**Introduction**

This lab was designed to study the effect that synchronized averaging has on noise as well as the effect that number of signals. This is method is to be used to increase the signal to noise ratio (SNR) of an observed signal by reducing the noise. The observed signal can be expressed as [1]:

Where the observed signal is the sum of the signal plus any noise present. Synchronized averaging is the average of multiple signals that are aligned with each other so that they have the same general form. This algorithm is therefore generally suited for signals that have a ‘trigger’ point or something of that sort that allows proper alignment of the multiple signals. This is to ensure that when taking the average of the observed signal you are mitigating the effect on the true signal and only averaging out the noise. The form of this synchronized averaging equation is [1] (where M is the number of signals averaged):

This works when the noise in the observed signal is random with zero mean and uncorrelated with the signal. This means when you sum the noise across many signals it will disappear; go to zero [1].

With the noise reducing to zero reducing to zero this leaves the synchronized average signal as being composed of only the average of the signal. To evaluate the effectiveness of signal averaging SNR will be used. This is calculated by [1]:

Where signal power and noise power are calculated by (where N is the number of samples in the signal and T is the sampling interval) [1]:

The noise power equation is essentially the sum of the difference between the observed signal and the synchronized average signal and the signal power equation is the average value of the synchronized minus the noise power.

**Results**

Chart, line chart, histogram

Description automatically generated

Figure: Signals 1-4 and Their Synchronized Average

Chart, line chart, histogram

Description automatically generated

Figure: Signals 1-8 and Their Synchronized Average

Chart, histogram

Description automatically generated

Figure: Signals 1 to 12 and Their Synchronized Average

Chart, histogram

Description automatically generated

Figure: Signals 1 to 24 and Their Synchronized Average

Graphical user interface, chart, histogram

Description automatically generated

Figure: Signals 17 to 24 and Their Synchronized Average

Chart, histogram

Description automatically generated

Figure: Signals 13 to 24 and Their Synchronized Average

Table 1. Signal Characteristics of Synchronized Average ERP Signals

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **M1 – M2** | **Noise Power** | **Signal Power** | **SNR** | **D** | **M** |
| **E11 – E44** | 7.6637e6 | 1.2242e7 | 1.5974 | 1.7087e4 | 4 |
| **E11 – E88** | 1.1461e7 | 8.3546e6 | 0.7290 | 2.1960e3 | 8 |
| **E11 – E1212** | 1.1301e7 | 9.0868e6 | 0.8041 | 2.2371e3 | 12 |
| **E11 – E2424** | 1.1891e7 | 4.4472e6 | 0.3740 | 2.3513e3 | 24 |
| **E1717 – E2424** | 1.0382e7 | 6.4716e5 | 0.0623 | 2.7786e3 | 8 |
| **E1313 – E2424** | 1.0994e7 | 1.2940e6 | 0.1177 | 2.6718e3 | 12 |

**Conclusion**

This lab looked at using synchronized averaging to reduce noise in event related potential (ERP) signals. The reason synchronized averaging works for these signals is that the signals follow the same structure and are repetitive. The trigger point is the stimulus event and aligning the signals around that point allows for the use of synchronized averaging. Synchronized averaging performance was evaluated for their SNR and their Euclidean distance. A higher signal to noise ratio is desirable because this means that there was either an increase in signal power or a decrease in noise power. From table 1 you can see that SNR was highest for 4 signals, decreased for 8 signals, increased for 12 signals and decreased for 24 signals. This seems to indicate that there is an optimal number of signals to average together. SNR improves up until a certain point this could be due to alignment of more signals decreases the noise but also decreases the signal power due to minute errors in the alignment. The SNR values acquired for 8 and 12 observed signals was done both with the first 8/12 signals and the last 8/12 signals. While the same number of signals is used there was a decrease in SNR for the synchronized average signal of the ones obtained later. This is due to the habituation phenomenon which is the irregular conditioned response to a repeated stimulus [2]. So, the last signals are more irregular responses to the stimuli and therefore when applying synchronized averaging to these signals the signal power is decreased due to its irregularity. The other evaluation parameter analyzed was the Euclidean distance (D) of each segment of signals. Euclidean distance performance on the two sets of 8 and 12 signals increased in the signals acquired later. This is indicative of the habituation phenomenon as well as Euclidean distance measures the distance from every point in the synchronized average signal to the corresponding point on the observed signal. A higher Euclidean distance is indicative of a larger distance/difference between the points and therefore the synchronized average signal has less of a relationship with the signal constituents.

**Appendix**

%% BME 672 Lab 1

clear all;

close all;

clc;

%% Load Signals

% Add Data path

%addpath('/Users/andrewmullen/Desktop/School/Fall 2020/BME 772/Lab1\_data')

% Create empty signal matrix

sig\_mat(24,511) = 0;

% Fill Array

for i = 1:24

sig\_mat(i,:) = load(strcat('E', num2str(i), num2str(i)));

end

% Create Time Vector

Fs = 1000;

Ts = 1/Fs;

N = size(sig\_mat, 2);

t = (0:N-1)\*Ts;

%% Extract Features for certain signals

M1 = 13; % First Signal

M2 = 24; % Last Signal

M = M2-M1 + 1; % Number of signals

% Allocate array filled with 0s

ybar = zeros(1, N);

% Calculate Average Signal

for i = M1:M2

ybar = ybar + sig\_mat(i, :);

end

ybar = ybar/M;

%% Calculate Noise Power

noise = 0;

for i = M1:M2

temp = 0;

for j = 1:N

temp = temp + (sig\_mat(i, j) - ybar(j))^2;

end

noise = noise + temp;

end

noise = noise / (N \* Ts \* (M-1));

%% Calculate Signal Power

pow = 0;

for i = 1:N

pow = pow + ybar(i)^2;

end

pow = pow / (N\*Ts) - (noise/M);

%% Signal to Noise ratio

SNR = pow / noise;

%% Calculate euclidean distance

D = 0;

for i = 1:M

temp = 0;

for j = 1:N

temp = temp + (sig\_mat(i, j) - ybar(j))^2;

end

D = D + sqrt(temp);

end

D = D/M;

%% Plot Signals

figure;

subplot(211)

for i = M1:M2

plot(t, sig\_mat(i, :));

hold on

end

a = 'Signals Number';

s = ' ';

b = num2str(M1);

c = 'to';

d = num2str(M2);

label = [a s b s c s d];

title(label);

xlabel('Time (s)');

ylabel('Amplitude');

subplot(212)

plot(t, ybar);

title('Synchronized Average Signal');

xlabel('Time (s)');

ylabel('Amplitude');

**References**

[1] Krishna, Sridhar. LAB 1 - Synchronized Averaging for Noise Reduction, BME772 (Biomedical Signal Analysis - FALL2020) -Laboratory Manual.  Toronto. Ryerson University, 2020.

[2] "Habituation | behaviour", *Encyclopedia Britannica*, 2020. [Online]. Available: https://www.britannica.com/topic/habituation. [Accessed: 07- Oct- 2020].