. K.M. Lynch, F.C. Park, Modern Robotics: Mechanics, Planning and Control, Cambridge University Press, 2017. (DOI: 10.1017/9781316661239)
2. https://pybullet.org/wordpress/

Robotics

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Robotics in the News

- Jimmy Drogtrop: https://www.youtube.com/watch?v=sqOPnPVTJ74, https://www.youtube.com/watch?v=sKjAp0iZ7dc
- Sartana Fitra Amir, swarm robotics for agricultural application. http://laral.istc.cnr.it/saga/
- Chen Wang, https://www.youtube.com/watch?v=6vYA8L_r850
- Simon van Wageningen: spotmini from boston:
  https://www.youtube.com/watch?v=aFuA50H9uek
  https://www.youtube.com/watch?v=7rgFtkMiXms
- Cailin Dagg: Following are the "coolest" robots I found:
  - A bipedal robot that combines walking and flying to navigate:
    Article https://newatlas.com/leonardo-robot-walks-flies/58165/
  - A bio-inspired robot that navigates using polarised sunlight and step-counting :
    Article https://www.wired.com/story/a-6-legged-robot-stares-at-the-sky-to-navigate-like-a-desert-ant/
    Paper http://robotics.sciencemag.org/content/4/27/eaau0307
  - A robot built to examine the locomotion of early tetrapods:
    Article https://www.wired.com/story/a-crocodile-like-robot-helps-solve-a-300-million-year-mystery/
    Paper https://www.nature.com/articles/s41586-018-0851-2

  Online Simulator https://biorob2.epfl.ch/pages/Orobates_interactive/
- Giovanni Calore, https://www.youtube.com/watch?v=W1LWMk7JB80 . (SpotMini - Boston Dynamics)

Robotics in the News

- Mathé Hertogh: These two examples I found really cool:
  https://confluence.acfr.usyd.edu.au/display/AGPub/Our+Robots
  https://www.kickstarter.com/projects/rse/worlds-first-eco-robot-protecting-reefs-from-lionf/description
- Jeroen Rook:
  https://www.oreilly.com/ideas/building-structures-with-robot-swarms
  Broad applications for construction, but also within agriculture.
  https://sydney.edu.au/engineering/our-research/robotics-and-intelligent-systems/australian-centre-for-field-robotics/agriculture-and-the-environment.html
- Pedro Santamaria: In my opinion Sony's Aibo
  https://us.aibo.com/
- Maxime Casara: ABB robot:
  https://www.youtube.com/watch?v=SOESSCXGhFo

Robotics in the News

- Luca Ballan: 9 robots developed by Boston Dynamics
  https://www.youtube.com/watch?v=bRHG7YObDuU
- Sophie Hendrikse:
  - https://robots.ieee.org/robots/aibo2018/
  - http://news.mit.edu/2019/robot-jenga-0130
  - https://techcrunch.com/2016/05/31/robots-date-mate-and-procreate-3d-printed-offspring-in-robot-baby-project/
  - https://techcrunch.com/wp-content/uploads/2016/05/robot-baby-bgw-1.jpg?w=591
- Koen Putman Going to start with an obvious one, but the work of Simone Giertz is lovely:
  https://www.youtube.com/channel/UC3KEoMzNz8eYnwBC34RaKCQ/
  I will never forget the banana peel slip in the Spot Mini introduction.
  https://youtu.be/tf7IEVTDjng It's also just a really great robot.
  And I've always thought robot pets for companionship are interesting.
  https://www.bbc.com/news/av/technology-35321227/ They're not really there yet though.
  The more recent Anki Vector also has a sort of buddy role and personality. https://www.anki.com/en-us/vector
- Laurens Arp:
  - Biological 'nanobots', used for medical purposes:
    Research paper: https://www.nature.com/articles/nbt.4071
    Quick article: https://www.ft.com/content/57c9f432-de6d-11e7-a0d4-0944c5f49e46

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Robotics in the News

- Renaie Leveridge: https://wyss.harvard.edu/robotic-insect-walks-on-water/
- Abdullah Alsaubie: https://www.anki.com/en-us/vector/vector-helpful
- Roos Doekemeijer:
  - Toddler-like exploring and learning: https://www.youtube.com/watch?v=NOLAwD4ZTW0
  - Hive mind controlled by drone https://www.youtube.com/watch?v=i3ernrkZ91E
  - Just for fun: pancake-making machine: https://www.youtube.com/watch?v=W_gxLKSsSIE
- Reinis Nudiens: Boston Dynamics robots: https://www.youtube.com/watch?v=LikxFZZO2sk
- Micky Faasen:
  - The Djedi-robot for pyramids research:
  - https://www.euronews.com/2015/07/23/robot-tries-to-unlock-giza-pyramid-s-secrets https://www.newscientist.com/article/mg21028144-500-first-images-from-great-pyramids-chamber-of-secrets/
  - Another one: https://news.artnet.com/art-world/tiny-robot-egyptian-pyramids-1180052
- Alexander Mulkidzhanyan: https://www.youtube.com/watch?v=8t8fyiiQVZ0
- Mei Chen: Kengoro from Japan: https://www.youtube.com/watch?v=3FlzxKuqzUM
- L.M. Vos: https://www.youtube.com/watch?v=kHBcVlqpvZ8