Impedance and force control of robotic manipulators

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Limits of position control

- Can not adapt to sudden changes in environment
- 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 transferred 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
  $Z = \frac{F}{v}$
Measurement 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
- Additional 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 \( \dot{x}(t) \) and acceleration \( \ddot{x}(t) \)
- Modifier: 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 $\Sigma$ 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 unknown parameters and environment
  – Changing control may be unstable
  – Intensive offline testing

• Fuzzy-Control and Machine Learning
  – Used, when precise system model is not available
Questions?

Feedback?