RelaxedIK: Real-time Synthesis of Accurate and Feasible Robot Arm Motion

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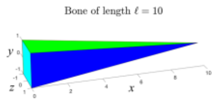
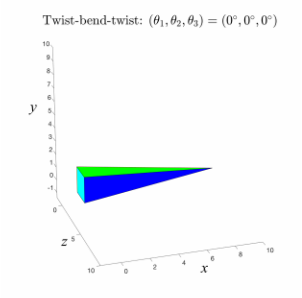
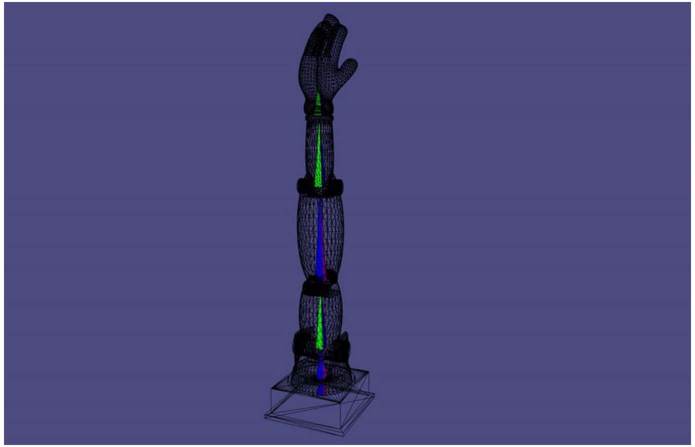
University Of Toronto, CSC-2621, Paper Reading Seminar

Recap: Forward Kinematics (FK)

1. Forward Kinematics
    a. A common robotic skeleton is a tree of rigid bones
    b. The relative Euler angles of all the bones determine the end-effectors
        i. End-effectors? A tool that's connected to the end of a robot arm

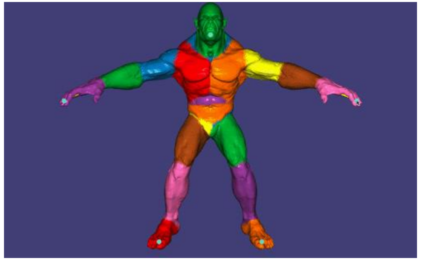






Recap: Inverse Kinematics (IK)

1. Inverse Kinematics
   a. The indirect control of forward kinematics makes it hard to use in application
      i. Achieve certain poses?
      ii. Achieve certain velocities (reward)?
   b. We formulate the inverse kinematics function as: $\Theta = IK(\mathbf{p})$, which can be easily written in an analytic form for a simple tree skeleton.
      i. Pose contains velocity?
      ii. Hard to find feasible state space?
   c. In reality, IK is often treated as an optimization problem



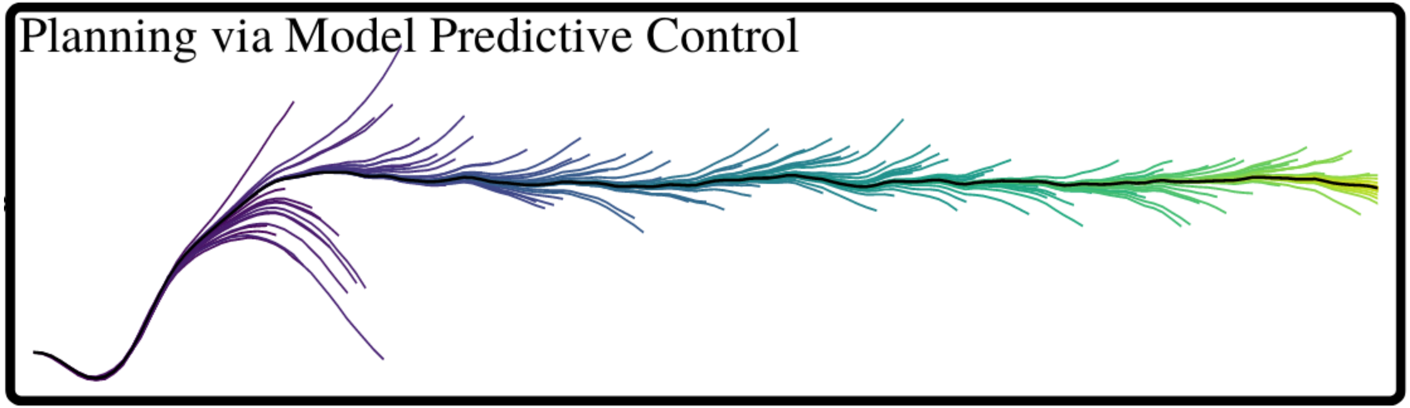
$$\chi_p(\Theta) = ||\ \mathbf{p}_g - FK(\Theta)\ ||_2$$

Imitation Learning

1. Imitation learning has been studied by different communities
    a. Motion synthesis in character animation?
    b. Inverse optimal control?
    c. Imitation learning?

Imitation Learning

1. Imitation learning has been studied by different communities
2. Within the focus of this course, people worked on imitation learning using
    a. Forward dynamics
        i. Shooting method (optimize the actions)



Imitation Learning

1. Imitation learning has been studied by different communities
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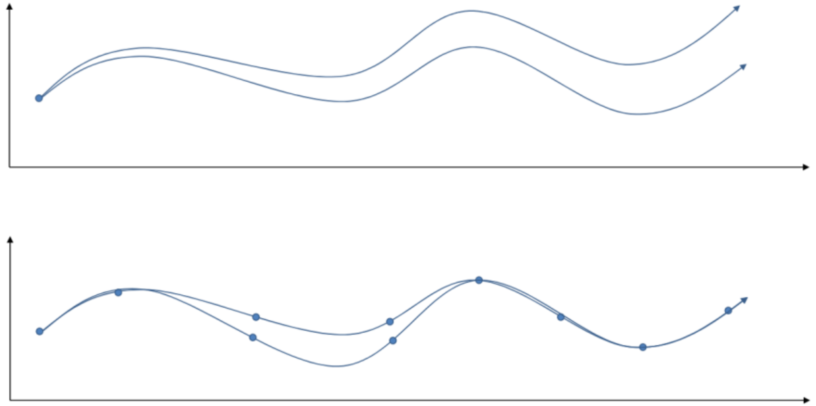
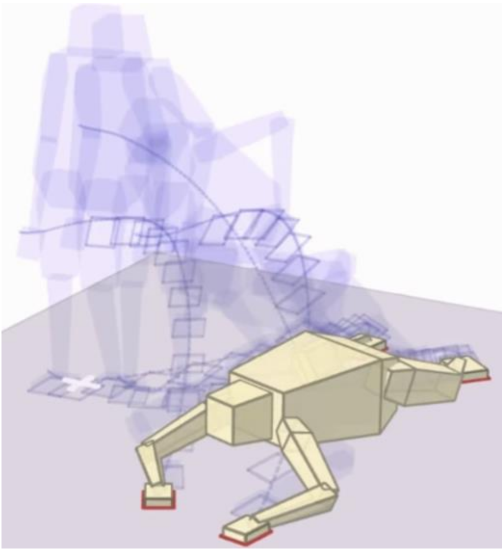
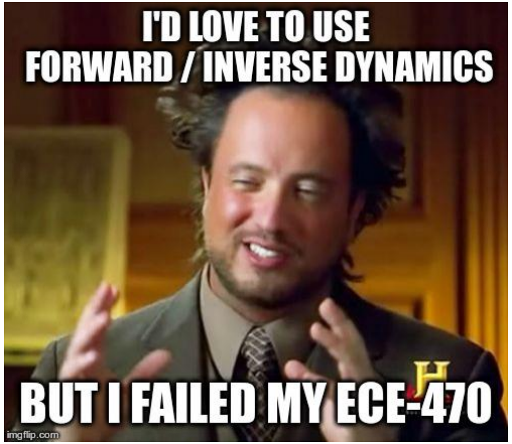
   a. Forward dynamics
   b. Inverse dynamics
      i. Collocation method (optimize states)





Imitation Learning

1. Imitation learning has been studied by different communities
2. Within the focus of this course, people worked on imitation learning using
    a. Forward dynamics
        i. Shooting method
    b. Inverse dynamics
        i. Collocation method
    c. Model-free method
        i. GAIL
    d. Motion synthesis with IK
        i. Today's paper
        ii. Old school but with new techniques



Imitation Learning

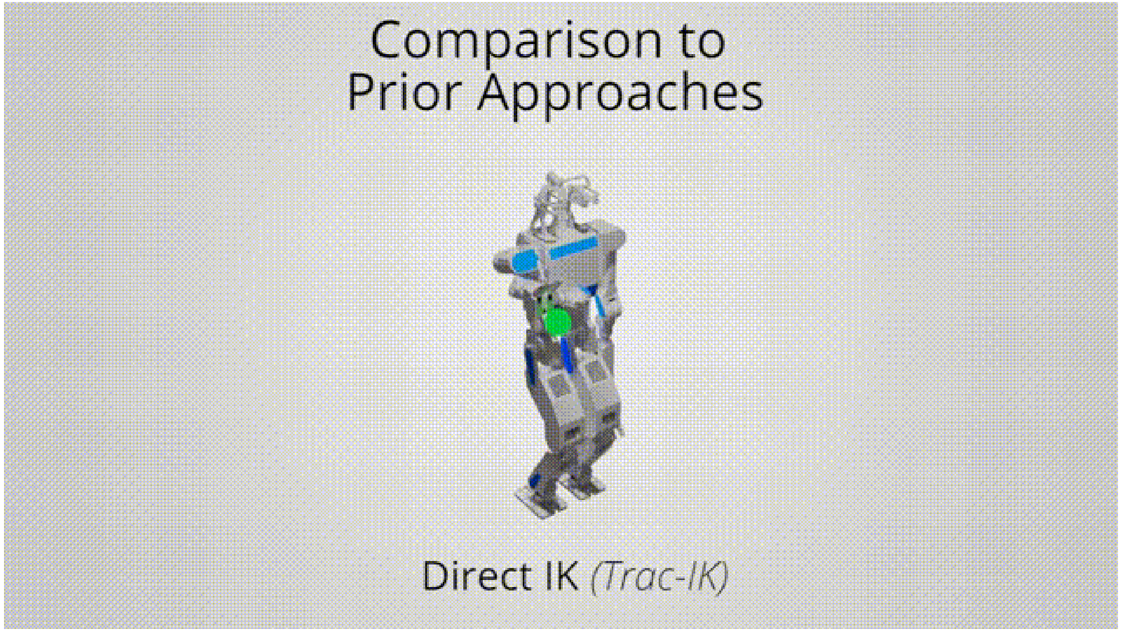
1. Imitation learning using IK
    a. Basic idea: Using IK to bridge between target pose and agent's angles
    b. Input: M (consecutive) expert (goal) poses
    c. Output: M (consecutive) frames of agent's euler joints
    d. Constraints:
        i. IK constraints (goal constraints)
        ii. Between-frames constraints
        iii. Etc.

Imitation Learning

1. Imitation learning using IK
   a. Basic idea: minimize the difference of target pose and agent pose
2. Direct point-to-point approach
   a. TRAC-IK (previous state-of-the-art)
   b. Pose2pose / frame2frame imitation learning
      i. Ignore most of the constraints between frames
   c. Problems
      i. Self-collision
         1. Time constraints

Imitation Learning

1. Self-collision



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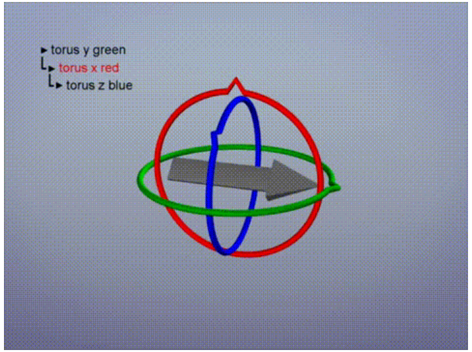
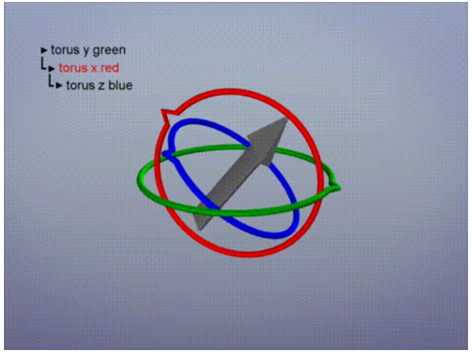
        i. Self-collision
        ii. Singularities

Imitation Learning

1. Singularities
   a. E.g. Losing a DoF
   b. Infinite control signals





Imitation Learning

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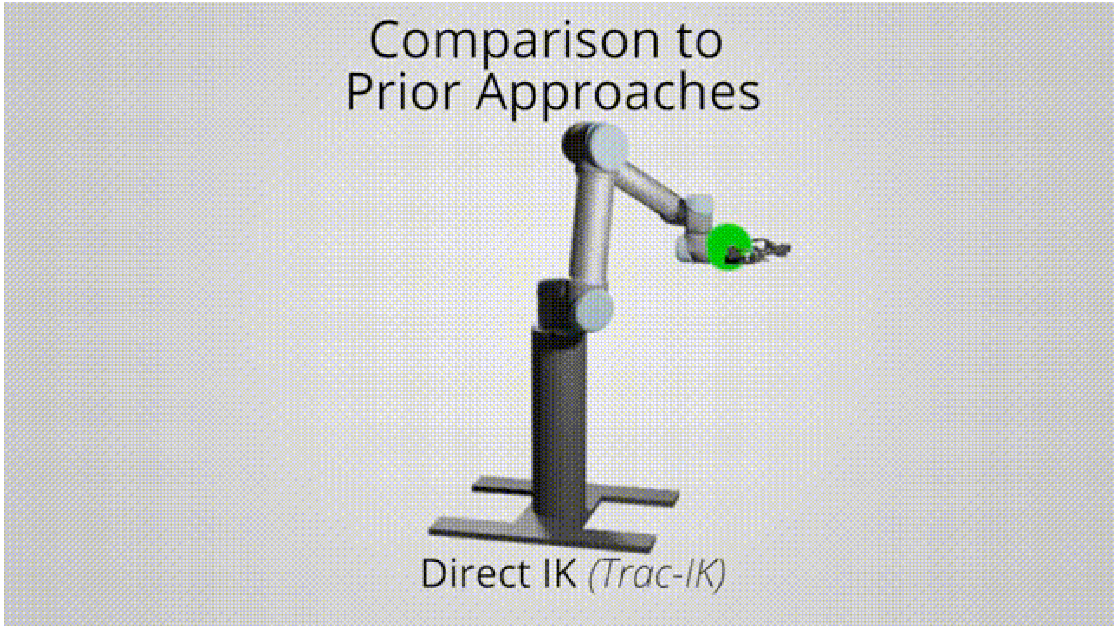
        i. Self-collision
        ii. Singularities
        iii. Discontinuity

Imitation Learning

1. Discontinuity

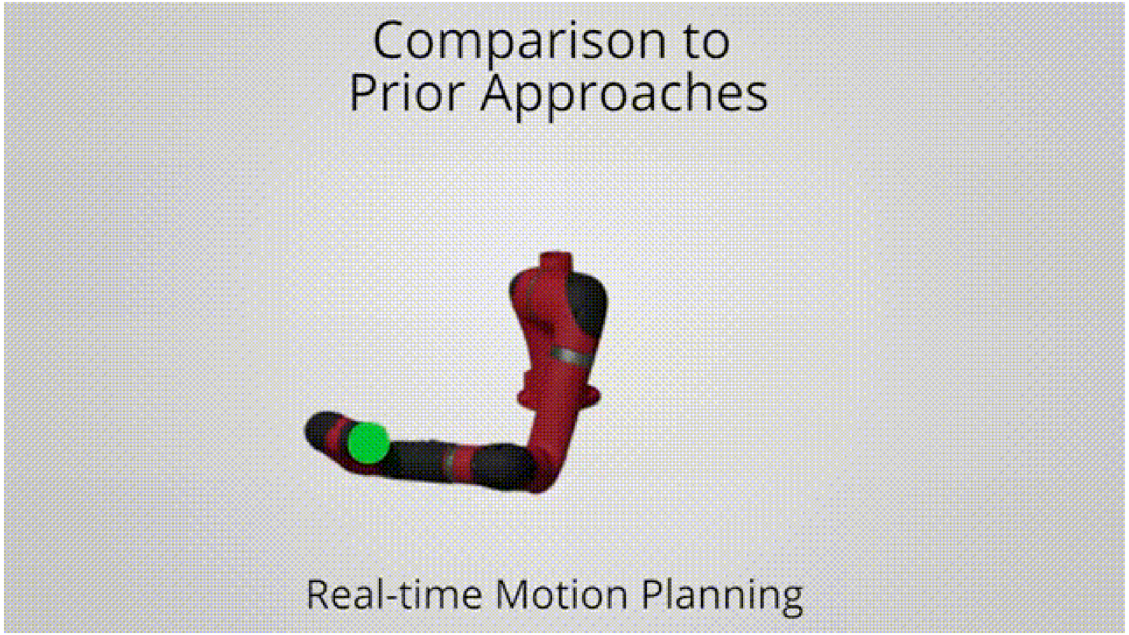


Imitation Learning

1. Imitation learning using IK
    a. Basic idea: minimize the difference of target pose and agent pose
2. Direct point-to-point approach
3. Real-time motion planning approach
    a. Output the (conservative) solutions real-time
        i. Always meet the control & collision constraints
        ii. Soft goal constraints
    b. Problems
        i. Goal mistracking

Imitation Learning

1. Goal mistracking



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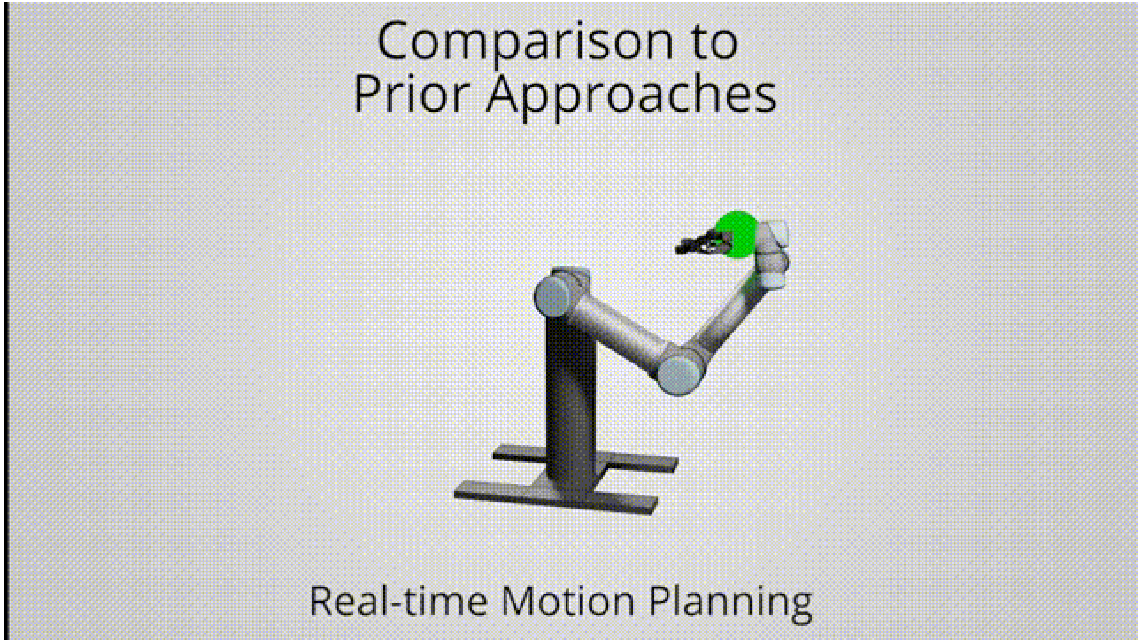
        ii. Unpredictable behaviors

Imitation Learning

1. Unpredictable behaviors



Relaxed IK

1. Basic Idea: Using soft (Relaxed) IK loss that considers self-collision and singularity for faster optimization

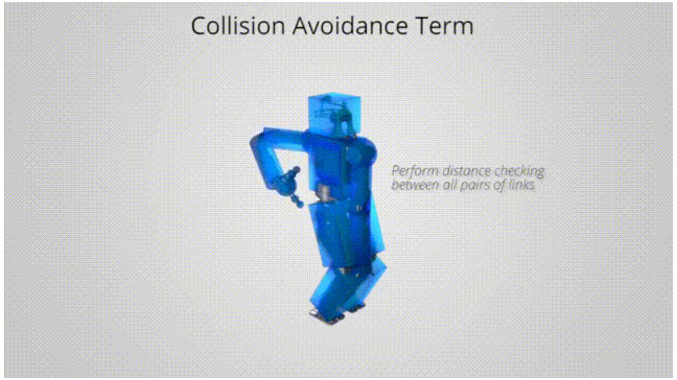
$$\mathbf{f}(\Theta) = \sum_{i=1}^{k} w_i f_i(\Theta, \Omega_i)$$

1. Loss functions
   a. End-effector position & orientation matching
   b. Minimize joint velocity, acceleration, jerk
   c. Self-collision loss (fast)
   d. Singularity loss

Relaxed IK

1. Self-collision loss
   a. Common approach: very slow
   b. Relaxed IK:
      i. Approximate how imminent the robot is to a collision state
      ii. Using simulated data to train a network to predict the distances between links

$$col(\Theta) = \sum_{i,j} b * exp(\frac{-dis(l_i, l_j)^2}{2c^2})$$



Relaxed IK

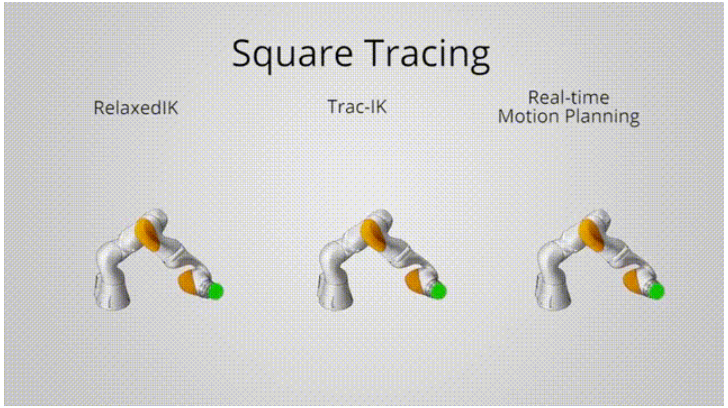
1. Singularity loss
   a. Kinematic singularities are well studied in robotics
   b. Relaxed IK:
      i. Find a metric that can approximate distance to a singularity
      ii. Jacobian's condition number is used as a proxy distance to singularity
         1. Why?

$$\dot{\mathbf{x}} = \mathbf{J}(\Theta)\dot{\Theta}$$

      i. Penalize condition values less than mean – b * std
         1. Estimate mean, std from simulated data

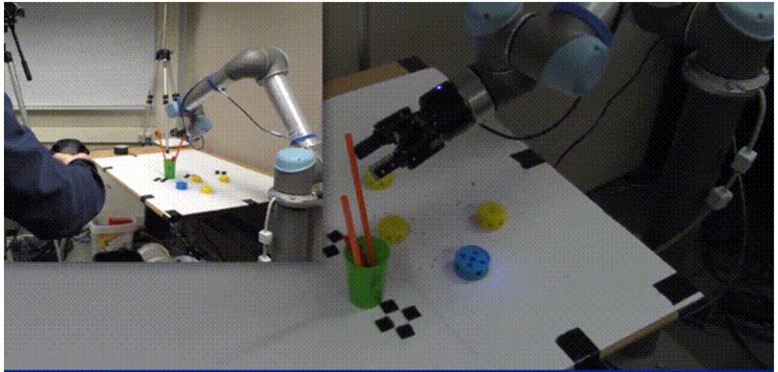
Relaxed IK

1. Pros
   a. Much faster and smoother performance
      i. combining neural network and traditional robotics
   b. Data driven, less human-engineering
      i. Novel singularity metric
   c. Easy to deploy
      i. Sim2Real



Relaxed IK

1. Pros
2. Cons
    a. No safety / convergence guarantee
    b. Weak experiments section
        i. Under-tuned baseline
        ii. Limited ablation study
    c. Slower than point2point methods
    d. Hyper-parameter sensitive



Rakita, D., Mutlu, B., & Gleicher, M. (2017, March).
A motion retargeting method for effective mimicry-based teleoperation of robot arms. HRI '17

Q&A

1. Thanks for listening ;P