An Experimental Test Bed For Robotic Grasping

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Thesis Presentation

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Outline

- Control System Design
  - Disturbance Rejection
  - Trajectory Formation
  - Selecting Control Gains
- Camera Design
  - Calibration Procedure
  - Coordinate Frame Transformations
- Database and Software Setup

System Dynamics

- Centrifugal/Coriolis negligible at low speeds
- Gravity is simple given the forward kinematics
- Friction is more difficult
  - Highly non-linear
  - Hard to estimate

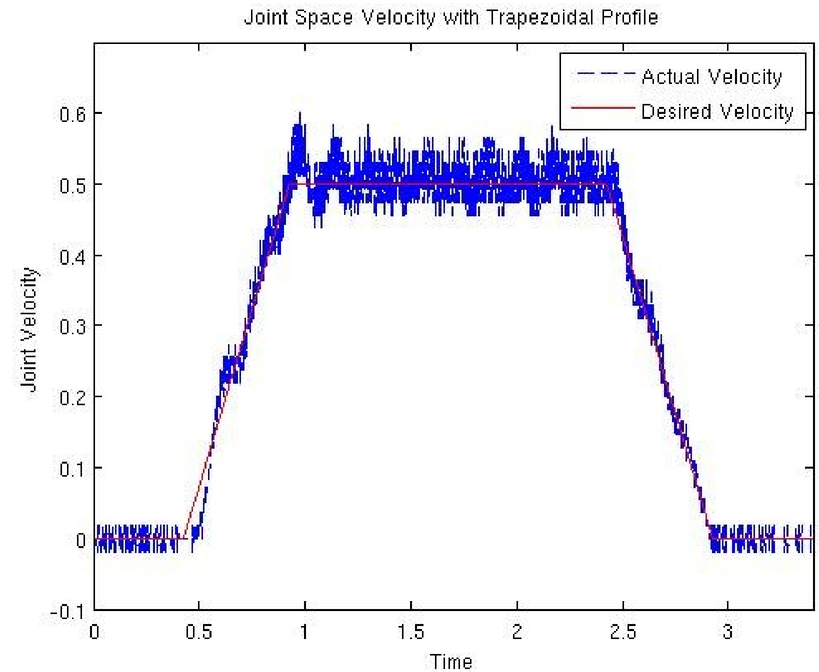
$$\tau = M(q)\ddot{q} + C(q, \dot{q}) + G(q) + B(q, \dot{q})$$

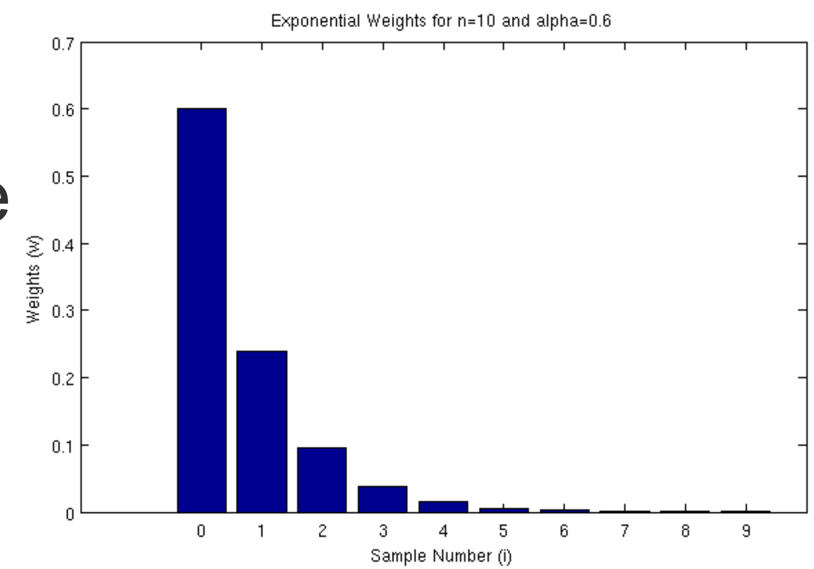
Velocity Feedback

- Differentiate position using Backward Euler

$$\dot{q}[k] = \frac{q[k] - q[k-1]}{\Delta t}$$

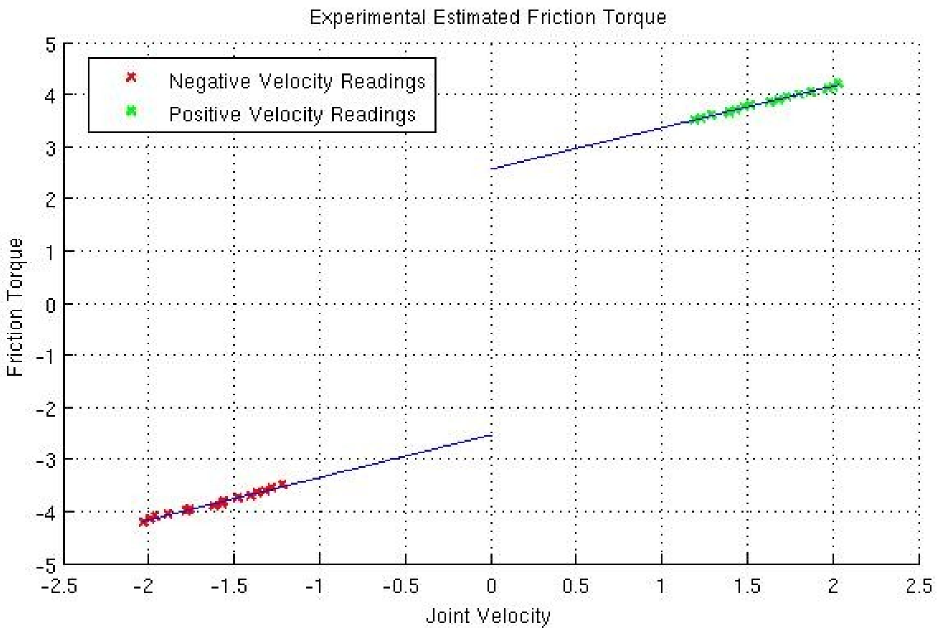
- Filtering Methods
  - Simple Moving Average
  - Exponential Moving Average
- Kalman Filter

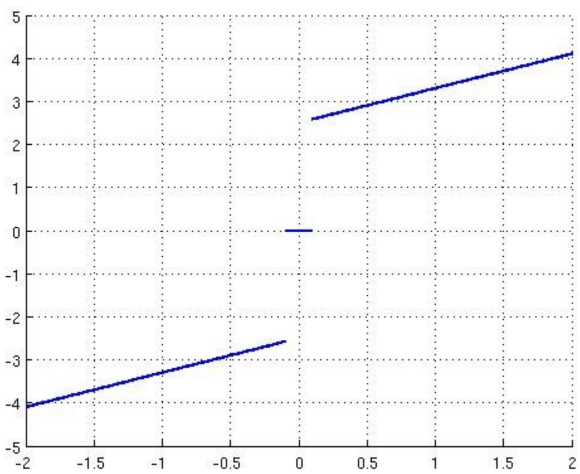


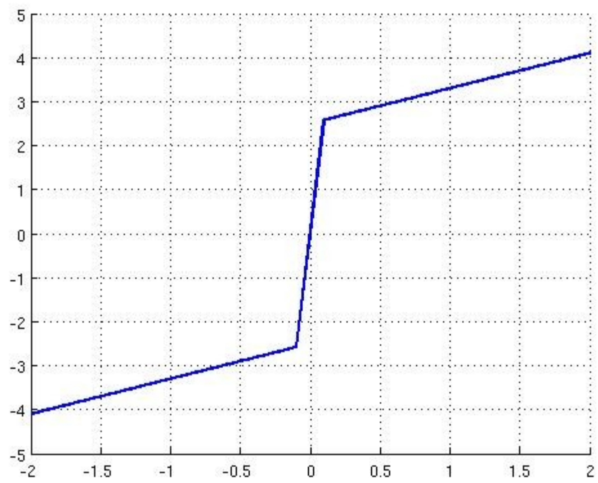


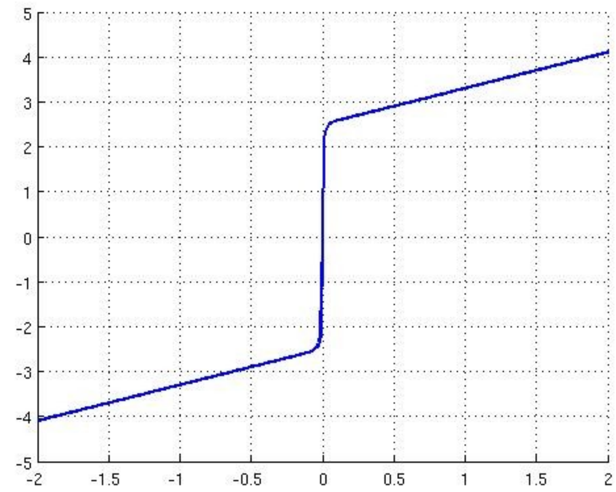
Friction Compensation

- Difficult due to poor velocity feedback
- Tough to model non-linearities









Controller Design

- Gravity + PID, neglect friction for now
- PID Output
  - Torques

$$\tau = G(q) + (K_p e + K_d \dot{e} + K_i \int e\, dt)$$

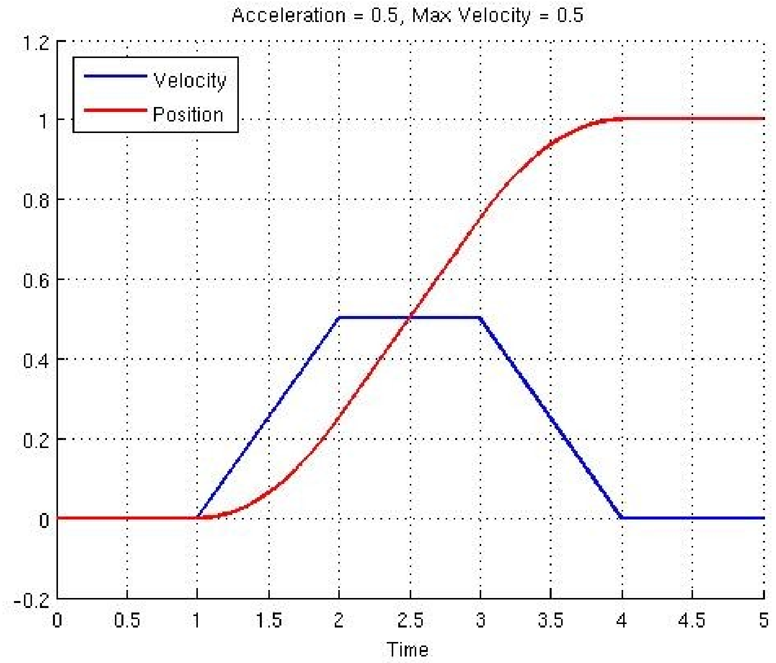
  - Accelerations

$$\tau = G(q) + M(q)(K_p e + K_d \dot{e} + K_i \int e\, dt)$$

- Jacobian for Cartesian space

Gain Selection

- Manual Selection
- Inertia Parameters
  - Similarity Transformation
  - Parallel Axis Theorem



$$M_i^j = R_i^j M_i^i (R_i^j)^T + m_i \begin{bmatrix} y^2+z^2 & xy & xz \\ xy & x^2+z^2 & yz \\ xz & yz & x^2+y^2 \end{bmatrix}$$

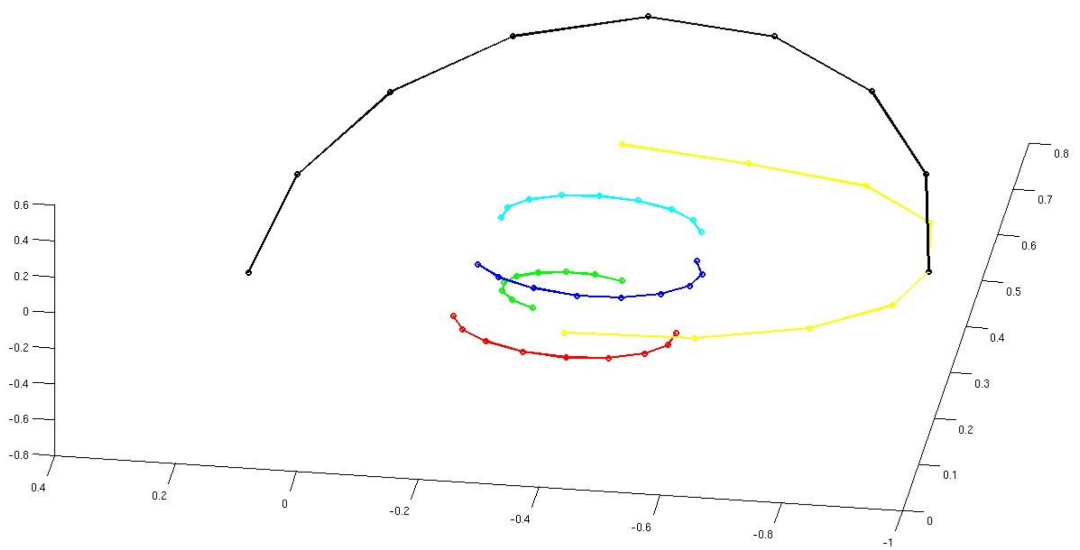
Interpolating Orientation

- Using axis-angle method
  - Two solutions for each rotation matrix
    - Axis +, Angle + ↔ Axis -, Angle -
  - Singularities at 0, 180 degrees
- Eventually implement quaternions + SLERP
  - Two solutions for each rotation matrix
  - Can become unstable near 0, 180 degrees but solution stays finite

Camera Calibration

- Wanding and Ground Frame
  - Cameras determine position/orientation in space
- 2[nd] calibration transforms data into WAM frame
  - Non-linear least squares
  - i = marker index, j = configuration index

$$r_{ij} = HT_{base}^{cam} \begin{bmatrix} p_{ij} \\ 1 \end{bmatrix} - HT_0^1(q_j) \begin{bmatrix} s_i \\ 1 \end{bmatrix}$$



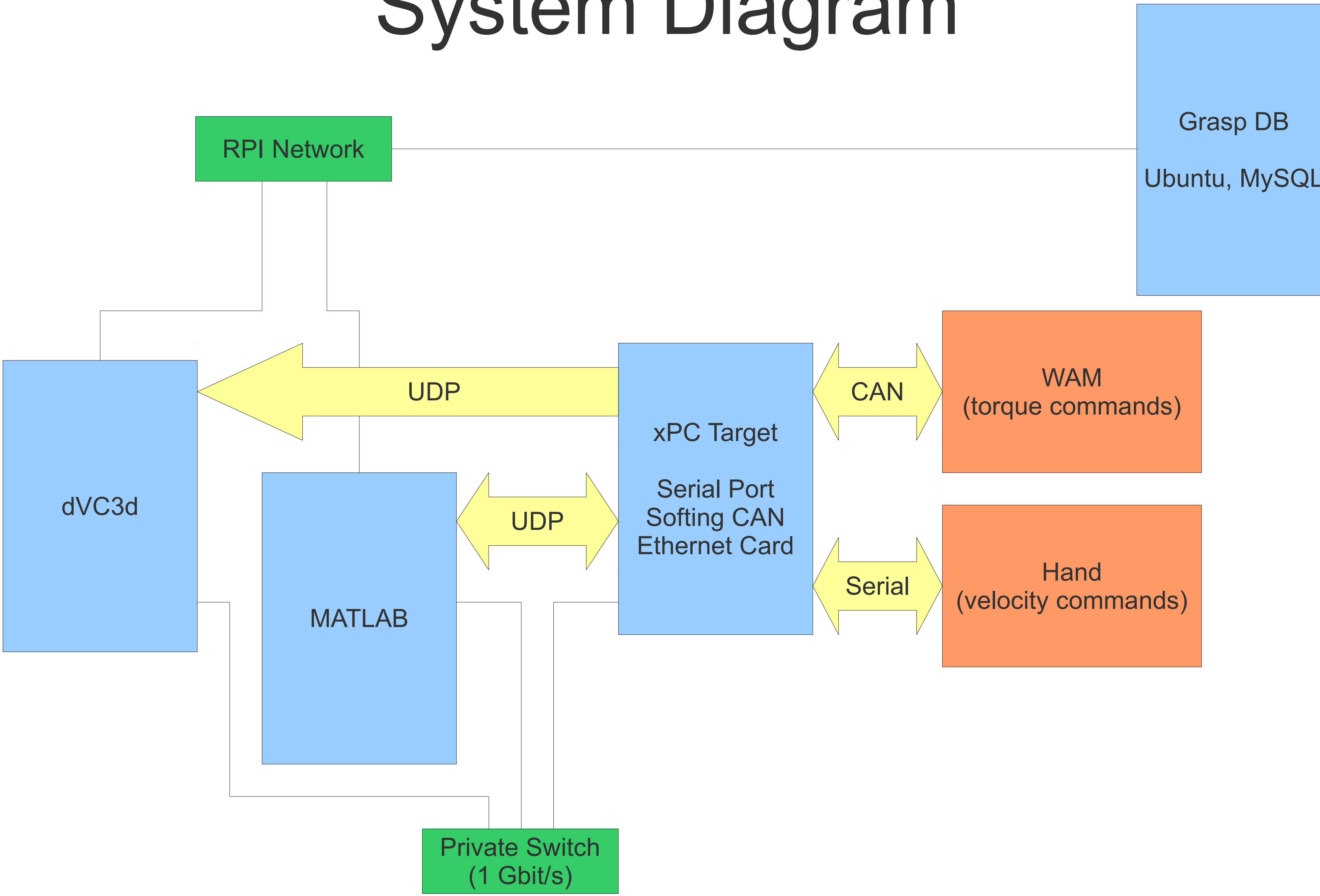
Coordinate Frame Transformations

- Left to right handed system
  - Flip any one axis (we choose the z-axis)
  - Axis +, RH rule ↔ Axis -, LH rule (same angle)
- Use transformation matrix into WAM frame

$$\epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \epsilon_4 \end{bmatrix} = \begin{bmatrix} k_x \sin(\frac{\theta}{2}) \\ k_y \sin(\frac{\theta}{2}) \\ k_z \sin(\frac{\theta}{2}) \\ \cos(\frac{\theta}{2}) \end{bmatrix}$$

$$\epsilon^r = \begin{bmatrix} \epsilon_1^l \\ \epsilon_2^l \\ -\epsilon_3^l \\ \epsilon_4^l \end{bmatrix} \qquad p^r = \begin{bmatrix} p_x^l \\ p_y^l \\ -p_z^l \end{bmatrix}$$

System Diagram



Grasp Database

- Experiments – description, time stamp, type
- Calibration – mean/max error, transformation matrix
- Frames – elapsed time, tracking frame captured
- Trackables – marker definitions; position, orientation, marker positions on each frame
- Raw markers – position on each frame
- WAM Data – joint/Cartesian space actual/desired positions/velocities, applied torques

Future Work

- Quaternions + SLERP
- Real-time Hand Controller
- Grasping Experiments
- dVC3d Simulations
- Improve Sample Rate/Camera Synchronization
- Velocity Blends in Trajectory
- Object Avoidance

The End

- Thanks! Questions?