PITT | SWANSON ENGINEERING
BIOENGINEERING

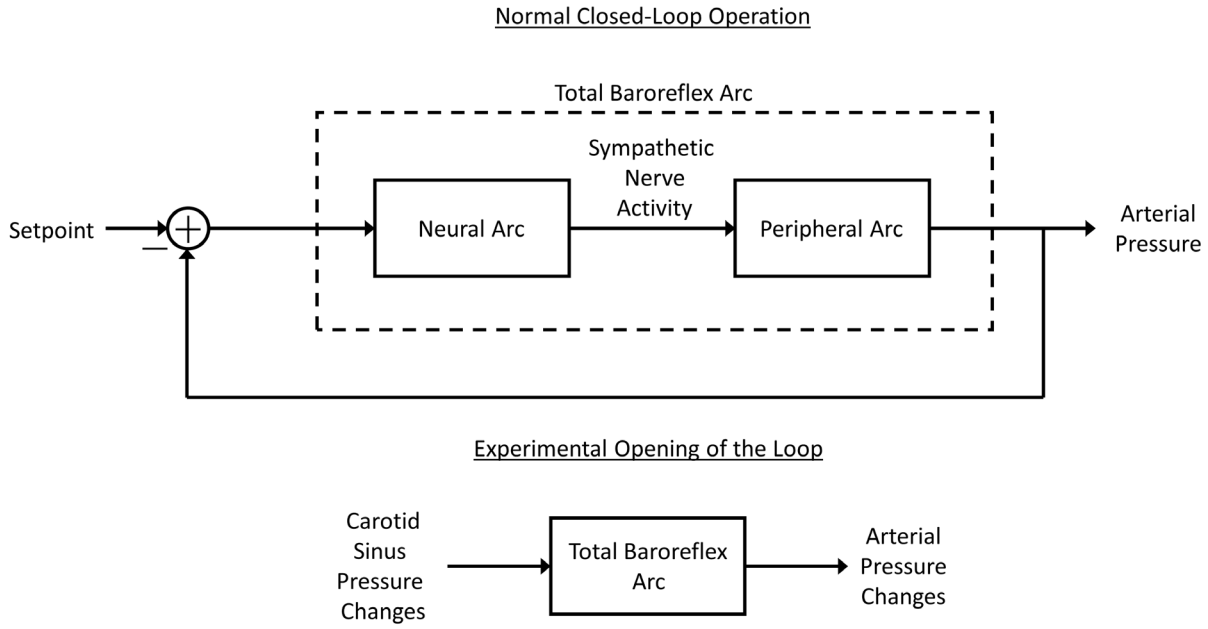
BIOENG 1320 – Biological Signals and Systems (Spring 2025)

MATLAB Project 1

Issued: January 22, 2025 Due: 6:00p, February 12, 2025 (via Canvas)

---

1. **Testing a biological system for linearity and time-invariance:** It is important for the body to keep arterial pressure within narrow limits. If arterial pressure is too low, tissue beds will not be adequately perfused with blood. If arterial pressure is too high, the tissue beds can be damaged. The baroreflex is a mechanism mediated by the autonomic nervous system for maintaining arterial pressure. Stretch receptors in the neck sense the arterial pressure in the carotid sinus region and relay this information to the brain. If the arterial pressure is above/below the desired level (i.e., setpoint), the brain responds by decreasing/increasing sympathetic nervous outflow to the circulation, which decreases/increases cardiac output and total peripheral resistance to restore the arterial pressure. The interaction between the baroreflex and circulation may be viewed as a negative feedback system as shown below.



This closed-loop system can be opened experimentally to investigate the total baroreflex arc, which relates changes in carotid sinus pressure to changes in arterial pressure. The total baroreflex arc will respond to an increase/decrease in carotid sinus pressure by decreasing/increasing the arterial pressure. The function **TotalBaroreflexArc** is a model of this system developed using experimental data from a rodent preparation. The function arguments are the carotid sinus pressure input and "n" for normotension or "h" for

hypertension, which developed after years of aging in the same subject. The function output is the resulting arterial pressure and corresponding time samples.

Use sinusoidal inputs with frequencies between 0.01 and 0.20 Hz, a "sampling interval" of 0.5 sec, and a duration of at least 50 sec to answer the following questions.

(a) Is the system linear or nonlinear?
(b) Is the system time-invariant or time-varying?
(c) If it is not linear and/or time-invariant, can it be approximated as such under certain conditions?
(d) What is the difference in classifying real biological systems versus systems defined by mathematical equations?
(e) Based on your work for (a)-(c), is the system stable? Why or why not?

Include properly labeled plots as supporting evidence.

2. **Filtering a biological signal to remove noise:** The electrocardiogram (ECG) is a recording of body surface potentials generated by the electrical activity of the heart. Measurement and interpretation of the ECG have a longstanding history and are an important aspect of the clinical evaluation of an individual's cardiac status and overall health.

   The normal heartbeat begins as an electrical impulse that propagates from the atria to the ventricles. (This electrical excitation is followed by mechanical squeezing of the heart to eject blood into the circulation.) The normal ECG signal corresponding to a single heartbeat consists of three temporally distinct wave shapes: (1) the low amplitude P wave indicating electrical excitation of the atria; (2) the high amplitude and sharp QRS complex representing electrical excitation of the ventricles; and (3) the medium amplitude T wave denoting electrical relaxation of the ventricles. These wave shapes generally occupy frequencies between 0.05 and 50 Hz.

   Naturally, noise can present a significant problem in the interpretation of the ECG signal. There can be substantial low frequency (< 15 Hz) noise due to electrode motion as well as high frequency (> 15 Hz) noise due to skeletal muscle activity. In addition, there is the possibility of noise at 60 Hz and its harmonics due to power-line interference. However, the signal-to-noise ratio is usually quite good in a patient at rest.

   The file **ecg.mat** contains two ECG signals, each of 10 sec in duration and at a "sampling frequency" of 250 Hz. One signal was obtained from a subject at rest, and the other signal was obtained while the subject was periodically contracting their chest muscles. Each signal is stored as a matrix named "clean" and "noisy" and consists of two columns. The first column represents the sample times (in sec), while the second column indicates the corresponding ECG amplitudes (in volts). The file **ecgfilter.mat** contains an impulse response at the same

sampling frequency for removing noise in an ECG signal while retaining information. The impulse response is stored as a single column vector. The discrete-time filter may be applied to the continuous-time ECG signals by approximating the convolution integral as follows:

$$y(t) = \int_{-\infty}^{\infty} h(\tau)x(t-\tau)d\tau \quad \rightarrow \quad y(nT_s) \approx \sum_{k=0}^{N-1} h(kT_s)x((n-k)T_s)T_s,$$

where $T_s = 1/250$ sec and N is the impulse response length here.

(a) Plot the two ECG signals versus time and label the P wave, QRS complex, and T wave for a single beat of the clean signal. Estimate the heart rate of the clean signal in beats per minute. Can the same information be provided for the noisy signal?
(b) Apply the filter to both ECG signals using the built-in **conv** function. Plot the two filtered signals versus time. The filtered signals are longer than the original signals and have some transients at the edges. What causes these edge effects and how should they be handled?
(c) Describe the results of the filtering. Can you now label and estimate the heart rate of the filtered noisy signal? Has all the noise been removed from the noisy signal?
(d) Could the provided filter be used to also remove noise in other biological signals (e.g., an arterial pressure signal)?

Deliverables: Submit a single pdf file containing answers to the questions, properly labeled plots, and the source code.