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Passive Trajectory Enhancing Robot

(PTER)

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Georgia Institute of Technology

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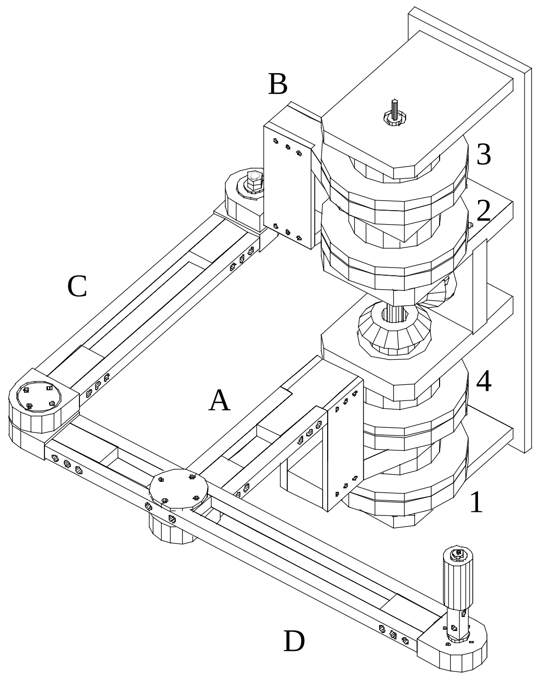
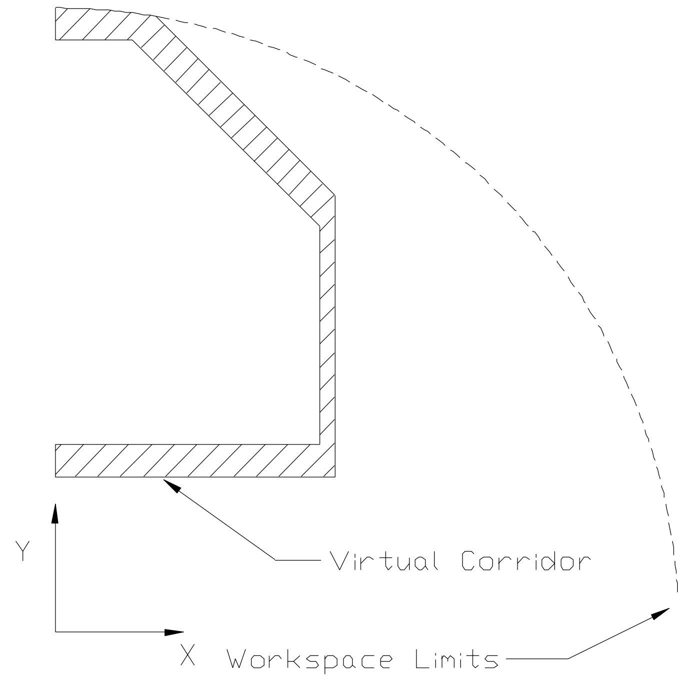
Background



Passive Trajectory Enhancing Robot (PTER)

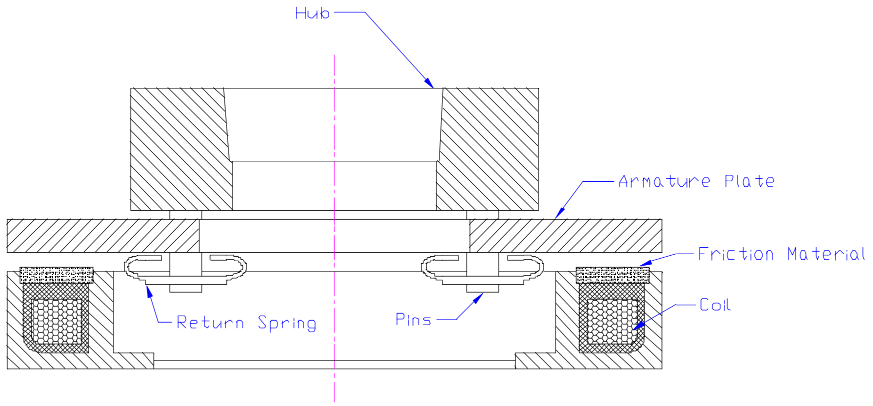


Virtual Corridor simulated on PTER

- PTER is a programmable constraint device for restricting motion and simulating haptic features (i.e. walls, preprogrammed paths, or elastic interfaces).
- Bilateral tele-operation of remote devices.
- PTER uses friction brakes to constrict motion for simulation of the haptic features.

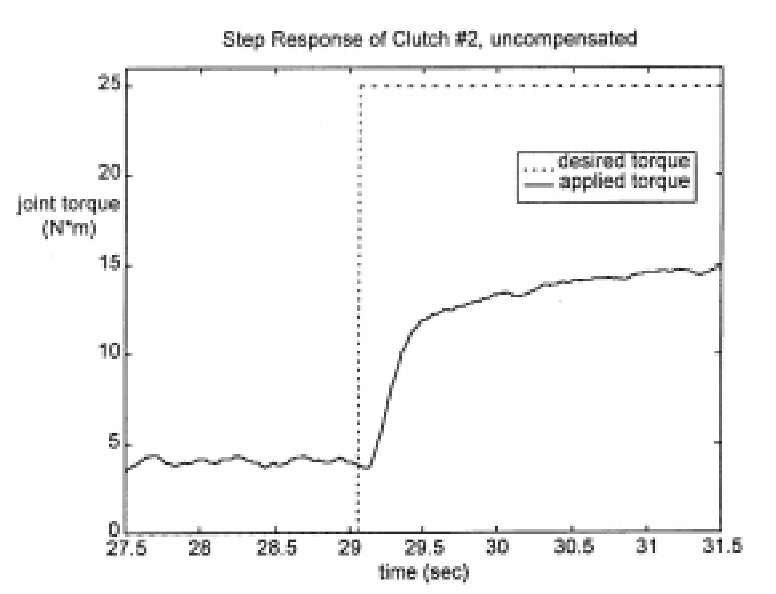
PTER's Existing Brakes / Clutches

- Industrial electromagnetic friction units from Dynacorp
  - Model 310
  - Original max torque
    300 ft-lbf (407 N-M)
  - Rated time constant
    0.105 sec (coil build up)
- Modified to eliminate metal to metal contact
  - Reduced available torque
- No provisions of measuring actual applied torque for feedback control



Dynamic Response of PTER's Actuators

- Open Loop Control
- Undesirable Dynamics
  - Non-linear electromagnet
  - Sliding on pins (binding)
  - First order response
    - R-L circuit
  - Pure time delay
    - Coil build up to attract armature plate
  - Steady state error
    - Each clutch's output torque different
    - Max torque ranged from 15 to 125 Ft-Lbf, depending on unit



(Borrowed from Gomes, 1997)

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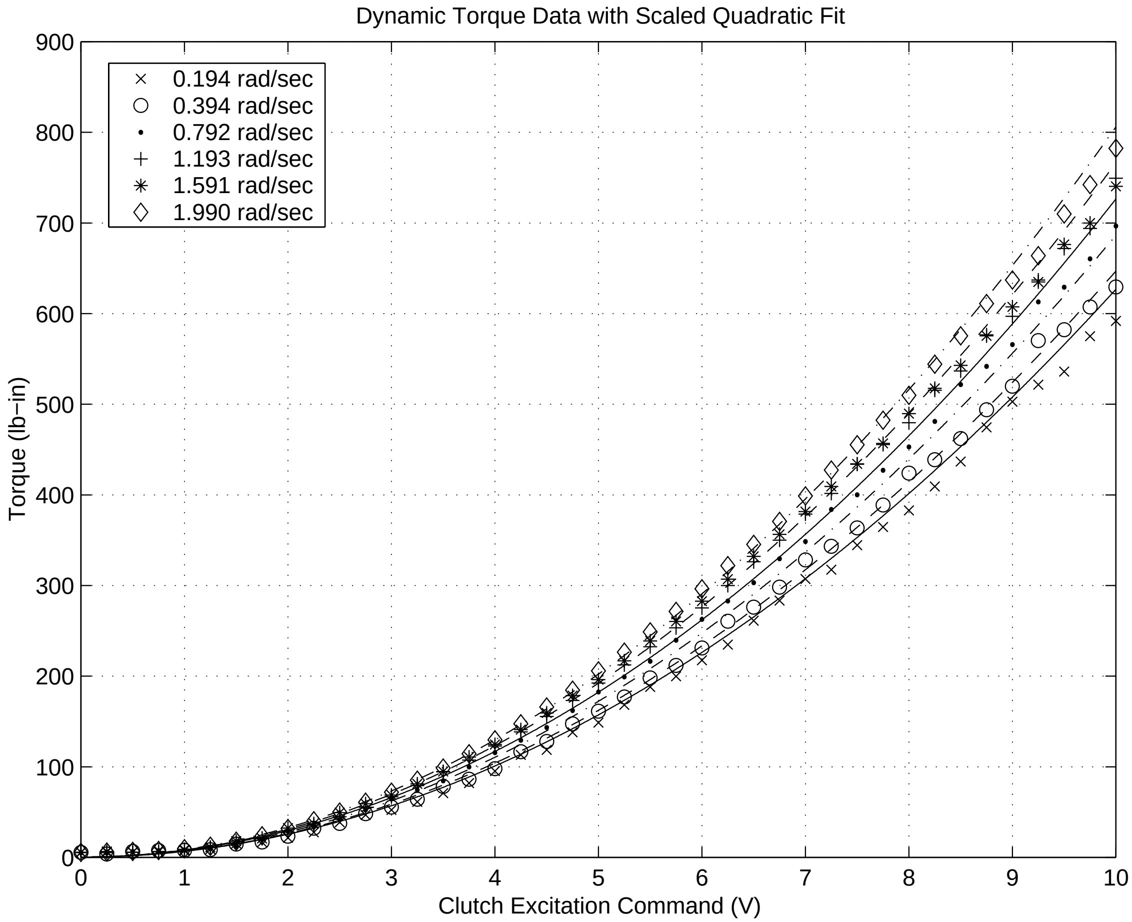
Motorized Clutch Testbed

- Motorized testbed developed to measure physical behavior of clutches under controlled conditions
- Desired parameters:
  - Dynamic response
    - Time delay
    - First-order time constant
  - Dynamic friction behavior
    - Two independent variables: clutch excitation and velocity
  - Static friction behavior
    - Breakaway torque

Clutch Testbed - Dynamic Friction

- Experimental data and model of dynamic torque produced by clutch



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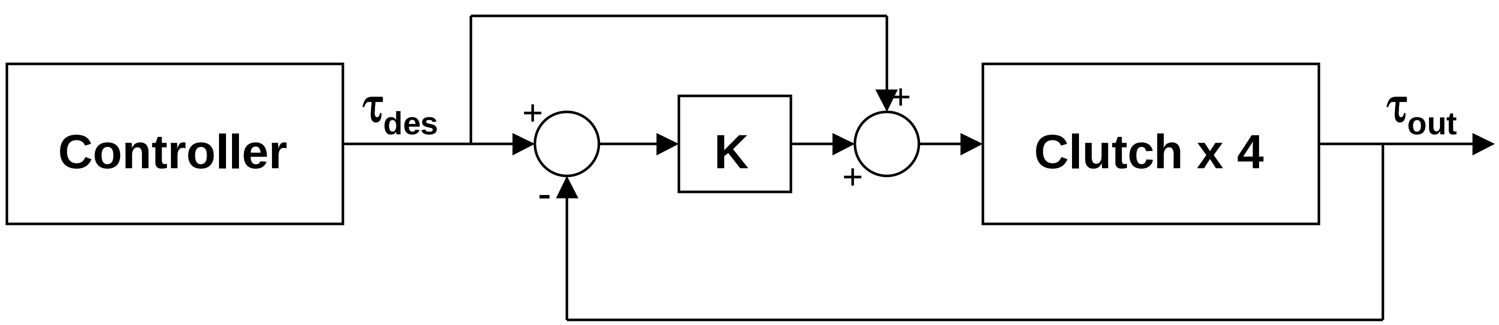
SimPTER - Dynamic Simulation

- Goal: Create an accurate simulation of PTER in order to better evaluate proposed system enhancements:
  - New controllers
  - Improved mechanical components
- Simulation features:
  - Clutch model
    - Dynamic response
    - Stick-slip friction model (Karnopp model)
    - Power supply dynamics
  - Full inertial model of PTER
  - Modular architecture (implemented in SIMULINK)
  - System parameters based on experimental data
- Actual applications of SimPTER to date:
  - Investigation of torque feedback and velocity-based controllers
  - Evaluation of Delrin as an alternate friction material

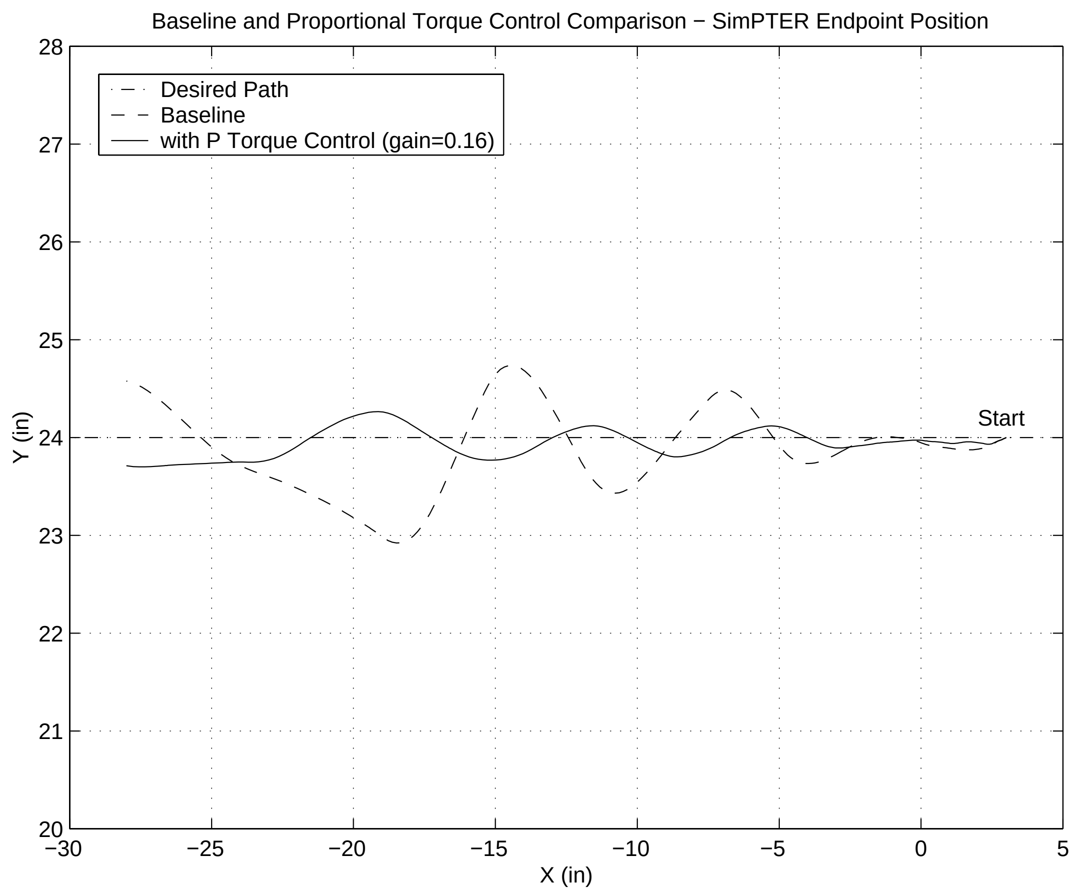
SimPTER - Torque Feedback Controller

- Concept: a clutch with integrated torque sensing could provide torque feedback
- Controller: Previous look up table with added proportional torque feedback
- Implemented in simulation



SimPTER - Torque Feedback Controller

- Simulation - Line Tracking Performance of PTER



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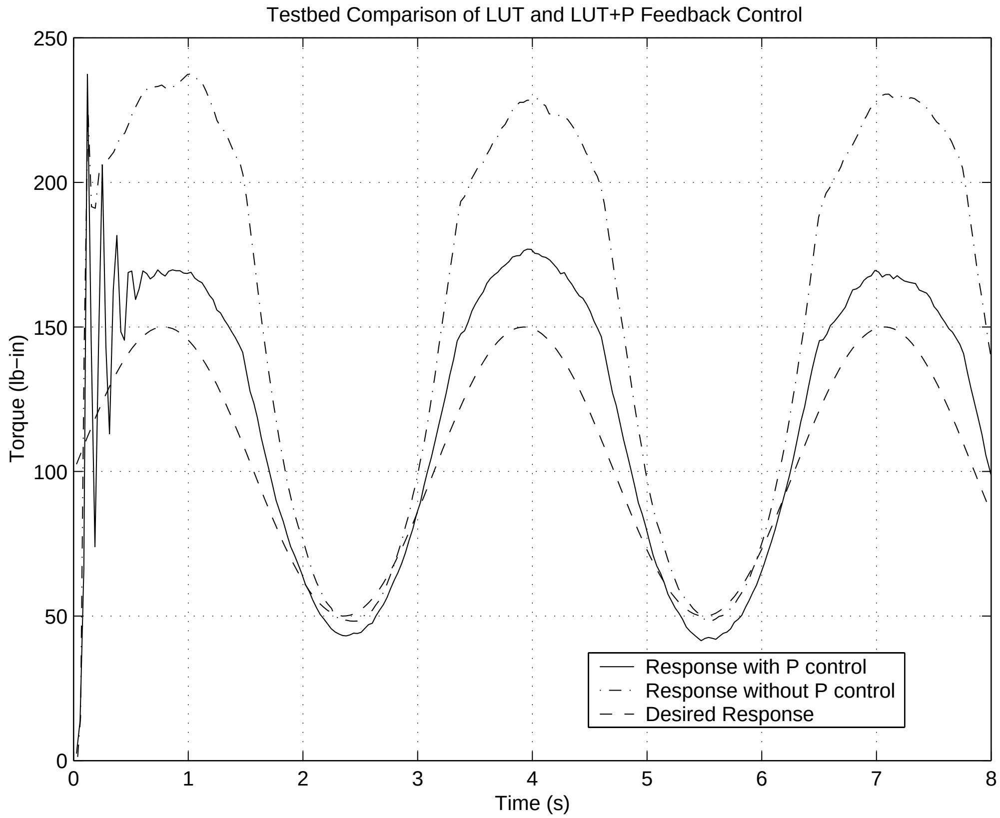
Torque Feedback Control - Testbed

- Testbed implementation - Improved torque following performance (~35Hz rate)



- Oscillation at higher gains may be reduced with higher controller sample rate

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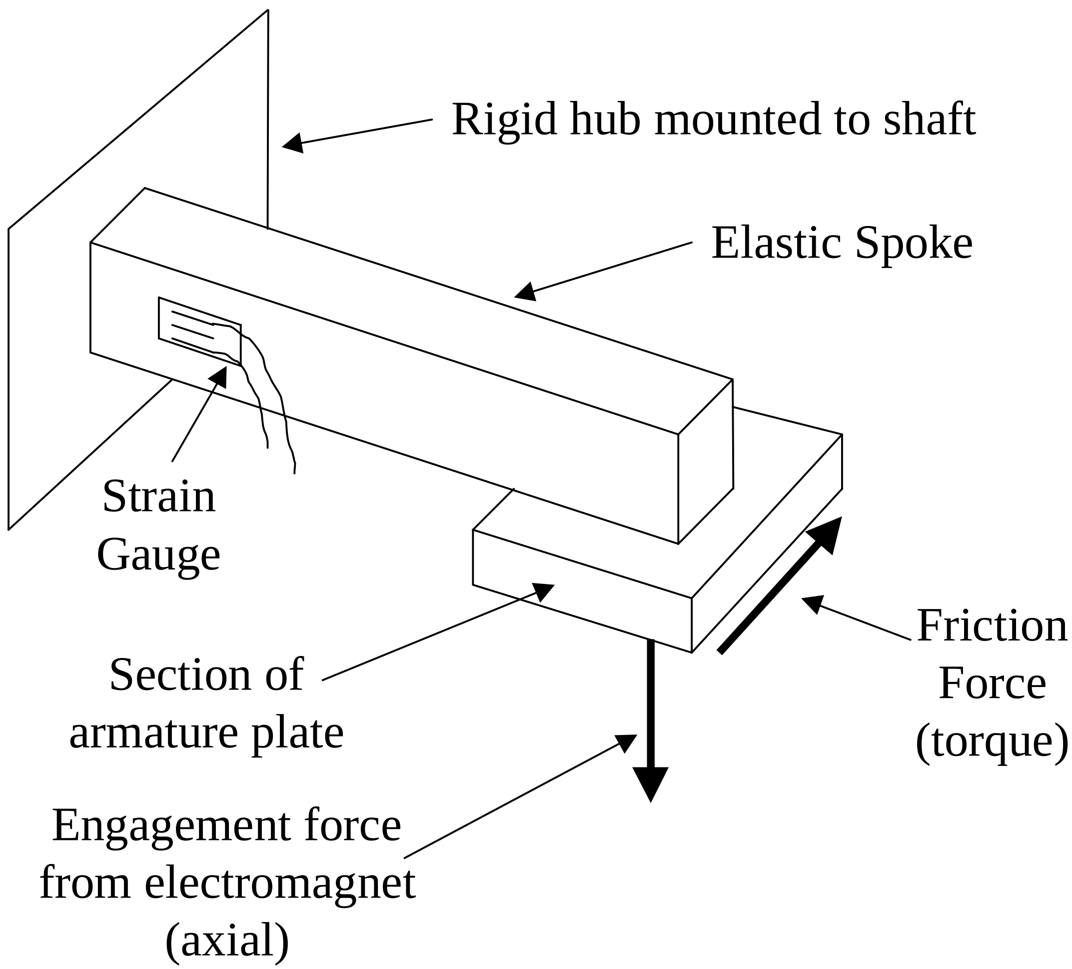
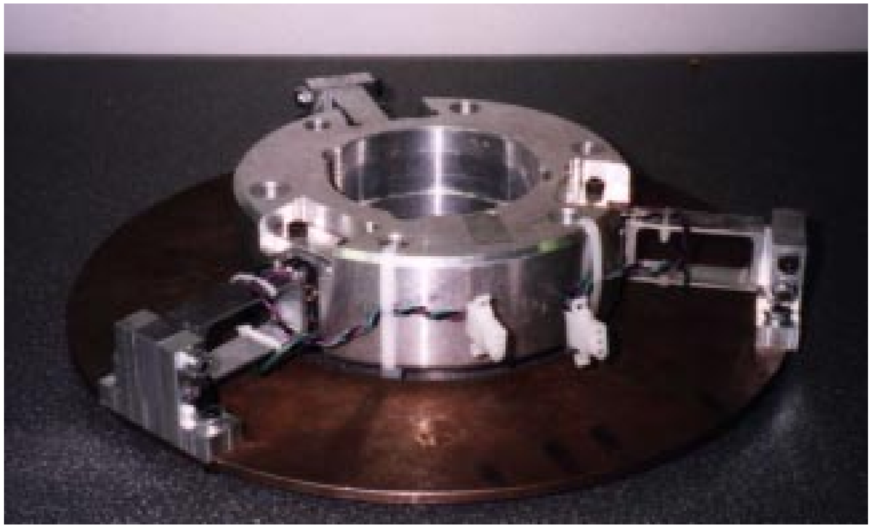
Clutch with Integrated Torque Sensor

- Spoke transmits torque from friction
- Spoke locates and supports armature plate
- Spoke deflects under vertical engagement and torque transmission
- Strain gauge measurement proportional to transmitted torque



Prototype Unit

- Three spokes to locate armature plate and transmit torque
- Total of four strain gauges mounted on two spokes
- Design Considerations
  - Available magnetic force
  - Strength / Cyclic fatigue
  - Sensor sensitivity
  - Material selection
    - Spokes
      - Aluminum 7075-T651
    - Armature Plate
      - Low carbon steel
    - Alternative friction material



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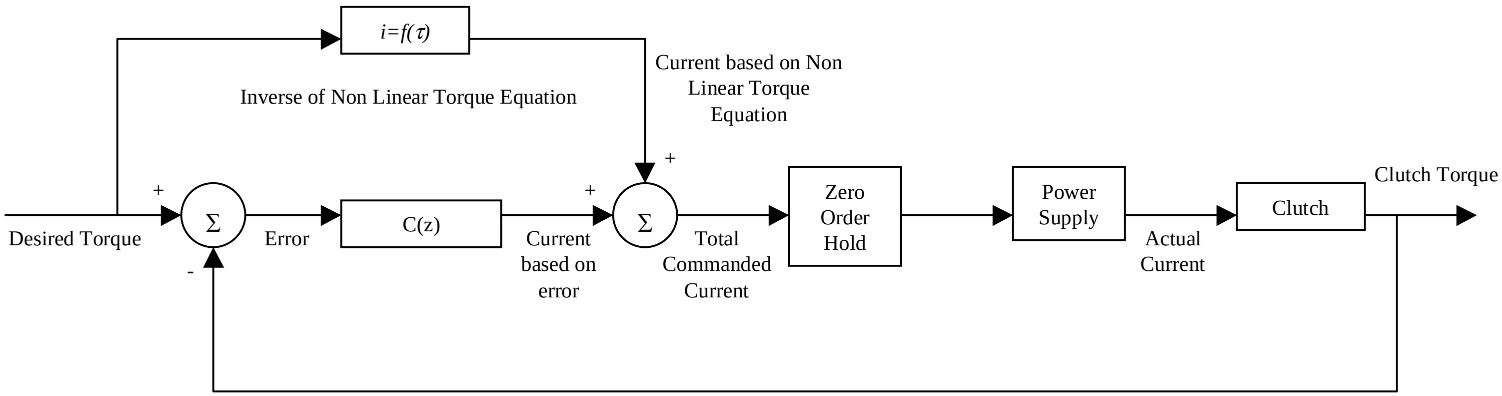
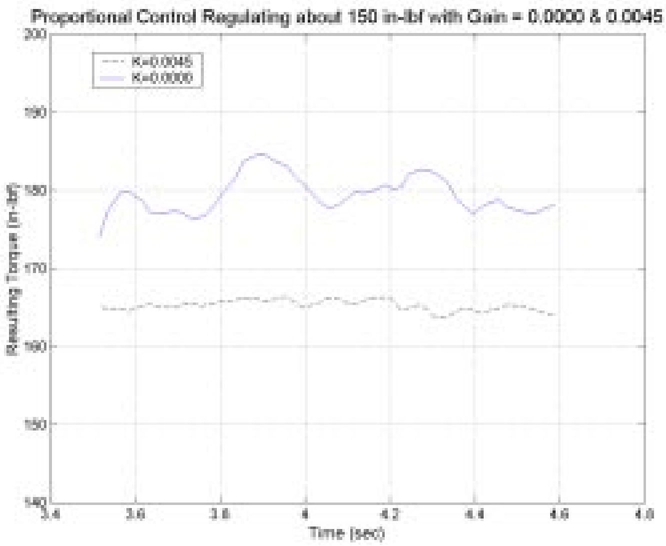
Experimental Digital Control of Prototype

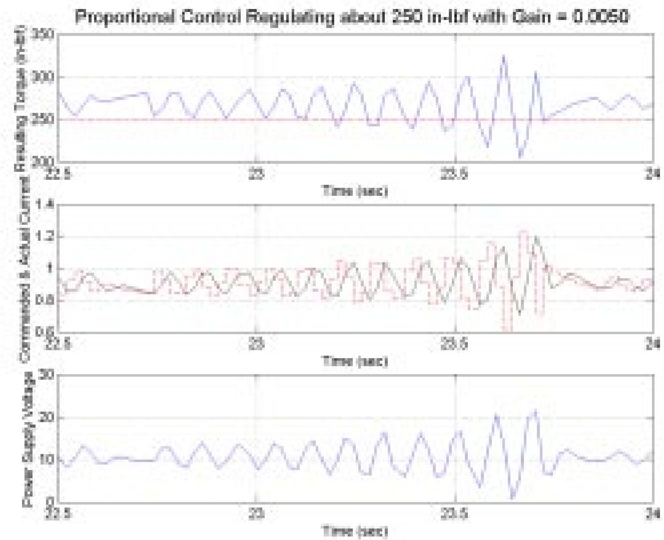


$$\tau = ai^2 + bi + c \Rightarrow k_{clutch} = \frac{d\tau}{di} = 2ai + b \qquad \tau = \tau_{eq} + \frac{k_p k_{clutch}}{1 + k_p k_{clutch}}(\tau_d - \tau_{eq}) + \frac{1}{1 + k_p k_{clutch}}\tau_{dist}$$

- Nonlinear feed-forward based on quadratic torque mapping
- Absolute value of torque fed back (direction insensitive)
- Proportional control based on error (k_p)
- Larger gain equates to larger disturbance and error rejection

Digital Control of Prototype - Results





- Labview processing controller at a non-deterministic 50 Hz ($t_s \approx 0.02$ sec)
- Small gains stabilized torque
- Large gains cause system to go unstable due to insufficient controller sampling rate.

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Future Work

- Faster Digital Controller
  - dSPACE & Real Time Workshop
- Alternative Friction Materials to moderate stick-slip transition
  - Delrin: $\mu_s = 0.20$, $\mu_d = 0.35$
- Power Supply Upgrade
  - Bipolar
  - Larger current and voltage ratings
- Make SimPTER more modular
  - Investigate further component improvements
  - Apply to other passive systems
- Manufacture three more redesigned clutches
- Upgrade other components of PTER
  - Replace position potentiometers (i.e., use encoders or resolvers)
  - Tachometers
  - Remount strain gauges in handle force sensor
  - Computer and software
- Program old and new haptic algorithms
- Bilateral control of Hurbirt