Development of a Discrete PID Control Laboratory for Undergraduate EET Curriculum:

Modeling, Analytical, and Empirical Data Collection Tool

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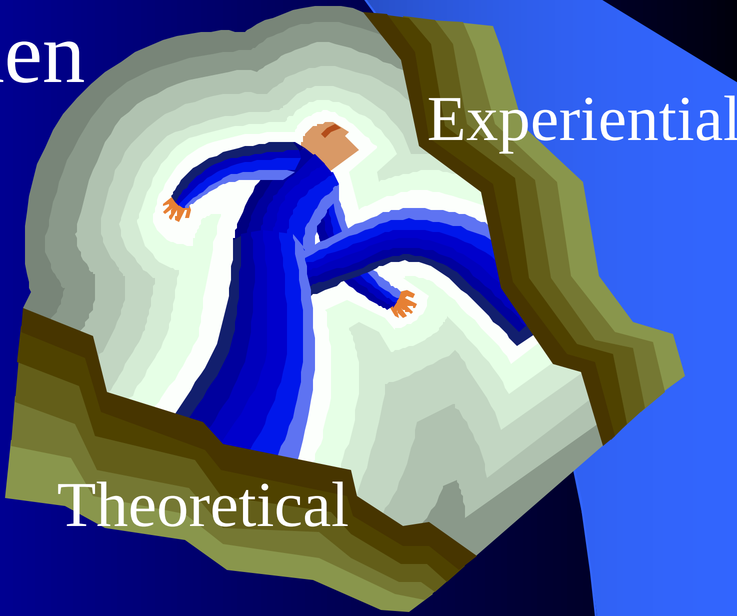
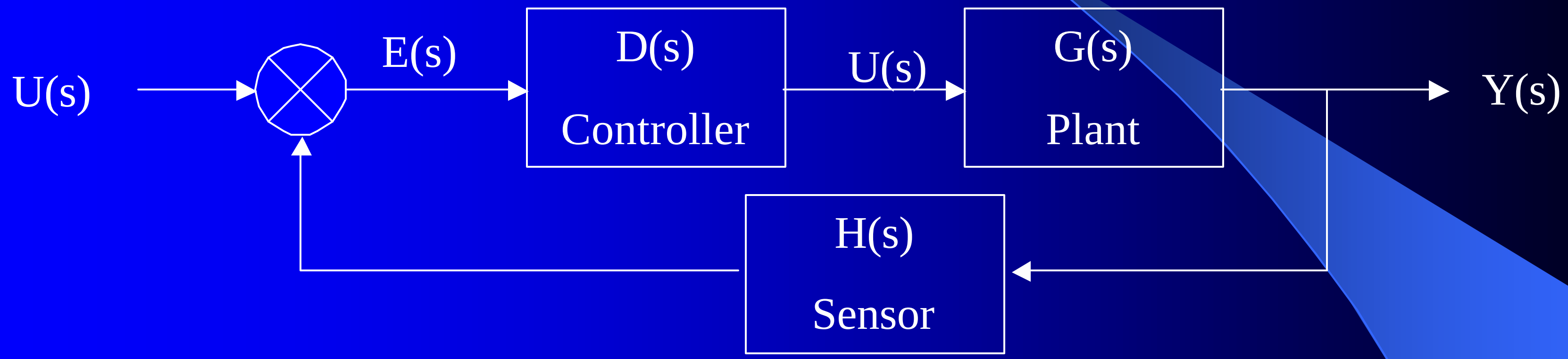
Seeing is Believing

- Control System concepts are abstract.
  - Unfamiliar terms + magical calculations = disillusioned student.
- Need a course based on a real world application to help strengthen these concepts.



Classroom Objectives

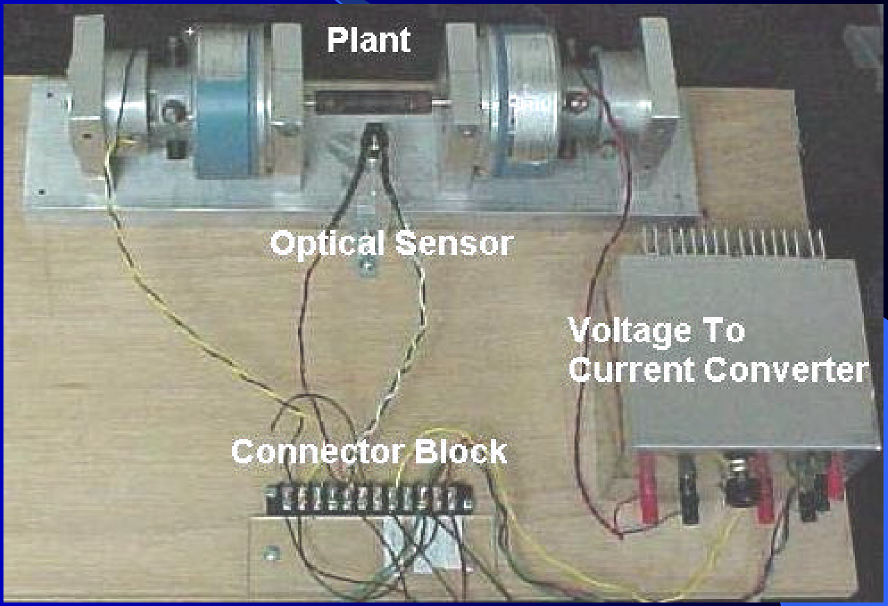
- Introduce Control Systems theory.



- Solidify understanding through simultaneous laboratory experimentation.
  - With what laboratory?

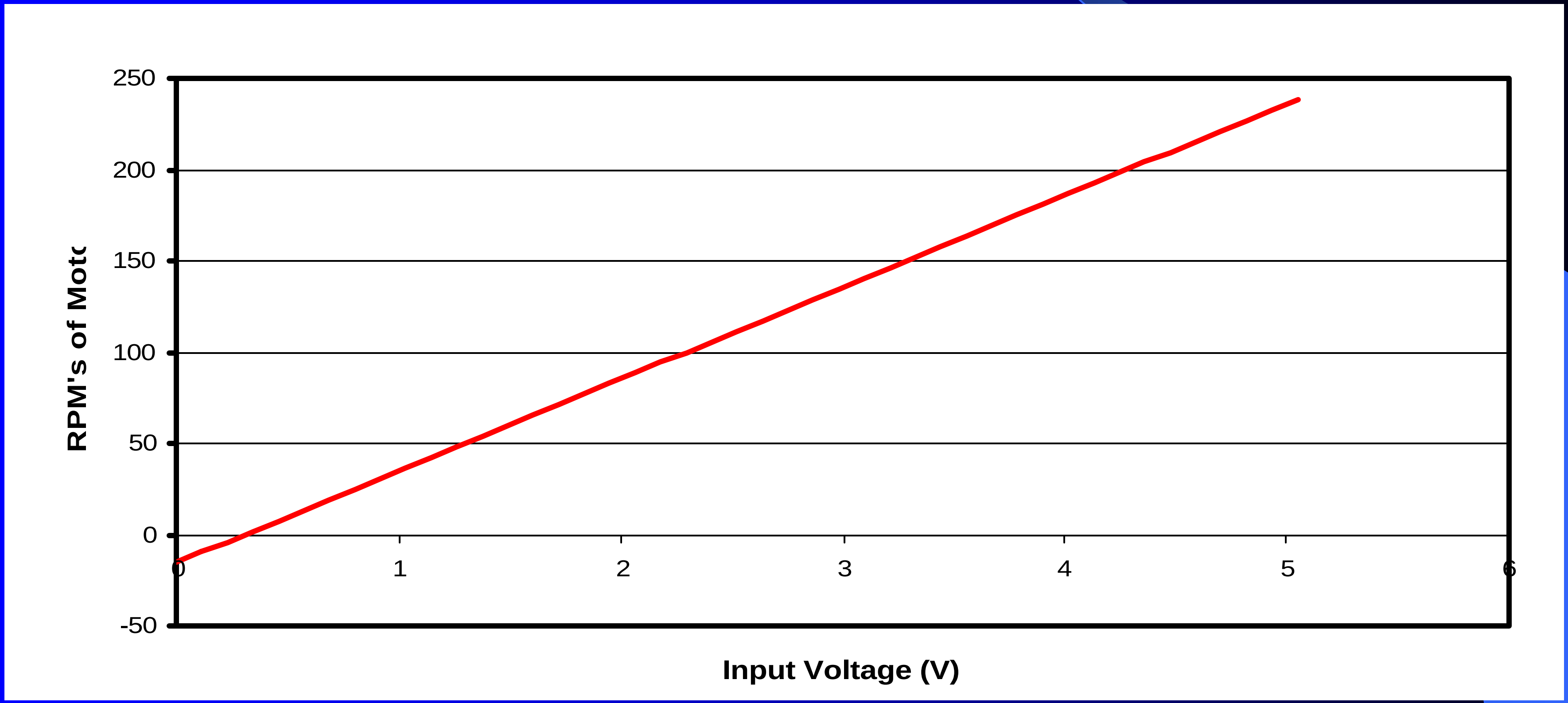
PID Motor Control Laboratory

- Motor Control apparatus
  - Motor/Generator
  - Optical Sensor
  - Voltage to Current
  - Connector Block
  - PC w/ DAQ
  - Intelligent Device



Plant Characterization

- Input Voltage—RPM relationship

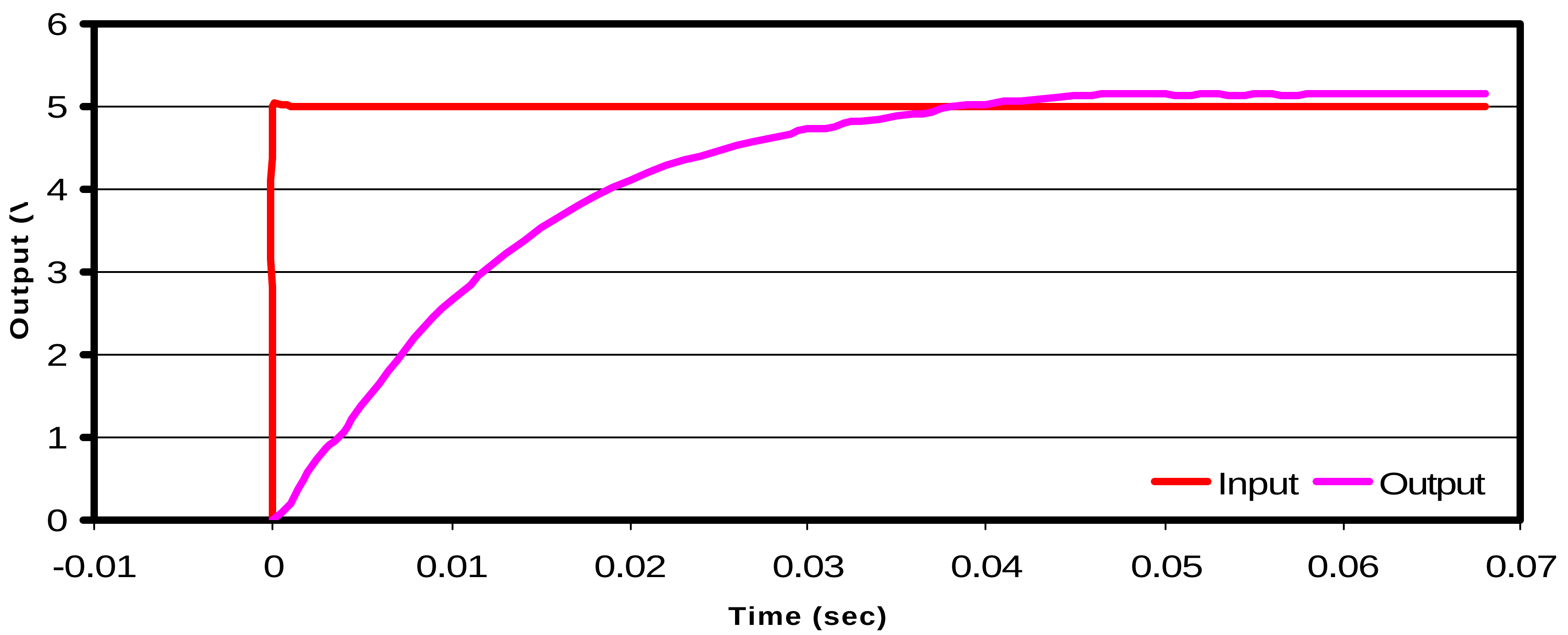


Plant Characterization

- Damping Ratio and Natural Frequency
  - Apply step input
  - Acquire generator output response
  - Determine time domain plant equation:
    - Curve fitting software
    - LabVIEW PID Simulation software

Plant Characterization

- Acquire generator output response



Plant Characterization

- 1st or 2nd Order Characterization?
  - 1st Order
    - Easier and faster to determine, but
    - Only models the exponential rise of the response.
  - 2nd Order
    - Slightly harder to determine, but
    - Can model the exponential rise and the steady state oscillations of the response.
  - Greater than 2nd Order?
    - Too cumbersome, detracts from learning.

Plant Characterization

- Determining 2nd Order Plant
  - Curve Fitting Software, or
  - LabVIEW PID Simulation software
    - Setup parameters to simulate reality:
      - Open Loop
      - Kp = 1, Kd = 0, Ki = 0
      - Reduce the time scale to the time of interest
    - Setting $\zeta_n = 1$, modify ω_n till the graphs are similar
    - Knowing that the system must be overdamped, make slight changes to ζ_n and ω_n until the simulated result matches the acquired data.

Plant Characterization

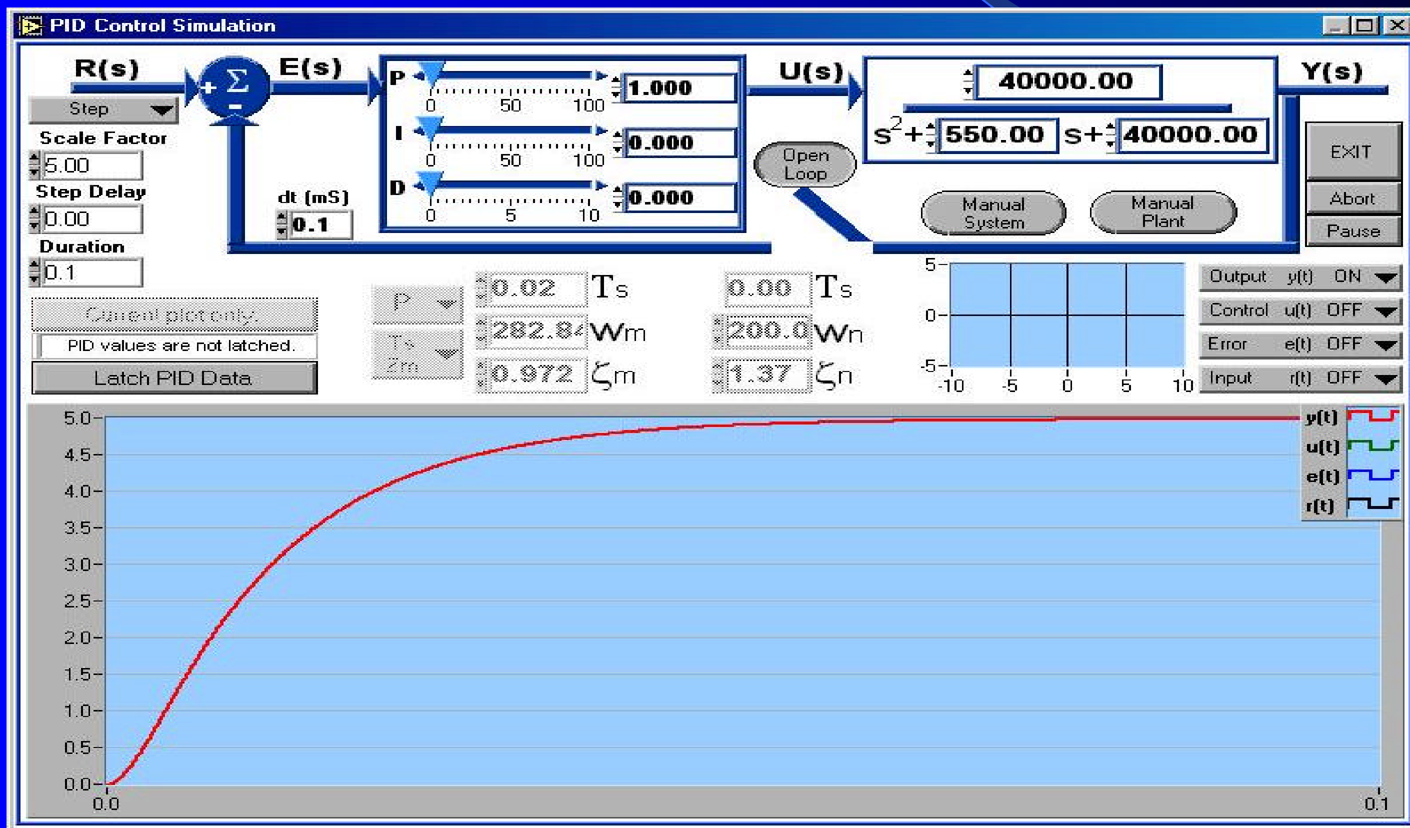
- Determining 2nd Order Plant
  - This allows us to make direct modifications to the plant equation and watch its result, rather than performing time to s-domain conversions.

$$Y(s) = \frac{40000}{s^2 + 550s + 40000}$$

  - $\zeta_n = 1.375$
  - $\omega_n = 200$

Plant Characterization

- EET/TET LabVIEW_PID*



* Developed by Mr. Justin Ewing in a prior semester

Simulation Software

- What else does it do?
  - Simulation of any combination of P, I, and D control systems.
  - Fixed or auto tune modes, suggests optimal PID coefficients or plant values.
  - Calculates ζ_m and ω_m.
  - Select from different input types.
  - Displays the system roots.
  - Graphical display of input, error, control, or output signals.

Other Analytical Tools

- Matlab's SIMULINK - quick and easy time domain plots of a PID system.
- LabVIEW - Discrete and Continuous system equation comparison using a custom VI.
- LabVIEW - Equation Solver VI
  - Finding fourth order roots.
  - Solving for coefficients in simultaneous equations.

Experiments

- Incremental learning by observing the effects of each coefficient:
  - Proportional
  - Proportional-Integral
  - Proportional-Derivative
  - **Proportional-Integral-Derivative**

Proportional-Integral-Derivative (PID)

- Continuous PID Transfer Function, s-domain:

$$\frac{Y(s)}{R(s)} = \frac{40000(K_d s^2 + K_p s + K_i)}{s^3 + (550 + 40000 K_d) s^2 + (40000 + 40000 Kp) s + 40000 Ki}$$

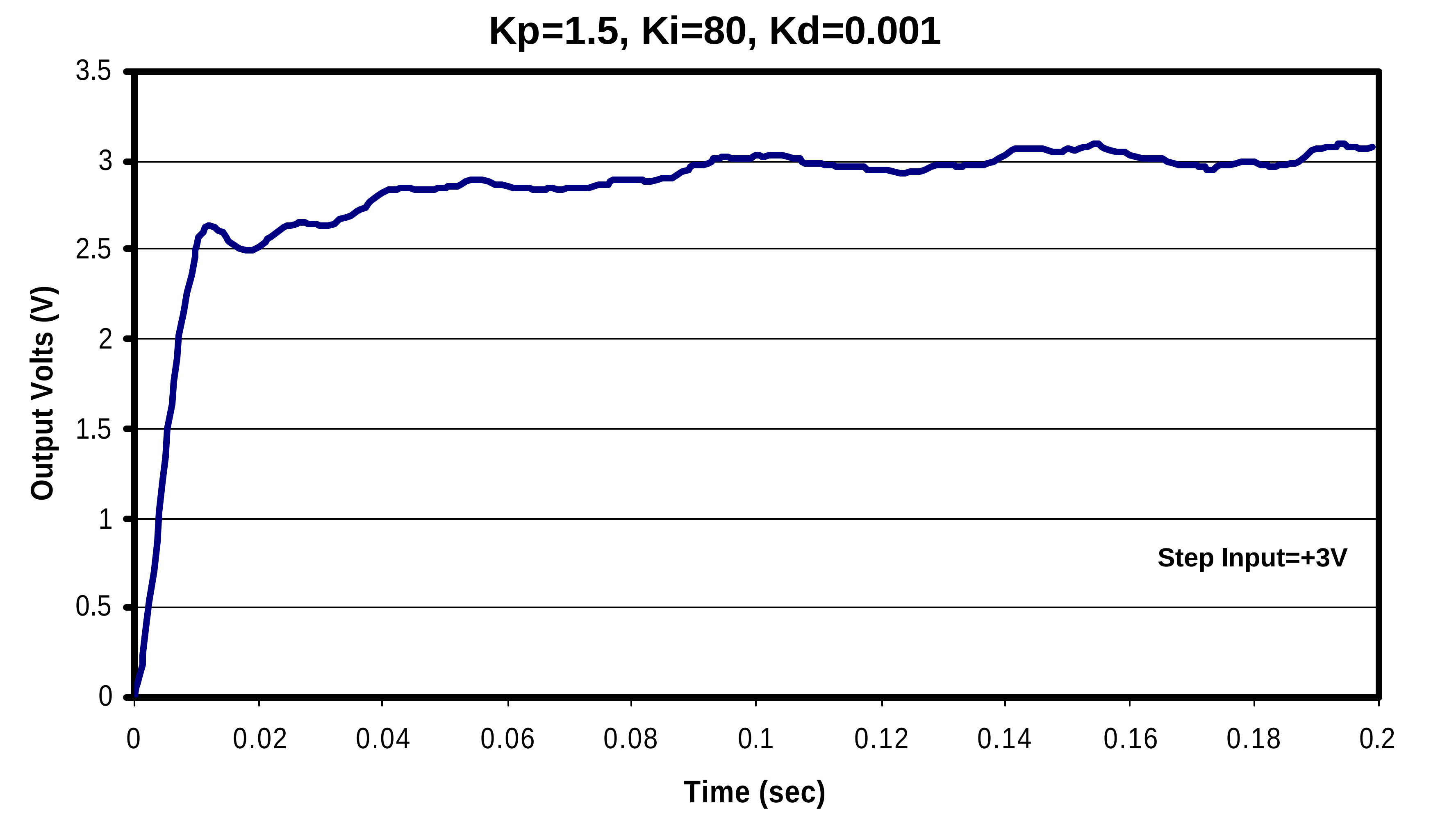
- Discrete PID Control Function:

$$u_k = e_k \left[\frac{K_d}{T} + K_p + K_i T \right] - e_{k-1} \left[\frac{2K_d}{T} + K_p \right] + e_{k-2} \left[\frac{K_d}{T} \right] + u_{k-1}$$

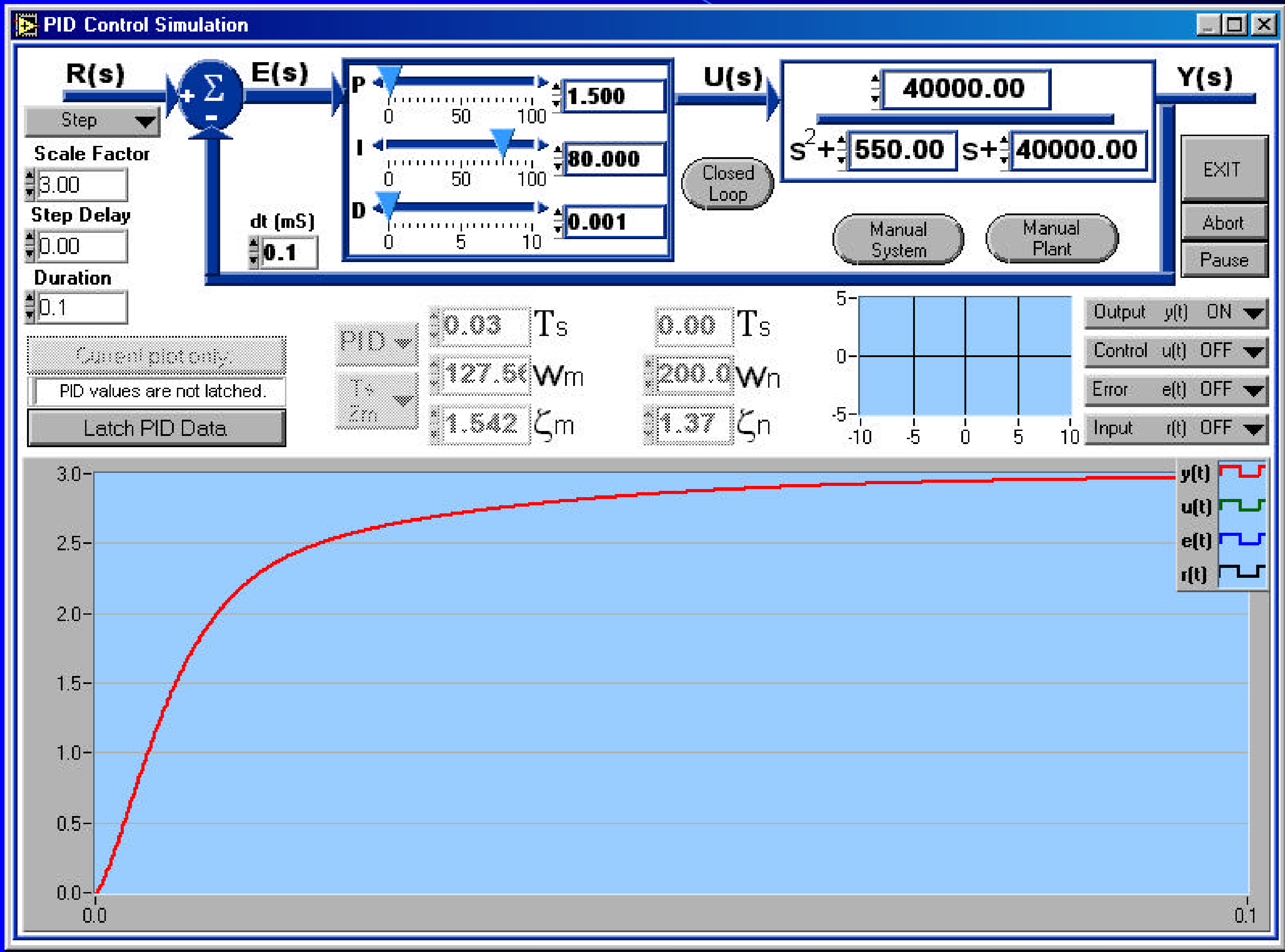
Discrete Implementation of PID Control

- Intelligent Device
  - 2 Analog Inputs
  - 1 Analog Output
  - Real time data acquisition
  - Adequate math operations
- Options
  - Microcontroller
  - Computer with DAQ and LabVIEW

PID Control (µC)

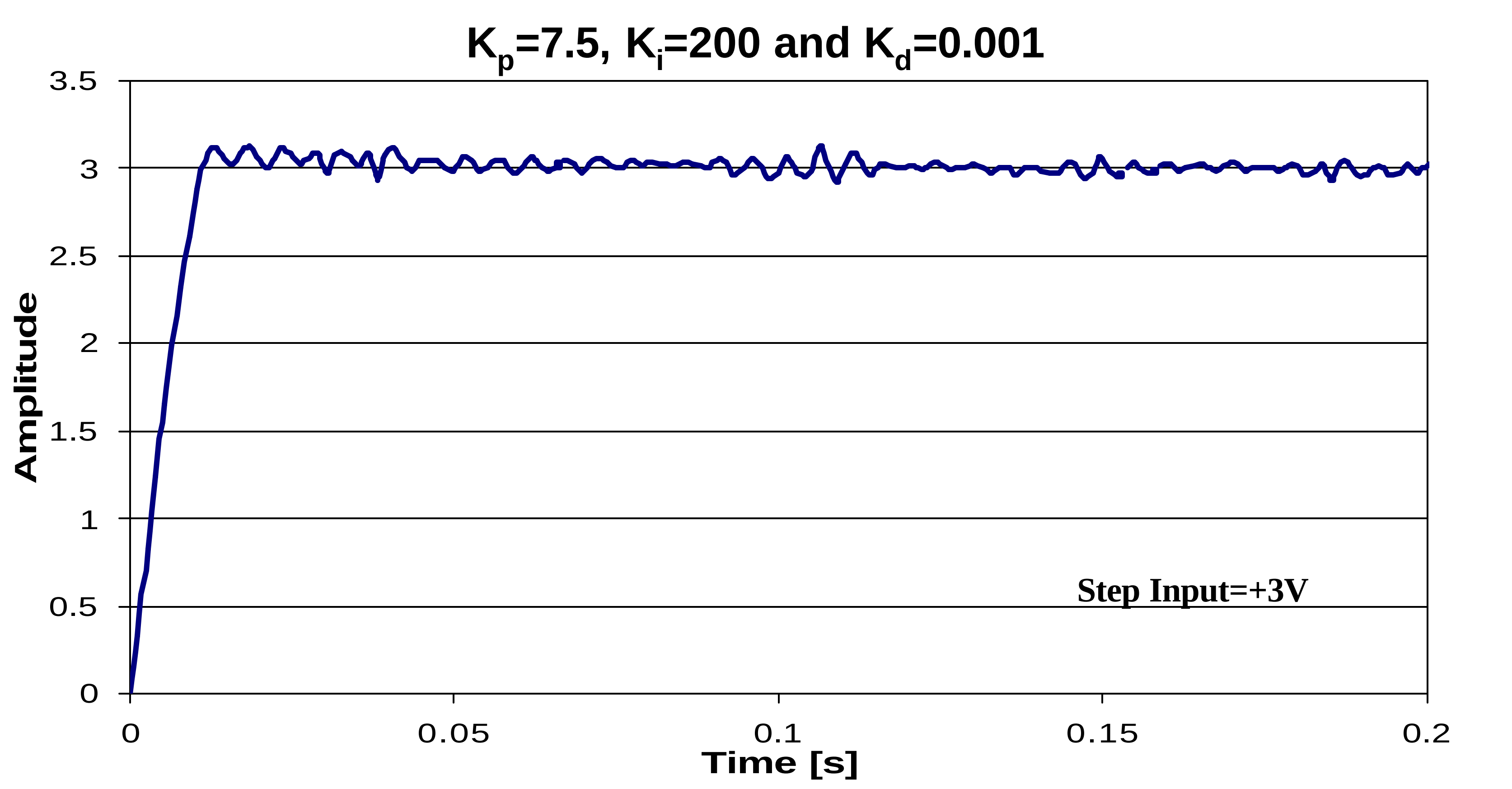


Simulation of µC Results



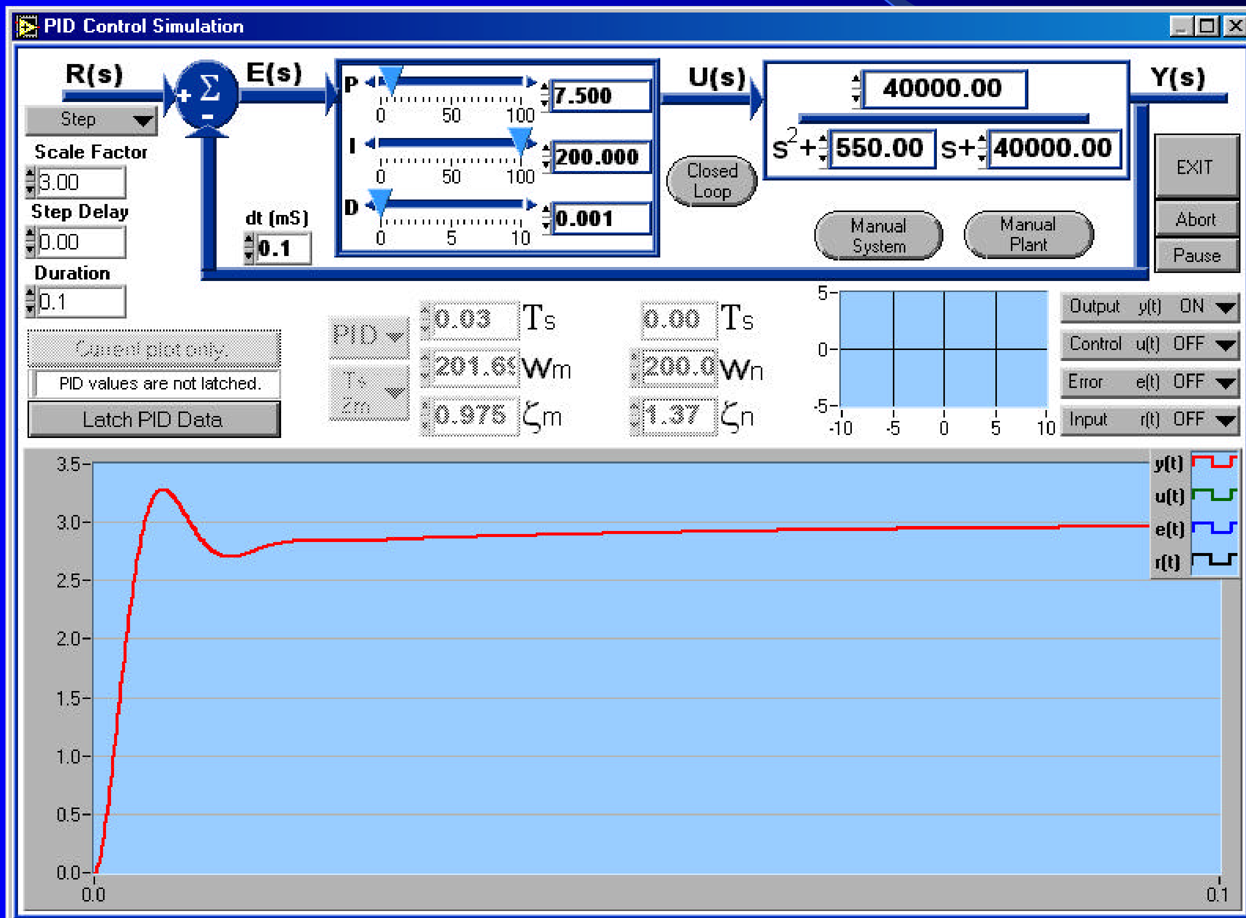
PID Control (Computer)

- Forced an overdamped plant to respond as an underdamped system!



Simulation of Computer Results

- $\zeta_m = .975!$

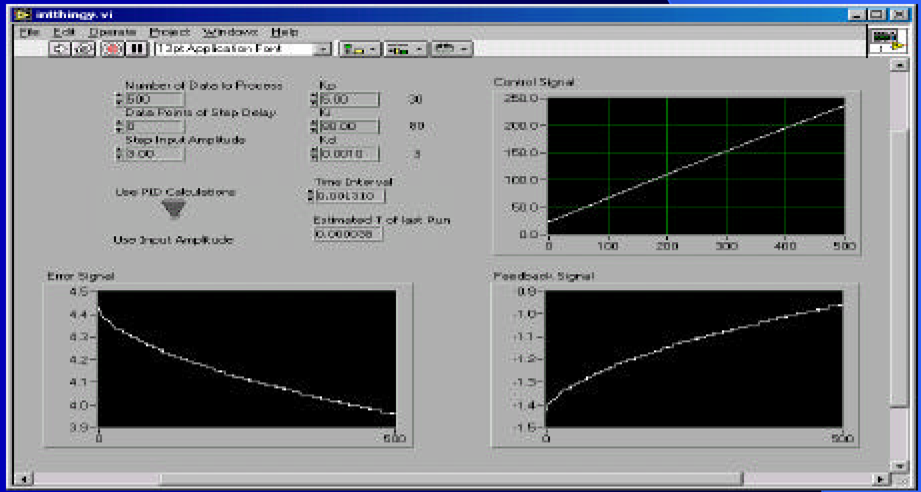


Microcontroller

- Advantages
  - Cost effective
  - Small
  - Easily portable
- Disadvantages
  - Extensive programming required (asm or C)
  - Not easily adjustable
  - Response calculations limited

PC with DAQ and LabVIEW

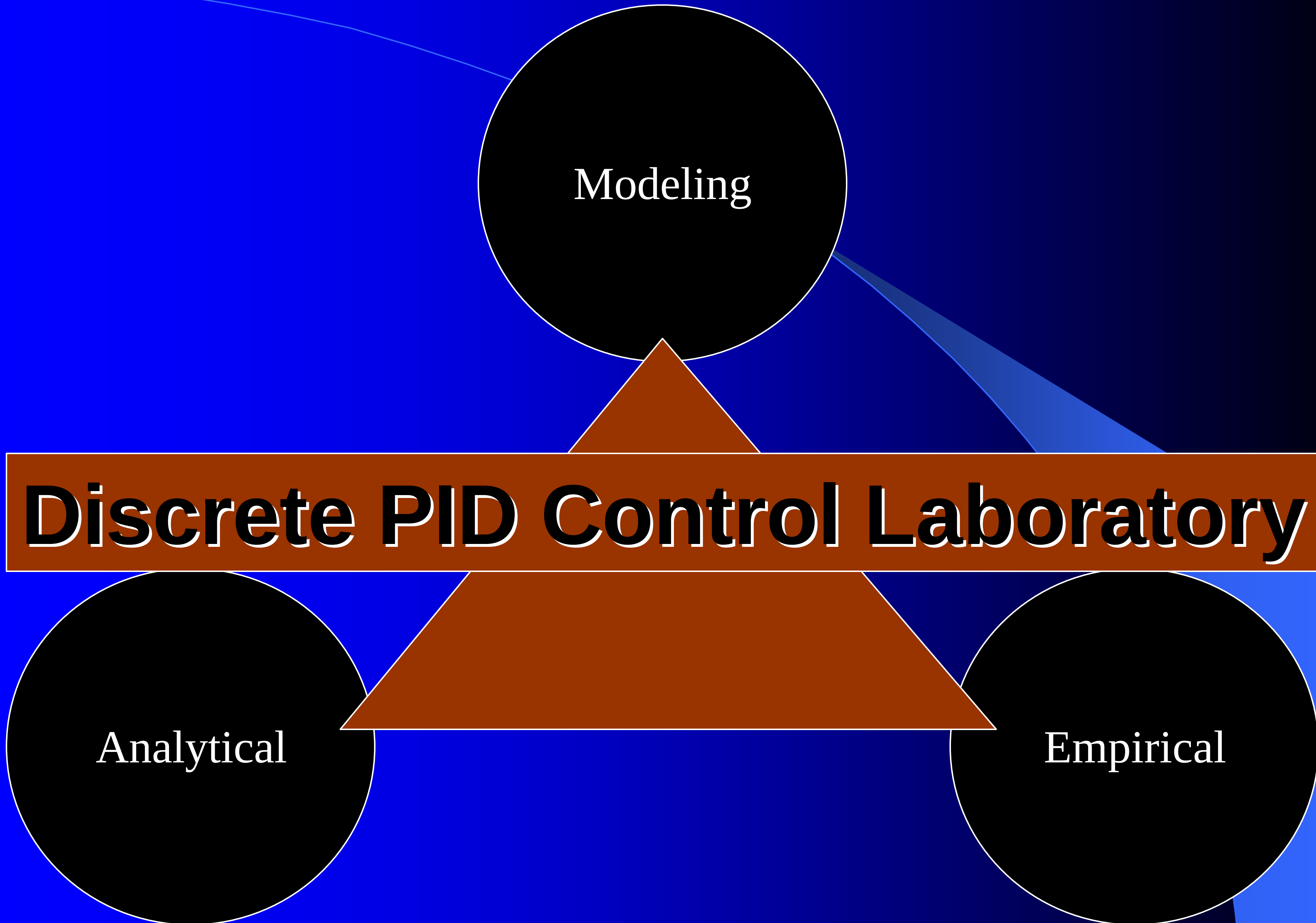
- Advantages
  - Easily modify the PID coefficients
  - Can modify the program at the test bench
  - View information by adding graphs and numerical displays
  - Minimum programming time
  - Friendly user interface
- Disadvantages
  - Higher cost
  - Larger size



Controller Conclusions

- Microcontroller vs. LabVIEW...
  - The Microcontroller is good for industrial applications.
  - LabVIEW is good for educational and development purpose because of its power and flexibility.

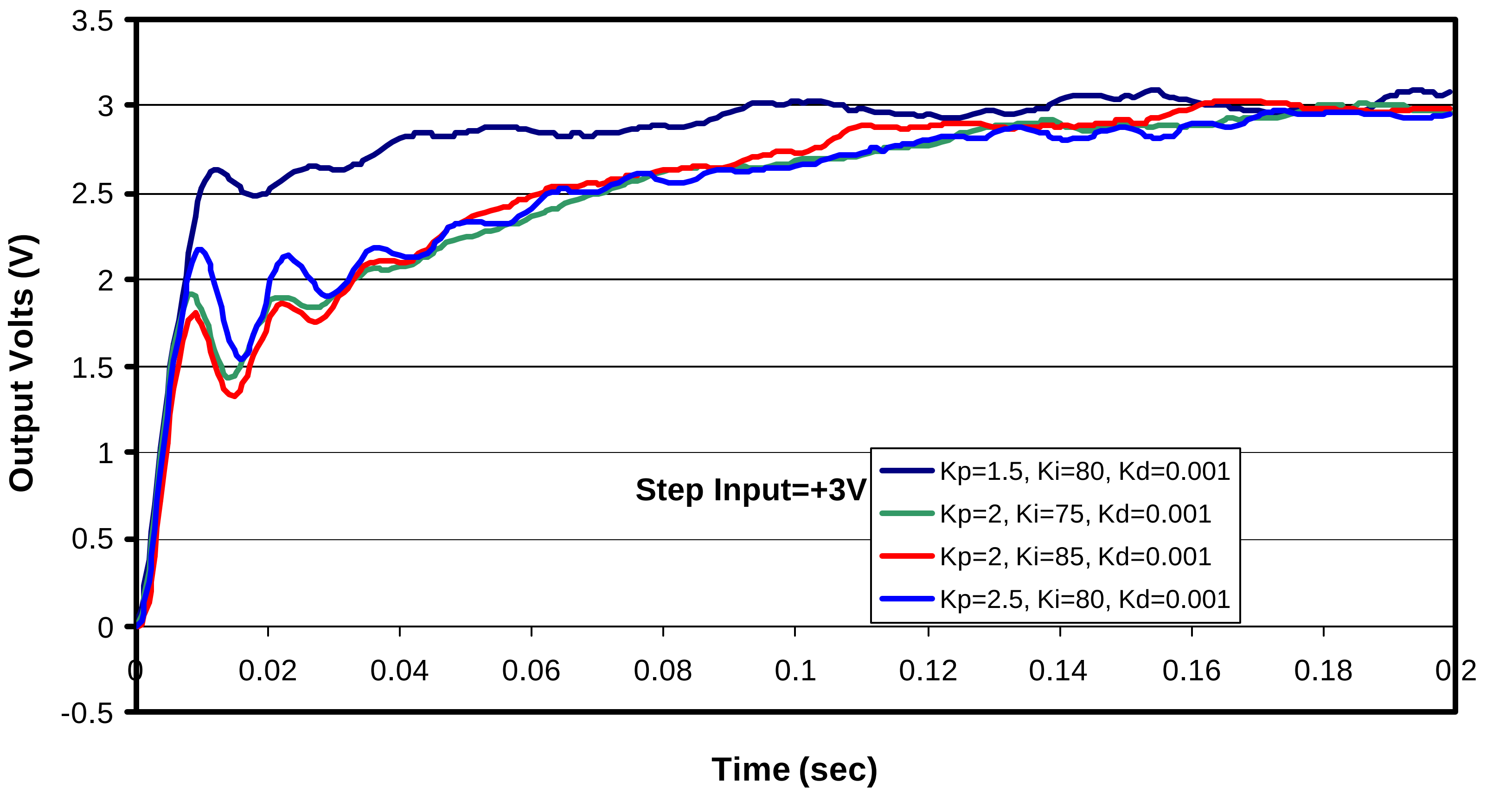
Discrete PID Control Laboratory



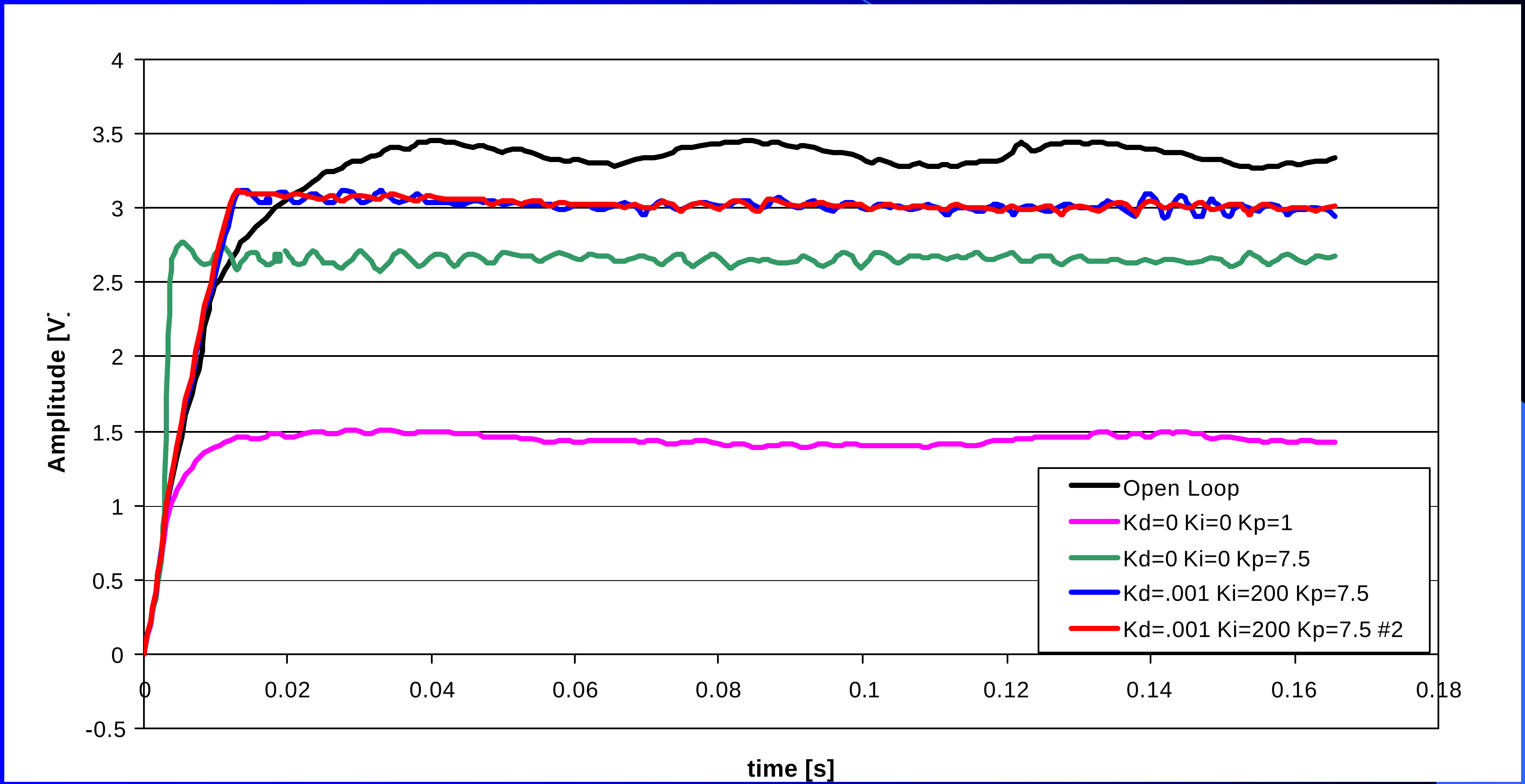
Questions?

Thank you for Coming!

PID Results-other (μC)



PID Results-other (LabVIEW)



Proportional Control

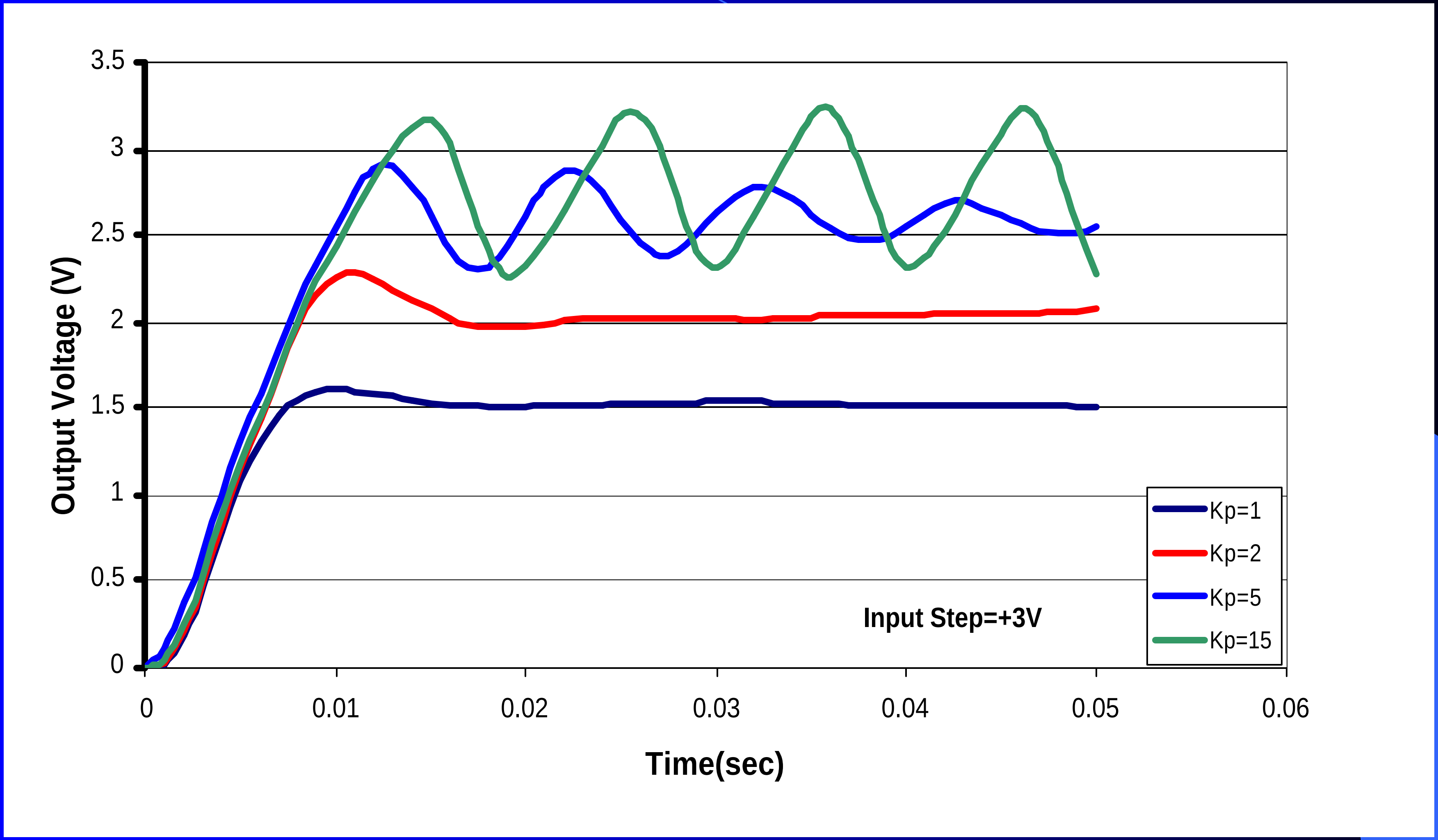
- Increasing Kp:
  - Final value is closer to set point
  - Decreases rise time
  - Response becomes unstable
- Continuous transfer function for Kp:

$$Y(s)/R(s) = \omega_n^2 K_P / (s^2 + 2\zeta_n \omega_n s + \omega_n^2 (K_P + 1))$$

- Discrete control function for Kp:

$$u_{k0} = (e_k - u_{k-1}) * k_p$$

Proportional Control



Proportional-Integral Control

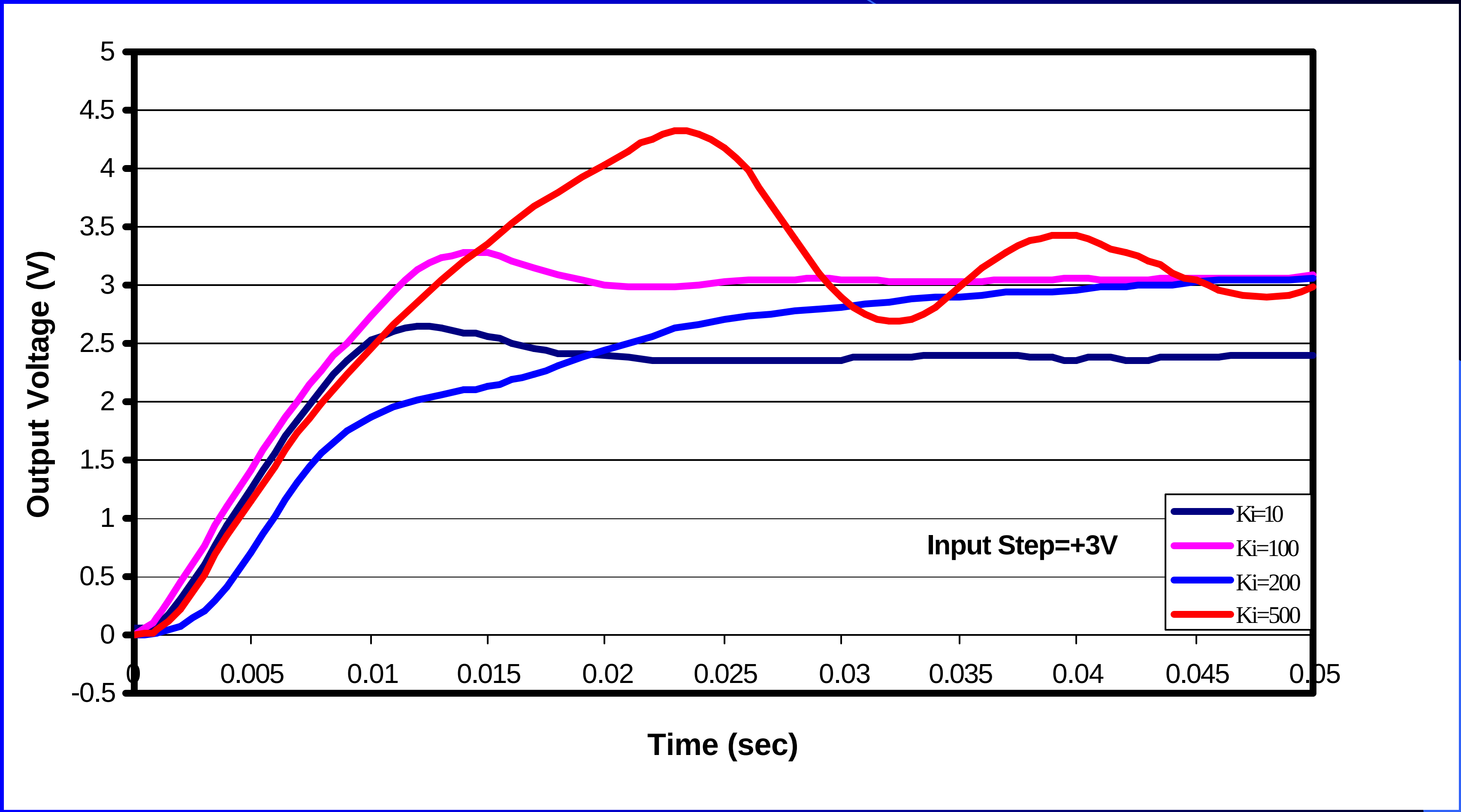
- Increasing Ki:
  - Causes overshoot and ring
  - Decreases rise time
  - Error goes to zero
- Continuous transfer function for Kp/Ki:

$$\frac{Y(s)}{R(s)} = \frac{40000(K_i + K_p s)}{s^2 + 550s^2 + 40000(K_p + 1)s + 40000K_i}$$

- Discrete control function for Kp/Ki:

$$u_{k0} = e_k * ((k_i * T) + k_p) - e_{k-1} * k_p + u_{k-1}$$

Proportional-Integral Control



Proportional-Derivative Control

- Increasing Kd:
  - Decreases rise time
  - Causes output to go to zero
- Continuous transfer function for Kp/Kd:

$$\frac{Y(s)}{R(s)} = \frac{42000(K_d s + K_p)}{s^2 + (550 + 42000K_d)s + (40000 + 42000K_p)}$$

- Discrete control function for Kp/Kd:

$$u_{k0} = e_k * ((k_d/T) + (k_p) - e_{k-1} * (((2*k_d)/T) + k_p) + ((e_{k-2} * k_d)/T) + u_{k-1}$$

Proportional-Derivative Control