FORCE CONTROL

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Introduction

- Pure position control is not adequate for tasks which involve extensive contact with the environment
  - Assembly, grinding, deburring
- Need to control the force as well
  - Slight deviation of the end effector would cause either to loose contact or to press too strongly
- A force control strategy is one that modifies position trajectories based on the sensed forces

Sensors for Force Feedback

- Three main types of sensors for force feedback
  - Wrist sensor
  - Joint torque: actuator shaft
  - Tactile: fingers

For the purpose of controlling
The end-effector/environment
Interactions: wrist F/T sensor

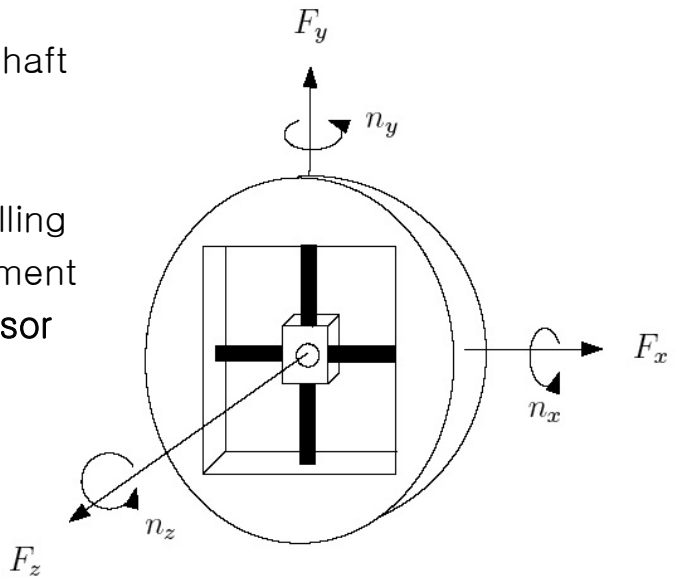


Figure 9.1: A wrist force sensor.

Coordinate Frames and Constraints

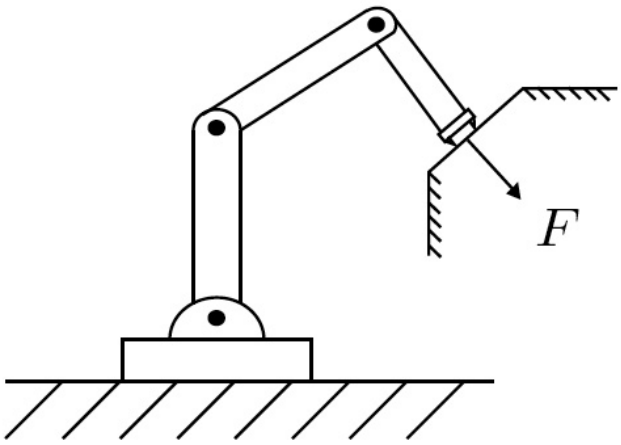
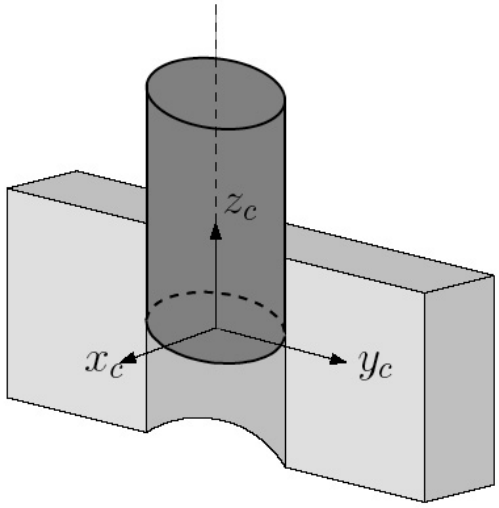


Figure 9.2: Robot end effector in contact with a rigid surface.

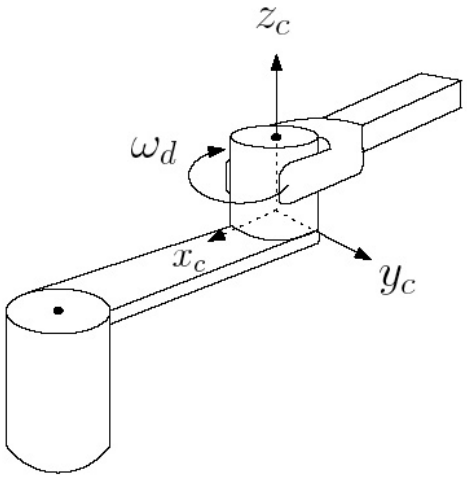
Natural and Artificial Constraints



Natural Constraints	Artificial Constraints
$v_x = 0$	$f_x = 0$
$v_y = 0$	$f_y = 0$
$f_z = 0$	$v_z = v_d$
$\omega_x = 0$	$n_x = 0$
$\omega_y = 0$	$n_y = 0$
$n_z = 0$	$\omega_z = 0$

Figure 9.3: Inserting a peg into a hole.

Turning a Crank



Natural Constraints	Artificial Constraints
$v_x = 0$	$f_x = 0$
$f_y = 0$	$v_y = 0$
$v_z = 0$	$f_z = 0$
$\omega_x = 0$	$n_x = 0$
$\omega_y = 0$	$n_y = 0$
$n_z = 0$	$\omega_z = \omega_d$

Figure 9.4: Turning a crank.

Network Models and Impedance

- The reciprocity condition means that the forces of constraint do not work in directions compatible with motion constraints and holds under the ideal conditions of no friction and perfect rigidity of both the robot and the environment
- In practice, compliance and friction in the robot/environment interface will alter the strict separation between motion constraints and force constraints

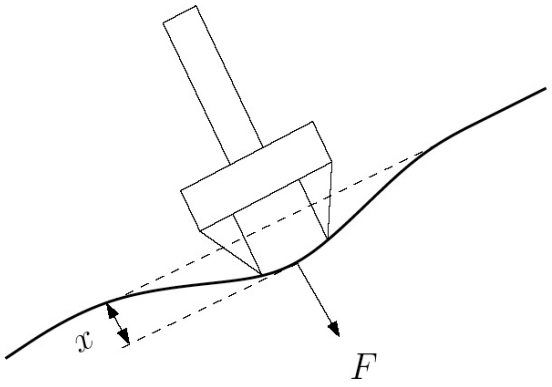


Figure 9.5: Compliant environment.

One-port Networks

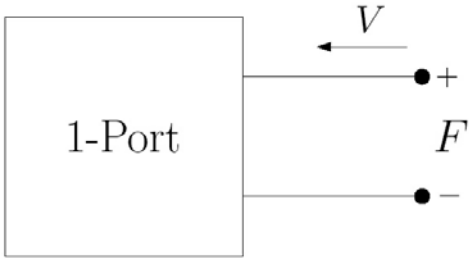


Figure 9.6: One-port network.

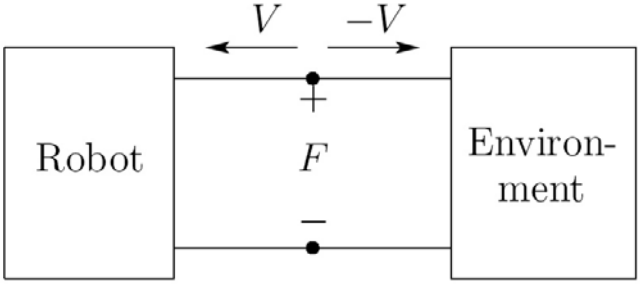


Figure 9.7: Robot/environment interaction.

Classification of Impedance Operators

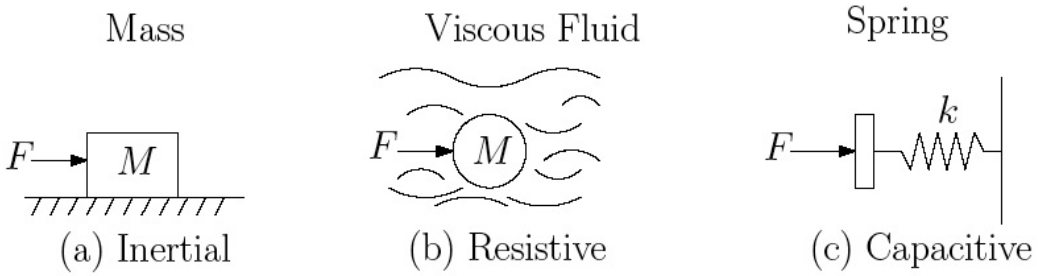


Figure 9.8: Examples of (a) inertial, (b) resistive, and (c) capacitive environments.

Thevenin and Norton Equivalents

- Any one-port network consisting of passive elements and current or voltage sources can be represented either as an impedance in series with an effort source or as an impedance in parallel with a flow source.

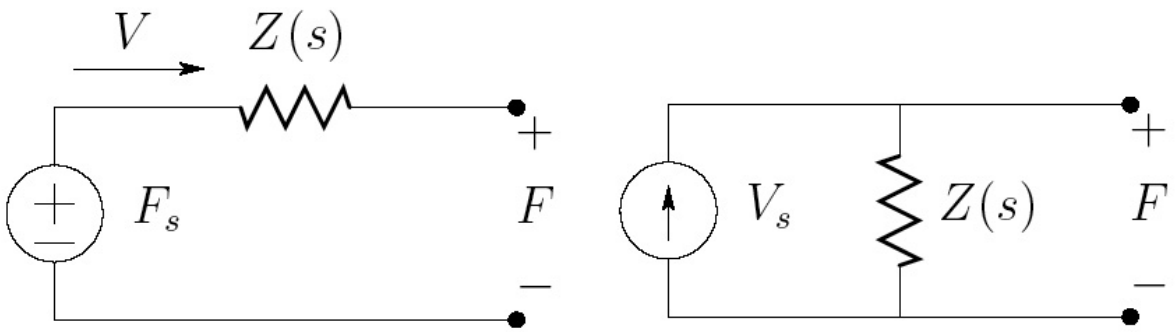


Figure 9.9: Thévenin and Norton equivalent networks.