Designing a Digital Control System

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Introduction

This project will address the theory and practice of using a digital controller to control an analog system. The analog system, or plant, will be represented in an opamp circuit whose output voltage will be sent through a feedback loop and controlled by a programmable microcontroller in order to optimize its response time and stability.

Problem Statement

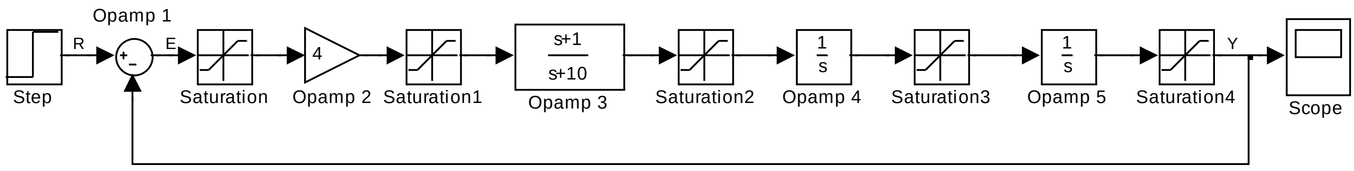
The plant, with a transfer function $G = {}^{1}/_{s^2}$, will be stabilized and controlled through a lead compensator of the form $K = k\frac{s+1}{s+10}$. The problem is how to implement this compensator digitally in software, as well as create an interface between the analog and digital portions of the hardware.

Proposed Solution

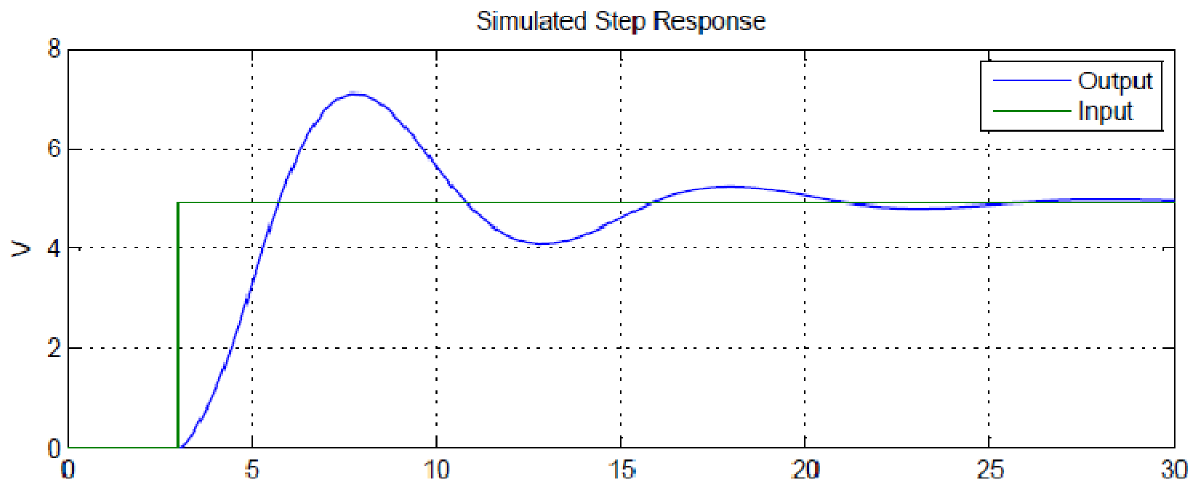
An Arduino Duemilanove board will be used for this project. The board contains an Atmel ATMEGA328 microcontroller which will take the place of the summing junction, ADC, and lead compensator. An external DAC will then convert the signal back to analog and feed it into the plant. Implementing the plant using opamps eliminates the need for sensors and actuators; it is really just an electrical representation of a real-world system since the digital aspects of the controller, both software and hardware, are the main focus of the project.

Simulation

The analog control system was simulated in MATLAB using a Simulink block diagram shown below:



Saturation blocks were added after each step to better model the opamps later used to build the circuit for this system. The signal between any two blocks was limited to ±9 volts, and as a result the system would behave nonlinearly if the gain was set too high or if the input was too large (positive or negative). After some trial and error, the gain k was set to 4 to give the following step response for a 5V input:



The response characteristics for the simulated system are computed as follows:

Rise Time (time to go from 10% to 90% of steady-state value):

5.5 – 3.5 = **2.0 s**

Percent Overshoot (peak value in relation to steady-state value):

(7.1-4.9)/4.9 = 0.44 = **44%**

Settling Time (time until output remains within 5% of steady-state value):

18.3 – 3.0 = **15.3 s**

Analog Controller Circuit

(schematic on next page)

Six opamps were used to build the analog system on a breadboard, along with various resistors, capacitors, and potentiometers.

Opamp #1: Summing Junction

$$v_o = -R_3\left(\frac{v_1}{R_1} + \frac{v_2}{R_2}\right), R_1 = R_2 = R_3 = 100\ k\Omega$$

Opamp #2: Variable Gain

$$v_o = -\frac{R_5}{R_4}v_i,\ R_4 = 10\ k\Omega$$

Opamp #3: Lead Compensator

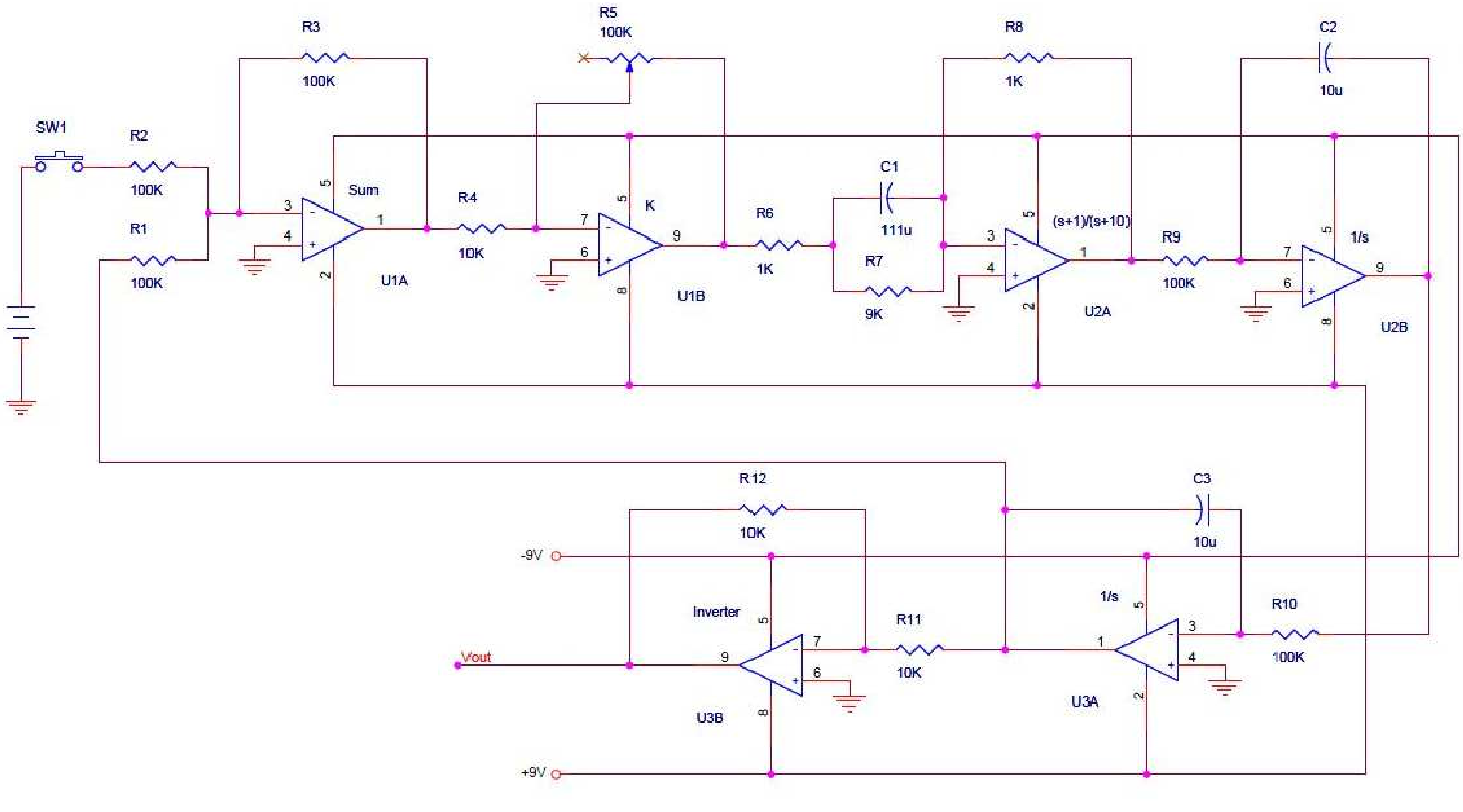
$$\frac{v_o}{v_i} = -\frac{R_8}{R_6}\left(\frac{s+\frac{1}{R_7C_1}}{s+\frac{R_6+R_7}{R_6R_7C_1}}\right),\ R_6 = R_8 = 1\ k\Omega,\ R_7 =\ 9\ k\Omega,\ C_1 = 111\mu F$$

Opamps #4/5: Integrators

$$\frac{v_o}{v_i} = \frac{1}{sRC}, R = 100\ k\Omega, C = 10\mu F$$

Opamp #6: Inverter (used only to flip $-v_o$ into v_o to obtain output signal)

$$v_o = -\frac{R_{12}}{R_{11}}v_i,\ R_{11} = R_{12} = 10\ k\Omega$$



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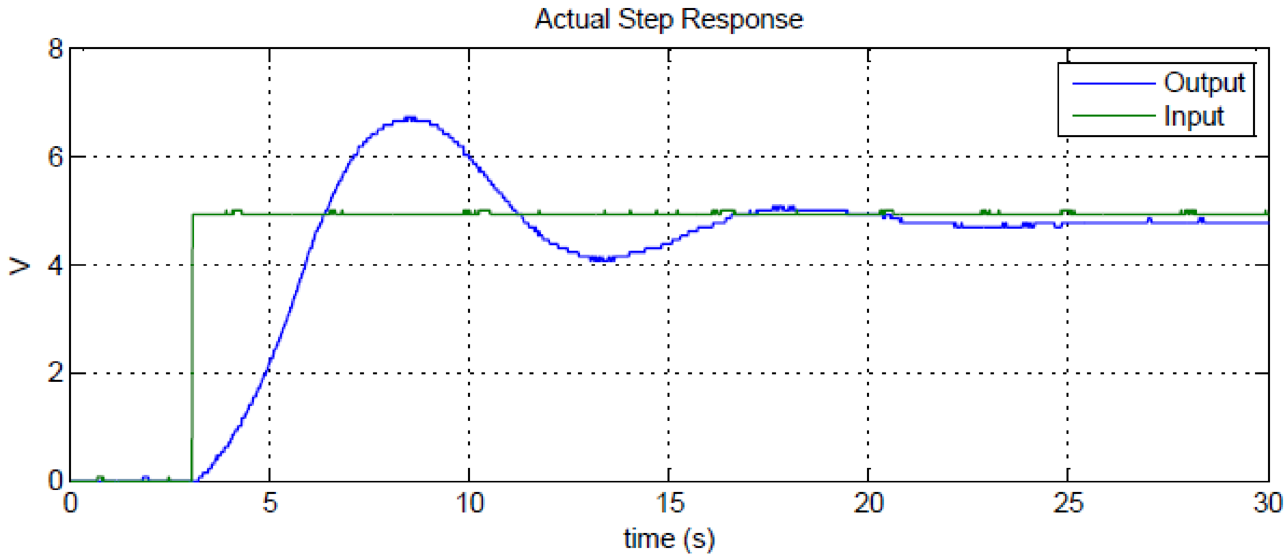
Experimental Output:



The response characteristics for the actual system are computed as follows:

Rise Time:

6.1 – 3.8 = **2.3 s**

Percent Overshoot:

(6.7-4.9)/4.9 = 0.44 = **37%**

Settling Time:

16.4 – 3.0 = **13.4 s**

A comparison between simulated and actual results shows that they are in agreement: