Intelligent Robot Control

Lecture 5: Force control

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Basics of robotics – in a nutshell

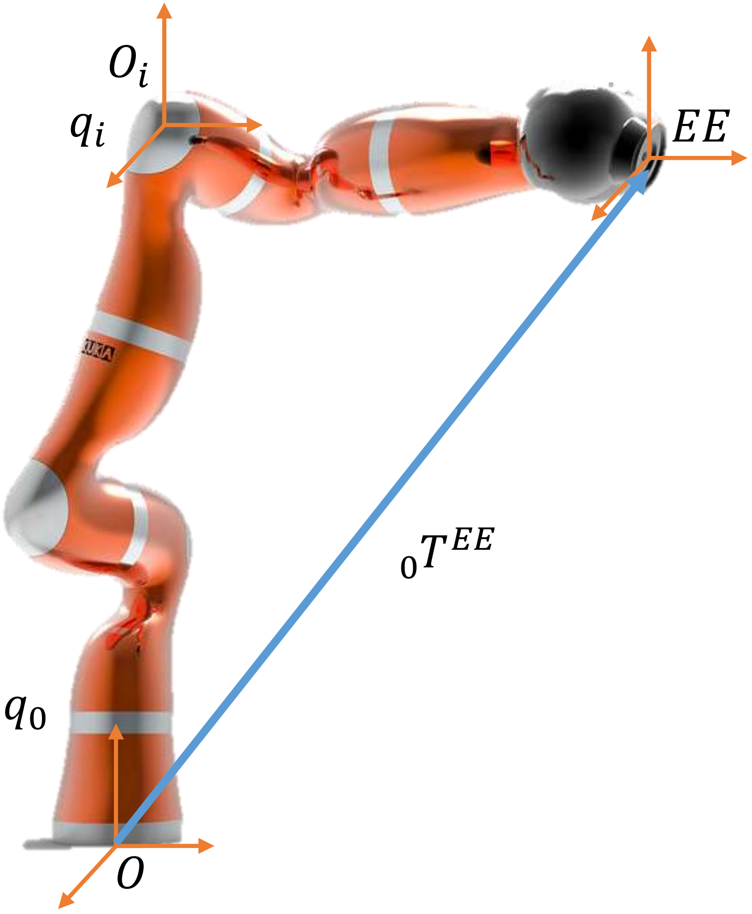
- Homogeneous transformations

$$T = \begin{bmatrix} R & p \\ 0_{1x3} & 1 \end{bmatrix}_{4x4}$$

- Translation vector: $p \in R^3$

- Rotation matrix: R_{3x3}
  $R^T R = I$ - orthogonal
  $\det(R) = 1$ - right-handed CS

- Forward kinematics
  - ${}_0T^{EF}(q) = {}_0T^1(q_0)\ {}_1T^2(q_1)\ldots\ {}_iT^j(q_i)\ldots{}_{n-1}T^{EE}(q_{n-1})$



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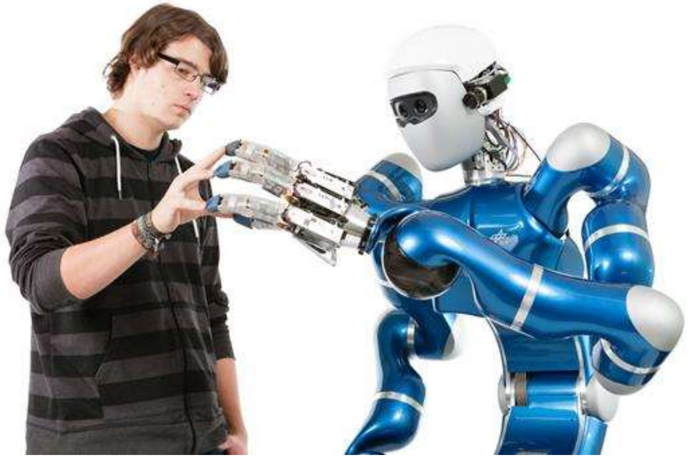
What about position control and contact

Is position control always a good idea?

Video source: Youtube

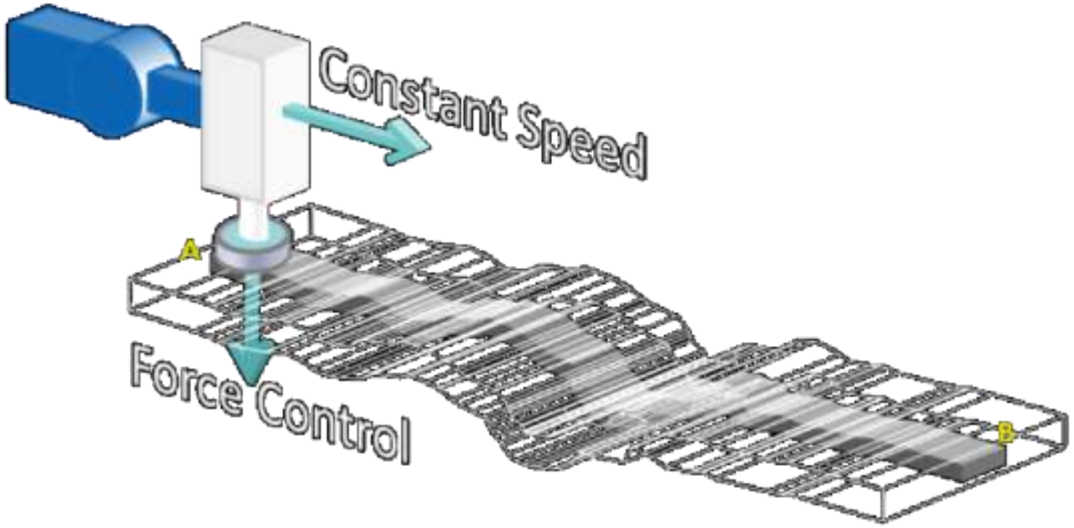
Interaction control

- Robots are typically programmed to move from A to B. This scenario actually does not represent the whole range of applications. There exists an increasing trends in developing mechanical devices and/or control schemes allowing robots to **interact with the environment**.
- There exists a fundamental distinction:
  - Free motion: the robot is free to move in any direction;
  - Contact motion: the robot is constrained to move in some direction, as others are constrained by the environment.



Interaction control

- During the interaction with the environments, the manipulator is subject to reaction forces in the constrained directions. Reaction forces are typically parallel to constrained directions which are normal to motion directions.
- In many applications **controlling the contact force** is as important as controlling the speed of the robot along the prescribed direction. We need to understand how to control forces!



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Passive compliance

- A special mechanical device is used to control the contact compliance or the compliance. Usually this is a special gripper, suitable for a particular task.
- Advantages:
  - simple;
  - cheap.
- Drawbacks:
  - no exibility,
  - special devices for each contact type;
  - high contact forces can arise.

- New trend in robotics: pasive variable complaince

  (Series Elastic Actuator)

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Active compliance control

- The control algorithm assures the desired compliance. The control includes also force feedback.
- Advantages:
  - controlled contact force;
  - Exibility.
- Drawbacks:
  - delay in response;
  - Expensive.

- Strategies for active force control:
  - Force control: allows direct force tracking
  - Impedance control: indirect force control
  - Admitace control: indirect force control

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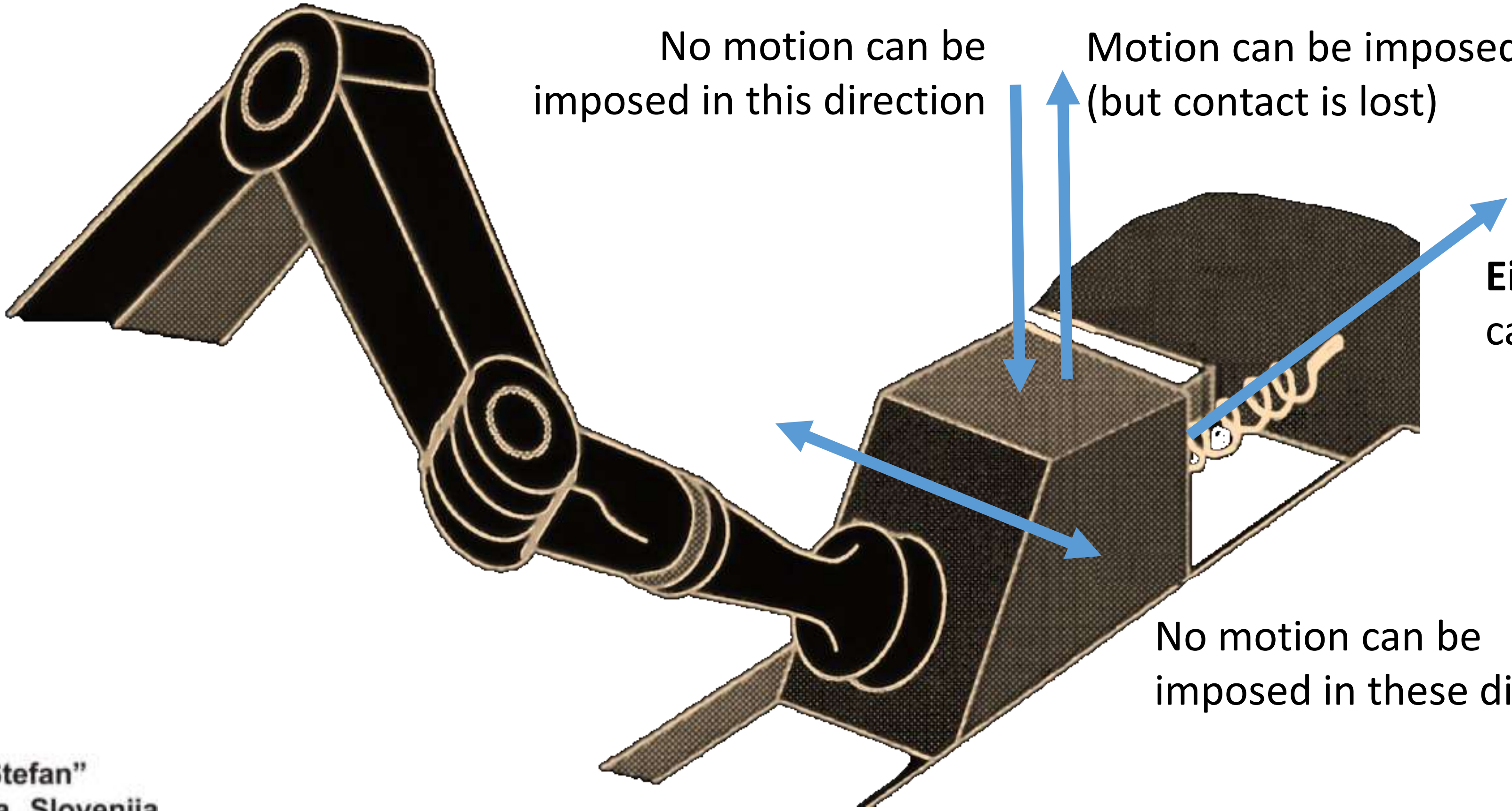
Force control

- Understanding the environment is a crucial task:



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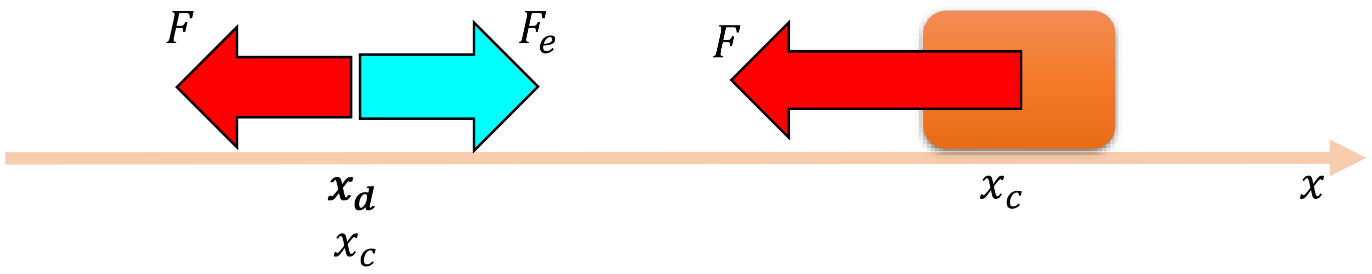
Force control

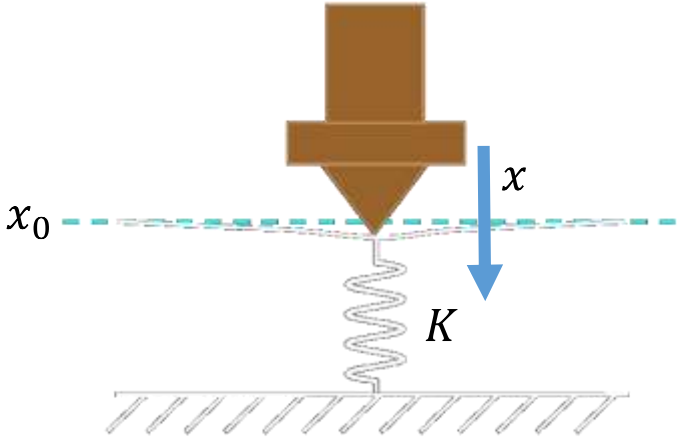


- $F = -K(x_c - x_d)$
- $F_e = -Kx_e, \ \ |x_e| = \left|\frac{F_e}{K}\right|$

The higher the gain, the less dependent on external forces and uncertainties!

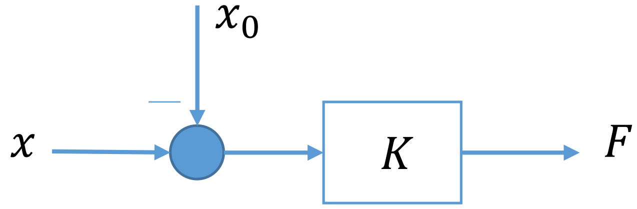
Force control

- A simplified (1 DOF) scenario: the environment is compliant (spring model, spring constant roughly known), the robot can only move in one direction (vertical), its displacement is perfectly controlled.



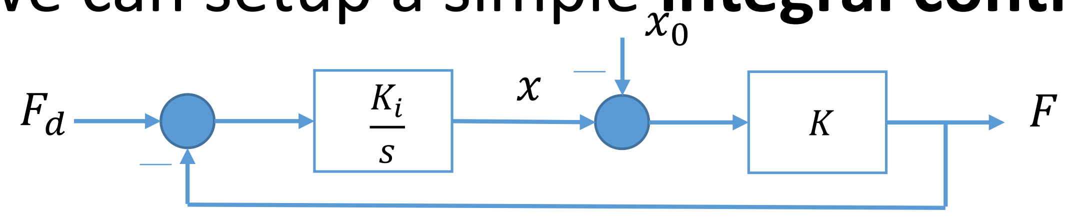
Force model:

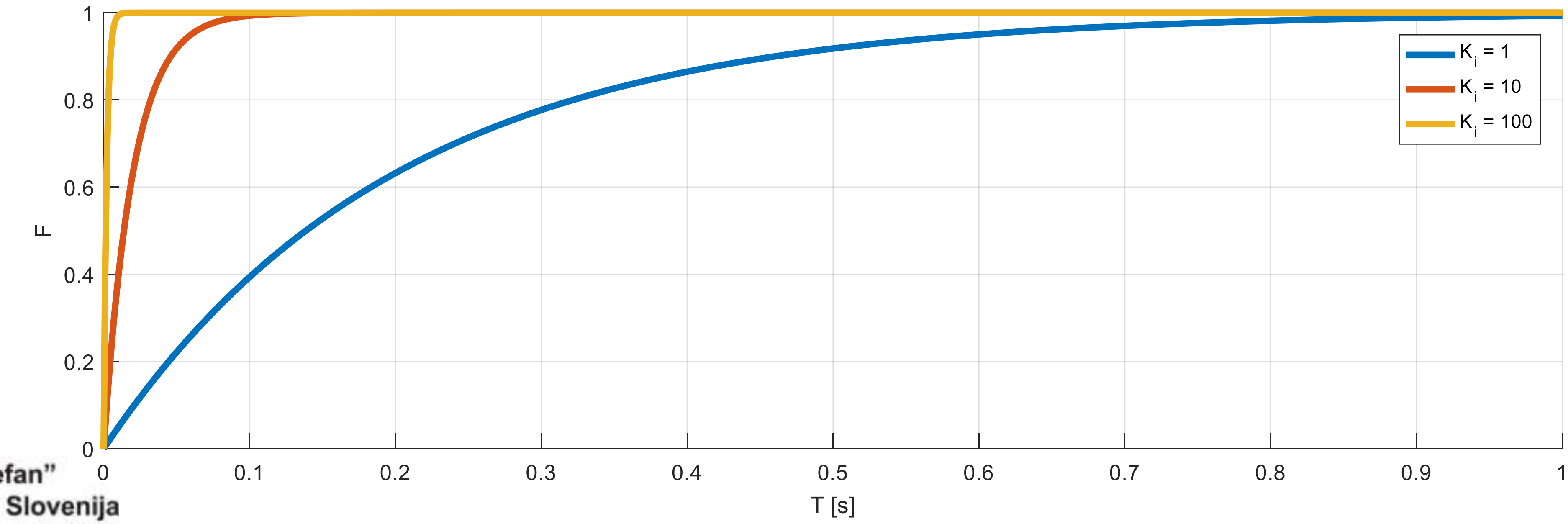
- $F = K(x - x_0);\ x \geq x_0$



Force control

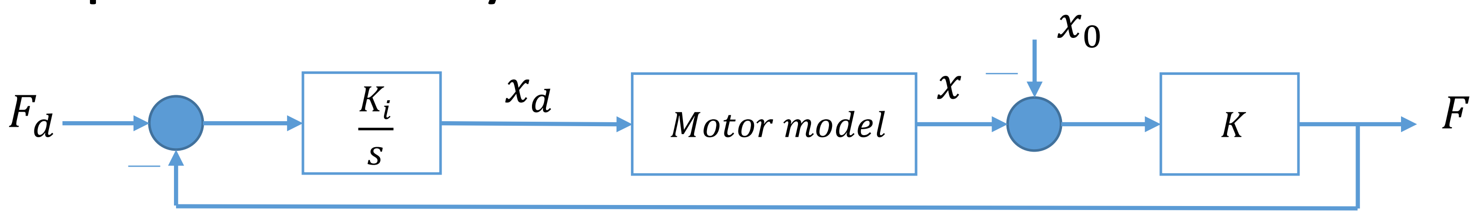
- Assuming we are able to measure the contact force (i.e. we have a force sensor), we can setup a simple **integral controller**.

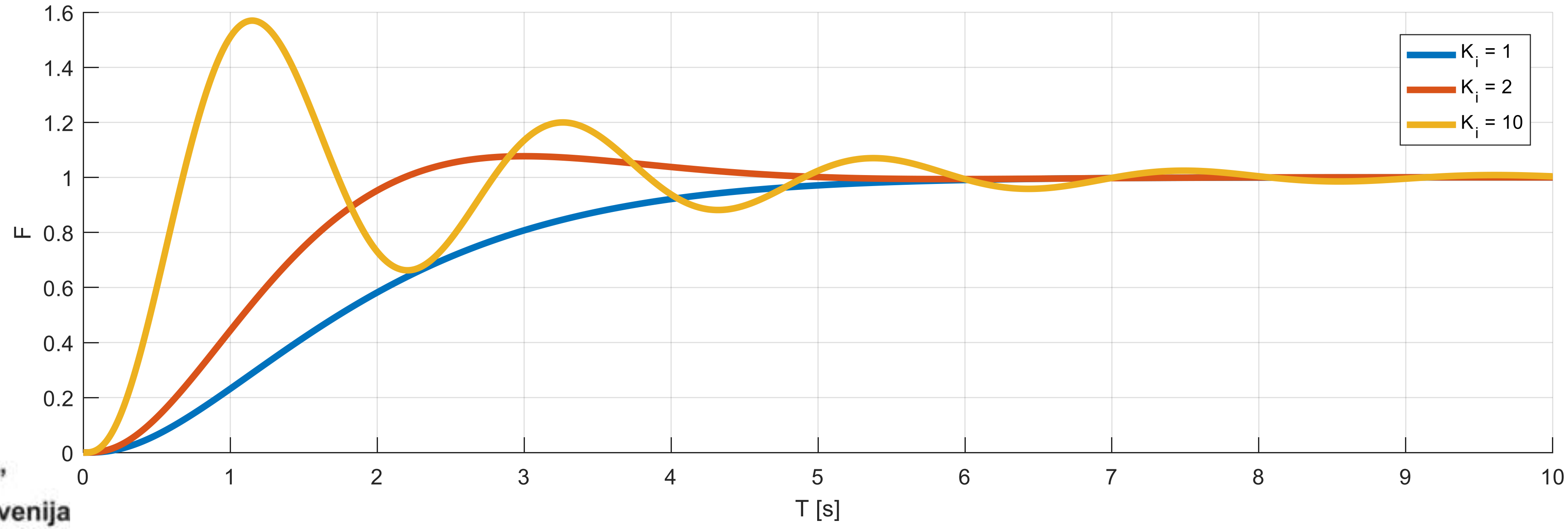




Force control

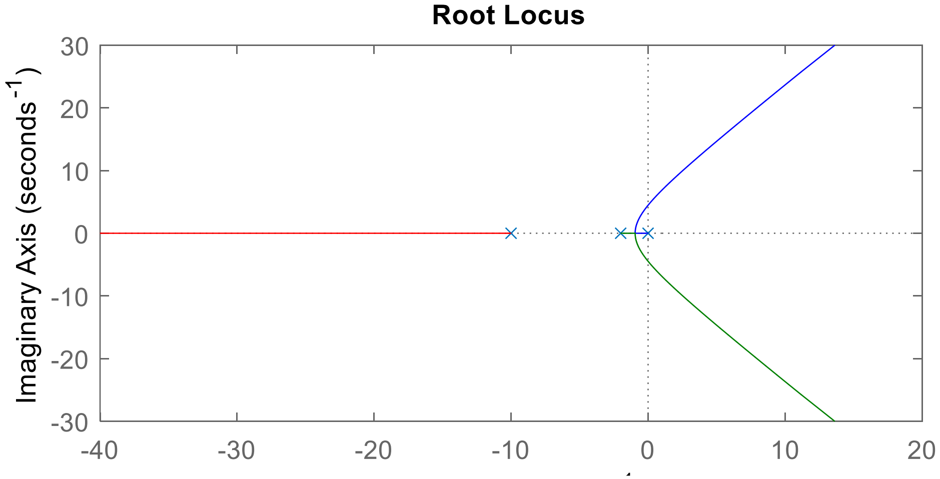
- A more realistic model that accounts for the existence of a low-level control loop and of delay.





Force control

- We learned that:
  - Performance (bandwidth) is highly related to the **knowledge of the environment stiffness**;
  - The real control loop might get **unstable** because of limited performance of the position loop;
  - **Delays** always affect stability and performance.



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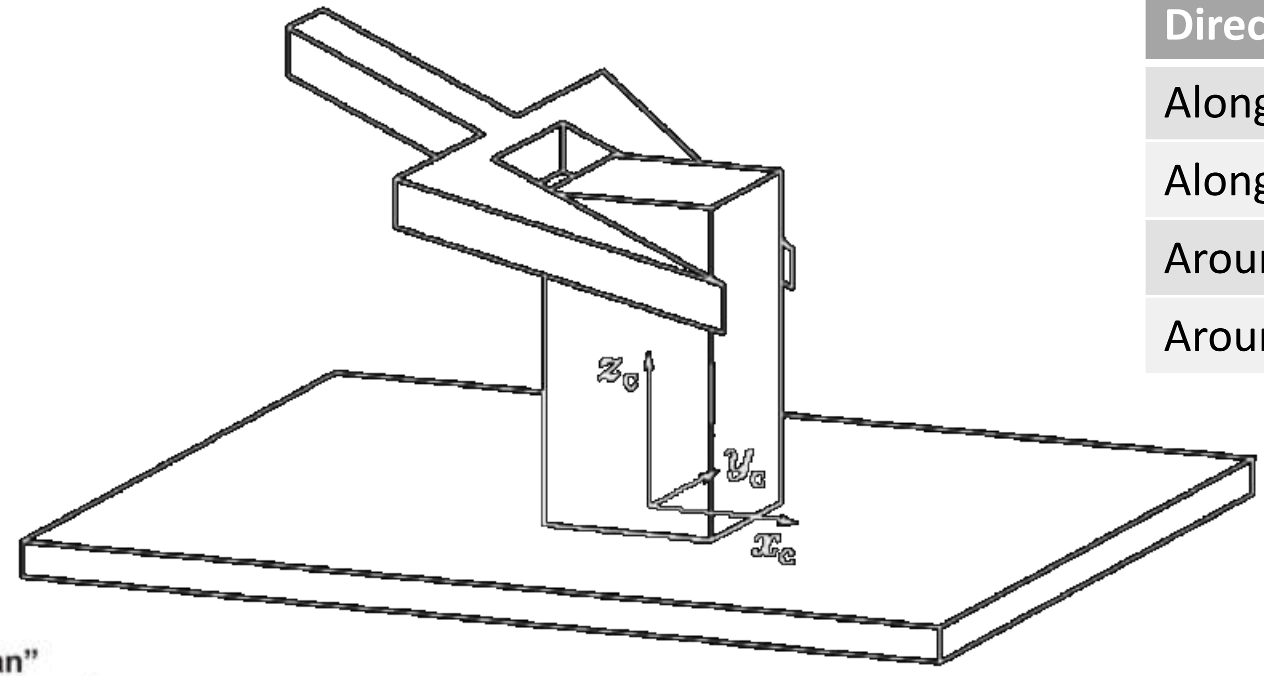
Hybrid force-position control

- Most applications require the force to be controlled, **while the robot is moving** in some direction. In order to understand what to do, let's try to introduce a useful formalism to describe what the robot is able to do.

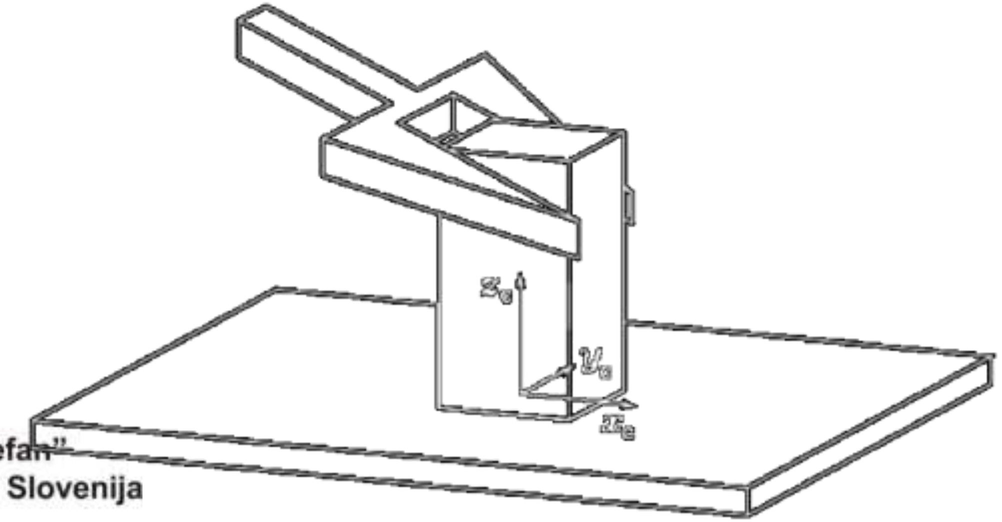


Direction	Type of control
Along x, y	Motion
Along z	Force
Around x, y	Force (moment)
Around z	Motion

Hybrid force-position control

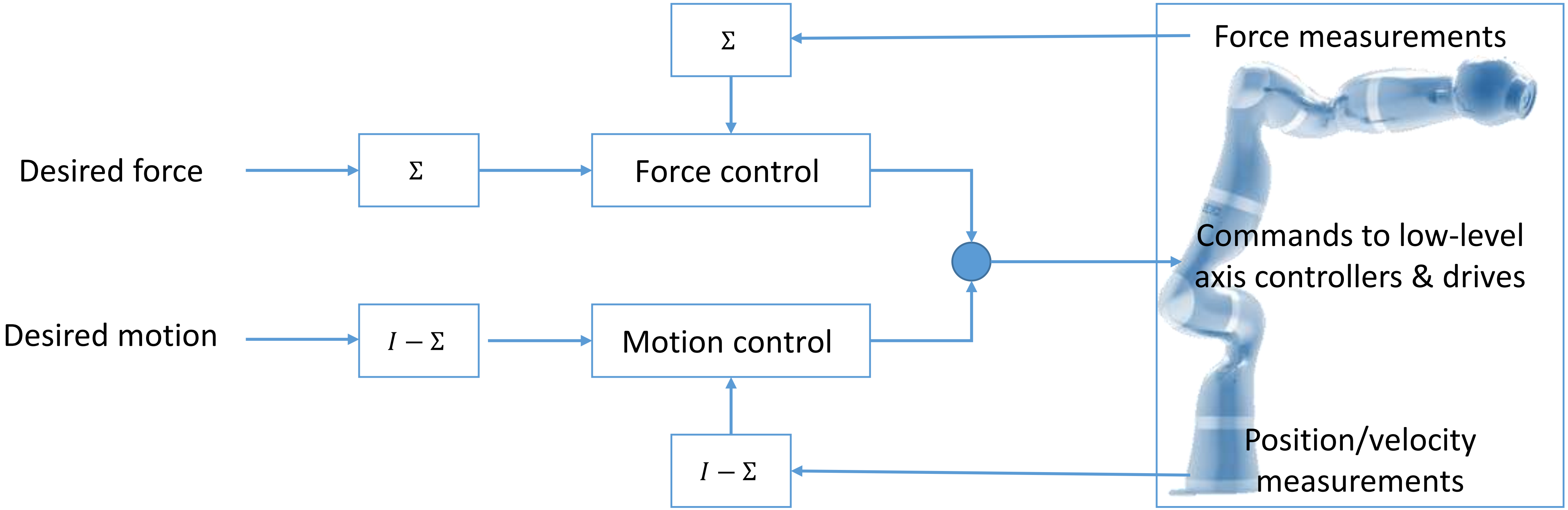
- It is convenient to introduce the so-called **selection matrix**: a diagonal matrix with:
  - Element equal to zero, corresponding to a velocity controlled direction;
  - Element equal to one, corresponding to a force/moment controlled direction.

- In our last example we have:



$$\Sigma = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Hybrid force-position control



SCREWING SELF-TAPPING BOLT
INTO UNKNOWN ENVIRONMENT