Filter 50/60 Hz signal from ECG simulated data

Table of Contents

This script demonstrate how to filter a noisy ECG signal. Over the simulated ECG signal is added baseband noise, white noise and power line hum.

User controlled variables

```
LPF_cutoff = 25; %ECG signal band => between 10 Hz and 25 Hz
HPF_cutoff = 1; % Baseline wander frequency is lower than 1Hz. Can be
 higher in special conditions (running)
LMS_conv = 0.009;

% noise amplitudes
Noise_amplitude = 0.020;
Mains_interference_amplitude = 8;
Baseline_wander_amplitude = 1;

f_baseline = 0.2;
f_interference = 50.5; % power line frequency

Fs = 50 * 16;  %sample rate
dt=1/Fs;
t=0:dt:16;

ref = sin(2*pi*f_interference*t);

% Insert a frequency offset for the interference signal
f_offset1 = 0;
f_offset2 = 0;
interference_noise = Mains_interference_amplitude * sin
 (2*pi*(f_interference-f_offset1)*t) + ...
                     Mains_interference_amplitude * 0.2
 *sin(2*pi*(f_interference-f_offset2)*t);
```

Create ECG simulated signal

```
Hearth_rate = 75;
```

```
ECG_period = Hearth_rate/60;
QRS_complex_duration = 0.08; % QRS complex duration is between 0.08 -
 0.12 seconds
PR_duration = 0.12;  % PR duration is between 0.12 -0.20 seconds
QT_duration = 0.40; % QT duration is between 0.35 - 0.43 seconds
```

Create QRS complex shape

```
QRS_t = 0:dt:QRS_complex_duration;
QRS_f = 1/QRS_complex_duration;
QRS_waveform = sin(2*pi*QRS_f/2*QRS_t).*(QRS_t<=QRS_complex_duration);
```

Create PR interval shape

```
PR_t = 0:dt:PR_duration;
PR_f = 1/PR_duration;
PR_waveform = 0.2*sin(2*pi*PR_f/2*PR_t).*(PR_t<=PR_duration);
```

Create QT interval shape

```
QT_t = 0:dt:QT_duration;
QT_f = 1/QT_duration;
QT_waveform = 0.2*sin(2*pi*QT_f/2*QT_t).*(QT_t<=QT_duration);
```

Create a vector that holds the exact location of the ECG pulse.

```
time_location = double(0==mod(t,ECG_period));
```

Create PR interval with respect to QRS complex position

```
ECG_PR = conv(circshift(time_location,[0, -ceil(PR_duration/dt +
 PR_duration/(2*dt))]), PR_waveform);
ECG_PR = ECG_PR(1:length(ECG_PR) - length(PR_waveform) + 1);
```

Create QT interval with respect to QRS complex position

```
ECG_QT = conv(circshift(time_location,QT_duration/(2*dt)),
 QT_waveform);
ECG_QT = ECG_QT(1:length(ECG_QT) - length(QT_waveform) + 1);
```

Repeat QRS complex according to ECG_period.

```
ECG_waveform = conv(time_location, QRS_waveform);
```

Merge signals PR_QRS_QT

```
ECG_waveform = ECG_waveform(1:length(ECG_waveform) -
 length(QRS_waveform) + 1) + ECG_PR + ECG_QT;
```

Add signal noise: random noise, interference noise and baseline noise

```
ECG_waveform_noise = ECG_waveform + Noise_amplitude * randn(size(t));
ECG_waveform_interference = ECG_waveform_noise + interference_noise;
ECG_waveform_final = ECG_waveform_interference +
 Baseline_wander_amplitude * sin(2*pi*f_baseline*t);
```

Low pass filtering and high pass filtering

```
[b,a] = butter(2, LPF_cutoff/(Fs/2));
%freqz(b,a)
ECG_LPF = filter(b, a, ECG_waveform_final );

[b,a] = butter(2, HPF_cutoff/(Fs/2),'high');
%freqz(b,a)
ECG_HPF = filter(b, a, ECG_LPF );
```

LMS 2 tap

Fs = 60*16 = 960 hz = 1.04 ms 16.66 ms/2 = 8.33 ms => 4 samples for 90 degree phase shift

```
% Fs=50*16 = 800 hz = 1.25 ms
% 50 hz -> 20ms => 20/1.25 = 16 samples/cycle => 16/4 = 4 -> 4 samples
% represents 90 degree phase shift

% narrow band filter that works only with frequencies near
 f_interference
% 2 tap filter - adjust b1 and b2 coefficients for in phase ref(i) and
 90 degree
% phase shift ref(i-4) signal

% if interference signal from ECG_HPF would be in phase with the ref
 signal
% then b2 would be 0 and b1 would be Mains_interference_amplitude/
ref_amplitude.

b1 = 0;
b2 = 0;

for i=5:length(t)

    ECG_out(i) = ECG_HPF(i) - (b1*ref(i) + b2*ref(i-4)) ;
    %b1 = b1 + LMS_conv*ECG_out(i)*sign(ref(i));
    %b2 = b2 + LMS_conv*ECG_out(i)*sign(ref(i-4));
    b1 = b1 + LMS_conv*ECG_out(i)*ref(i);
    b2 = b2 + LMS_conv*ECG_out(i)*ref(i-4);

end
```

LMS 4 taps

```
a1 = 0;
a2 = 0;
a3 = 0;
a4 = 0;
for i=13:length(t)

    ECG_4tap(i) = ECG_HPF(i) -  (a1*ref(i) + a2*ref(i-4) + a3*ref(i-8)
 + a4*ref(i-12));
```

```
    a1 = a1 + LMS_conv*ECG_4tap(i)*(ref(i));
    a2 = a2 + LMS_conv*ECG_4tap(i)*(ref(i-4));
    a3 = a3 + LMS_conv*ECG_4tap(i)*(ref(i-8));
    a4 = a4 + LMS_conv*ECG_4tap(i)*(ref(i-12));

end
```

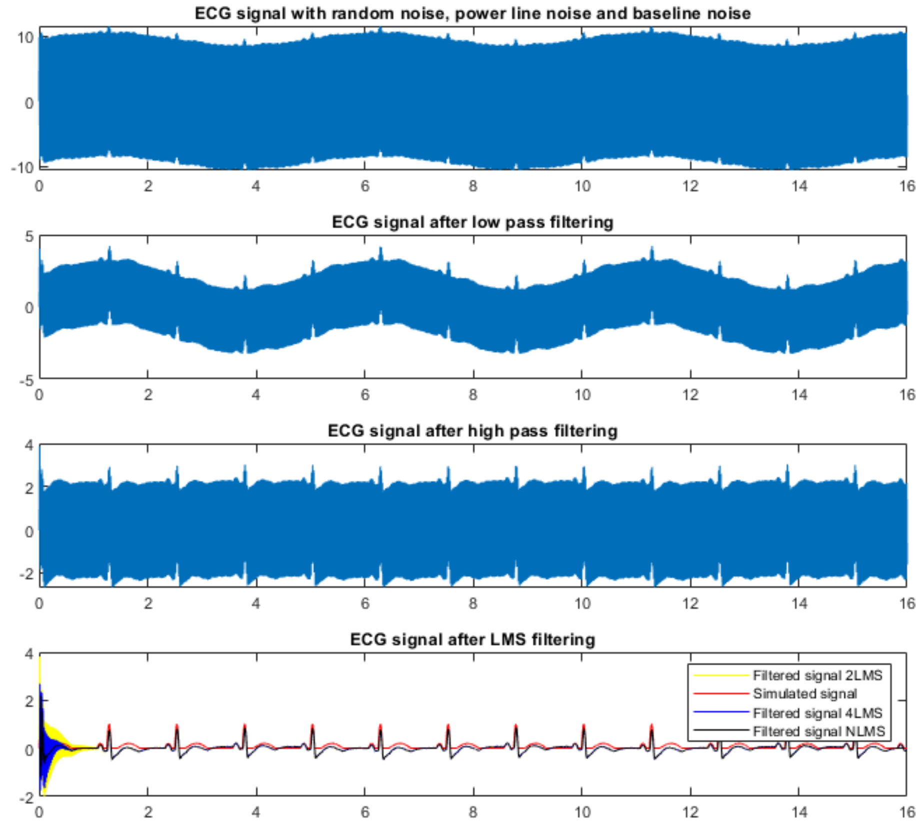
LMS n taps

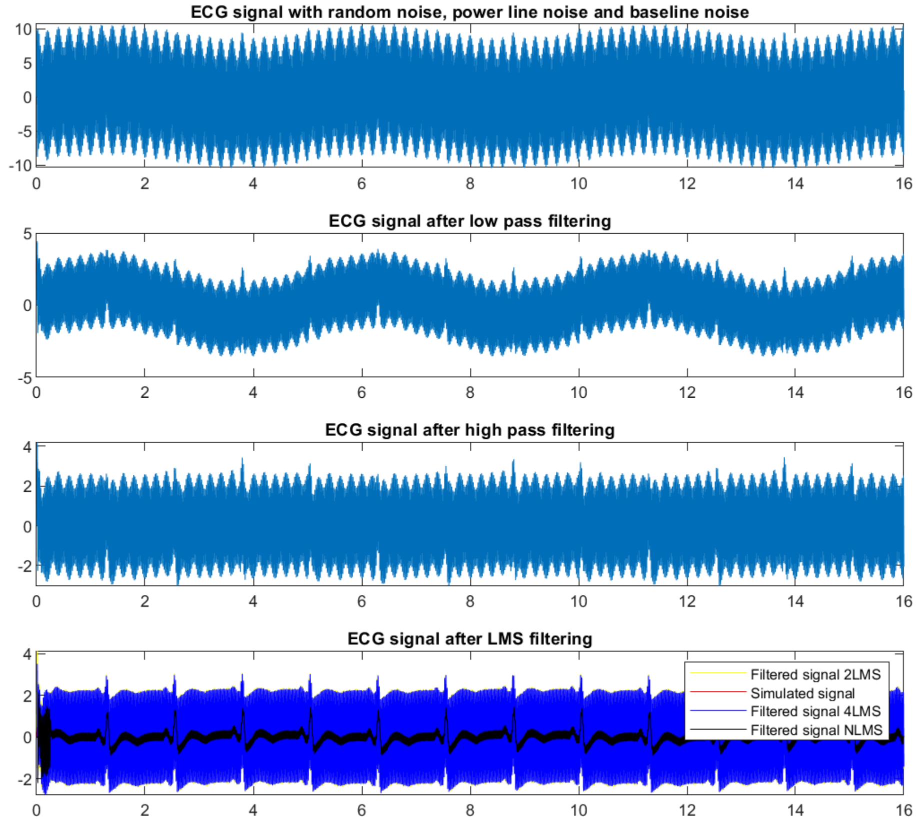
```
n = 20;
h = zeros(1,n+1);
offset = 0:-1:-n;
for i=n+1:length(t)
    % keep a history buffer
    buffer = ref(i+offset);
    ECG_ntap(i) = ECG_HPF(i) - dot(h,buffer);
    h = h + LMS_conv * ECG_ntap(i) * buffer;
end

% smoothdata - not mandatory, just for eye comparation
% ECG_out  = smoothdata(ECG_out);
% ECG_4tap = smoothdata(ECG_4tap);
% ECG_ntap = smoothdata(ECG_ntap);
```

Output plots

ECG signal filtering when interference frequency is equal to reference signal 50/60Hz

```
figure
subplot(4,1,1);
plot(t,ECG_waveform_final);
title("ECG signal with random noise, power line noise and baseline
 noise");
subplot(4,1,2);
plot(t,ECG_LPF);
title("ECG signal after low pass filtering");
subplot(4,1,3)
plot(t,ECG_HPF);
title("ECG signal after high pass filtering");
subplot(4,1,4);
plot(t,ECG_out,'y');
title("ECG signal after LMS filtering");
hold on
plot(t,ECG_waveform,'r');
hold on
plot(t,ECG_4tap,'b');
hold on
plot(t,ECG_ntap,'black');
legend('Filtered signal 2LMS','Simulated signal', 'Filtered signal
 4LMS', 'Filtered signal NLMS');
set(gcf,'Position',[380 80 800 680]);
saveas(gcf,'ECG_filtering.png');
```


ECG signal with random noise, power line noise and baseline noise
ECG signal after low pass filtering
ECG signal after high pass filtering
ECG signal after LMS filtering
Filtered signal 2LMS
Simulated signal
Filtered signal 4LMS
Filtered signal NLMS



Published with MATLAB® R2020a