BIOMEDICAL SIGNALS

LAB SESSION 5 WITH MATLAB
MATCHED FILTERING

MATCHED FILTERING – Detection of Spike-and-wave Complexes in EEG Signals

In signal processing, a matched filter is obtained by correlating a known delayed signal, or template, with an unknown signal to detect the presence of the template in the unknown signal. This is equivalent to convolving the unknown signal with a time-reversed version of the template. The matched filter is the optimal linear filter for maximizing the signal-to-noise ratio (SNR) in the presence of additive stochastic noise.

Objectives:

• Detection of spike-and-wave complexes in EEG signals using template matching.
• Design and implementation of a matched filter to detect spike-and-wave complexes in EEG signals.

1. BACKGROUND

A spike-and-wave complex (SWC) is a well-defined event in an EEG signal. The complex is composed of a sharp spike followed by a wave with a frequency of about 3 Hz; the wave may contain a half period or a full period of an almost-sinusoidal pattern. One may, therefore, extract a copy of an SWC from an EEG channel and use it for template matching. By computing the cross-correlation function (CCF), the template may be correlated with the same EEG signal from which it was extracted to detect similar events that appear at other instants of time, or with the EEG from another channel of the same subject or even a different subject to search for similar patterns or events.

Another approach to solve this problem is to design a matched filter to facilitate the detection of SWCs in EEG signals. When a sample observation of a typical version of a signal event available (a template of an SWC in the present exercise), it becomes possible to design a filter that is matched to the characteristics of the event. If an observed signal is expected to contain repetitions of the event with almost the same characteristics, the signal may be passed through the matched filter. The output should provide peaks at the time instants of the occurrences of the event. Matched filters are designed to perform correlation between the input signal and the signal template. The output of the matched filter may be thresholded to detect peaks that correspond to SWCs in the given EEG record.

2. TEMPLATE MATCHING

Consider the files *eeg2*.dat* and uploaded them using the script *eeg2.m* Signals are sampled at the rate of 100 Hz. Select an EEG signal and a template corresponding to an SWC (for example channel c3 between 0.6 and 0.82 ms). Write your own Matlab code to compute the CCF between the template and the signal. Better if you normalize the CCF. Apply a peak-detection algorithm to locate the peaks in the result. Mark the locations of the corresponding SWC complexes in the EEG signal. Apply time-delay corrections as required and explain.

Plot the EEG signal and the CCF, including marks to identify the peaks in the CCF and the SWC complexes detected in the EEG signal.

Apply the same template and procedures to two other EEG channels and analyze the results, for example a close channel (c4) and a farther one (p4) where the SWC is not so clear .

3. MATCHED FILTERING

Derive the impulse response of the matched filter from the template selected in the preceding experiment. Plot the template and the impulse response of the matched filter on the same figure and explain the relationships between the two.

Perform the matched filtering operation on the same EEG signals as in the preceding experiment by using the *filter.m* command in MATLAB. Process the output of the matched filter to detect peaks and mark SWCs in the original EEG signals corresponding to each of the peaks detected in the matched filter output.

The filter which maximizes the output energy is the one with the impulse response of $h(t)=Kx(-t+t_o)$. The paramenter/constant K scaled the template accordingly. Using the *filter.m* command in MATLAB probably you have considered K=1. Find the proper K value to have the same filter output as you obtained with the normalized CCF, that is, the output must be between -1 and 1. For this purpose, K must be time variant because it is the reciprocal of the normalization factor which depends on the signal energies. Remember from previous Lab sessions, that these energies must be calculated from the template and from the other signal segment which overlaps with the template at each shift lag. Code a function for this filtering considering the time variant K as explained above.

Apply the same matched filter and procedures to the two other EEG channels (c4 and p4 for example) and analyze the results.

Discuss the similarities and differences between template matching and matched filtering and the results provided by the two methods.

Finally, test the matched filtering under noise effect. For this purpose, add white gaussian noise to the EEG signal (only channel c3) and try to detect the spikes plus complex by matched filtering. You can add the noise with the MATLAB command *signal_with_noise = awgn(signal_without_noise,SNR,'measured')* . Check the following Signal to Noise Ratios (SNR): 20 dB, 15 dB, 10 dB, 5dB, 0 dB (the same signal and noise powers), -5 dB (more noise than signal powers). Discuss the robustness of the matched filtering from the results obtained in the exercise.