HARMONIC ANALYSIS OF ACOUSTIC WAVES

Equipment

PC with sound card, microphone and loudspeaker, programs for sound analysis: ANALIZA (**Part 1**) and PRAAT (**Part 2**).
Tuning -forks with unknown frequencies

PART I

Theory

Phonetics is study of speech sounds. This scientific field focuses largely on acoustic studies that base on physics laws since information generated by speech organs of a speaker has a form of sound waves. Sounds can easily be recorded with a high accuracy, and physical parameters, such as intensity or frequency, are used to describe their properties. However, the most important tool for sound analysis is **harmonic analysis**. It is known that sound is a periodic wave of fluctuation in air pressure over time. Harmonic analysis involves decomposition of a sound wave into its components, sine and cosine, which, when added, re-create the output sound wave. From the mathematical point of view, harmonic analysis is performed using the **Fourier theorem,** which assumes that each continuous function can be created as an infinite sum of sine and cosine waves. In other words, the Fourier transformation takes data as a function of time (sound is the pressure change over time) and converts it into data as a function of frequency (dependence of the wave components' intensity on frequency). Thus, after the Fourier transformation, a given sound is described by the frequencies of wave components and their amplitudes, which, taken together, constitute the sound.

The human speech apparatus generates sounds as a result of vibrations of specific anatomical structures. Similarly, musical instruments generate certain tones as a result of vibrations of, for example, strings or membranes. The lowest frequency of any vibrating object is called the **basal frequency.** Frequencies of **overtones** are integer multiples of the **basal frequency**. For example, a vibrating h string of a guitar produces a sound characterized by a basal frequency of 247 Hz and its overtone frequencies are 494 Hz (2x247), 741 Hz (3x247), etc. The main didactic aim of this practical is harmonic analysis of the sound. Research that exploit sound analysis constitute an important part of modern medicine because of its the application for example, in the designing of hearing aids or speech synthesizers.

Course of the Part I

Aim: The aim of PART 1 of the practical is to analyse the spectrum of the sound obtained by tuning-forks provided by the Tutor.

1. Turn on the PC. Double click on the icon **„PART 1"** shown on the computer desktop – this action will open the sound analysing program „Analiza" (eng. Analysis). Click the OK at the bottom of the welcome screen.

   The program is in polish version. Figures showing the English translation of the Polish program options are depicted below.

2. Using the microphone record the sound of the first tuning-fork. Remember to hit with the tuning-fork first and then, after 1 second, click the option *Rejestruj* (eng. *Record*). This will result in obtaining the proper – clean sound, without crackling associated with hitting the tuning fork. Click *Stop* and then *Koniec* (eng. *Quit*) – in the window you will see a graph of changes in acoustic pressure over time for the sound under study.

The figure shown below depicts the English translation of the Polish program options during recording the sound.

3. Analyse the recorded sound by choosing the option *Analiza -> Transformacja Fouriera* (eng. *Analysis -> Fourier transform*). For analysing, select fragments of the record sound that are characterized by constant sound intensity and clear periodicity (you can set the appropriate fragment using the spectrum in the window *Cały zapis* (eng. *Entire record*). Put the results (basal tone frequency and amplitude ratios) into the table 1.

4. Record the sound derived from the second tuning-fork and analyse it, according to the point 2 and 3. Put the results (frequency of the basal tone and amplitude ratios) into the table 1.

5. Based on the analysis from point 3 and 4, synthesize the sounds of the tuning-forks. In order to make synthesis, click option *Synteza -> Dane dźwięku* (eng. *Synthesis -> Sound data*). A new panel will appear, in which **„Częstotliwość"** is **„Frequency" (basal)** and **„Stosunek amplitud"** is „**Amplitude ratio"**. After having entered the data for synthesis click on **"Gotowe"** (**"Ready")** button. Play the synthesized sounds and compare with the original sounds derived from tuning-forks.

PART II

Aim: The purpose of the PART II of the practical is to analyse the timbre using the Praat program.

1. Double click on the icon **„PART 2"** shown at the computer desktop – this action will open the sound analysing program „Praat". After having started the program, two windows will appear: one of them, "PRAAT objects", contains all the analysis options, while the other, "PRAAT picture", allows creation of graph objects based on the results of analysis.

2. Analyse a pure tone C5 and the same sound derived from different music instruments: the piano, the trumpet, the violin and the flute. In this part of the practical use the files from the folder **„Recordings for practical 33"** shown at the Computer Desktop.

   a) Click option *Open -> Read from file* and then choose the recording
   b) Choose the loaded recording from the list *Objects* and click option *View & Edit*. After this action you will see the window with time course of the sound. In order to obtain a spectrogram (the amplitude spectrum of the tested sound for each moment *t* for which this sound is defined) select the option *Spectrum -> Show spectrogram.*
   c) Generate the envelope of density spectrum of the sound by clicking *Spectrum ->View spectra slice*
   d) Read the amplitudes of the overtones of the tested sound, determined with the frequencies given in Table 2 (523 Hz, 1046 Hz, 1569 Hz, etc.). In order to read the amplitude, click the cursor on the appropriate harmonic point - then the value of amplitude will be displayed automatically. Put the results into the table 2. At the end of this part of the practical answer the question contained in the report.

PART III

Theory

The most important aspect of the acoustic description of vowels is the spectral analysis. The articulation of all vowels is similar but the differences between them are related to the timbre of the sound. Vowels are usually voiced - the vocal folds in the larynx vibrate as the vowels are spoken. In a standard speech, the frequency lies in the range from 80 Hz to 400 Hz. As it was mentioned above, the sound wave includes the basal frequency as well as the frequencies of overtones equal to integer multiplies of the basal frequency. This signal is then "filtered" through the upper part of the vocal tract (pharynx, mouth and nasal cavity). In this part of speech organ some frequencies are dumped, whereas not damped frequencies are defined as „formants". These are the components of speech sounds that underwent the highest amplification in the epiphyseal cavities (pharyngeal, oral and / or nasal) as a result of acoustic resonance. The sound generated in the larynx as a result of vibrations of the vocal folds (laryngeal tone) is further transformed in the supralaryngeal structures, because the vocal canal behaves like a system of filters (resonators) with specific resonance frequencies. They depend on the shape and length of the vocal tract. The acoustic wave modified by the voice channel sounds as the proper sound. In case of vowels, the first two formants are sufficient for the perceptual identification of the sounds of speech, while the third and fourth formants are related to the individual characteristics of the voice. The "filtering" of the sound frequency is mainly related to the position of the tongue in the mouth and the size of the labial fissure.

Course of the part III

Aim: The aim of PART III of the practical is to show the correlation between the frequency of F1 and F2 formants of individual vowels and the position of the tongue in the mouth during their articulation through the preparing of so-called vowel diagram. Due to the physiological differences in the structure of the speech apparatus in humans, it is recommended that each student prepares diagram based on the formants obtained from their own recordings.

1. Using the microphone record (3-times) the vowels: /i/, /e/, /a/, /o/ and /u/. In order to record, click the option *New-> Record mono Sound* in the window of *Praat Objects*. Then, choose *Record*. The time of recording should be about 3 seconds. In order to quit and save the recording, click *Stop* and next *Save to the list*.

2. Find the average frequencies of F1 and F2 formants for individual vowels. In order to analyse the vowel:

    a) Choose appropriate recording from the list *Objects* and click option *View & Edit*. After this action you will see the window with time course of the sound. In the next step, select the proper spectrum fragment and choose the *sel* option from the toolbar at the bottom of the window.

    b) In order to obtain a spectrogram select the option *Spectrum -> Show spectrogram*. You can mark the formants on the spectrogram by clicking option *Formant -> Show formants*
    c) The frequencies of the formants can be determined in two ways: by analysing the envelope of the density spectrum (the graph is obtained by clicking *Spectrum -> View spectra slice*) or by selecting *Formant -> Get first formant / Get second formant / Get third formant / Get fourth formant*. Put the values of formant frequencies F1 and F2 into the table in the third part of the report. Calculate the mean values from three independent records.

3. On the plotting paper, create the coordination system of F1 (Y axis) and F2 (X axis) (look at the picture below) and mark the points based on the mean values of F1 and F2 for each of vowels studied. Then, draw the vowel quadrilateral.
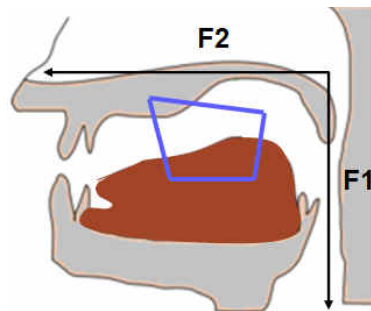
Required theoretical knowledge

1. The speech organ, the ear and their structure.
2. Acoustic waves, objective (physical) and subjective properties of sound. Loudness, loudness level.
3. Spectrogram and sound spectrum.
4. Fourier theorem. Fourier analysis. Sound timbre.
5. Helmholtz and Bekesy theory of hearing.
6. Spectrogram and spectrum of a sound

Wroclaw Medical University Department of Biophysics and Neuroscience	Practical No 33 Harmonic analysis of acoustic waves

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Grade:	Tutor`s signature

PART I - Table 1

Tuning-fork	Basal frequency [Hz]	Amplitude ratios								
		2:1	3:1	4:1	5:1	6:1	7:1	8:1	9:1	10:1
1										
2										

PART II – Table 2

Frequency of harmonic component [Hz]	Amplitudes of sound components [dB]				
	Pure tone	piano	trumpet	violin	flute
523					
1046					
1569					
2092					
2615					
3138					
3661					
4184					
4707					
5230					

Which of the physical parameters describing the sound of an instrument influences the timbre of the sound most significantly?

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Student 1

Vowel „**i**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**e**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**a**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**o**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**u**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Student 2

Vowel „**i**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**e**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**a**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**o**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		

Vowel „**u**"

Record	Formant F1 [Hz]	Formant F2 [Hz]
1		
2		
3		
Mean value		