Impedance and force control of robotic manipulators

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Michael Apelt
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Limits of position control

- Can not adapt to sudden changes in enviroment
- If path is obstructed and contact occurs, the controller will increase motor torque
- Risk of damage or injuries
- Not possible to work on geometrical complex workpieces
- Bad results for tasks, which need constant contact
- Loaded manipulators can not be seen as closed systems

Problems solved by force control

- Working on complex and variable workpieces
- Tasks, which require direct and constant contact
- Preventing damage and injury
- Measuring and recording of surfaces
- Enables teaching by guiding of the manipulator

Definition of force control

- Controlling the motion of a manipulator by adapting the force applied to its joints

- Force is measured at the end effector

- Force of motors is torque

History

- Salisbury (1980) first work on stiffness control
- Raibert / Craig (1981) combination of force and position control
- Koivo (1989) further development of the work of Raibert/Craig

Impedance

- Concept for understanding the flow of energy
- Push on a moving object with a force F and it moves with velocity v
- Energy transfered equals the force multiplied by the velocity

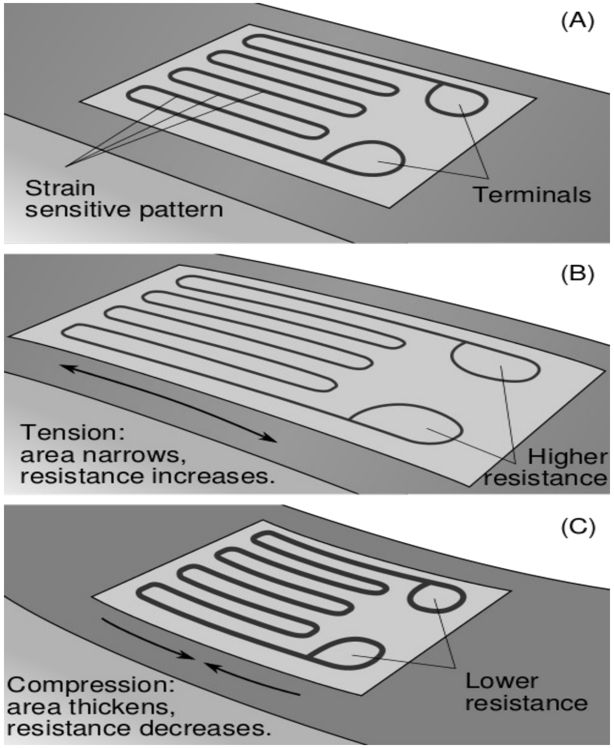
$$P=Fv$$

- Force and velocity are dependent
- For a harmonic force, the ratio of force to velocity tells you how hard it is to move the object

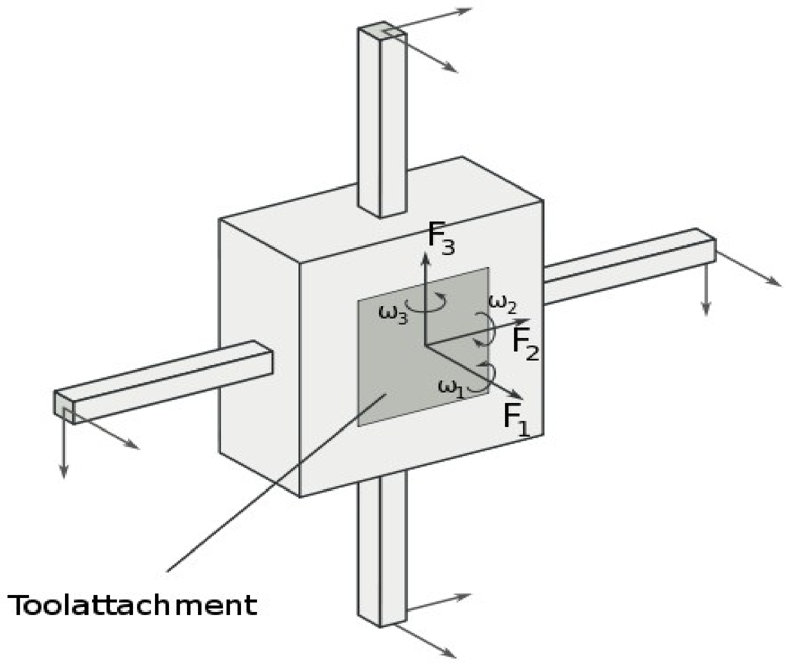
$$Z = F / v$$

Measurment of Force

Foil strain gauge



Six axis force and momentum sensor



- Translation of force and momentum to the end effector

Estimating the force

- Especially six axis sensors are expensive
- Addional wires at the manipulator
- Susceptible to damage
- Limits the maximal load of manipulator

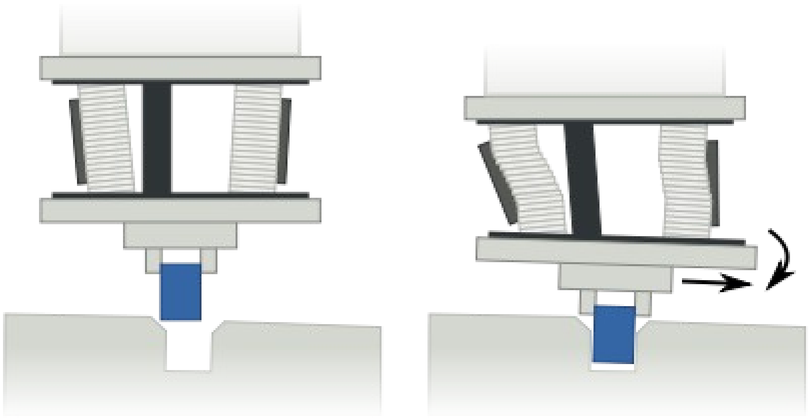
- Motor current proportional to torque in a defined range
- Cheap and reliable, but not so accurate
- Loads, inertia and friction must be taken into account

Ways to control the force

- Adapting Impedance
  - Passive
  - Active
- Direct Force Control
  - Exclusive
  - Parallel
  - Hybrid

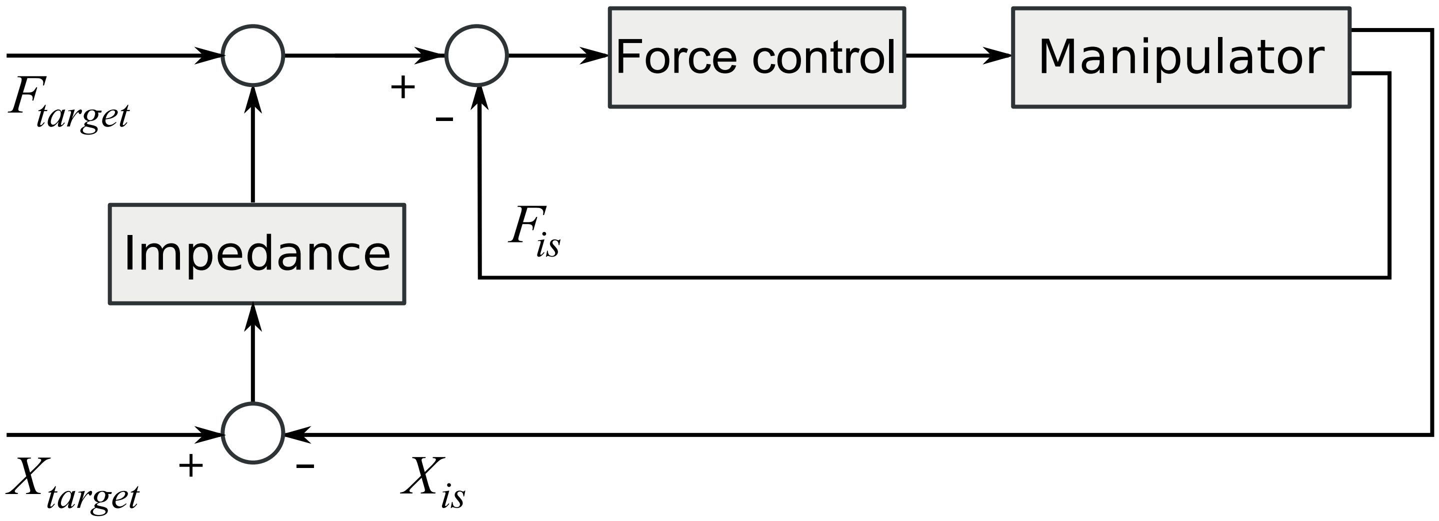
Passive Adaption of Impedance

- Special tools
- Expensive and limited to specific task
- No control needed → nearly instant adaption
- e.g Remote Center Compliance



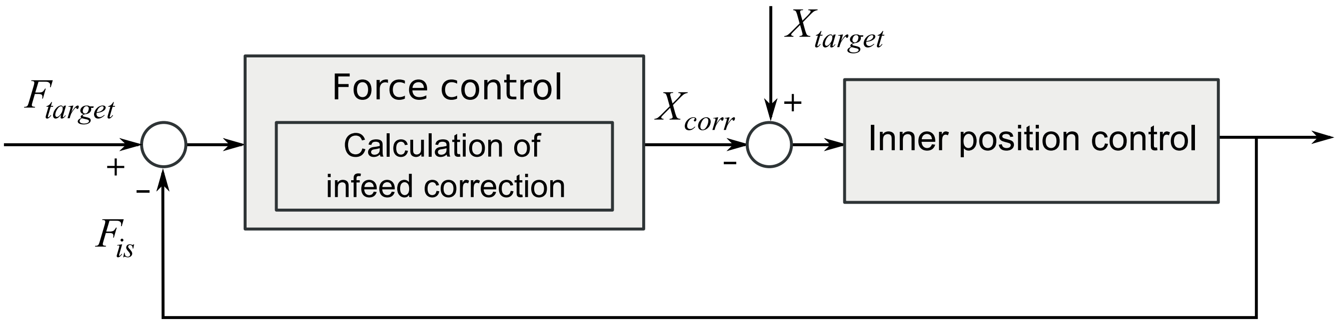
Active Adaption of Impedance

- mass–spring–damper system $f(t) = d \cdot x(t) + b \cdot \dot{x}(t) + m \cdot \ddot{x}(t)$
- Motion: position *x(t)*, velocity *ẋ(t)* and acceleration *ẍ(t)*
- Modificator: stiffness *d*, damping *b* and inertia *m*



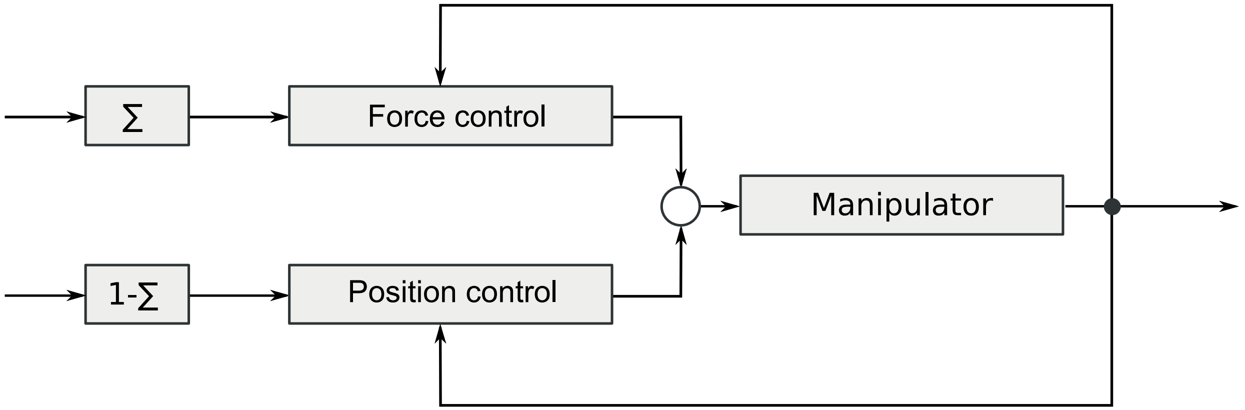
Parallel force control

- Cascaded control
- Force control has higher priority → position error may be accepted
- Position control can be changed into a more dynamic velocity control



Hybrid force control

- Position or force control
- Predefined Matrix Σ for the constrained zone and directions
- Switchable on force threshold



Establishing and holding contact

- Impact is critical point
- Sudden change of control structure
- 3 stages:
  - Free motion
  - Establishing contact = impact
  - Holding contact
- Implementation depends on type of control

Further development

- Adaptive Force control:
  - Used for unkown parameters and enviroment
  - Changing control may be unstable
  - Intensive offline testing
- Fuzzy-Control and Machine Learning
  - Used, when precise system modell is not available
  -

Questions?

Feedback?