Syllabus

- **Robotic Manipulators**
  - Applications in assistive robotics: medical robotics, prostheses, companion, monitorization, assistance
  - Structure of the robot manipulators
  - Drives and sensors
  - Spatial location: transformations
  - Geometric model
  - Motion control

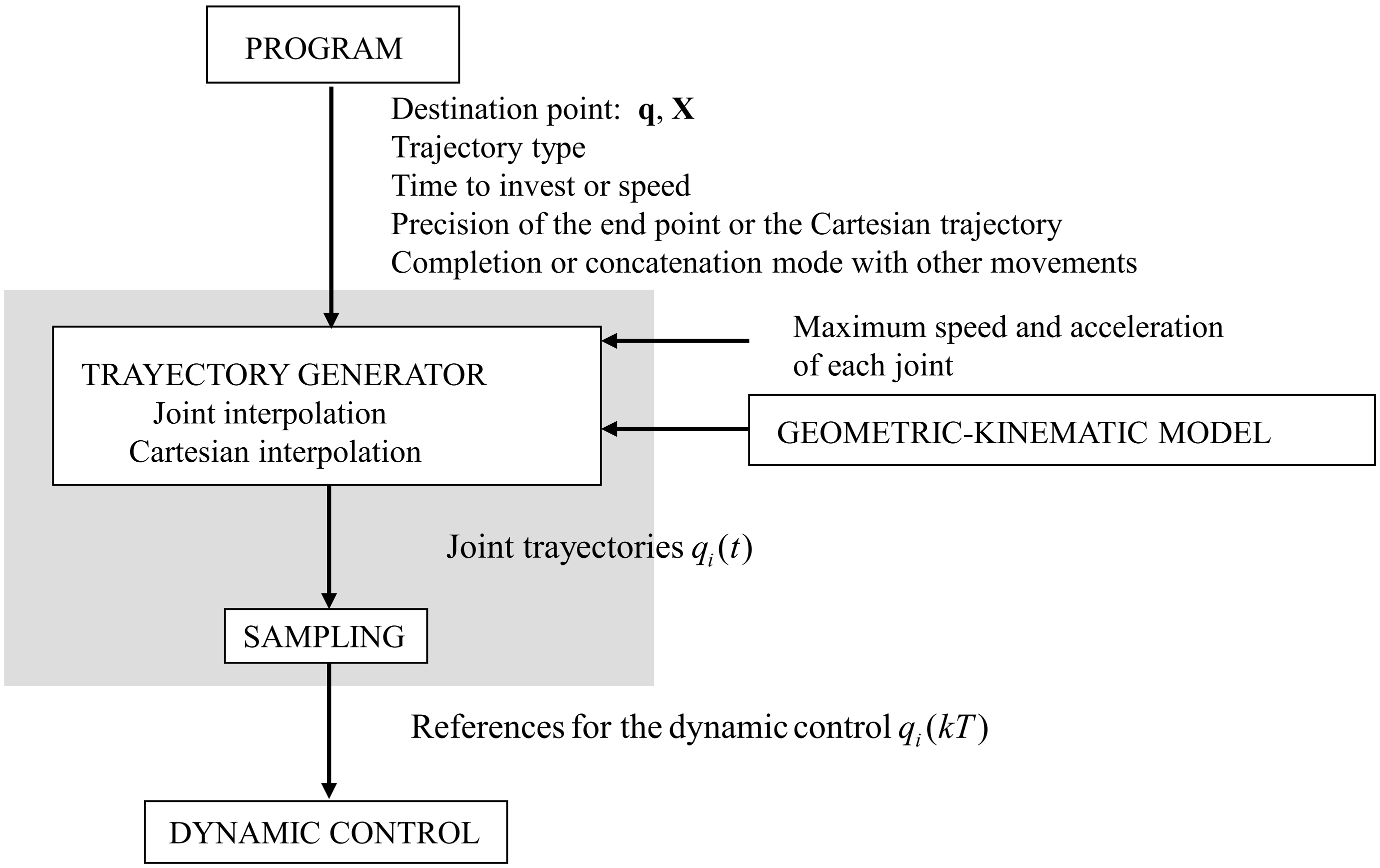
- **Visual Servoing**
  - Position-Based Visual Servoing. 3D scene model, two-view geometry, stereo cameras. Control laws.
  - Image-Based Visual Servoing. Definition of targets. Interaction matrix. Image-based visual control loop.
  - Stability analysis. Lyapunov.
  - Hybrid Visual Servoing.

Motion control and trajectory generation

Kinematic control

- Functions of the kinematic control
- Types of trajectories
- Generation of joint trajectories
- Cartesian trajectories

Kinematic control



Kinematic control

- Convert the motion specification given in the program to a **time** analytical **trajectory**
- Trajectory type: **Cartesian or joint** trajectories
- (optional) Sample the Cartesian trajectory and convert the points to joint coordinates using the
- Interpolation of the joint points obtained by generating for each joint variable a time trajectory that passes or approaches them
- Restrictions: achievable by the actuators (speeds, accelerations), coordinated, continuous
- Joint trajectory sampling to generate references to dynamic control

Types of trajectories

Point-to-point trajectory

Each joint evolves without taking into account the others

– Joints moves one by one (long movement time)

– Simultaneous movement of joints, the fastest finishes first (not very useful, high demands on the actuators)

Simple manipulators, with limited control unit

Robot motions easy to predict

Types of trajectories

Joint coordinated trajectory

- Each joint evolves in a coordinated way
- All joints start and finish the motion at the same time
- Duration: depending on the joint maximum speeds and their displacements
- Easy for the robot controller
- Smooth
- Efficient and fast (minimal joint movement)
- Difficult to predict intermediate positions (difficult for the user)

Types of trajectories

Cartesian trajectory (line, circle)

All joints start and finish the motion at the same time

To follow a line or a circle in the 3D world

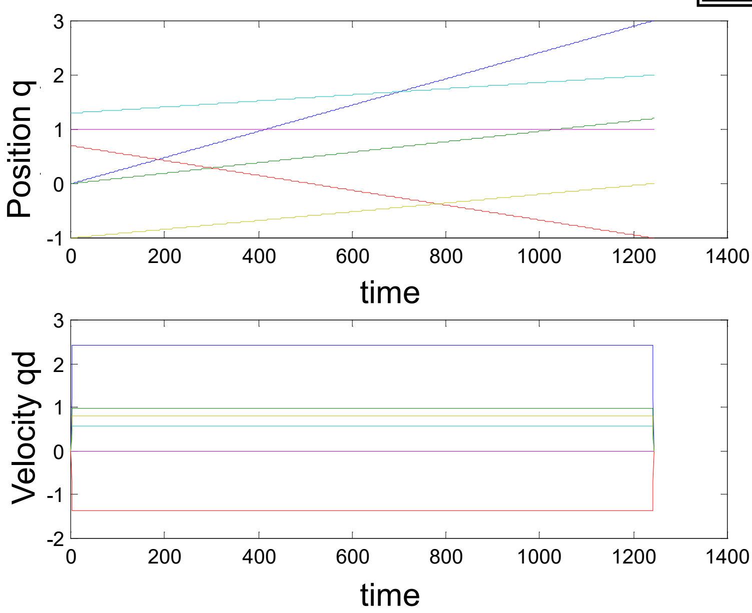
- Easy to predict and visualize (easier for the user, avoid collisions)
- Minimum movement of the load or tool (<load inertial stress)
- Slow; increased joint movement (back and forth)
- Heavier computations (100 times more) for the robot controller (Cartesian interpolator, coordinate transformer)
- They are needed by many applications: assembly, arc welding, sealing, conveyor tracking
- Continuity problems (joint limits, singularities)

Joint coordinated trajectories: linear interpolation

Coordinated trayectory from $\mathbf{q}_0 = \left(q_0^{\ 1},\ q_0^{\ 2},\ \ldots,\ q_0^{\ i},\ldots,\ q_0^{\ 6}\right)$ to $\mathbf{q}_1$

Considering movement with constant velocity in T seconds : $v^i = \dfrac{q_1^{\ i} - q_0^{\ i}}{T}$

Therefore, each joint : $$q^i(t) = q_0^{\ i} + \frac{q_1^{\ i} - q_0^{\ i}}{T}(t - t_0); \quad t_0 < t < t_1$$



¿ T ?

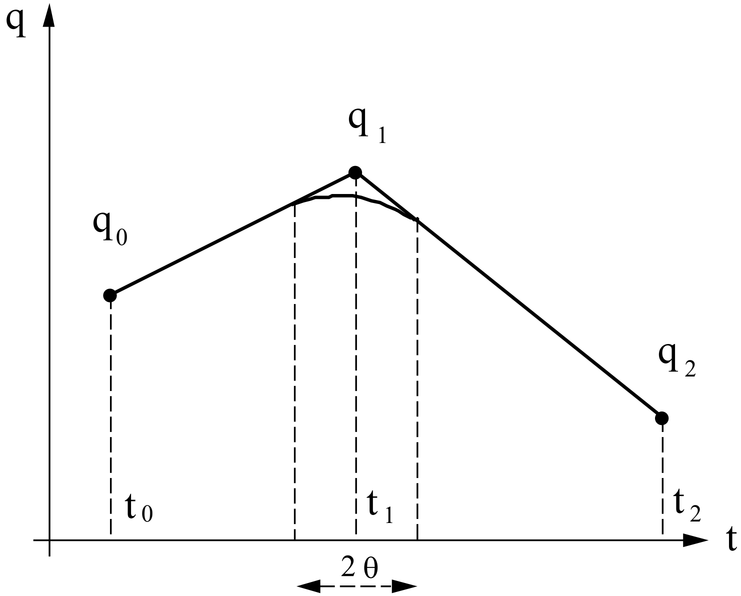
- If set by user or task, check maximum speeds and increase T if necessary
- If the user sets the speed in % over the maximum;

$$T = \max_{i=1,\ldots,n}\left(\frac{q_1^{\ i} - q_0^{\ i}}{v^i_{\ max}}\right) * \frac{100}{V(\%)}$$

<u>Discontinuous velocity, infinite acceleration?</u>

Joint coordinated trajectories: trapezoidal speed profile

- If we move at a constant and maximum speed, it is easier to plan times and we take better advantage of the kinematic restrictions
- Linear interpolation requires infinite accelerations
- Constraint: Transition with constant acceleration, maintaining continuity in speed.



$$v_0 = \frac{q_1 - q_0}{t_1 - t_0}; \quad v_1 = \frac{q_2 - q_1}{t_2 - t_1}$$

In the transition section, $t_1 - \theta \le t \le t_1 + \theta$:

$$a = \frac{v_1 - v_0}{2\theta}$$

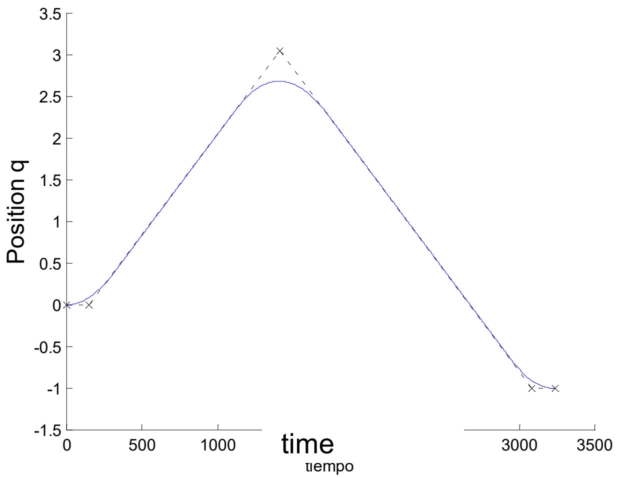
$$v(t) = v_0 + a\left(t - (t_1 - \theta)\right)$$

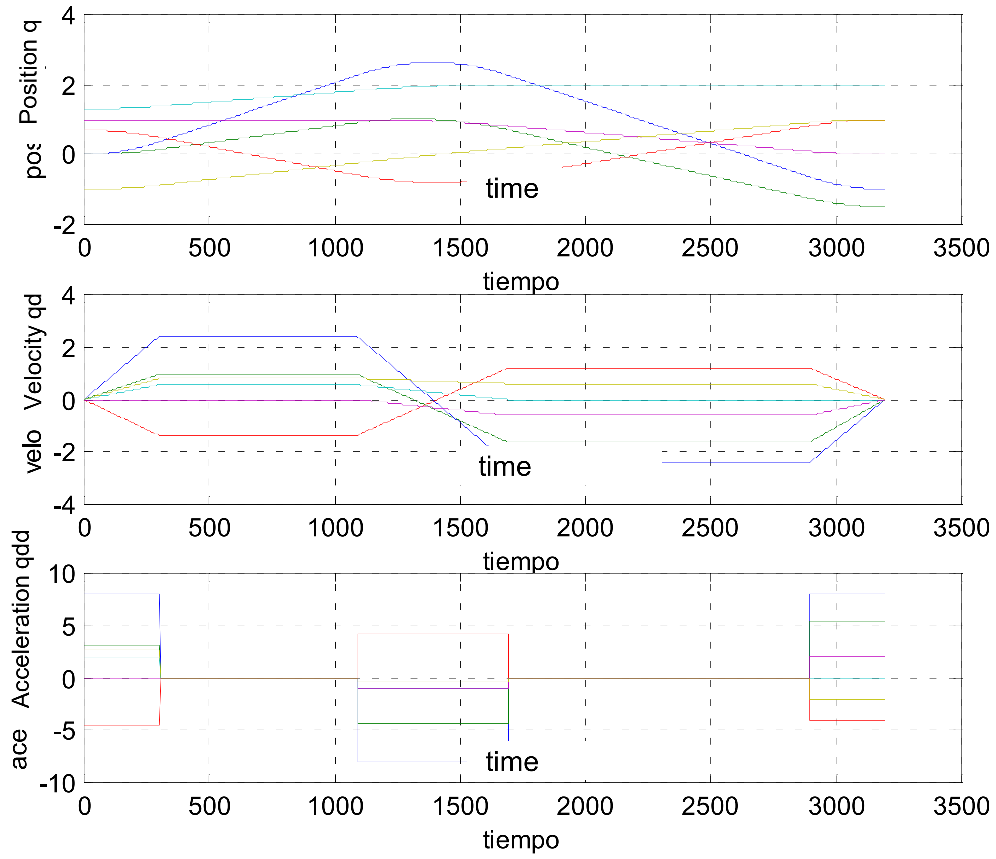
$$\boxed{q(t)} = q_1 - v_0\theta + v_0\left(t - (t_1 - \theta)\right) + \frac{a}{2}\left(t - (t_1 - \theta)\right)^2 =$$

$$\boxed{= q_1 + v_0(t - t_1) + \frac{v_1 - v_0}{4\theta}\left(t - (t_1 - \theta)\right)^2}$$

Joint coordinated trajectories: trapezoidal speed profile

- Accelerations: steps
- Speeds: trapezoidal
- Cartesian positions: smooth changes





Cartesian trajectories

- MoveL destination, vcte

$$p_x(t);\ p_y(t);\ p_z(t);$$

- Cartesian interpolation: positions
  - Similar interpolation techniques
  - Cost of coordinate transformation and Cartesian interpolation: Tc, Ta

- Interpolation of orientation in 3D
  - Roll-Pitch-Yaw or Euler => unpredictable tool results
  - Single axis or rotation & interpolate the angle => smooth results

- Every Cartesian pose => to joint coordinates
  - Inverse kinematics

Cartesian trajectories: singularities

- In a singularity of the manipulator some Cartesian degree of freedom is lost
- It is not possible to make a Cartesian trajectory that passes through the singularity and that requires moving over that DoF
- In practice, in the vicinity of a singularity, it can be achieved the configuration, but to maintain a certain Cartesian speed, high joint speeds and accelerations are necessary.
- Solutions:
  - Impose restrictions on movement (detect them and avoid going through them)
  - Redundant robot (other problems)
  - Avoid them by allowing greater deviations in position or Cartesian velocity, when passing near the singularity
  - Devise hybrid Cartesian-articular interpolations, which can avoid problems (wrist singularity)

Motion control and trajectory generation. Exercise

- Run **rtbdemo** at MATLAB
- Pay attention to the instructions for defining joint trajectories and cartesian trajectories
- Plot the evolution of the position, speed, and accelerations of each joint. What are the differences in each case?
- Find out the type of velocity profile that is generated.
- Note that these instructions will be used in the Work Assignment I.

Motion control and trajectory generation. List of papers

Option 1 (in Spanish) Fortea, A. (2024). Adrián Fortea , Rodrigo Aldana, Rosario Aragüés - Alimentación asistida por brazo robótico basada en visión. Jornada De Jóvenes Investigadores Del I3A, 12. **https://doi.org/10.26754/jjii3a.202410889**.

- https://papiro.unizar.es/ojs/index.php/jji3a/article/view/10889/9123 (poster)
- https://papiro.unizar.es/ojs/index.php/jji3a/article/view/10645/8725 (paper)
- Associated to the final degree project of student A. Fortea (Computers Engineering, Univ. Zaragoza)

Motion control and trajectory generation. List of papers

Option 2 (in English) Choose one of the papers in the Workshop RObotic MAnipulation of Deformable Objects: challenges in perception, planning and control for Soft Interaction (ROMADO)

https://romado-workshop.github.io/ROMADO2022/

Research papers on deformable object manipulation