sim.exe Exercises for Chapter sim

Exercise sim.freud

In Exercise nlin., you derived a nonlinear state-space model for the RLC circuit of Fig. fluid.1, which includes a nonlinear capacitor, and linearized the state equation about an operating point. Use these results to perform the following analysis.

a. Write a program to simulate the nonlinear state-space model for initial condition $\mathbf{x}(0) = \begin{bmatrix} 1 & 0 \end{bmatrix}^\top$ and step input $\mathbf{u}(t) = 5u_s(t)$. Let $R = 10\ \Omega$, $L = 1$ mH, and $k = 10^{-6}$. Try simulating for 1 ms.
b. Add to the program the simulation of the linearized system for the same initial condition and input.
c. Compare (by graphing) the nonlinear and linearized step responses. (Don't forget that $\mathbf{x}^* \neq \mathbf{x}$!)

Exercise sim.kafka

Let the nonlinear state equation of a circuit like Fig. exe.2, including a diode, be

$$\begin{aligned}\frac{d\mathbf{x}}{dt} &= \mathbf{f}(\mathbf{x}, \mathbf{u}) \\ &= \begin{bmatrix} \frac{1}{C} i_L \\ \frac{1}{L}(-V_{TH} \ln(i_L/I_s + 1) - R i_L + V_S - v_C) \end{bmatrix}.\end{aligned}$$

a. Write a program to simulate the nonlinear state-space model for initial condition $\mathbf{x}(0) = \begin{bmatrix} 0 & 0 \end{bmatrix}^\top$ and input $\mathbf{u}(t) = 1 + 0.1\cos(8000\pi t)$. Let $I_s = 10^{-12}$ A, $V_{TH} = 25$ mV, $R = 10\ \Omega$, $L = 1$ mH, and $C = 10\mu$F. Try simulating for 1 ms. Hint: the ode is stiff, so simulate with `ode23s`.
b. Add to the program the simulation of the linearized system (with operating point

$x_o = \begin{bmatrix} 0 & I_s \end{bmatrix}^\top$, $u_o = 0$) with A and B matrices

$$A = \begin{bmatrix} 0 & 1/C \\ -1/L & -(V_{TH}/(2I_s) + R)/L \end{bmatrix} \quad \text{and} \quad B = \begin{bmatrix} 0 \\ 1/L \end{bmatrix}$$

for the same initial condition and input.

c. Compare (by graphing) the nonlinear and linearized step responses. (Don't forget that $x^* \neq x$!)

Exercise sim.hootenanny

Design a home rainwater catchment system and sprinkler distribution system. Most places, a surprising amount of water falls on a house's roof throughout a year. Capturing it for irrigation can save water costs and reduce the environmental impact of watering lawns, plants, and gardens.
Design a home rainwater catchment and irrigation system. The design constraints are as follows.

1. It should be designed for Olympia, Washington rainfall, as described in Table exe.1.
2. For a house, large tanks are unsightly. Instead, use a series of connected barrels.

After discussions with the customer, the following design requirements for the system are identified.

1. It should be capable of distributing one inch of water per unit area June through September, even during drought conditions, during which there is half the average rainfall in the months March through September (see Table exe.1.
2. The roof area for collection is 400 square ft.
3. The lawn area for distribution is 600 square ft.

4. It should be low-maintenance.
5. The distribution system should be capable of being "blown out" during winter months or it must be designed to handle sudden dips from 33 down to 22 deg F for up to two days.[4]
6. When tanks are full, it should be able to gracefully dump excess water. If possible, designing it to refresh itself by dumping old water for new water is desired.
7. It should be able to handle a heavy rain of 1 inch per hour via an overflow mechanism, but be able to handle a moderate rain of 0.2 inches per hour without requiring overflow (unless the tanks are full).
8. It should be designed to be fed from typical house rain gutter downspouts.
9. Distribution should be automated.
10. Energy efficiency is desired. If possible, using tanks' potential energy for distribution is desired. In this case, unconventional distribution networks are allowable (e.g. "drip" systems without conventional sprinkler heads that require high pressure). However, the distribution hardware should not be custom-designed.
11. Commercially available parts are desired. Minimize the number of custom parts (zero is best).

4. A potential way to mitigate freezing is keeping the water in motion. Care must be taken not to create inadvertent ice skating rinks.

The focus of the design problem is the sizing of the pipes, barrels, and mechanisms based on a dynamic system analysis.[5]

5. A design that is not informed by a thoroughly presented system model will receive no credit.

It is highly recommended that you use the following Fourier Series fit to the Olympia drought rainfall data, presented as trigonometric series coefficient vectors `a` and `b` for easy definition in Matlab.[6]

6. The fit is an 8-term Fourier series fit performed via Matlab's `fit` function.

```
w = 0.5236; % fundamental frequency
a0 = 3.579; % dc offset
```

Table exe.1: mean monthly rainfall data and corresponding "drought conditions" for Olympia, Washington, USA (NOAA. Mothly Average Precipitation 1951-2008 Olympia Regional Airport—NOAA Station. august 2017).

month	mean precip. (in)	drought precip. (in)
January	8.51	8.51
February	5.82	5.82
March	4.85	2.43
April	3.11	1.55
May	1.84	0.92
June	1.42	0.71
July	0.67	0.34
August	1.31	0.65
September	2.36	1.18
October	4.66	4.66
November	7.66	7.66
December	8.52	8.52

```
a(1) = 4.144;
b(1) = 0.6244;
a(2) = 1.332;
b(2) = 0.07578;
a(3) = -0.07667;
b(3) = 0.03167;
a(4) = -0.2469;
b(4) = 0.0004836;
a(5) = -0.09448;
b(5) = 0.01735;
a(6) = 0.07417;
b(6) = -2.131e-06;
a(7) = -0.06748;
b(7) = -0.0124;
a(8) = -0.1235;
b(8) = -0.0002381;
```

A system model response to this input can be used to determine the system parameters, such as the number of barrels required. Do not forget to include the effect of distribution, which can be modeled as a negative source. Although we have the tools to perform the analysis analytically, it is highly recommended that a Matlab simulation is developed using `ss` to define the system and `lsim` to simulate the response. A frequency response analysis using `bode` may also prove useful. It may be possible to simply iteratively tweak design parameters until the simulation meets the requirements. A thorough report is required. It is highly recommended that LaTeX is used. Thorough analysis, results, and design is required. All sizing and specific parts are required. Either an analytic or a numerical (simulation) demonstration of the design's fulfillment of the requirements is required.

Part VII

Appendices

Mathematics reference