Ryerson University

Department of Electrical & Computer Engineering
Faculty of Engineering & Architectural Science

Course Title:	Biomedical Signal Analysis
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Instructor:	Sri Krishnan

Assignment/Lab Number:	4
Assignment/Lab Title:	Speech Analysis

Submission Date:	11 / 19 / 2020
Due Date:	11 / 20 / 2020

Student LAST Name	Student FIRST Name	Student Number	Section	Signature*
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Reset Form

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BME 772 Lab 4 Report

Introduction

Speech is produced using both the vocal tract system and the larynx vocal fold vibration to regulate air from the lungs [1]. Speech is composed of two components. The voiced component is the periodic excitation of the vocal folds. Pitch is the fundamental frequency of the voiced component [1]. The other component of speech is considered unvoiced and this is the white noise part of speech [1]. Autocorrelation is the degree of correlation between the values of the same variable [2]. This can be used to detect non-randomness in a signal such as a pitch [2]. Pitch is found by taking the time difference between the first two peaks of the autocorrelation of the signal. Another aspect of speech is the formants, which are a concentration of acoustic energy in a speech signal [3]. This occurs around a particular frequency and is known as the formant frequency [3]. The formant ratio is the ratio between the first and second formants and are consistent across all persons for various sounds made [4]. Speech signals are useful in biomedical engineering to detect any vocal cord disorders such as dysphonia which is the spasming of vocal cords [5]. This lab is an introduction to speech analysis through automated detection of pitch, formant frequencies and formant ratio.

Results

Total figures = 9, Tables = 2

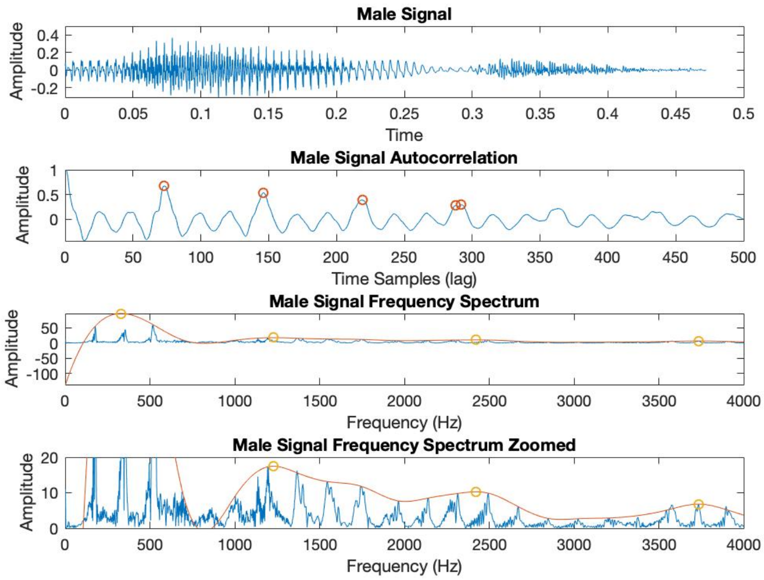

Figure 1: Male ‘rainbow’ signal, autocorrelation & frequency spectrum

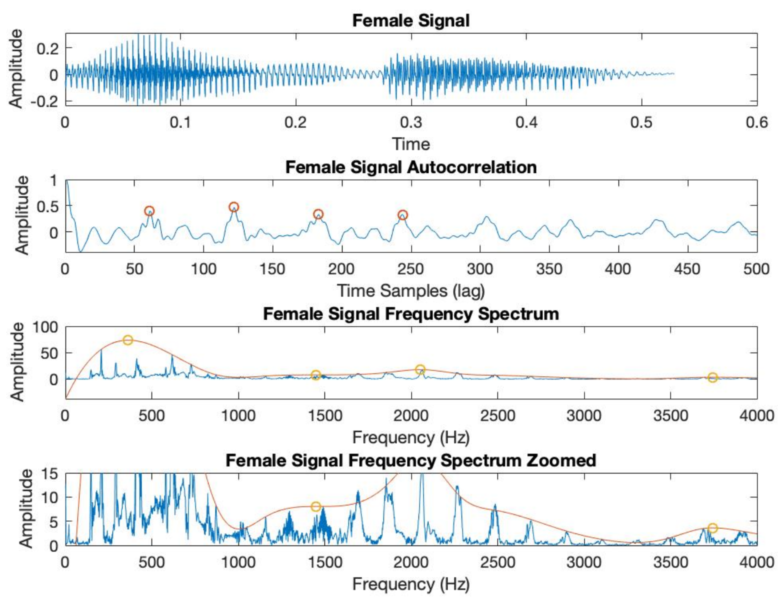

Figure 2: Female ‘rainbow’ signal, autocorrelation & frequency spectrum

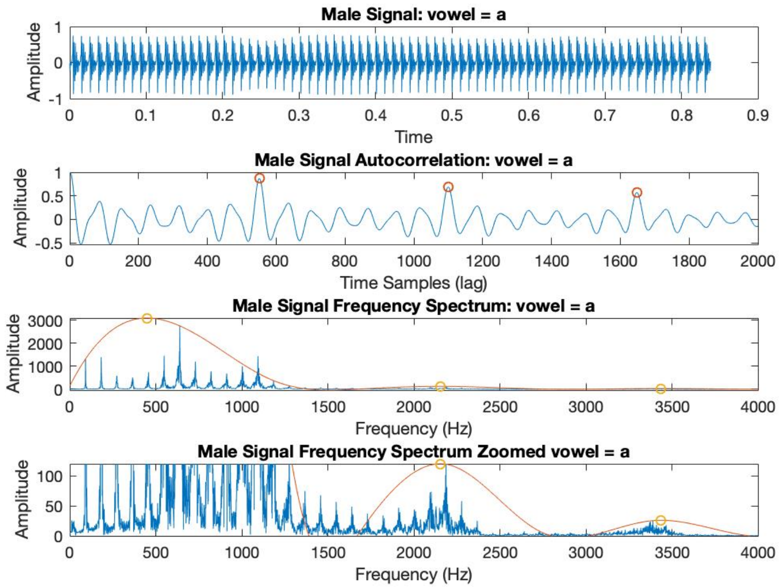

Figure 3: Male ‘a’ signal, autocorrelation & frequency spectrum

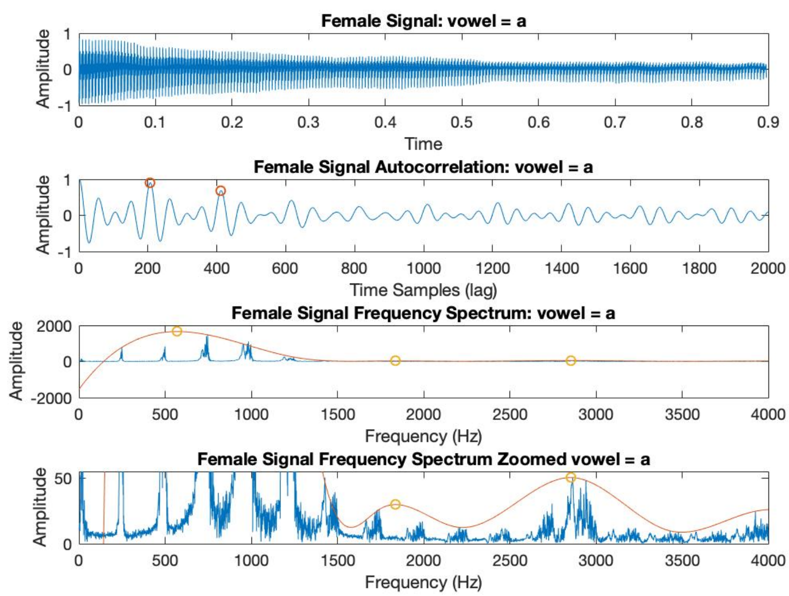

Figure 4: Female ‘a’ signal, autocorrelation & frequency spectrum

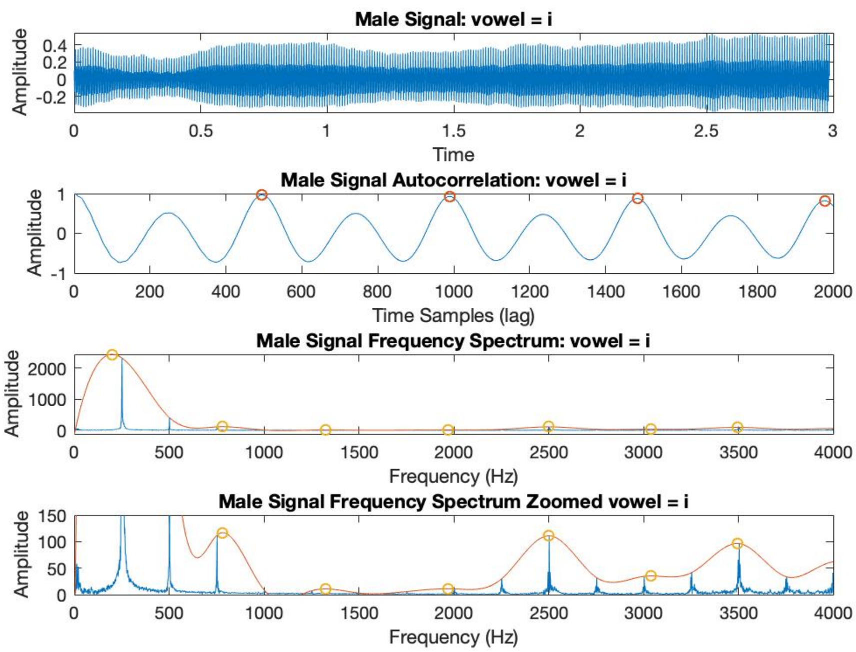

Figure 5: Male ‘i’ signal, autocorrelation & frequency spectrum

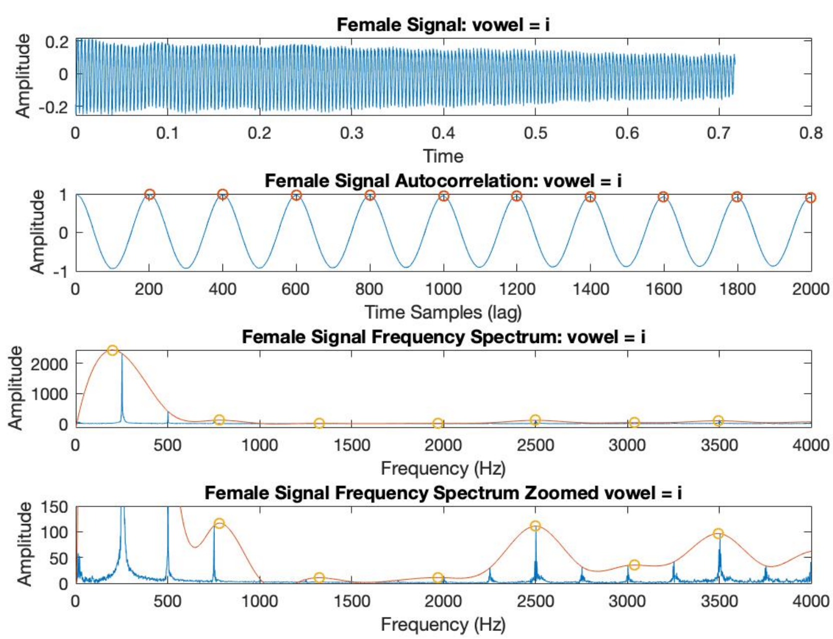

Figure 6: Female ‘i’ signal, autocorrelation & frequency spectrum

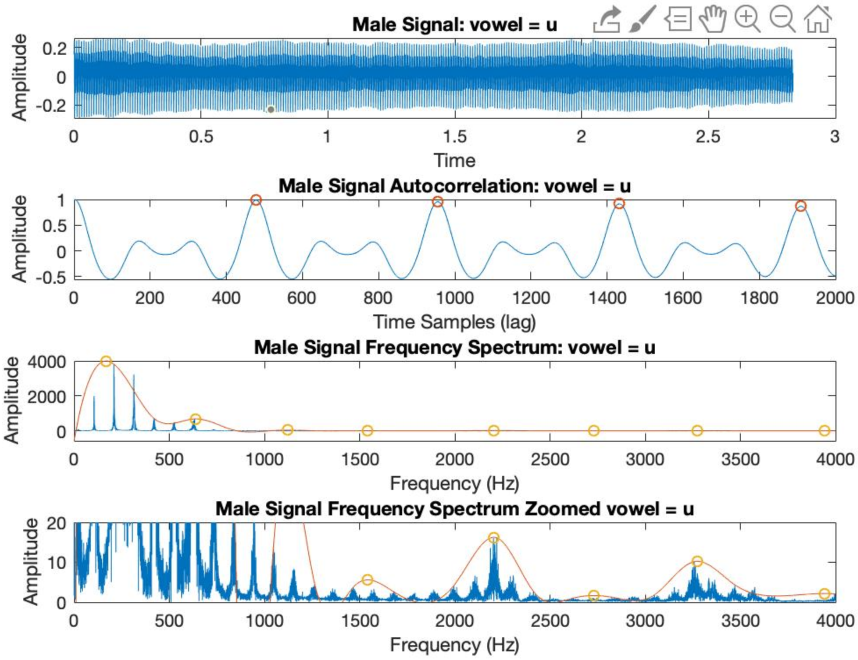

Figure 7: Male ‘u’ signal, autocorrelation & frequency spectrum

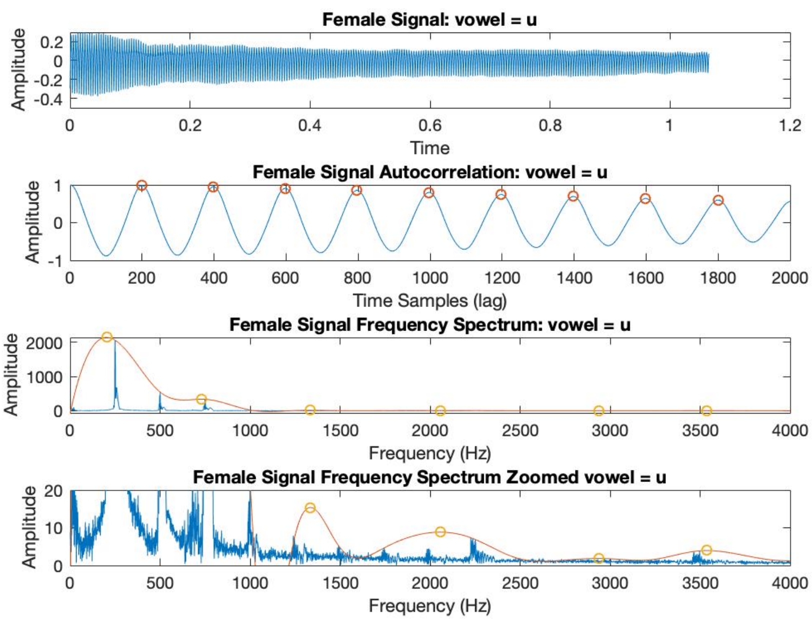

Figure 8: Female ‘u’ signal, autocorrelation & frequency spectrum

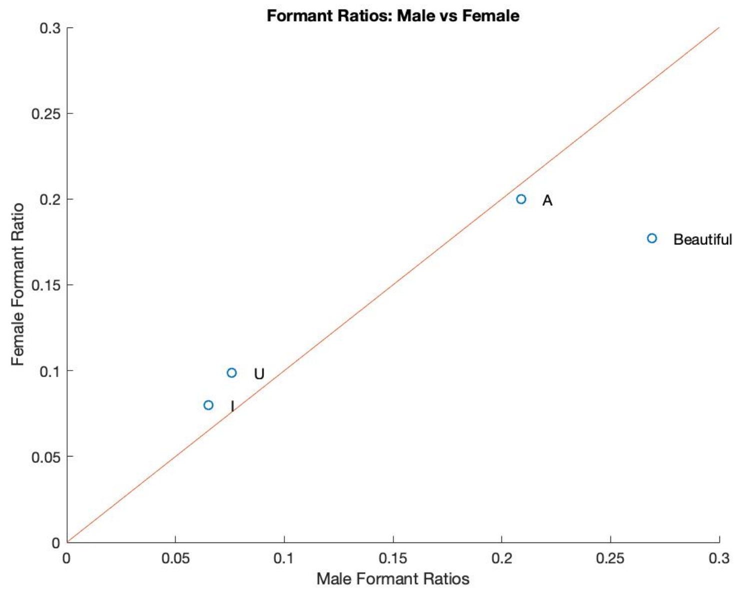

Figure 9: Male vs. female formant ratios for all sounds analyzed

Table 1: Male and female pitch periods for various sounds

Sound	Female Pitch Period	Male Pitch Period
A	205	549
I	199	494
U	198	477
Rainbow	61	73

Table 2: Male and female formants for various sounds

	Sound	F_1 (Hz)	F_2 (Hz)	F_1/F_2
Female	**A**	570	2853	0.199790
	I	199	2501	0.079568
	U	203	2055	0.098783
	Rainbow	363	2053	0.176814
Male	**A**	449	2153	0.208546
	I	152	2335	0.065096
	U	168	2205	0.076190
	Rainbow	330	1227	0.268949

Conclusion

Comparing the formants for the male subjects and the female subjects, it shows that the males had a lower frequency for each different sound. In both males and females, the ‘A’ sound was the highest, ‘Rainbow’ was the second highest, ‘U’ was the third and ‘I’ was the lowest. Looking at the formant ratios, the different sounds maintained a similar ratio regardless of whether the subject was male or female. This demonstrates the ability of using formant ratios to identify what sounds are being produced during speech. This gives a quantitative measure of different sounds. This is shown in the formant ratio plot, which compares the male formant ratios to the female formant ratios. The linear line has a slope of 1 and would correspond to equal male and female formant ratios. The points are all close to that line indicating that formant ratios remain equal for different sounds across genders. When looking at the pitch periods females had a lower pitch period than males. This means that females have a higher pitch frequency which is what we would expect for the gender differences. Pitch periods ordered with respect to their magnitude were also the same across the genders for vowel sounds. ‘A’ had the highest frequency with ‘U’ having the lowest for both genders. This lab demonstrated how different speech signal features can relate to the sound and features of the speaker.

References:

[1] Krishna, Sridhar. “Lab 4 – Speech Analysis”, BME 772, Ryerson University

[2] G. Jenkins, "Time Series Analysis: Forecasting and Control", 1976. [Accessed 18 November 2020].=

[3] Wood, Sidney. “Praat for beginners: What are formants?” 2005

[4] “Formant Analysis.” 2020. [online]. Available.
https://ccrma.stanford.edu/~jmccarty/formant.htm

[5] “10 Most Common Speech-Language Disorders.” 2018. [Online]. Available.
https://www.speechpathologygraduateprograms.org/2018/01/10-most-common-speech-language-disorders/

Appendix:

Main.m

```
%% Lab 4 Speech Analysis
% Andrew Mullen
clear all;
close all;
clc;

%% Part 1
% Load Data
data = load('lab4data.mat');
male = data.MALE_S;
female = data.FEMALES;
[FA, fs2] = audioread('female_a.wav');
[FI, fs2] = audioread('female_i.wav');
[FU, fs2] = audioread('female_u.wav');
[MA, fs2] = audioread('male_a.wav');
[MI, fs2] = audioread('male_i.wav');
[MU, fs2] = audioread('male_u.wav');

% Initialize variables
fs = 12500;
NM = length(male);
NF = length(female);
NFa = length(FA); NFi = length(FI); NFu = length(FU);
NMa = length(MA); NMi = length(MI); NMu = length(MU);

% Time Vectors
tM = [1:NM]./fs;
tF = [1:NF]./fs;
tFa = [1:NFa]./fs2; tFi = [1:NFi]./fs2; tFu = [1:NFu]./fs2;
tMa = [1:NMa]./fs2; tMi = [1:NMi]./fs2; tMu = [1:NMu]./fs2;

%% Compute auto correlation
%male_ACF = autocorrelation(male);
%female_ACF = autocorrelation(female);
%FA_ACF = autocorrelation(FA); FI_ACF = autocorrelation(FI); FU_ACF =
autocorrelation(FU);
%MA_ACF = autocorrelation(MA); MI_ACF = autocorrelation(MI); MU_ACF =
autocorrelation(MU);
load('male_ACF.mat'); load('female_ACF.mat');
load('FA_ACF.mat'); load('FI_ACF.mat'); load('FU_ACF.mat');
load('MA_ACF.mat'); load('MI_ACF.mat'); load('MU_ACF.mat');

male_ACF_seg = male_ACF(1:500);
female_ACF_seg = female_ACF(1:500);
FA_ACF_seg = FA_ACF(1:2000); FI_ACF_seg = FI_ACF(1:2000); FU_ACF_seg =
FU_ACF(1:2000);
MA_ACF_seg = MA_ACF(1:2000); MI_ACF_seg = MI_ACF(1:2000); MU_ACF_seg =
MU_ACF(1:2000);

%% Pitch period
% FIND APPROPRIATE MINIMUM PEAK HEIGHT
[pksM, locM] = findpeaks(male_ACF_seg, 'MinPeakHeight', 0.25);
[pksF, locF] = findpeaks(female_ACF_seg, 'MinPeakHeight', 0.3);
```

```
[pksFA, locFA] = findpeaks(FA_ACF_seg, 'MinPeakHeight', 0.5);
[pksFI, locFI] = findpeaks(FI_ACF_seg, 'MinPeakHeight', 0.5);
[pksFU, locFU] = findpeaks(FU_ACF_seg, 'MinPeakHeight', 0.5);

[pksMA, locMA] = findpeaks(MA_ACF_seg, 'MinPeakHeight', 0.5);
[pksMI, locMI] = findpeaks(MI_ACF_seg, 'MinPeakHeight', 0.6);
[pksMU, locMU] = findpeaks(MU_ACF_seg, 'MinPeakHeight', 0.5);


pitchPeriodM = (locM(2) - locM(1));%/fs;
pitchPeriodF = (locF(2) - locF(1));%/fs;

pitchPeriodFA = (locFA(2) - locFA(1));%/fs2;
pitchPeriodFI = (locFI(2) - locFI(1));%/fs2;
pitchPeriodFU = (locFU(2) - locFU(1));%/fs2;

pitchPeriodMA = (locMA(2) - locMA(1));%/fs2;
pitchPeriodMI = (locMI(2) - locMI(1));%/fs2;
pitchPeriodMU = (locMU(2) - locMU(1));%/fs2;
%% Frequency Spectrum
% Plot xlim 0:4000
ssM = abs(fft(male)); fM = [1:NM]*(fs/NM);
ssF = abs(fft(female)); fF = [1:NF]*(fs/NF);

ssFA = abs(fft(FA)); fFa = [1:NFa]*(fs2/NFa);
ssFI = abs(fft(FI)); fFi = [1:NFi]*(fs2/NFi);
ssFU = abs(fft(FU)); fFu = [1:NFu]*(fs2/NFu);

ssMA = abs(fft(MA)); fMa = [1:NMa]*(fs2/NMa);
ssMI = abs(fft(MI)); fMi = [1:NMi]*(fs2/NMi);
ssMU = abs(fft(MU)); fMu = [1:NMu]*(fs2/NMu);

%% Envelope Signals
[upM, lowM] = envelope(ssM, 80, 'peak');
[upF, lowF] = envelope(ssF, 110, 'peak');

[upFA, lowFA] = envelope(ssFA, 400, 'peak');
[upFI, lowFI] = envelope(ssFI, 176, 'peak');
[upFU, lowFU] = envelope(ssFU, 260, 'peak');

[upMA, lowMA] = envelope(ssMA, 400, 'peak');
[upMI, lowMI] = envelope(ssMI, 600, 'peak');
[upMU, lowMU] = envelope(ssMU, 560, 'peak');


[EpksM, ElocM] = findpeaks(upM);
[EpksF, ElocF] = findpeaks(upF);

[EpksFA, ElocFA] = findpeaks(upFA);
[EpksFI, ElocFI] = findpeaks(upFI);
[EpksFU, ElocFU] = findpeaks(upFU);

[EpksMA, ElocMA] = findpeaks(upMA);
[EpksMI, ElocMI] = findpeaks(upMI);
```

```
[EpksMU, ElocMU] = findpeaks(upMU);


ElocM = ElocM*(fs/NM); ElocF = ElocF*(fs/NF);

ElocFA = ElocFA*(fs2/NFa); ElocFI = ElocFI*(fs2/NFi); ElocFU =
ElocFU*(fs2/NFu);

ElocMA = ElocMA*(fs2/NMa); ElocMI = ElocMI*(fs2/NMi); ElocMU =
ElocMU*(fs2/NMu);


%% Plot signals
figure;
subplot(411); plot(tM, male); xlabel('Time'); ylabel('Amplitude');
title('Male Signal');
subplot(412); plot(male_ACF_seg); hold on; scatter(locM, pksM); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Male Signal Autocorrelation');
subplot(413); plot(fM, ssM, fM, upM); hold on; scatter(ElocM, EpksM);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum'); xlim([0, 4000]);
subplot(414); plot(fM, ssM, fM, upM); hold on; scatter(ElocM, EpksM);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum Zoomed'); xlim([0, 4000]); ylim([0, 20]);

figure;
subplot(411); plot(tF, female); xlabel('Time'); ylabel('Amplitude');
title('Female Signal');
subplot(412); plot(female_ACF_seg); hold on; scatter(locF, pksF);
xlabel('Time Samples (lag)'); ylabel('Amplitude'); title('Female Signal
Autocorrelation');
subplot(413); plot(fF, ssF, fF, upF); hold on; scatter(ElocF, EpksF);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum'); xlim([0, 4000]);
subplot(414); plot(fF, ssF, fF, upF); hold on; scatter(ElocF, EpksF);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum Zoomed'); xlim([0, 4000]); ylim([0, 15]);

figure;
subplot(411); plot(tFa, FA); xlabel('Time'); ylabel('Amplitude');
title('Female Signal: vowel = a');
subplot(412); plot(FA_ACF_seg); hold on; scatter(locFA, pksFA); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Female Signal Autocorrelation:
vowel = a');
subplot(413); plot(fFa, ssFA, fFa, upFA); hold on; scatter(ElocFA, EpksFA);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum: vowel = a'); xlim([0, 4000]);
subplot(414); plot(fFa, ssFA, fFa, upFA); hold on; scatter(ElocFA, EpksFA);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum Zoomed vowel = a'); xlim([0, 4000]); ylim([0, 55]);

figure;
subplot(411); plot(tFi, FI); xlabel('Time'); ylabel('Amplitude');
title('Female Signal: vowel = i');
```

```
subplot(412); plot(FI_ACF_seg); hold on; scatter(locFI, pksFI); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Female Signal Autocorrelation:
vowel = i');
subplot(413); plot(fFi, ssFI, fFi, upFI); hold on; scatter(ElocFI, EpksFI);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum: vowel = i'); xlim([0, 4000]);
subplot(414); plot(fFi, ssFI, fFi, upFI); hold on; scatter(ElocFI, EpksFI);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum Zoomed vowel = i'); xlim([0, 4000]); ylim([0, 150]);

figure;
subplot(411); plot(tFu, FU); xlabel('Time'); ylabel('Amplitude');
title('Female Signal: vowel = u');
subplot(412); plot(FU_ACF_seg); hold on; scatter(locFU, pksFU); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Female Signal Autocorrelation:
vowel = u');
subplot(413); plot(fFu, ssFU, fFu, upFU); hold on; scatter(ElocFU, EpksFU);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum: vowel = u'); xlim([0, 4000]);
subplot(414); plot(fFu, ssFU, fFu, upFU); hold on; scatter(ElocFU, EpksFU);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Female Signal Frequency
Spectrum Zoomed vowel = u'); xlim([0, 4000]); ylim([0, 20]);

figure;
subplot(411); plot(tMa, MA); xlabel('Time'); ylabel('Amplitude'); title('Male
Signal: vowel = a');
subplot(412); plot(MA_ACF_seg); hold on; scatter(locMA, pksMA); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Male Signal Autocorrelation:
vowel = a');
subplot(413); plot(fMa, ssMA, fMa, upMA); hold on; scatter(ElocMA, EpksMA);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum: vowel = a'); xlim([0, 4000]);
subplot(414); plot(fMa, ssMA, fMa, upMA); hold on; scatter(ElocMA, EpksMA);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum Zoomed vowel = a'); xlim([0, 4000]); ylim([0, 120]);

figure;
subplot(411); plot(tMi, MI); xlabel('Time'); ylabel('Amplitude'); title('Male
Signal: vowel = i');
subplot(412); plot(MI_ACF_seg); hold on; scatter(locMI, pksMI); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Male Signal Autocorrelation:
vowel = i');
subplot(413); plot(fMi, ssMI, fMi, upMI); hold on; scatter(ElocMI, EpksMI);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum: vowel = i'); xlim([0, 4000]);
subplot(414); plot(fMi, ssMI, fMi, upMI); hold on; scatter(ElocMI, EpksMI);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum Zoomed vowel = i'); xlim([0, 4000]); ylim([0, 150]);

figure;
subplot(411); plot(tMu, MU); xlabel('Time'); ylabel('Amplitude'); title('Male
Signal: vowel = u');
subplot(412); plot(MU_ACF_seg); hold on; scatter(locMU, pksMU); xlabel('Time
Samples (lag)'); ylabel('Amplitude'); title('Male Signal Autocorrelation:
vowel = u');
```

```
subplot(413); plot(fMu, ssMU, fMu, upMU); hold on; scatter(ElocMU, EpksMU);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum: vowel = u'); xlim([0, 4000]);
subplot(414); plot(fMu, ssMU, fMu, upMU); hold on; scatter(ElocMU, EpksMU);
xlabel('Frequency (Hz)'); ylabel('Amplitude'); title('Male Signal Frequency
Spectrum Zoomed vowel = u'); xlim([0, 4000]); ylim([0, 20]);

%% Formant Ratio
ratio_female = ElocF(1)/ElocF(3);
ratio_FA = ElocFA(1)/ElocFA(3);
ratio_FI = ElocFI(1)/ElocFI(5);
ratio_FU = ElocFU(1)/ElocFU(4);
ratio_male = ElocM(1)/ElocM(2);
ratio_MA = ElocMA(1)/ElocMA(2);
ratio_MI = ElocMI(1)/ElocMI(5);
ratio_MU = ElocMU(1)/ElocMU(5);

ratio_female = [ratio_female, ratio_FA, ratio_FI, ratio_FU];
ratio_male = [ratio_male, ratio_MA, ratio_MI, ratio_MU];

figure;
scatter(ratio_male, ratio_female)
hold on;
plot([0, 0.3],[0,0.3]);
title('Formant Ratios: Male vs Female')
xlabel('Male Formant Ratios'); ylabel('Female Formant Ratio');
text(ratio_male(1)+0.01, ratio_female(1), 'Beautiful')
text(ratio_male(2)+0.01, ratio_female(2), 'A')
text(ratio_male(3)+0.01, ratio_female(3), 'I')
text(ratio_male(4)+0.01, ratio_female(4), 'U')

%% Check formants
figure;
plot(fM, ssM, fM, upM); hold on; scatter(ElocM, EpksM); xlim([0, 4000]);
ylim([0, 100]);

figure;
plot(fF, ssF, fF, upF); hold on; scatter(ElocF, EpksF); xlim([0, 4000]);
ylim([0, 100]);

figure;
plot(fMa, ssMA, fMa, upMA); hold on; scatter(ElocMA, EpksMA); xlim([0,
4000]); ylim([0, 4000]);

figure;
plot(fMi, ssMI, fMi, upMI); hold on; scatter(ElocMI, EpksMI); xlim([0,
4000]); ylim([0, 2000]);

figure;
plot(fMu, ssMU, fMu, upMU); hold on; scatter(ElocMU, EpksMU); xlim([0,
4000]); ylim([0, 100]);

figure;
plot(fFa, ssFA, fFa, upFA); hold on; scatter(ElocFA, EpksFA); xlim([0,
4000]); ylim([0, 3000]);
```

```
figure;
plot(fFi, ssFI, fFi, upFI); hold on; scatter(ElocFI, EpksFI); xlim([0,
4000]); ylim([0, 500]);

figure;
plot(fFu, ssFU, fFu, upFU); hold on; scatter(ElocFU, EpksFU); xlim([0,
4000]); ylim([0, 500]);
```

Autocorrelation.m

```
function [output] = autocorrelation(input)

for k = 1:length(input)
    for i = 1:length(input)-k
        temp(i) = input(k+i-1)*input(i);
    end
    output(k) = sum(temp);
    temp = 0;
end
output = output./max(abs(output));
end
```