The Kinematics of End-Effectors in Collaborative Robots

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Outline

- **Introduction**
  - **Collaborative Robots**
  - **End Effector Systems**
- **Kinematics in End Effectors**
- **Hand Guiding Applications**
- **Summary**

COllaborative RoBOTs

Cobot - robot with direct physical interaction

- a human user
- a shared workspace[3]

- Invented professors J. Edward Colgate and Michael Peshkin in 1996

- At Northwestern University[2]

Sawyer and Baxter cobots from Rethink Robotics.[1]

2 http://peshkin.mech.northwestern.edu/cobot/

3 https://en.wikipedia.org/wiki/Cobot#cite_note-1

1 https://www.roboticsbusinessreview.com/wp-content/uploads/2018/05/Sawyer_and_Baxter-300x229.jpg

End Effectors

Human-Hand Force-Closure[1]

- Device at end of the arm[2]
- Designed to interact with environment

Last Link of the Robot

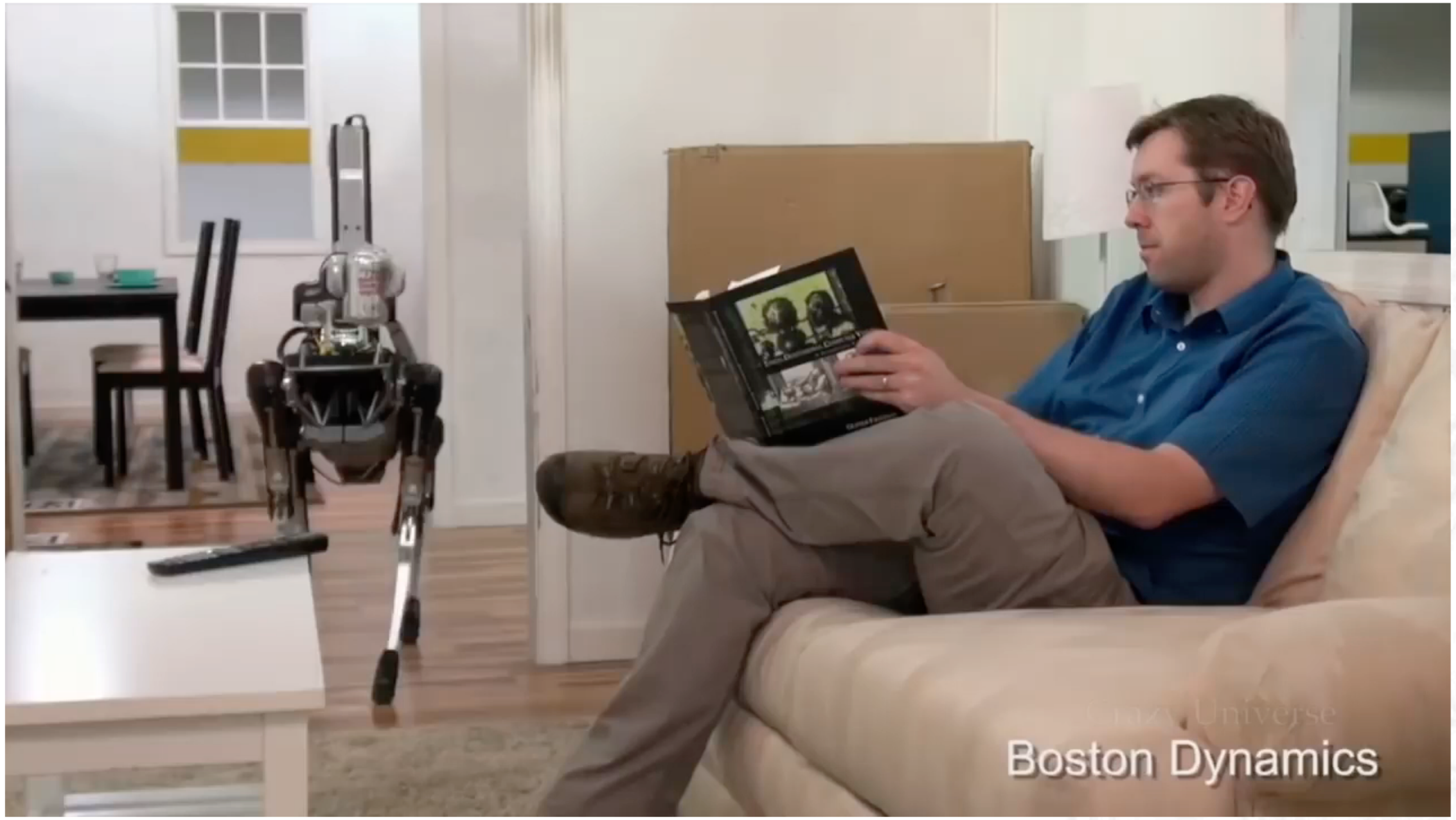
Types
- Impactive
- Ingressive
- Astrictive
- Contigutive

Magnetic Robot End-Effector[3]

2 https://en.wikipedia.org/wiki/Robot_end_effector

1 Richard Greenhill and Hugo Elias (myself) of the Shadow Robot Company
3 https://blog.robotiq.com/bid/65794/Magnetic-Robot-End-Effector-Top-5-Pros-and-Cons

Importance of End Effectors



https://www.youtube.com/watch?v=1EpJv34gQ88

Kinematics

Forward Kinematics

- Description of End-Effector Configuration (Position & Orientation)
- Function of Joint Coordinates

Reverse Kinematics

- Description of Joint Coordinates
- Function of End-Effector Configuration

$\Rightarrow$**What are we learning?**

$\Rightarrow$**Relative pose between frame coordinates**

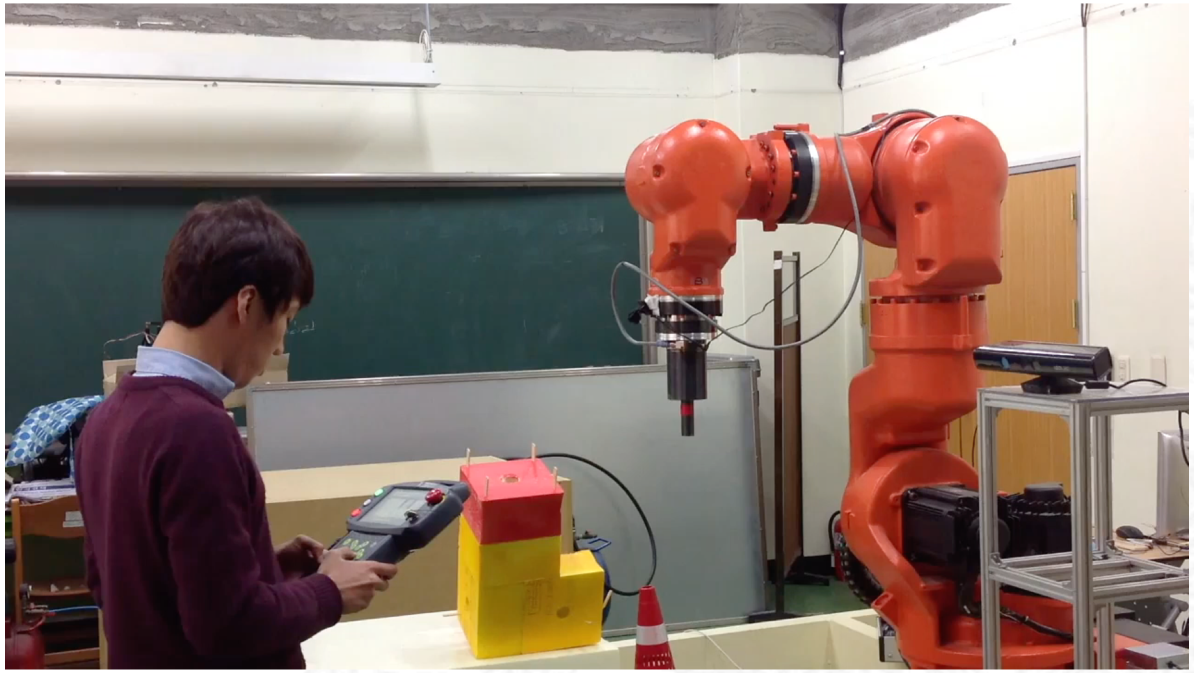
Kinematics

Influencing Factors: [6]

- End-Effector Weight
- Degree of Freedom
  - Number of joints
  - Length of the links
- External force/moment
  - Human force
  - Collisions in dynamic environments
- Noise
  - Inertial Forces/moments dues to acceleration
  - Friction at joints

Hand Guiding

-> Representative Functionality of Cobots



- Teaching Pendant -> Unskilled users **interact** and **program** robots

⇒**Limits intuitiveness**

⇒**What are we teaching them?** [4]

⇒**Position and Orientation**

https://sites.google.com/site/hoomanleerobot/research

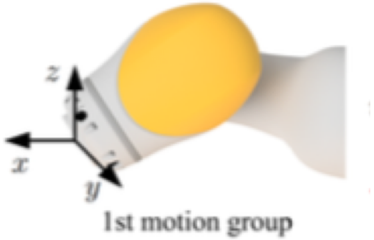
Hand Guiding

Assumption

- A Force Feedback at the robot end-effector

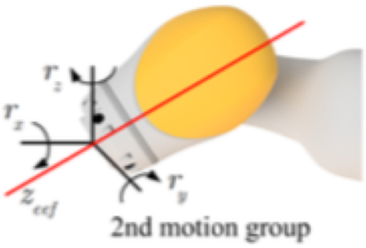
Three m

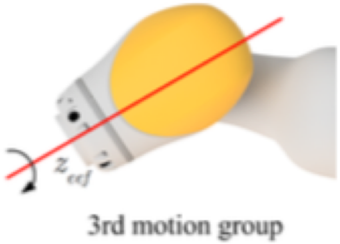
1. Positi
   coord
   base



space

round





Hand Guiding Force -> Linear positioning

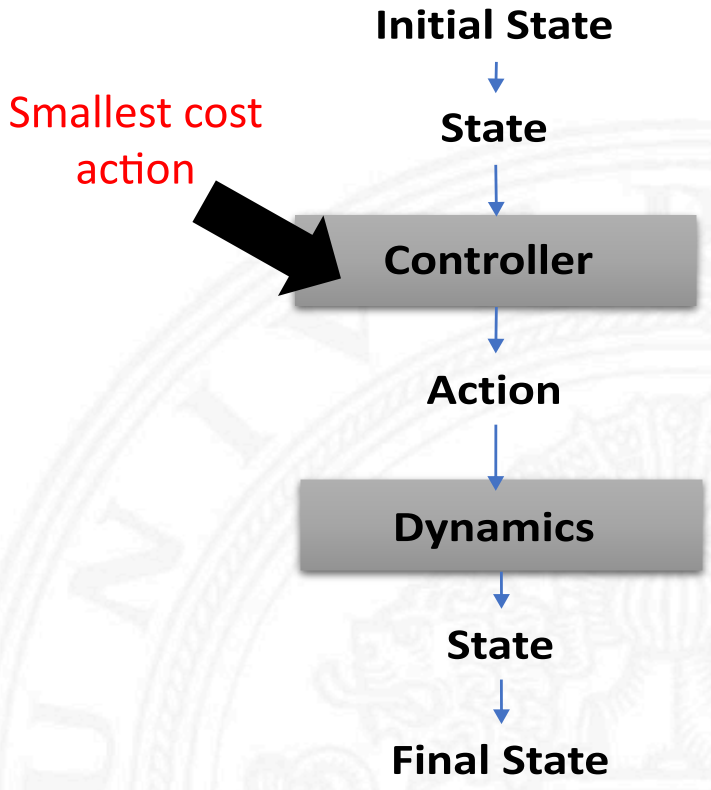
Hand Guiding Moment-> Angular positioning

Self-Learning: Trajectory

Aim: Learning of a Trajectory

- **Trajectory** [2]
  - A length defined by repetition of pattern

  - State – joint position vectors
  - Controller – optimization function
  - Action – joint target positions
  - Dynamics – cost function and next state

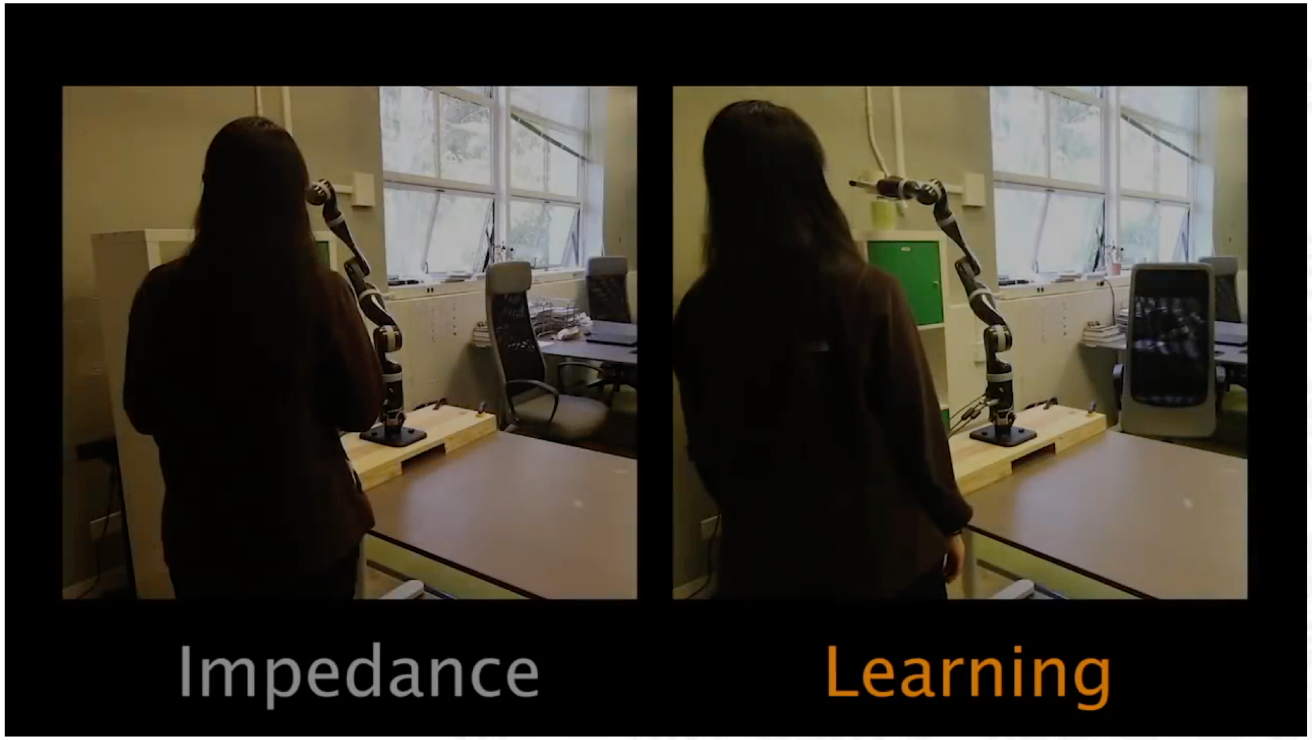


Trajectory Pattern [2]

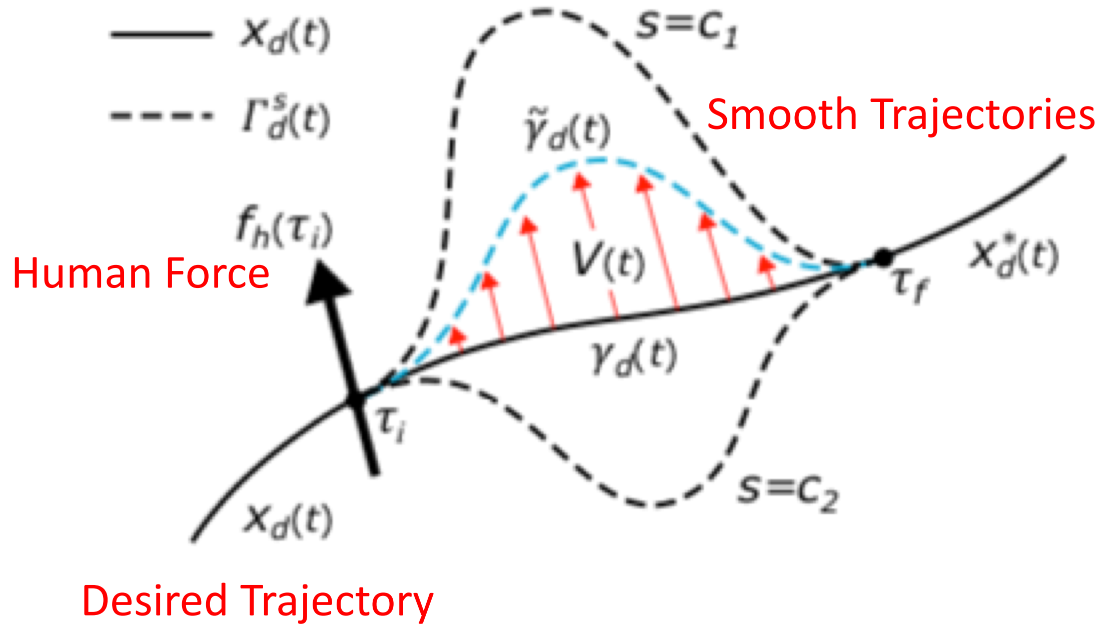
Self-Learning: Trajectory

Aim: Learning of a Trajectory

- **Challenges** [3]
  - **Desired** future trajectories
- **Solution**
  - Impedence Control with Interactive Trajectory Deformation



Self-Learning: Trajectory



Trajectory Deformation [3]

1. Energy Function

Maps: trajectory deformations
-> cost function

2. Constrainted Optimization

Fixed end point
-> Position
-> Velocity

3. Variation Field Estimation

-> Trajectory deformation

Self-Learning: Trajectory

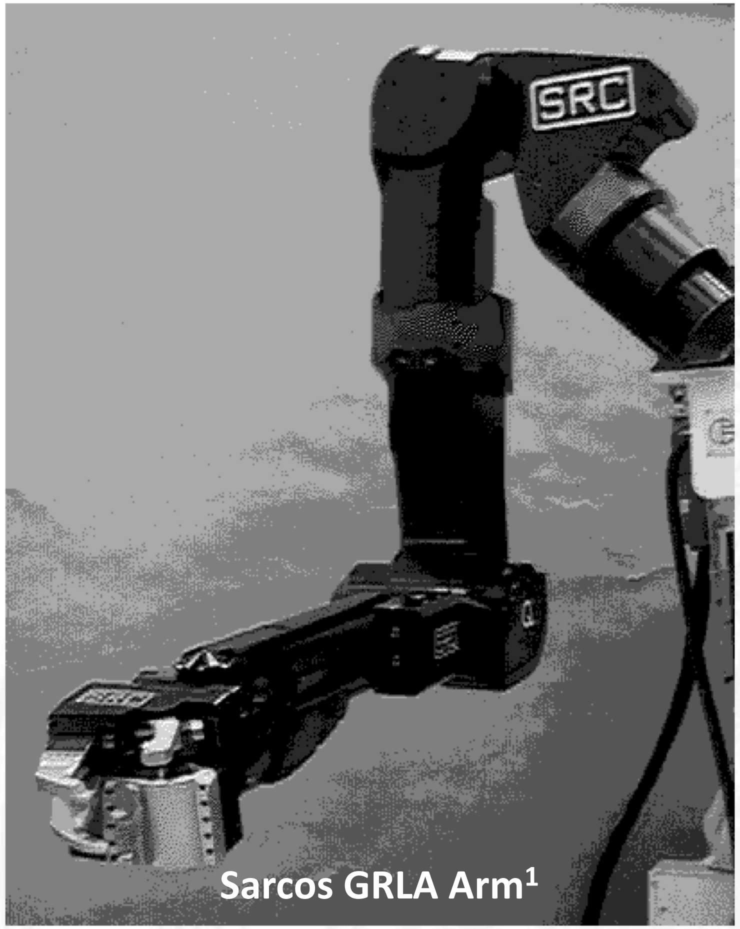
Achievements

- Compatible with traditional Impedence Control
- Experiments
  - ✓ Reduction in human intervention
  - ✓ Reduction in torque application
  - ✓ Improvement in movement quality

Self-Learning: Gripper

Aim: Learning of Gripper Orientation

- **Dextrous Gripper Mechanism[2]**
    - Inputs: Position, force and vision Sensors
    - Robot joints – Position and Velocity
    - Fingers and Arms - Force
    - Controller: Torque Control
        - Robot joints
        - Robot hand fingers



Sarcos GRLA Arm[1]

2 http://users.cecs.anu.edu.au/~rsl/rsl_dextrous.html

1 http://www.cim.mcgill.ca/research/94-95AnnualReport/node99.html

Self-Learning: Gripper

Aim: Learning of Gripper Orientation

- **Challenges**[5]
  - Correspondence problem
  - Generalization
  - Robustness to Disturbances
- **Solution**
  - Modified Dynamic Movement Primitive Framework

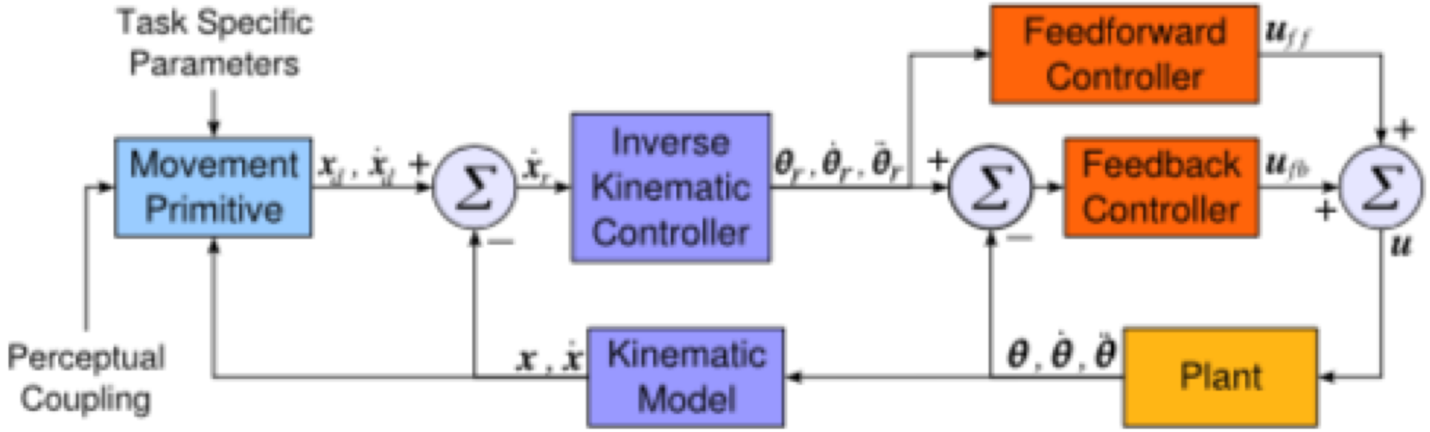
Self-Learning: Gripper

1. Dynamic Movement Primitives

Transformation & Canonical System
-> Converges to a Goal

2. Obstacle Avoidance

Coupling Term
-> Rotational Matrix
-> Relative angle



DMP Control Diagram [5]

Self-Learning: Gripper

Achievements

- ➢ Improvement to dynamic movement primitives
- ➢ Experiments
  - ✓ Adapt movements with changing goals
  - ✓ Adapt movements with moving obstacles
  - ✓ Movement library that could be reused

Summary

- ✓ **Introduction**
  - ✓ **Collaborative Robots**
  - ✓ **End Effector Systems**
- ✓ **Kinematics in End Effectors**
- ✓ **Hand Guiding Applications**
  - ✓ **Trajectory**
  - ✓ **Gripper**

References

[1] Monkman, G. J.; Hesse, S.; Steinmann, R.; Schunk, H. (2007). *Robot Grippers*. Wiley-VCH. p. 62.

[2] Joris Gué́rin, Olivier Gibaru, Eric Nyiri and Sté́phane Thiery, *Learning local trajectories for high precision robotic tasks : application to KUKA LBR iiwa Cartesian positioning.*

[3] Dylan P. Losey, Student Member, IEEE, and Marcia K. O'Malley, Senior Member, IEEE, *Trajectory Deformations from Physical Human-Robot Interaction.*

[4] Mohammad Safeea, Richard Bearee, and Pedro Neto, *End-Effector Precise Hand-Guiding for Collaborative Robots.*

[5] Peter Pastor, Heiko Hoffmann, Tamim Asfour, and Stefan Schaal, *Learning and Generalization of Motor Skills by Learning from Demonstration.*

[6] Hatem A. Al-Dois, A. K. Jha and R. B. Mishra. *Investigations into the Parameters Influencing the Dynamic Performance of 3-RRR Planar & Articulated Robot Manipulators*

Thank you.