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Department of Electrical, Electronic and Computer Engineering

Control Systems EBB 320

Practical 3

Smith predictor

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FORM A

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Subject of the work **Practical 3 - Smith predictor**

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Introduction

Aim

The aim of the practical was to design a controller for a plant with a time delay, utilizing the concept of a Smith Predictor. The Smith Predictor is a predictive controller for systems with pure time delay. It is implemented together with a closed loop feedback controller. The time delay of the plant is moved outside of the feedback loop making designing the system easier as if there was no time delay in the plant.

Design and Implementation

Design of Smith Predictor

The first step is to design the smith predictor feed back circuit, the calculations for this is shown bellow.

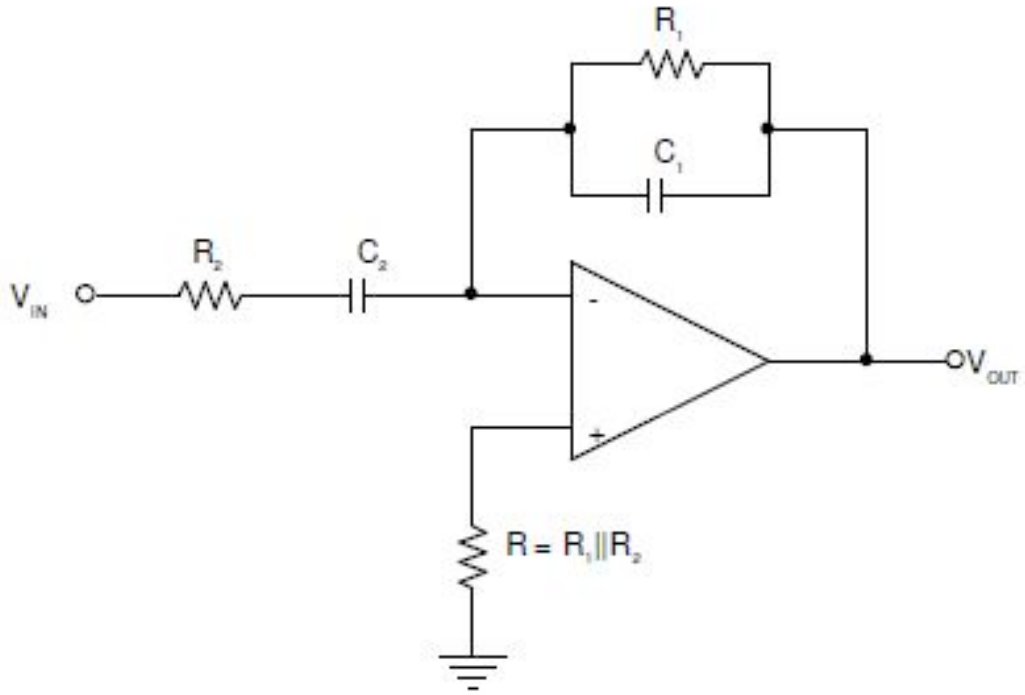


Figure 1. Circuit implementation of smith predictor

Calculations:

$$G(S) = \frac{1-0.0001s}{(1+0.0001s)(0.001s+1)}$$

$$Gq(s) = \frac{1}{0.0001s + 1}$$

$$Gd(s) = \frac{1-0.0001s}{1+0.0001s}$$

$$\begin{aligned} Gq(s)-G(s) &= Gq(s)-Gq(s)Gd(s) \\ &= \{1-Gd(s)\}Gq(s) \\ &= \left\{1-\left[\frac{1-0.0002s}{1+0.0001s}\right]\right\}\left\{\frac{1}{0.001s+1}\right\} \\ &= \frac{0.0002s}{(1+0.0001s)(1+0.001s)} \end{aligned}$$

$$\begin{aligned} \frac{Vout(s)}{Vin(s)} &= \frac{R1\cdot C2\cdot s}{(R1\cdot C1\cdot s+1)(R2\cdot C2\cdot s+1)} \\ &= \frac{0.0002s}{(1+0.0001s)(1+0.001s)} \end{aligned}$$

$$\begin{aligned} \therefore \quad R1\cdot C1 &= 0.0002 \\ R1\cdot C1 &= 0.001 \\ R2\cdot C2 &= 0.001 \end{aligned}$$

$$\begin{aligned} \text{choosing} \quad C1 &= 20nF \\ C2 &= 10nF \\ R1 &= 50k\Omega \\ R2 &= 10k\Omega \end{aligned}$$

Design of Controller

After adding the smith predictor, the controller can be designed as if there is no time delay as shown in the block diagrams and mathematical manipulations below.

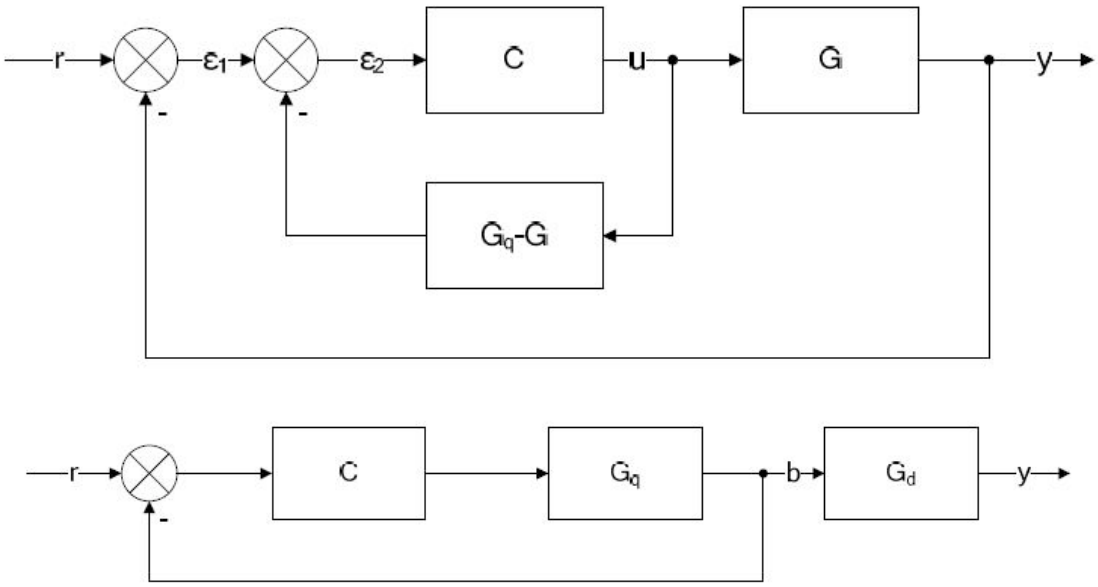


Figure 2. Controller simplification by smith predictor

Calculations to prove the transfer function with the smith predictor is a transfer function with the delay of the plant removed and a controller can be applied to this as if there is no delay.

$$\omega_n = 4000$$

$$\xi = 2^{-0.5} = 1/\sqrt{2} = 0.707$$

$$T^*(s) = \frac{b(s)}{r(s)} = \frac{\omega_n}{s^2+2\xi\omega_n+\omega_n^2}$$

$$\therefore T(s) = \frac{\frac{C\cdot G}{1+C\cdot G_q-C\cdot G}}{1+\frac{C\cdot G}{1+C\cdot G_q-C\cdot G}}$$

$$\therefore T(s) = \frac{C\cdot G_q}{1+C\cdot G_q} G_d = T^*\cdot G_d$$

$$\therefore T^*(s) = \frac{C\cdot G_q}{1+C\cdot G_q} = \frac{C(s)\left(\frac{1}{1+0.001s}\right)}{1+C(s)\left(\frac{1}{1+0.001s}\right)}$$

$$\frac{T_d\cdot 4000^2}{s^2+\sqrt{2}\cdot 4000\cdot s+4000} = \frac{C(s)\left(\frac{1}{1+0.001s}\right)}{1+C(s)\left(\frac{1}{1+0.001s}\right)}$$

$$\therefore C(s) = \frac{16\times10^3\cdot s+16\times10^3}{s(s+5656.855)}$$

The transfer function for the controller is realized using the following circuit as with the calculated component values shown bellow.

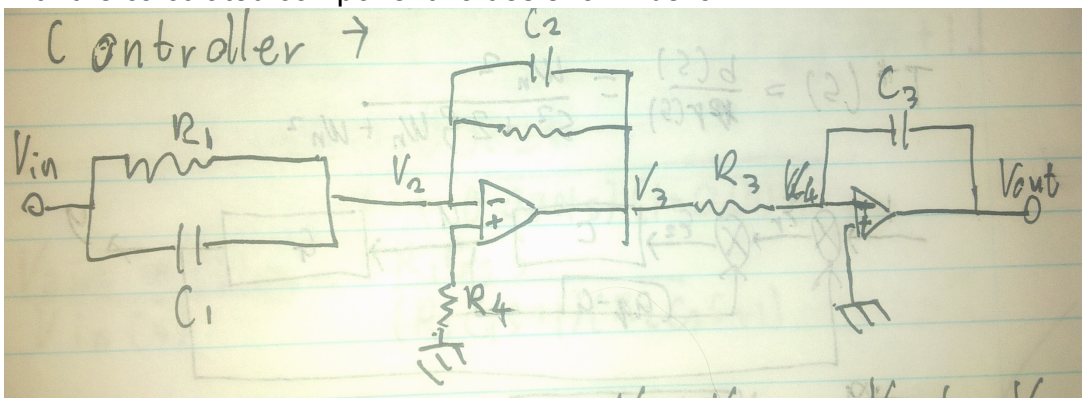


Figure 3. Controller Circuit

$$\frac{V_1-V_m}{R_1||C_1} = \frac{V_2-V_1}{R_2||C_2}$$

$$\frac{V_3-V_2}{R_3} = \frac{V_{out}-V_3}{3}$$

$$R_1||C_1 = \frac{R_1}{1+R_1C_1s}$$

$$R_2||C_2 = \frac{R_2}{1+R_2C_2s}$$

$$R_1||C_1 = \frac{R_1}{1+R_1C_1s}$$

$$V_3 = V_4 = 0$$

$$\frac{V_2}{V_{in}} = \frac{-R_2||C_2}{R_1||R_1}$$

$$\therefore V = V_{out} + R_3 \cdot C_3 \cdot s$$

$$\frac{V_{out}}{V_{in}} = \frac{s(R_1C_1R_2) + R_2}{s^2(R_1R_2C_2R_3C_3)+S(R_1R_3C_3)} = \frac{16\times10^3 \cdot s+16\times10^3}{s(s+5656.855)}$$

$$R_1C_1R_2 = 16\times10^3$$

$$R_2 = 16\times10^3$$

$$R_1R_2C_2R_3C_3 = 1$$

$$R_1R_3C_3 = 5656.855$$

Choosing:

$$C_1 = 100nF$$

$$C_2 = 100nF$$

$$C_3 = 10nF$$

$$R_1 = 10k$$

$$R_2 = 1.8k$$

$$R_3 = 6.25k$$

$$R_4 = 0$$

Simulation

Two kinds of simulation was carried out, a PSPICE simulation and a simulation using Matlab and Simulink. The measured values of these simulations are shown later in Table 1 together with the experimental results.

PSPICE

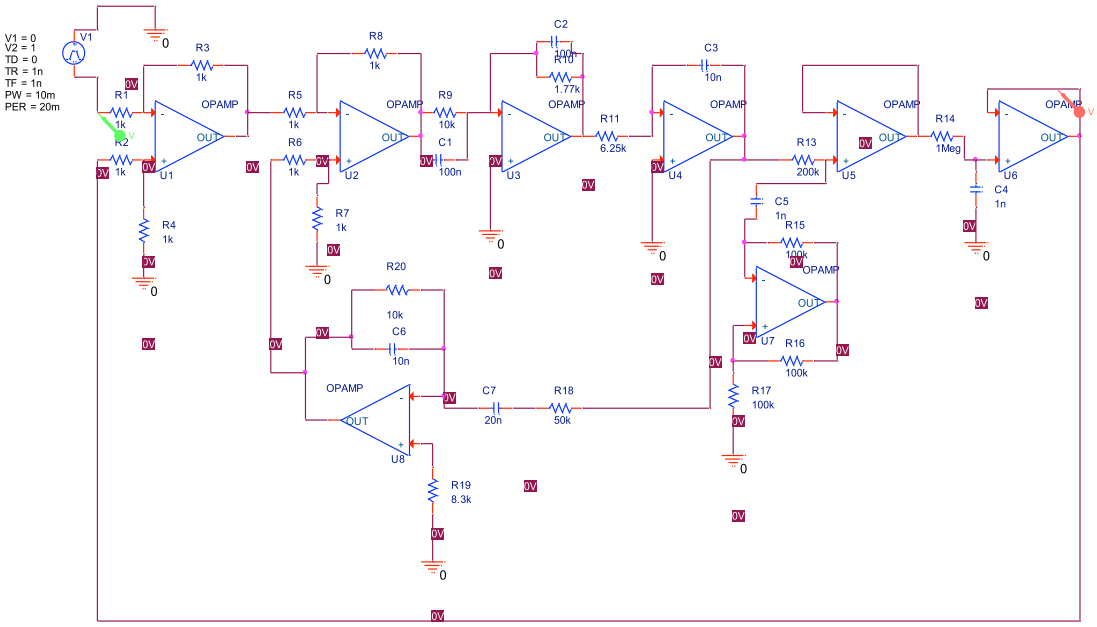


Figure 4. Circuit of complete system

The figure bellow shows the resulting waveform in from the SPICE simulation:

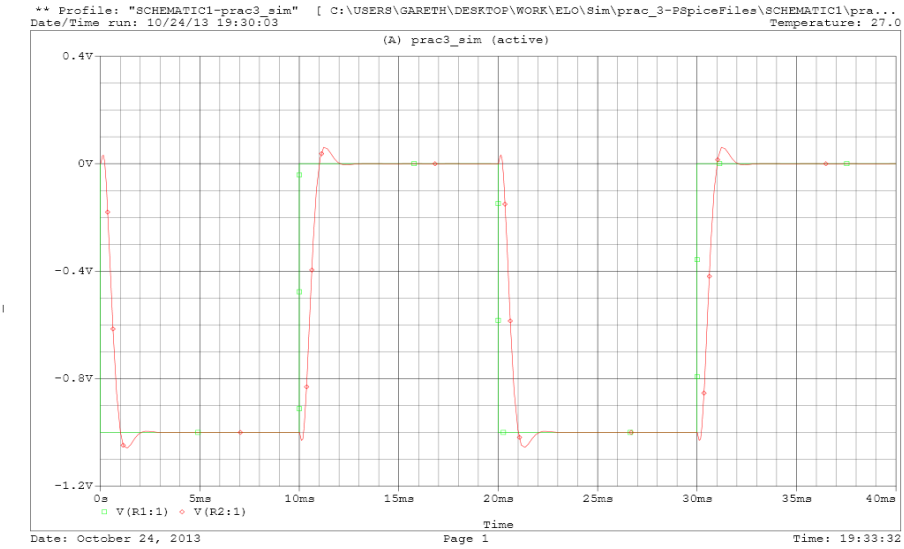


Figure 5. PSPICE waveform

Simulink

Simulink schematic and waveform

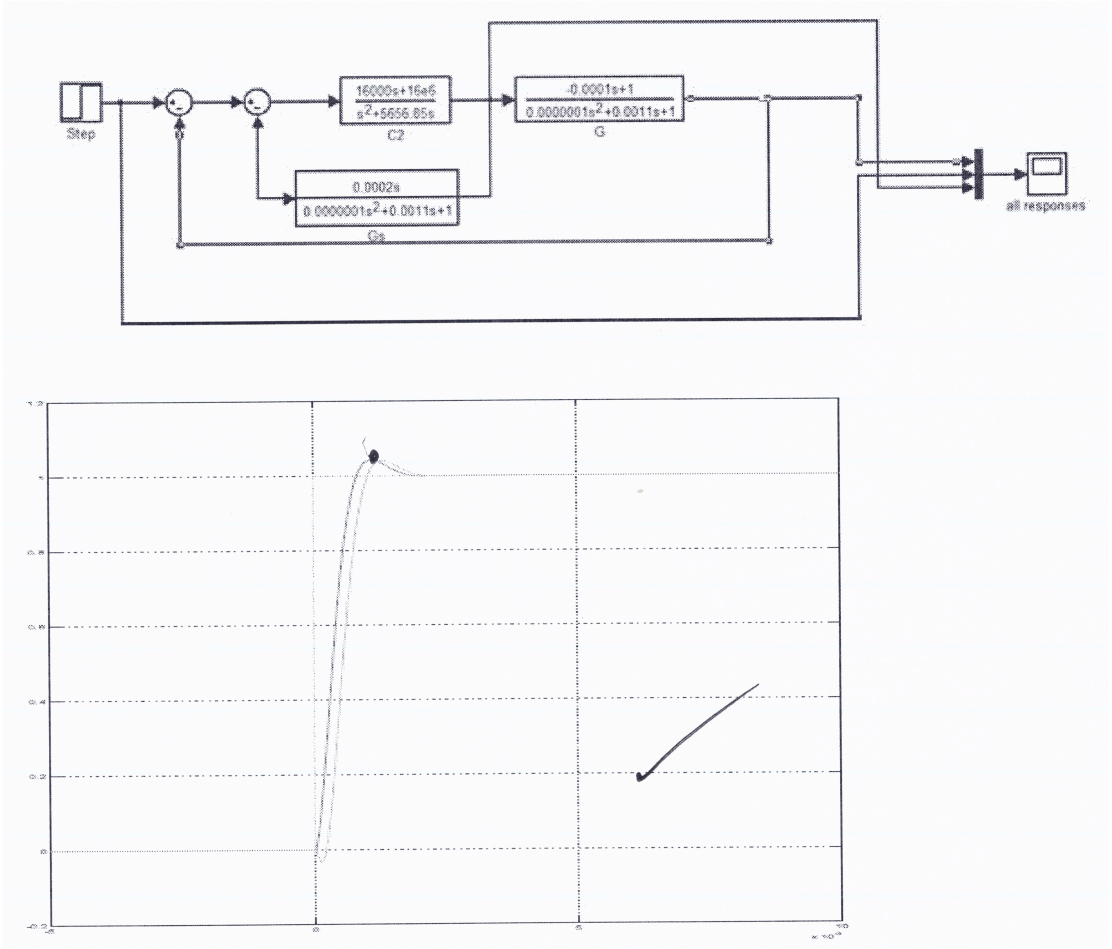


Figure 6. Simulink results: schematic and waveform

Experimental Results

The figure bellow shows the resulting wave form of the actual circuit.

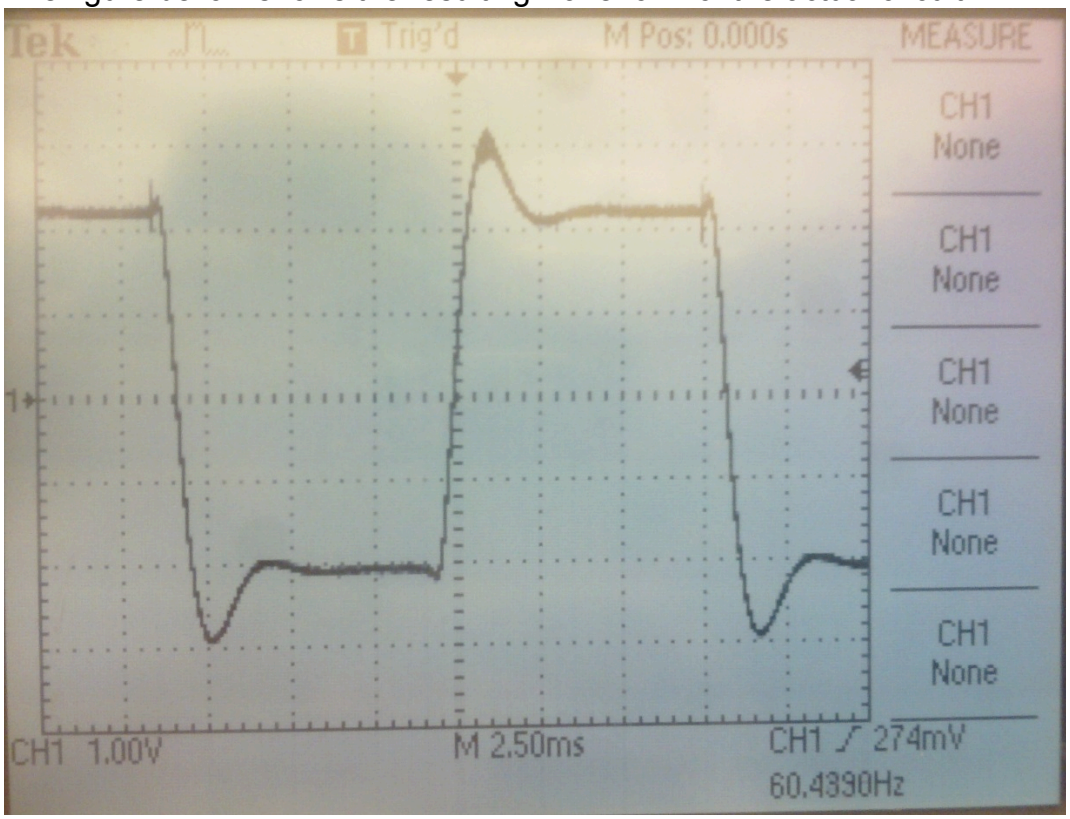


Figure 7. Experimental waveform

The table bellow shows the results obtained theoretically and by simulation for easy comparison. Results are measured off waveform as shown in **Figure 8.**

	Theoretical	Simulink	PSPICE	Practical
T_d	200 μs	200 μs	200 μs	300 μs
T_p	$\frac{\pi}{\omega_n\sqrt{1-\xi^2}} =$ 1.11 ms	1.1 ms	1.13 ms	1.64 ms
%OS	$e^{-(\xi\pi/\sqrt{1-\xi^2})} =$ 4.32%	4.32 %	4.82 %	13%
ξ	0.7071	0,695	0,695	0,695
T_r	---	0.9 ms	0.9ms	0. 86 ms
T_s	$\frac{4}{\xi\omega_n} =$ 1.4 ms	3ms	1.5 ms	3.2ms
ω_n	4000 rad/s	4375 rad/s	4375 rad/s	3868 rad/s

Table 1. Comparative results

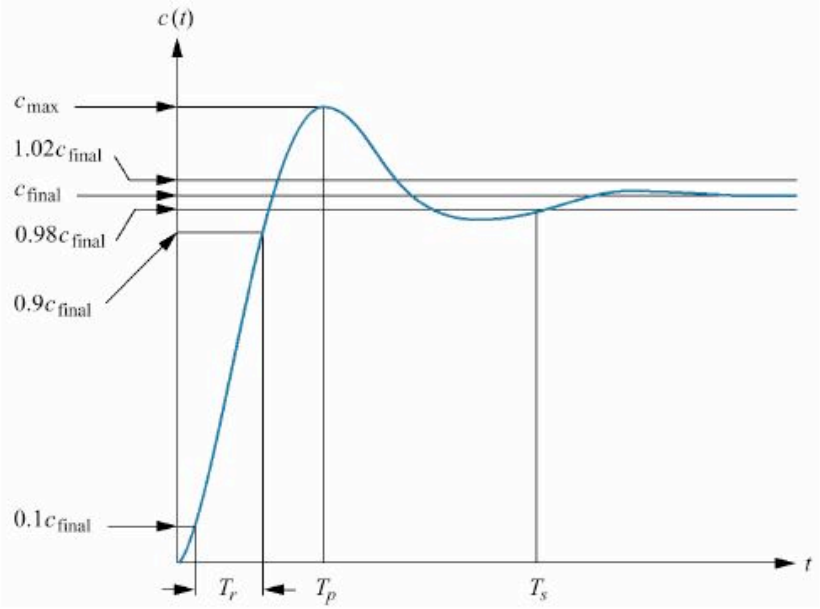


Figure 8. Typical second order response characteristic parameters. From Nise N.S., *Control Systems Engineering*, 3rd Edition, Wiley, New York, 2000. p. 193.

Observations and Conclusions

When comparing the measured results with the simulation results we noticed that they were fairly similar. The values for the % overshoot, peak time, rising time and settling time varied slightly from the expected values, however that was to be expected due to the tolerances of the components that were used. The Smith Predictor is clearly an effective method for predictive control if you have an accurate model of the plant.

References

Camisani-Calzolari, F.R. and Swart, S. 2013. *Practical 3 Guideline Control Systems: EBB 320*. Pretoria: University of Pretoria

Norman S. Nise, *Control Systems Engineering,* 6th Ed., 2011, *John Wiley & Sons*.