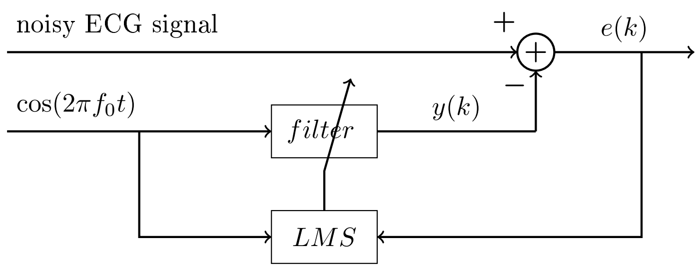
Exercise 2: Filtering of noisy ECG signals

In this exercise we will use the LMS algorithm for suppressing interference from a signal of interest. The signal is a measurement of a electrical activity of the heart of a human. This is also known as an electrocardiogram (ECG). In our case the measurement is contaminated by sinusoidal interference from the power network. The ECG signal can be found in the ascii file `ecg.dat` on Brightspace. The ECG signal has been captured using a Blackfin based hardware prototype. The system uses 2 electrodes and has a sample-rate of 500 Hz. The acquired signal contains a considerable amount of powerline interference, which we now attempt to remove using two different methods of adaptive signal processing.

The first method is called interference cancellation and makes use of a reference signal that contains no ECG signal but just noise that is correlated with the noise in the ECG signal. In principle a reference signal containing the 50 Hz interference can be measured directly at a power outlet. In this exercise, the reference signal is created in MATLAB as shown below.



1. Load the ECG signal into MATLAB and find the power line frequency using an appropriate method.
2. How many filter coefficients are needed in the adaptive filter?
3. Implement an LMS filter which removes the ECG signal from a MATLAB generated sinusoid at the power line frequency. Implement the LMS loop in your own `.m` file using the algorithm from the textbook.
4. Select an appropriate value for the step-size μ.
5. Examine the error-signal $e(k)$ by plotting it and comparing it with the original noisy ECG-signal.
6. Adjust your parameters μ and the number of filter coefficients and see how good results you can acheive. If possible, estimate the improvement in signal-to-noise ratio.

The interference cancelling can also be carried out with a setup known as an adaptive line enhancer (section 6.4.3 in the textbook). In this scenario we don't need to generate our own sinusoidal signal. Instead only the signal itself is used. The noise contaminated signal is used as the desired signal and a delayed copy of this signal is sent through the filter. With a proper adjustment of the delay the filter will lock on to the sinusoidal signal. The adaptive line enhancer is potentially superior to the above setup as it will automatically track changes in the frequency of the interfering signal.

7. Implement an adaptive line enhancer in MATLAB.
8. Find good values for μ, the delay and the length of the filter and compare the performance of the adaptive line enhancer with the solution from the first part of the exercise.
9. In principle, both the sinusoidal interference and the ECG signal are periodic functions. Explain why the adaptive line enhancer still works and explain the pitfalls for this specific signal.

Interference from a 50 Hz powerline signal is quite common and can in principle also be removed with a notch filter.

10. Design and implement a notch filter. Compare the results with the adaptive solutions.

A very important design feature of a noise filter for ECG signals is that the filter must leave the shape of the ECG signal unaltered to avoid wrong diagnosis.

11. Comment on the efficiency of the adaptive and non-adaptive solutions in this aspect.