ENGINEERING SYSTEMS: ROBOTICS

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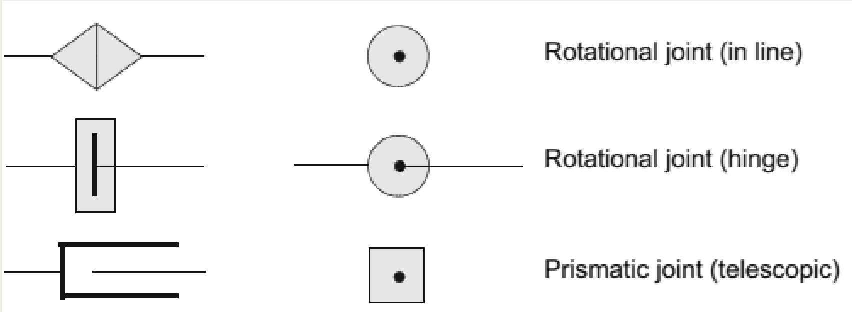
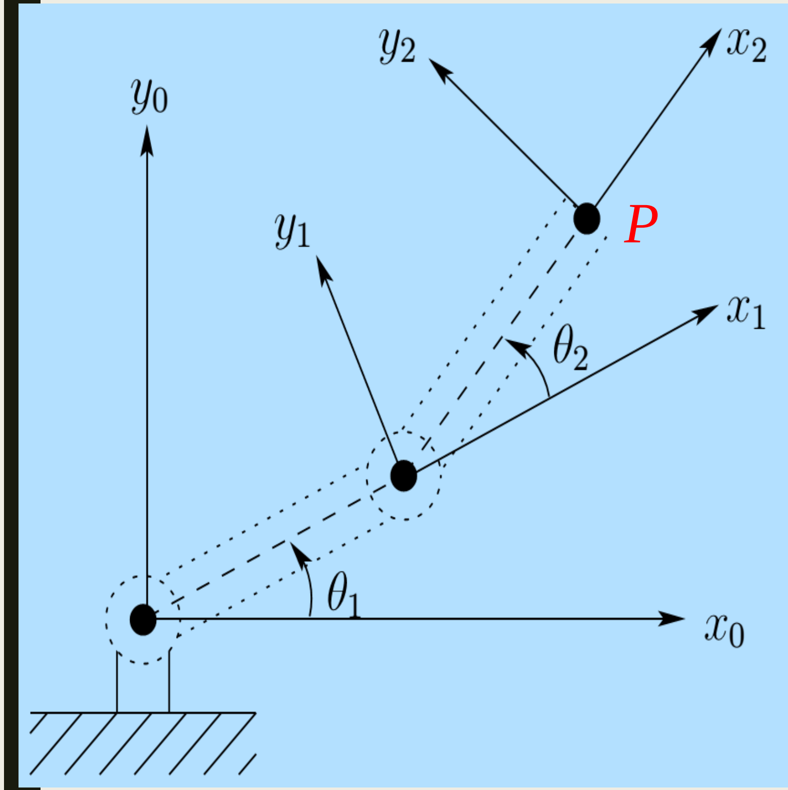
To perform the task, we need to know

- A parameterization of all positions
  - ***Initial position and orientation*** *of the object* (x_P, y_P, θ_P)
  - ***Final position and orientation*** *of the object* (x_G, y_G, θ_G)
- **Forward Kinematics:** the initial position (x_0, y_0, θ_0) of end-effector as a function of joint angles $(\theta_1, \theta_2, \dots)$
- **Inverse Kinematics:** angles $(\theta_1\ \theta_2, \dots)$ as functions of (x_P, y_P, θ_P) and (x_G, y_G, θ_G).
- Path and Trajectory

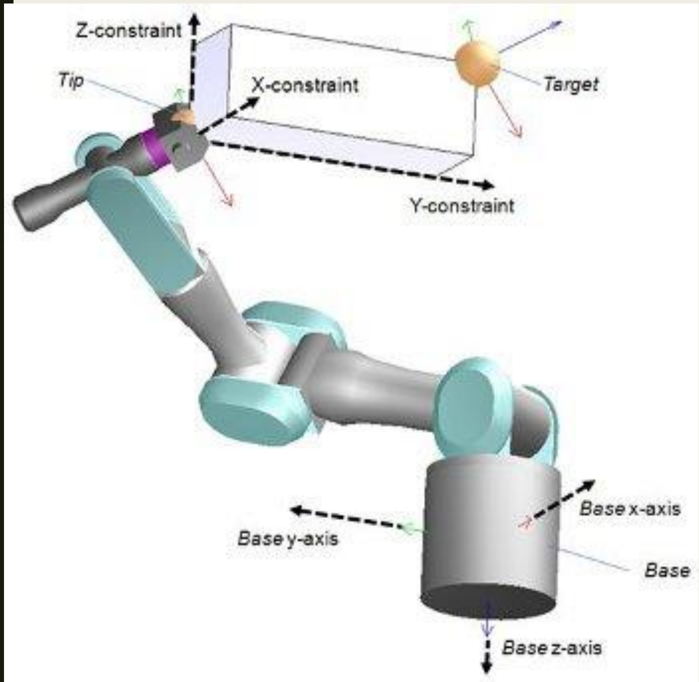


Forward Kinematics



- The orientation of the tool frame relative to the base frame is given by the direction cosines of the x_2 and y_2 axes relative to the x_0 and y_0 axes,
- Find $P_0 = \begin{bmatrix} p_{x0} \\ p_{y0} \end{bmatrix}$

Inverse Kinematics:



- If the tool position (x, y) is given, but the orientation is not defined, then, except particular cases, there are two configurations: Elbow Up and Elbow Down.

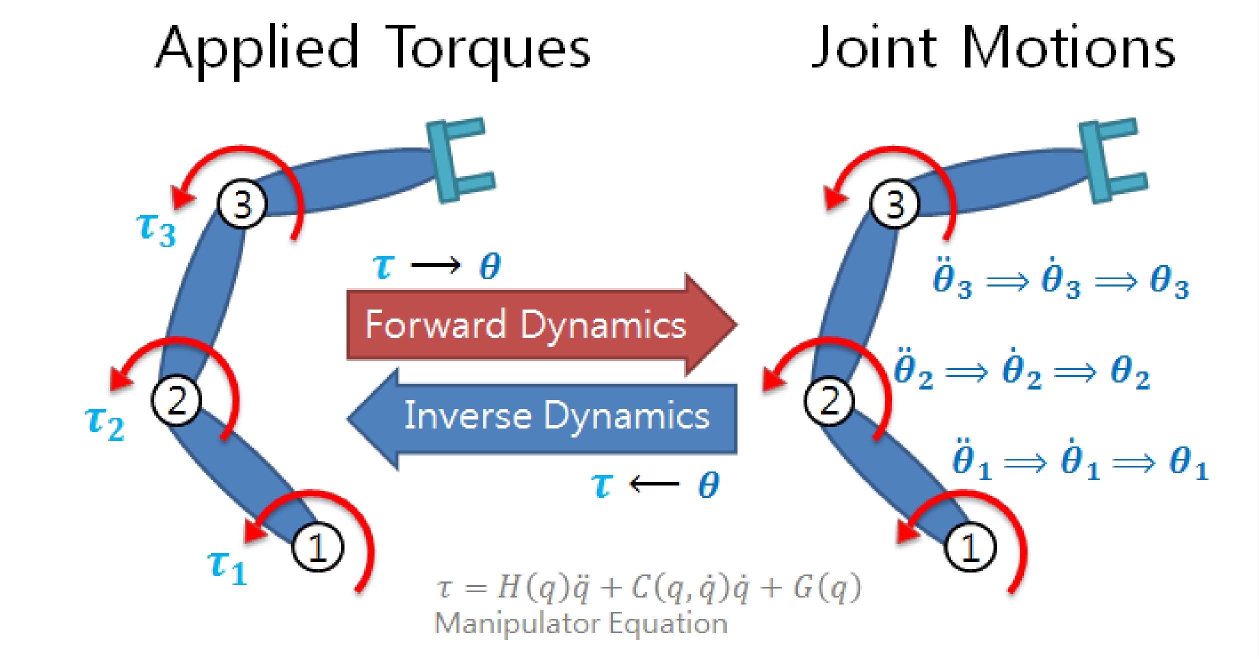
Velocity Kinematics:

- Geometrical relations between the tool velocity $(\dot{x}, \dot{y})$ and joint velocities $(\dot{\theta}_1, \dot{\theta}_2)$.
- $\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = J(\theta_1, \theta_2) \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$
- The matrix $J(\cdot)$ is called the Jacobian of the manipulator.
- Allows to compute the joint velocities $(\dot{\theta}_1, \dot{\theta}_2)$ to achieve the particular velocity of the tool!

Dynamics

- **Robot dynamics** is concerned with the relationship between the forces acting on a robot mechanism and the accelerations they produce.
- Typically, the robot mechanism is modelled as a rigid-body system, in which case robot dynamics is the application of rigid-body dynamics to robots.
- The two main problems in robot dynamics are:
  - ***Forward dynamics:*** *given the forces, work out the accelerations.*
  - ***Inverse dynamics:*** *given the accelerations, work out the forces.*

Dynamics



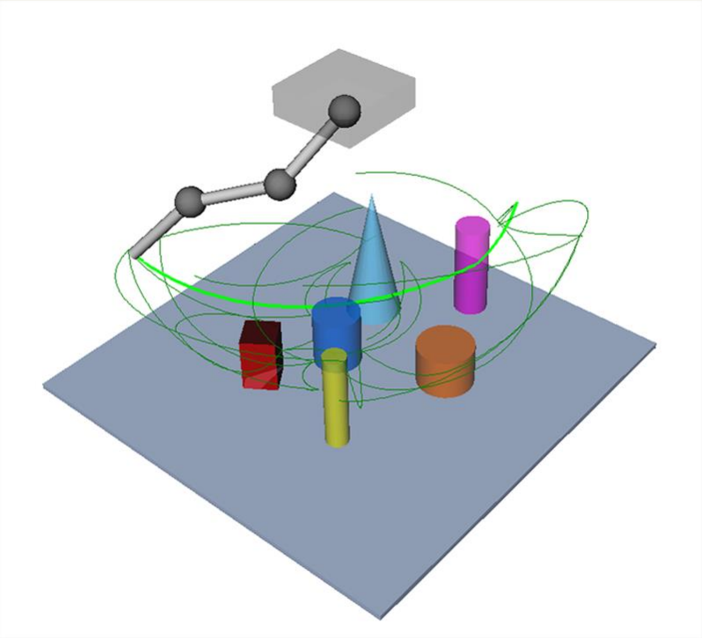
Applied Torques
Joint Motions
τ_3
τ_2
τ_1
3
2
1
$\tau \longrightarrow \theta$
Forward Dynamics
Inverse Dynamics
$\tau \longleftarrow \theta$
$\ddot{\theta}_3 \Longrightarrow \dot{\theta}_3 \Longrightarrow \theta_3$
$\ddot{\theta}_2 \Longrightarrow \dot{\theta}_2 \Longrightarrow \theta_2$
$\ddot{\theta}_1 \Longrightarrow \dot{\theta}_1 \Longrightarrow \theta_1$
$\tau = H(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q)$
Manipulator Equation

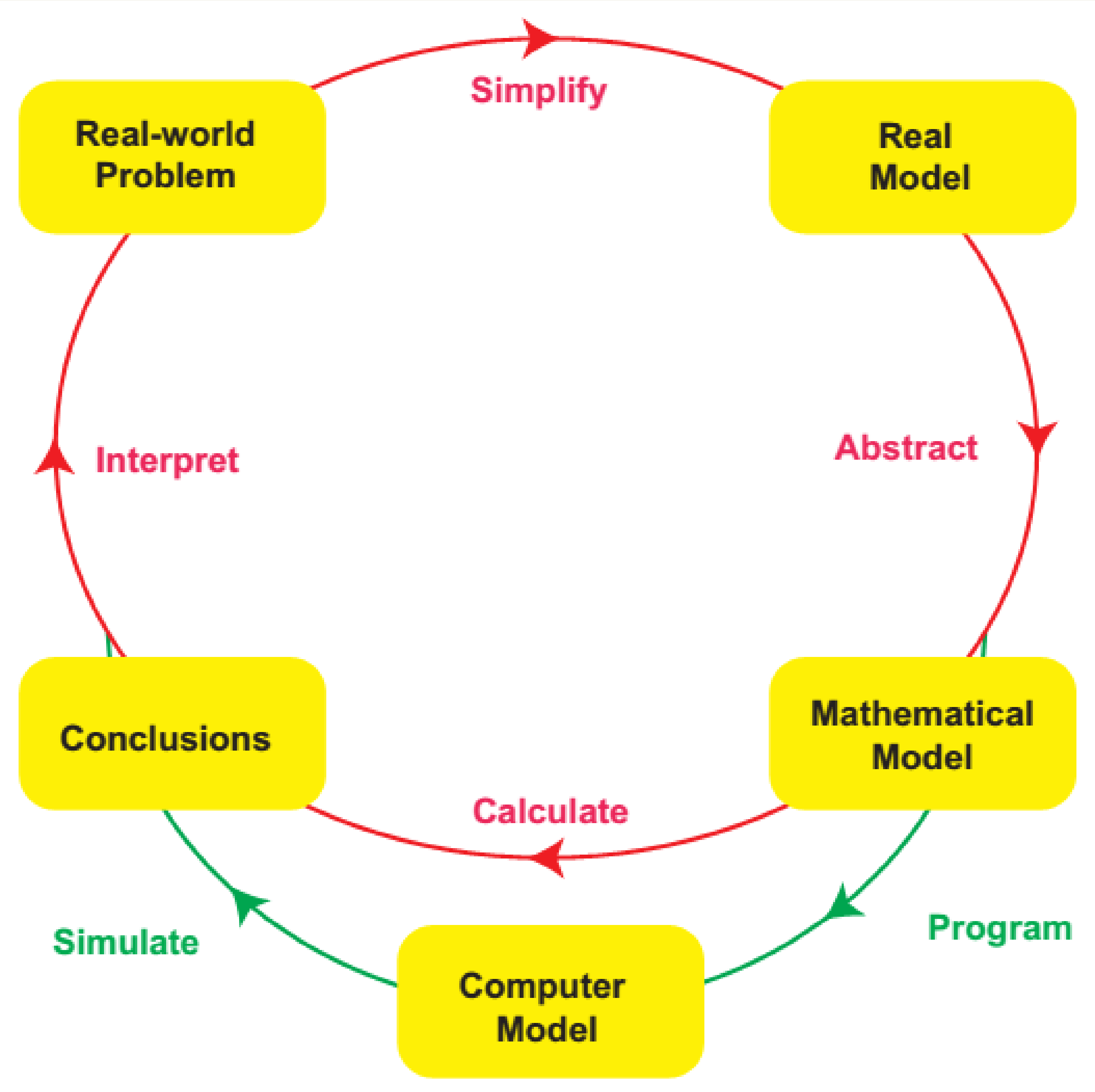
Path Planning and Trajectory Generation

- Path is a curve in the configuration space of the robot.
- Trajectory is the path augmented with the information on velocities how the system links will travel along the path.
- Planning trajectory might

include also specifications

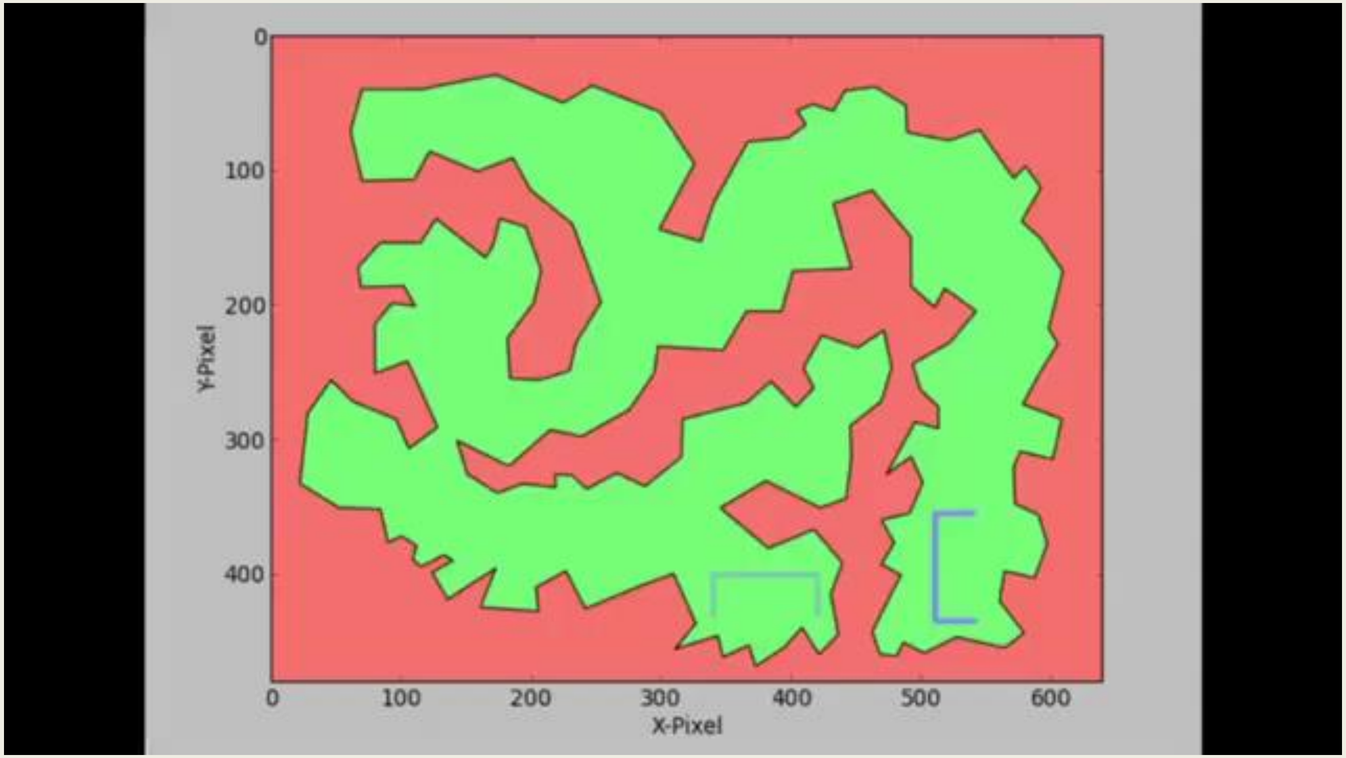
on accelerations.



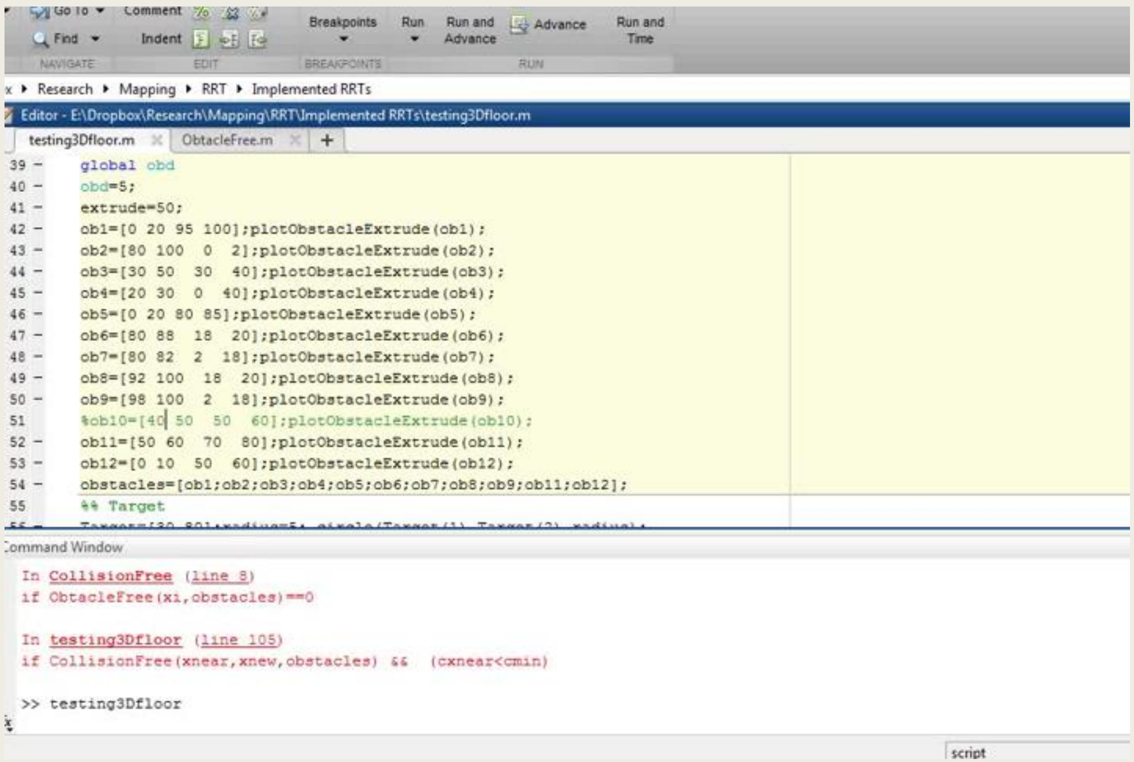


Simplify
Real-world Problem
Real Model
Abstract
Interpret
Conclusions
Mathematical Model
Calculate
Simulate
Program
Computer Model

Motion Planning

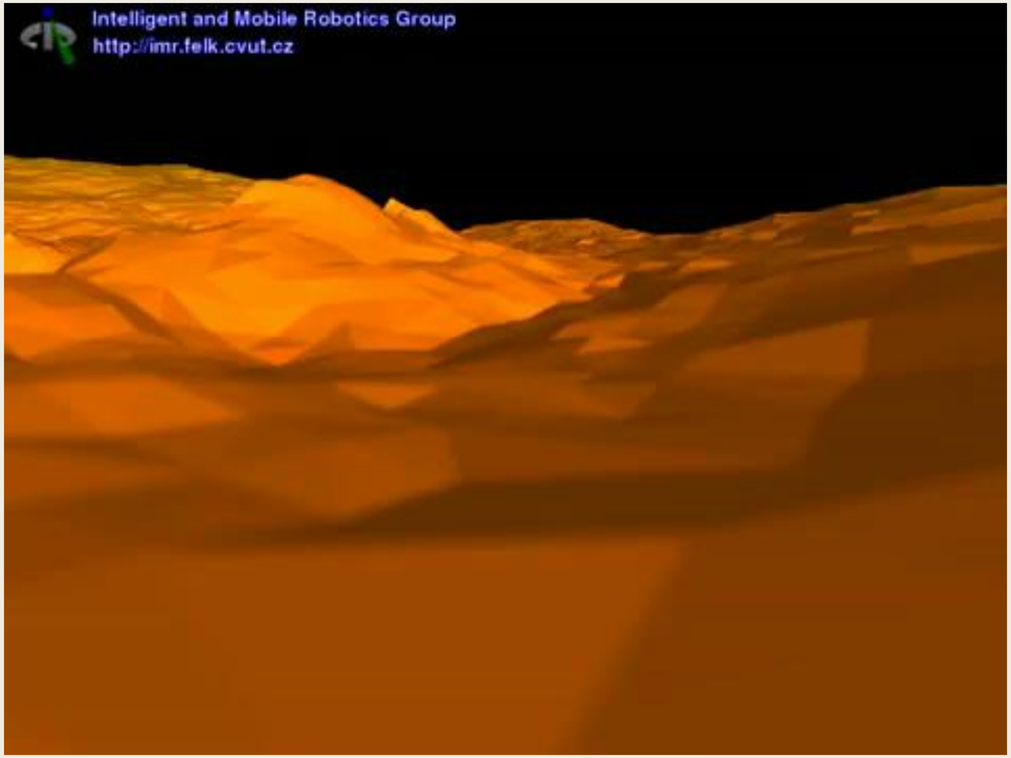


https://www.youtube.com/watch?v=UuZWCVxWAsI



https://www.youtube.com/watch?v=E-IUAL-D9SY

Motion Planning in 3D Terrain

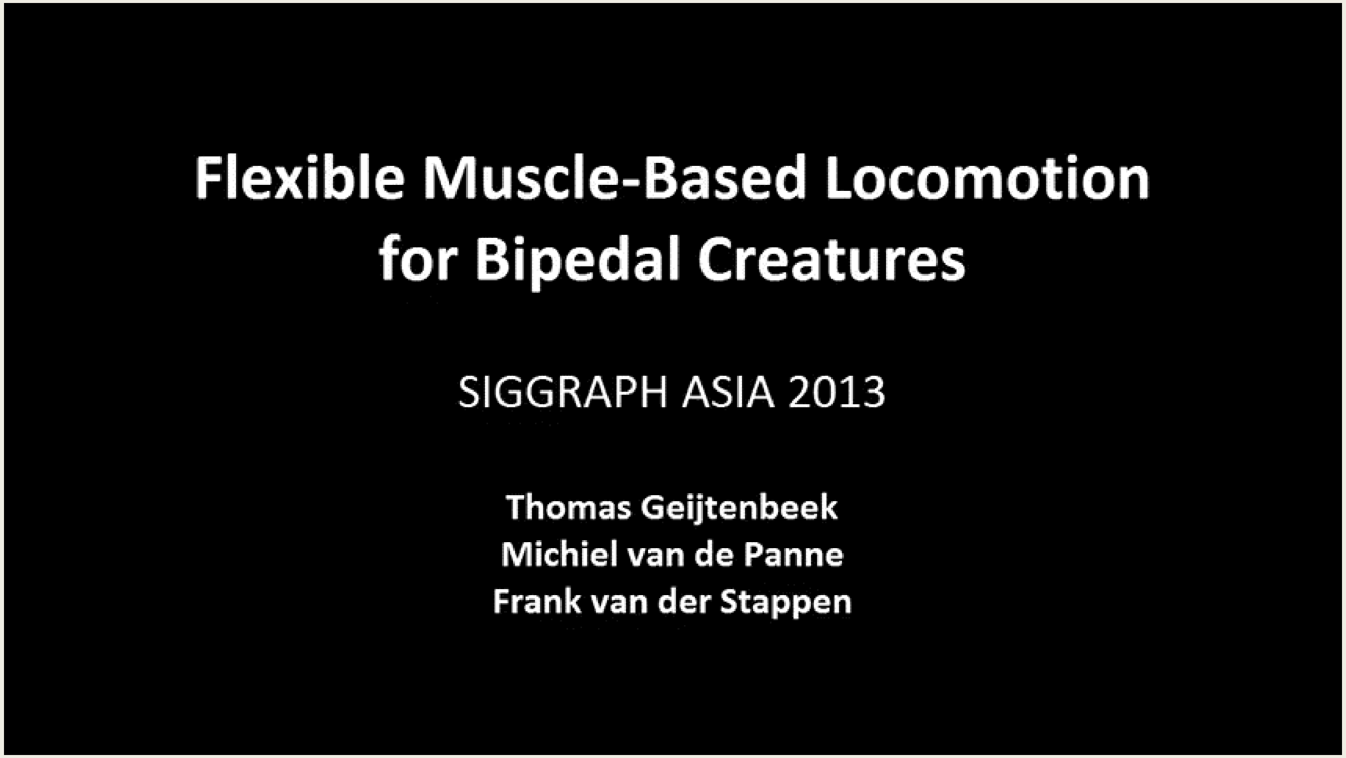


https://www.youtube.com/watch?v=TFtviVfdU0c

Intelligence

- **Intelligence** has been defined in many different ways including as one's capacity for **logic**, **understanding**, self-awareness, **learning**, emotional knowledge, reasoning, **planning**, creativity, and **problem solving.**
- It can be more generally described as the **ability to perceive or infer information**, and to **retain it as knowledge** to be applied towards adaptive behaviors within an environment or context.

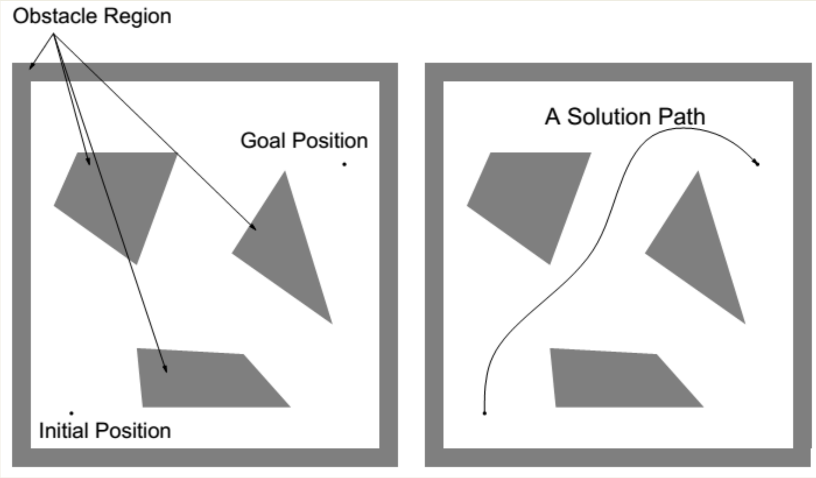
https://www.youtube.com/watch?v=zsXP8qeFF6A



https://www.youtube.com/watch?v=pgaEE27nsQw

Planning

- A fundamental need in robotics is to have algorithms that can automatically tell robots how to move when they are given high-level commands.
- Basic Ingredients of Planning
  - **State**: Planning problems will involve a state space that captures all possible situations that could exist.



- **Time**: All planning problems involve a sequence of decisions that must be applied over time.
- **Actions**: A plan generates actions that manipulate the state
- **Initial and goal states**: Planning generally involves starting in some initial state and trying to arrive at a specified goal state. The actions are selected in a way that causes this to happen.
- A **criterion**: This encodes the desired outcome in terms of state and actions that are executed.
  - **Feasibility**: whether the plan results in arriving at a goal state.
  - **Optimality**: Find feasible plans that optimize performance in some carefully specified manner, in addition to arriving in a goal state.
- A **plan**: In general, a plan will impose a specific strategy or behavior on decision makers. A plan might simply specify a sequence of actions to be taken; however, it may be more complicated.

Wheeled Mobile Robots

- Differentially Driven WMR
- Car-type WMRs
- Omnidirectional WMRs

- Types of Wheels

Standard

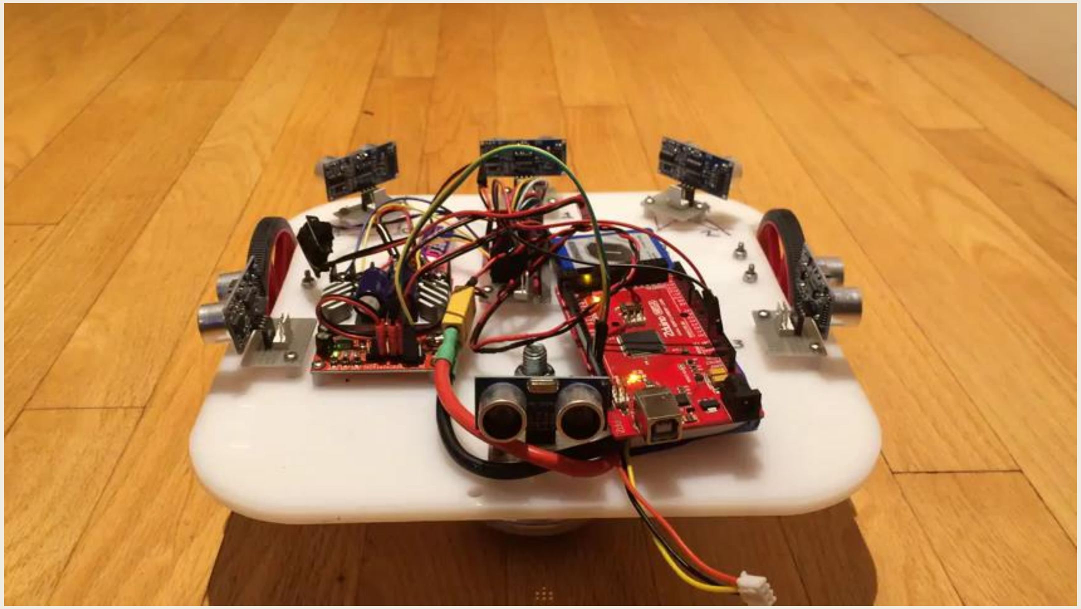
Castor

Swedish

Spherical

Differentially Driven WMR

- consists of two driving wheels and one or two castor wheels
- the relative motion of the two driving wheels with respect to each other achieves the required motion.
- The castor wheels are used just to support the structure.



https://www.youtube.com/watch?v=gFr6DormD2o

Car-type WMRs

- one (tricycle-drive) or two driven front wheels and two passive rear wheels (or vice versa)

https://www.youtube.com/watch?v=2Gwp-d_qz3U

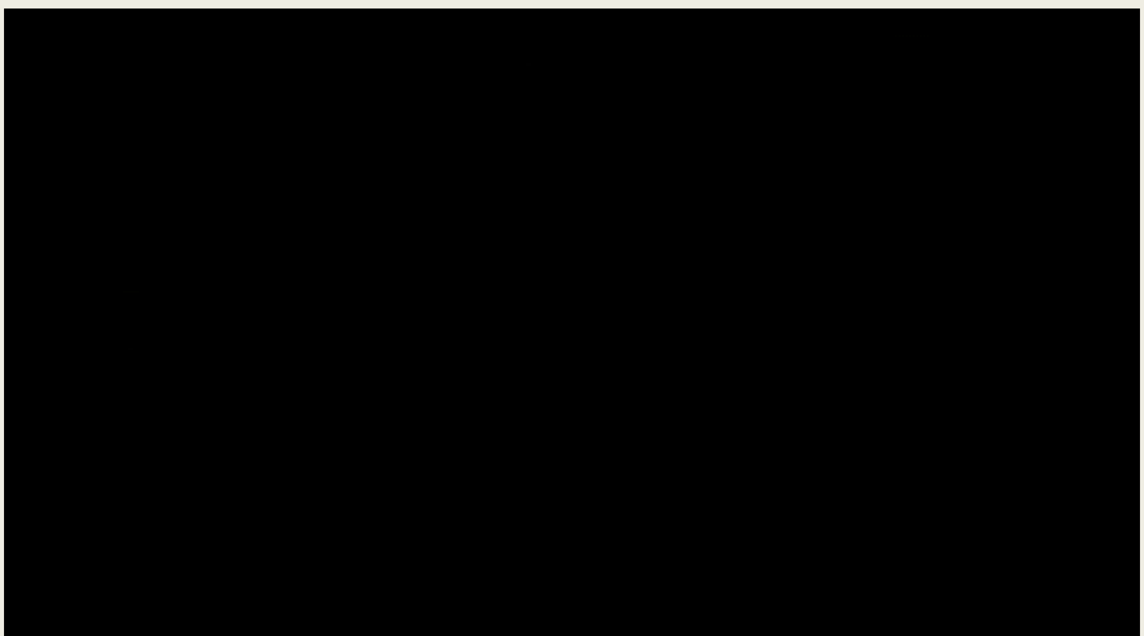
Omnidirectional WMRs

- There are two different wheel configurations to achieve Omnidirectional movement
  - Swedish wheel
  - Spherical wheel

https://www.youtube.com/watch?v=xL8deJDusns

Synchro Drive WMRs

- An innovative configuration known as synchro drive features three or more wheels mechanically coupled in such a way that all rotate in the same direction at the same speed, and similarly pivot in unison about their respective steering axes when executing a turn.



https://www.youtube.com/watch?v=MFxjIthqXVs

Actuation

- **DC Motors**: Pulse Width Modulation
- **Stepper Motors** have two independent coils which can be independently controlled. As a result, stepper motors can be moved by impulses to proceed exactly a single step forward or backward, instead of a smooth continuous motion in a standard DC motor.
- **Servo motor** is a high-quality DC motor that qualifies to be used in a “servoing application”, i.e. in a closed control loop. Such a motor must be able to handle fast changes in position, speed, and acceleration, and must be rated for high intermittent torque

Other Mode of Actuation

- Pneumatic and Hydraulic actuators
- Artificial muscles : prosthetic, bio applications.
- Ultrasonic motors : micro robots, cameras, micro motion devices
- Molecular motors : bio applications

Sensors

- Classify sensors using two important functional axes
  - proprioceptive/exteroceptive and
  - passive/active
- **Proprioceptive** – sensors measure values internal to the system (robot); for example, motor speed, wheel load, robot arm joint angles, and battery voltage.
- **Exteroceptive** sensors acquire information from the robot's environment; for example, distance measurements, light intensity, and sound amplitude. Hence, exteroceptive sensor measurements are interpreted by the robot in order to extract meaningful environmental features.

- **Passive** sensors measure ambient environment energy entering the sensor. Examples of passive sensors include temperature probes, microphones, and CCD or CMOS cameras.
- **Active** sensors emit *energy into the environment*, and then measure the environmental reaction.
- **Analog versus Digital Sensors:** A number of sensors produce analog output signals rather than digital signals. This means an A/D converter (analog to digital converter) is required to connect such a sensor to a microcontroller.

Computer Vision

- Computer vision automatically **extracts**, **analyzes**, and **comprehends** useful information from a single image or an array of images.
- This process involves development of **algorithms** to accomplish automatic visual comprehension.

Tasks of Computer Vision

- **OCR** – In the domain of computers, ***Optical Character Reader***, a software to convert scanned documents into editable text, which accompanies a scanner.
- **Face Detection** – Many state-of-the-art cameras come with this feature, which enables to read the face and take the picture of that perfect expression. It is used to let a user access the software on correct match.
- **Object Recognition** – They are installed in supermarkets, cameras, high-end cars such as BMW, GM, and Volvo.
- **Estimating Position** – It is estimating position of an object with respect to camera as in position of tumor in human's body.

Edge Detection

- The Laplace and Sobel edge detectors, two very common and simple edge operators.
- The Laplace operator produces a local derivative of a grayscale image by taking four times a pixel value and subtracting its left, right, top, and bottom neighbors

Motion detection

- The idea for a very basic motion detection algorithm is to subtract two subsequent images
- 1. Compute the absolute value for grayscale difference for all pixel pairs of two subsequent images.
- 2. Compute the average over all pixel pairs.
- 3. If the average is above a threshold, then motion has been detected.

Image Segmentation

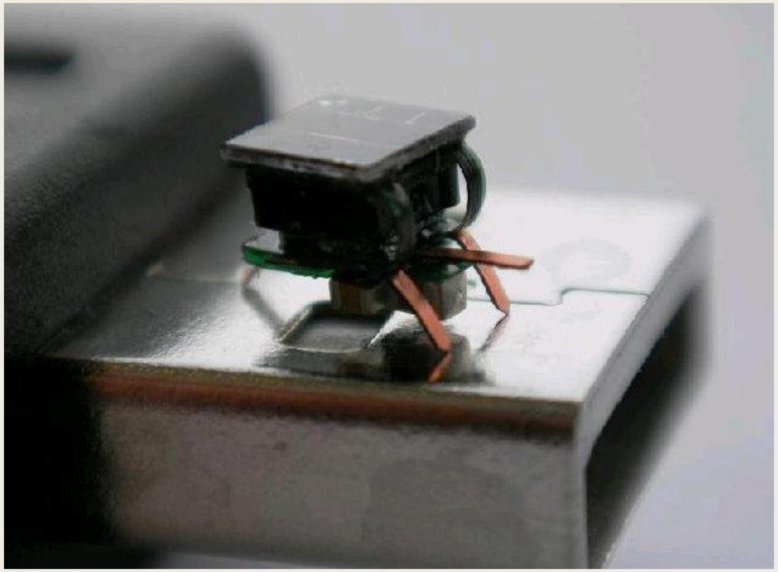
- Detecting a single object that differs significantly either in shape or in color from the background is relatively easy.
- A more ambitious application is segmenting an image into disjoint regions. One way of doing this, for example in a grayscale image, is to use connectivity and edge information

Object Localization

Image Coordinates versus World Coordinates

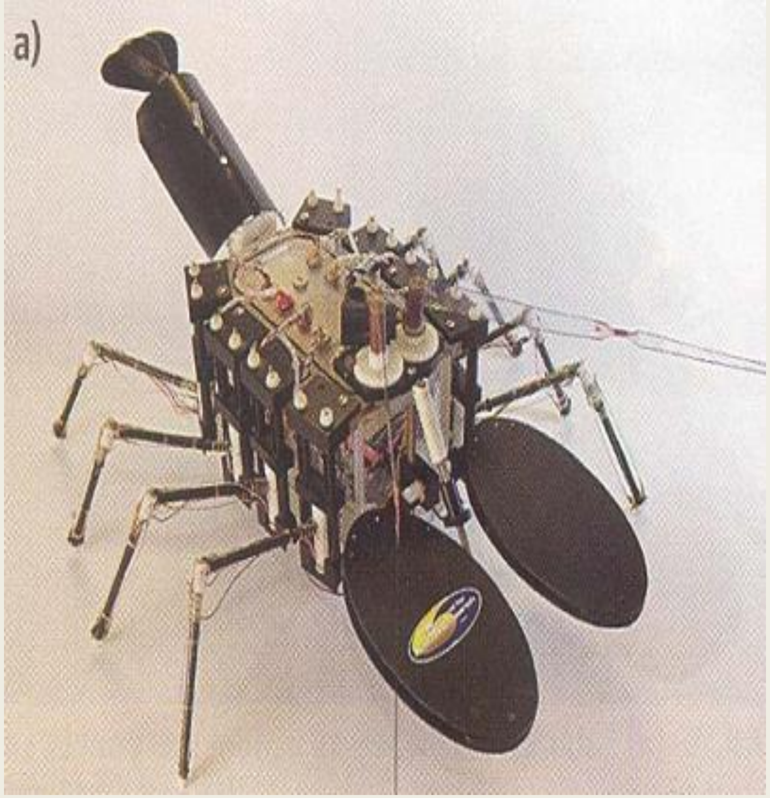
- Whenever an object is identified in an image, all we have is its image coordinates. Working with our standard 60×80 resolution, all we know is that our desired object is, say, at position [50, 20]

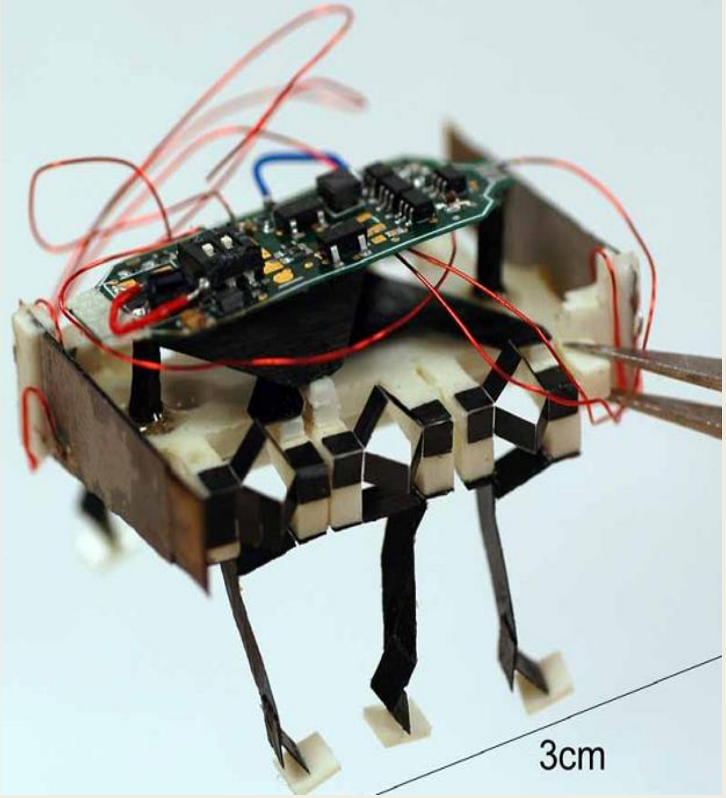
I-Swarm Micro Robot



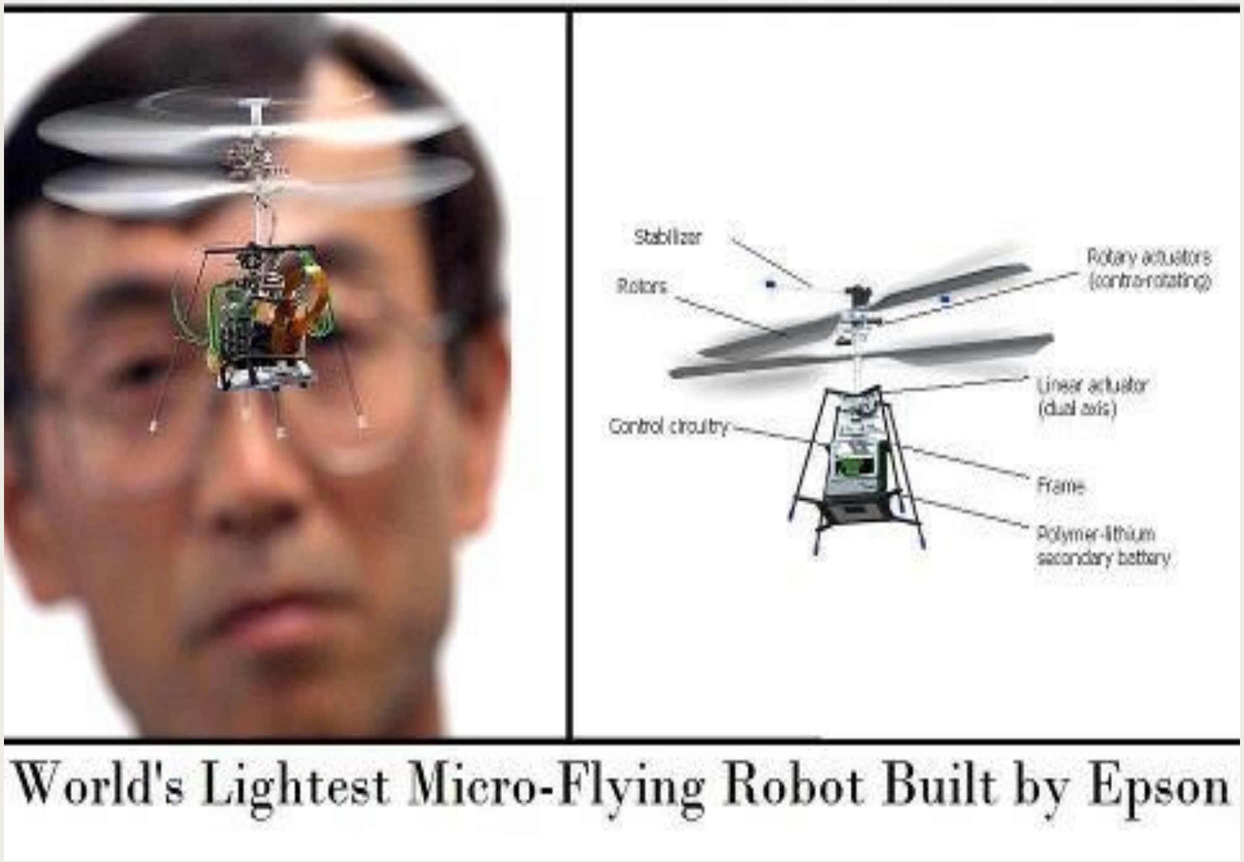
http://www.hizook.com/blog/2009/08/29/i-swarm-micro-robots-realized-impressive-full-system-integration

Insect designs





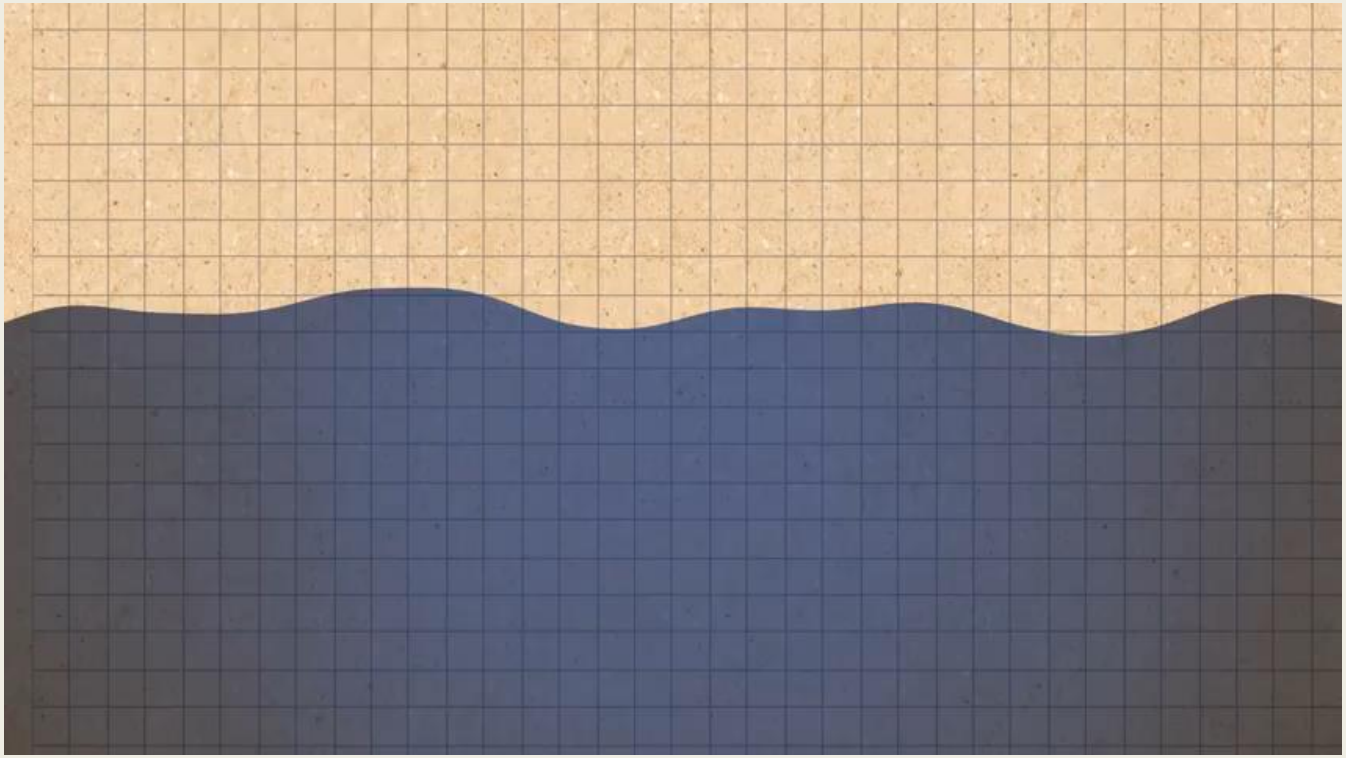
Flying Micro-Robot



Soft micromachines

https://www.youtube.com/watch?v=397h1MIBRxM

Micro Robotics: **robo-bees**



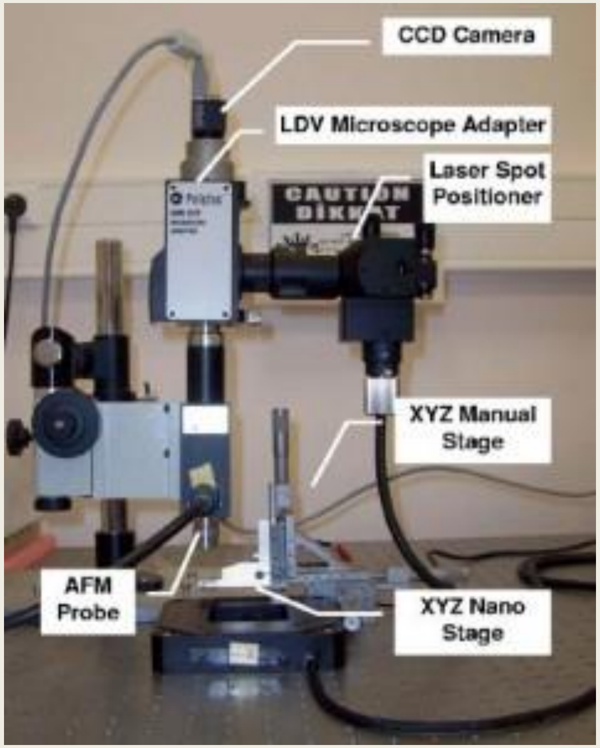
https://www.youtube.com/watch?v=dEbLeuUIaHI

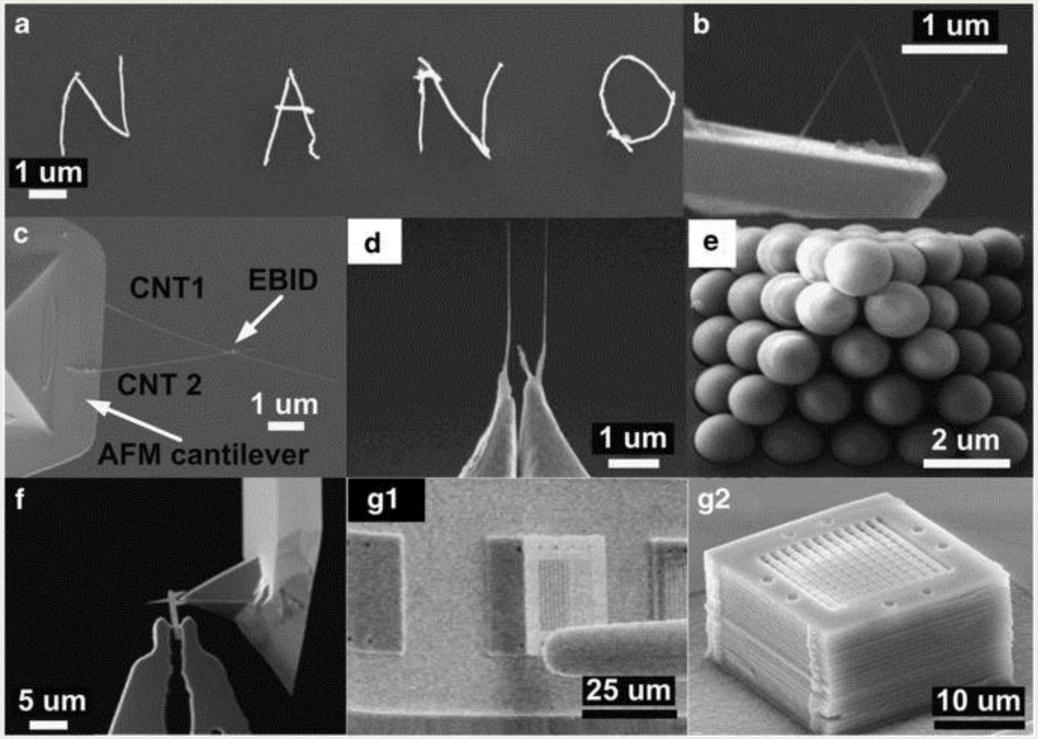
https://www.youtube.com/watch?v=gEvSewJwrTw

Robotic Micro-Scallops Can Swim Through Your Eyeballs

Source: IEEE Spectrum

Examples of nano device and nanostructure assembly.





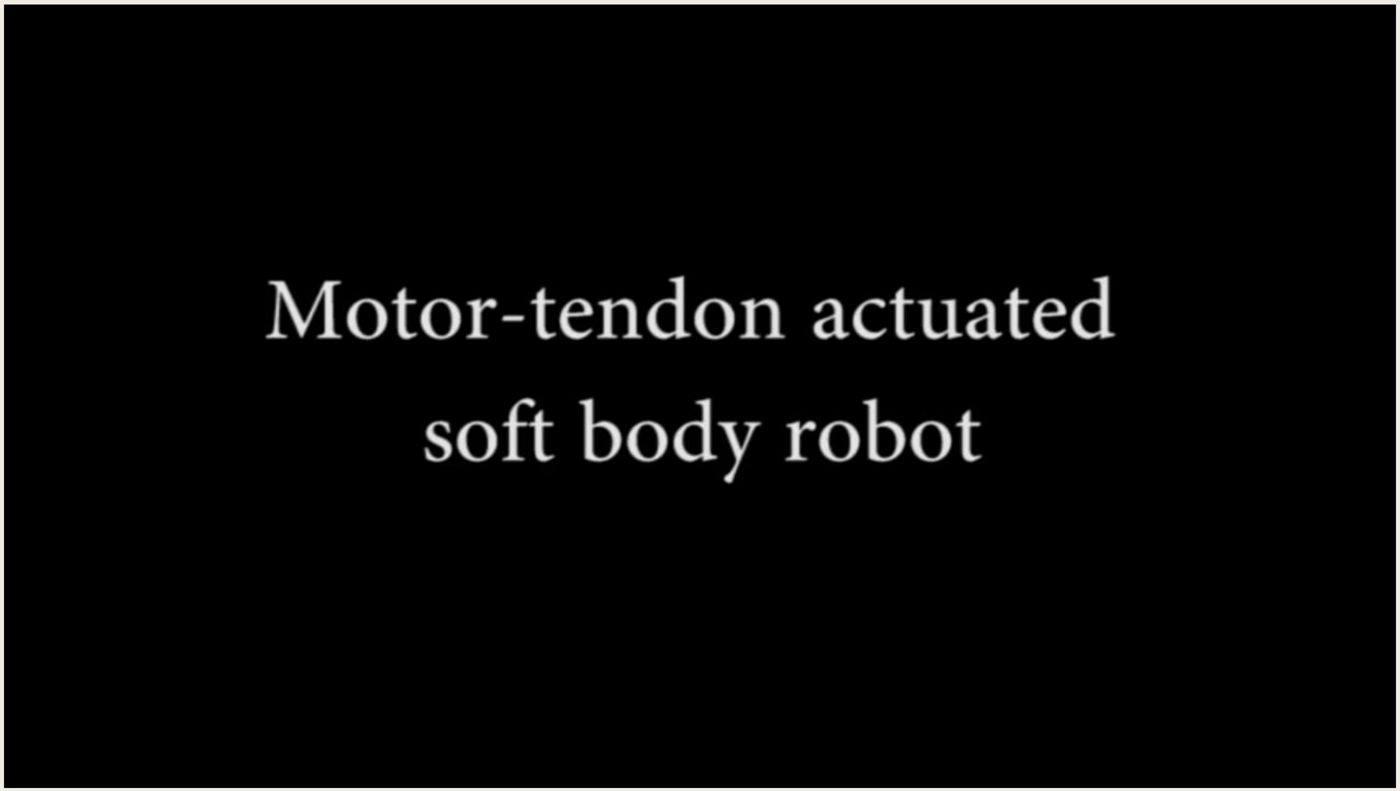
Piezoactuated AFM Probe
Koç University

Nano assembly
(https://www.nature.com/articles/micronano201624)

Soft Robot

https://www.youtube.com/watch?v=DfHehxz_-Hc

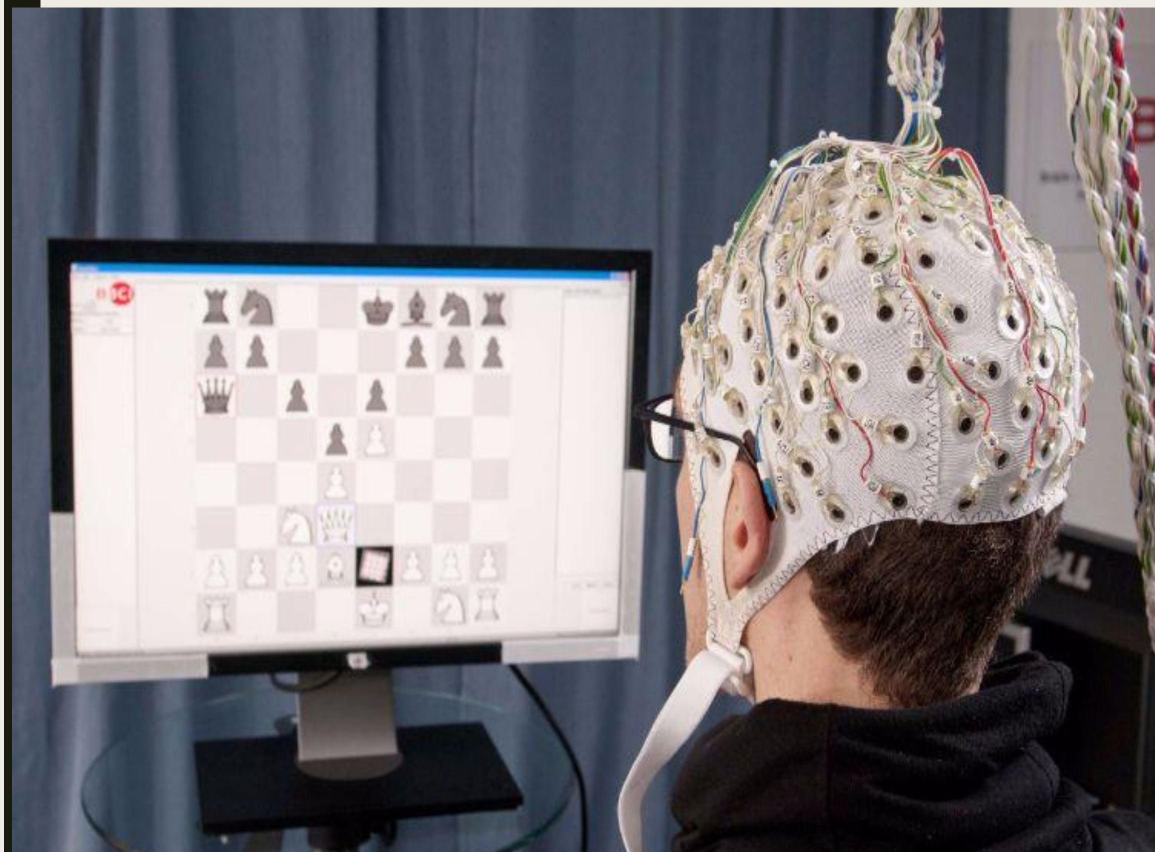
Soft Robot



Dr. Vishesh Vikas

https://www.youtube.com/watch?v=AxYVaj60oC8

Brain Computer Interfaces



Brown University and Blackrock Microsystems

TU Graz