14. Force Control

Today's Topic outline

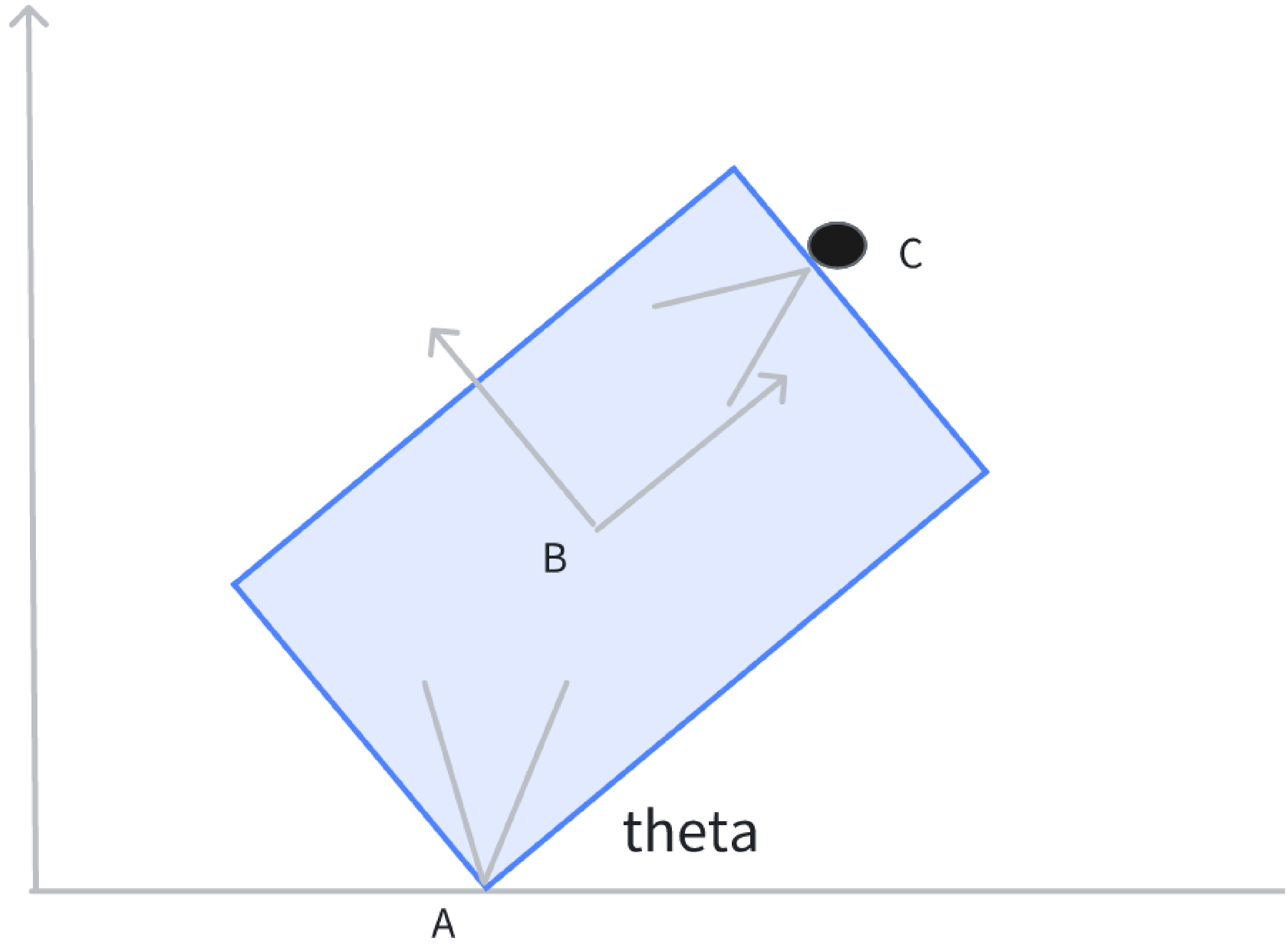
- Manipulation is more than pick and place. Gripper not large enough, objects gathered unorderly
  - Prehensile manipulation ~ grasping
  - Non-Prehensile manipulation
  - The need for regulating force
- Impedance Control
  - Point finger robot in 2D case

    - Free body diagram for the finger (R~robot)
    - force balance (static equation)
    - $f^{Rr}_{gravity} + f^{Rr}_{contact} + u = 0$, u: control effort
    - $F^{Rr}_{gravity} = [\tau^{Rr}_{gravity}, f^{Rr}_{gravity}]'$, $f^{Rr}_{contact} = -u - f^{Rr}_{gravity}$
    - So if we have a desired contact force/torque, follow this control law:
    - $u = -f^{Rr}_{contactDesired} - f^{Rr}_{gravity}$ The same happens in big robot scenarios.
    - **Important: What happens if not in contact following this strategy?** Robot gonna accelerated in the oppsite of desired force direction to make the contact. Thats why people like locomotion being done in a force controlled mannar.
    - This is actually one of the reasons that people like force control in walking. Walking robots there'll be extra effort to put sort of force control either by sensing the feet or by having torque control in the legs right. When you're swinging your leg forward people often use position control for that because they want to control where the foot plates plans. But as soon as you go into the mode of trying to be in contact with the ground, then you tend to try to use force control if it's available on your robot. That's precisely because you want to be relatively insensitive to the location of the ground.

- What happens after making contact? The box's movement will depend on friction cone & force scales: resides or move.

1. Direct force control: lifting the box in 3D space

- Directly control the interaction forces explicitly
- Spatial force representation needed



- F_{finger}^{Bc} , the force between finger and the box, which is described in frame C. It is applied to body B at point C.
- Force, where it is applied to, where it is expressed in. Dealing with care.
- $F_{gravity}^{Bcom}, F_{ground}^{B_A}$
- $F_{finger,C_z}^{Bc} \geq 0$ spatial force between finger and box taking in the Cz direction must greater than 0, finger doesnot pull
- $|F_{finger,C_x}^{Bc}| \leq \mu_c f_{finger,C_z}^{B_c}$
- Direct force control based on optimization
- $\tau_{finger,A}^{B_A} = PID(\theta_d, \theta)$, subject to friction cones
- Using static analysis to create a non-zero moment, to break equilibrium in the moment direction

- Direct force control should depend a little less on geometry. In simulation, don't assume knowing the position of finger, but box can be lifted too.
- Torque PID controller to be the objective, friction cone is the constraint; or you can switch them to get different control goal.

2. Indirect force control

Program the dynamics of interaction; Do not program the force explicitly, program the way you want forces to react.

- Stiffness control:
  - Creating a virtual spring, program the stiffness of the spring. You change the location of origin of spring to get the desired spring force.
  - I would like the response of my finger to that contact to be as if I was still moving towards this point, but somebody knocked me and I'm going to respond as if I was attached to a spring.
  - Instead of program explicitly the force, you gonna program the stiffness of that spring and damper.
  - $m\ddot{q} = f^{R_r}_{gravity} + u + f^{R_r}_{contact}$
  - Goal: $m\ddot{q} + b\dot{q} + k(q - q_d) = f^{Rr}_{contact}$, mass is mass of finger
  - $u = -f^{R_r}_{gravity} + k(q_d - q) - b\dot{q}$, after gravity compensation term, PD can tuned really small
  - Advantage: when contacting the environment, nothing gonna go crazy/unstable. There is whole theory about passivity theory or more generally Port Hamiltonian theory stating that under some passive assumption of environment, the controller is stable.
  - Franka/IIWA human safe functionality are based on sort of passivity theory and the passive properties of their controllers
  - The biggest point of this lecture: it turns out, programming the stiffness is an extremely intuitive way to do some interesting complex contact tasks. Naturally doing the right thing.
- Impedance control
  - very similar to stiffness control
  - impedance control if you also program the mass, m,b,k both tuned to get better control results
  - IIWA, reshape the rotor inertia, not link inertia, because that would have exceeded the bandwidth requirements.
- Stiffness vs Impedance control

- Programming the interaction (indirect force control) can be way better. If you are designing a learning controller in RL or if you are running behavior cloning, it is much more natural ways for some tasks.

3. Student Questions

1. Handcraft planning or learing planning?
    a. Russ: so there's a whole world of extending motion planning to planning these kind of maneuvers. You can also do reinforcement learning to do to get them. There's a handful of approaches we'll talk about to to get these sort of planning through contact or control through contact.
    b. Oftentimes I would say that the tide is turning I think it not it wasn't long ago where people would handcraft them and we're starting to now replace those with you know automatically generated.
2. Impedance control
    a. mass of robot, mass of finger(might reshaped), how can input u impose both of them
    b. Donot use feedback accelerations, donot put high acceleration feedback into high bandwidth feedback control. Minimal sensing requirement