Work Package 9

Deliverable 32

Statistical Comparison of Islamic and Byzantine chant in the Worship Spaces

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1 Introduction

1.1 Scope of work

Within the CAHRISMA project the work carried out in WP 9 consists of the analysis of the data provided by our partners at the Technical University of Denmark (Department of Acoustic Technology) and at the Universita' Degli Studi di Ferrara (Dipartimento di Ingegneria) who were responsible to provide waveforms of chants within the Mosques and Churches.

The aim of the Work Package was to obtain a statistical comparison of Islamic and Byzantine chants in the worship spaces. In order to look at this from an acoustical point of view, two ideas were developed.

One uses the intrinsic (anechoic) record to look at the intonation of Islamic and Byzantine chant. The other uses the different Islamic and Byzantine chants available both in anechoic format as well as synthesised in their respective worship spaces, in order to compare them statistically. This also includes obtaining statistical information on the effects of the respective Mosques and Churches on the different chants and to investigate if any general acoustical patterns could be found which could characterise the building and distinguish between the buildings. After several discussions it was agreed that the parameter that was to be analysed was the Effective Duration of the Autocorrelation Function.

1.2 Data available

The study was conducted on the following data:

?? Anechoic Islamic and Byzantine chants wave files (*Technical University of Denmark – Department of Acoustic Technology*)

?? Echoic Islamic and Byzantine wave files synthesised in their respective worship spaces using impulse response techniques (*Universia' Degli Studi di Ferrara – Dipartimento di Ingegneria.*

A more detailed breakdown of the data available could be found in section 2.2 on page number 3.

2 Prefix

2.1 Definition of acronyms used

This is a list of the acronyms used throughout this report and the CD.

Mosques and Churches

SB	SS Sergius Bacchus Church
SO	Sokullu Mosque
SU	Süleymaniye Mosque
SI	St. Irene Church
SS	St. Sophie Church

Receiver location

CM	Centre of Mosque / Church - The receiver is positioned at the Centre Of the Mosque / Church
GL	Gallery of Mosque / Church – The receiver is positioned in the Gallery within the Mosque / Church
BL	Balcony of Mosque / Church – The receiver is positioned in the Balcony of the Mosque / Church

2.2 Data Available, in more detail.

This study was carried out on the following Anechoic and Echoic waveform chants (reference Section 1.2 page 3).

Anechoic waveforms available:

Bahir, Byzantine Hymn, Hatim Duasi, Ic Ezan, Mimber Duasi, Salà, Tekbir, Tevsih

Synthesised (Echoic) waveforms available:

Bahir, Hatim Duasi, Ic Ezan, Mimber Duasi, Salà, Tevsih synthesised in SB, SO and SU Mosques.

Byzantine Hymn synthesised in the SI and SS Churches.

2.3 Classification of the chants

In order to have a better understanding of the material available, the waveforms have been analysed, content wise, and have been grouped into the following groups:

Solo Chant

Chant	Comments
Bahir	The last 8% of it is Choir Chant
Byzantine Hymn	
Ic Ezan	
Salà	

Choir Chant

Chant	Comments
Tekbir	
Tevsih	

Mixed

Chant	Comments
Mimber Duasi	The first 64% of the waveform is Solo Prayer. The rest is Solo Chant
Hatim Duasi	Solo chant, choir chant (very small parts in between the Solo chant). The last 2 minutes is Solo talk with a bit of Group talk in between

3 Intonation Model

3.1 Introduction

The aim of this work is to analyse the pitch contour or envelope of chant and to compare the contour shape in order to deduce whether there are preferred ranges and rate of change in ranges of the pitch. While this is usually a function of the chant, by looking at various Byzantine and Islamic chants some more general conclusions may be deduced.

The pitch contour can be obtained since most Byzantine and Islamic chant is a voice recitative with no musical instruments and for most of the time with only one person involved. It is therefore relatively easy to use standard speech techniques for the extraction of the pitch information. In this study the pitch is obtained as an average over windows of 20ms. Using autocorrelation techniques. The overall chant is divided into contiguous windows without overlap.

3.2 Pitch Primitives

In order to be able to look analytically at the intonation contour it is necessary to build a set of pitch primitives. These primitives are basic line shapes. By having a suitable set it should be possible to model the natural intonation contour. The possibility of having a known set of primitives that are concatenated together to obtain the final shape, also makes it possible to analyse the shape by finding the number and position of the primitives used in modelling a chant.

Figure 1 shows the set of primitives used in this modelling. These shapes are themselves a subject of a statistical analysis based on postulating a given shape and then finding how much it appears within natural intonation. The present set was obtained based on previous work on speech intonation. It can be however easily adapted to chant by adding a particular shape if it is necessary due to particular intonation contours in chant not normally met with in speech.

In order to keep the size of the primitive set to a minimum, each primitive has two fundamental properties. These are a normalised shape referred in Y-axis relative to the start point as position with Y = 0. A 'stretch' of the shape is possible in the Y-axis only so that the slope of the basic shape can change. Primitives are defined with 3, 5, and 7 points. Figure 2 gives a few typical primitive definitions that can be related to the shapes in Figure 1. For example primitive E30 is a 5-point primitive with a V-shape.

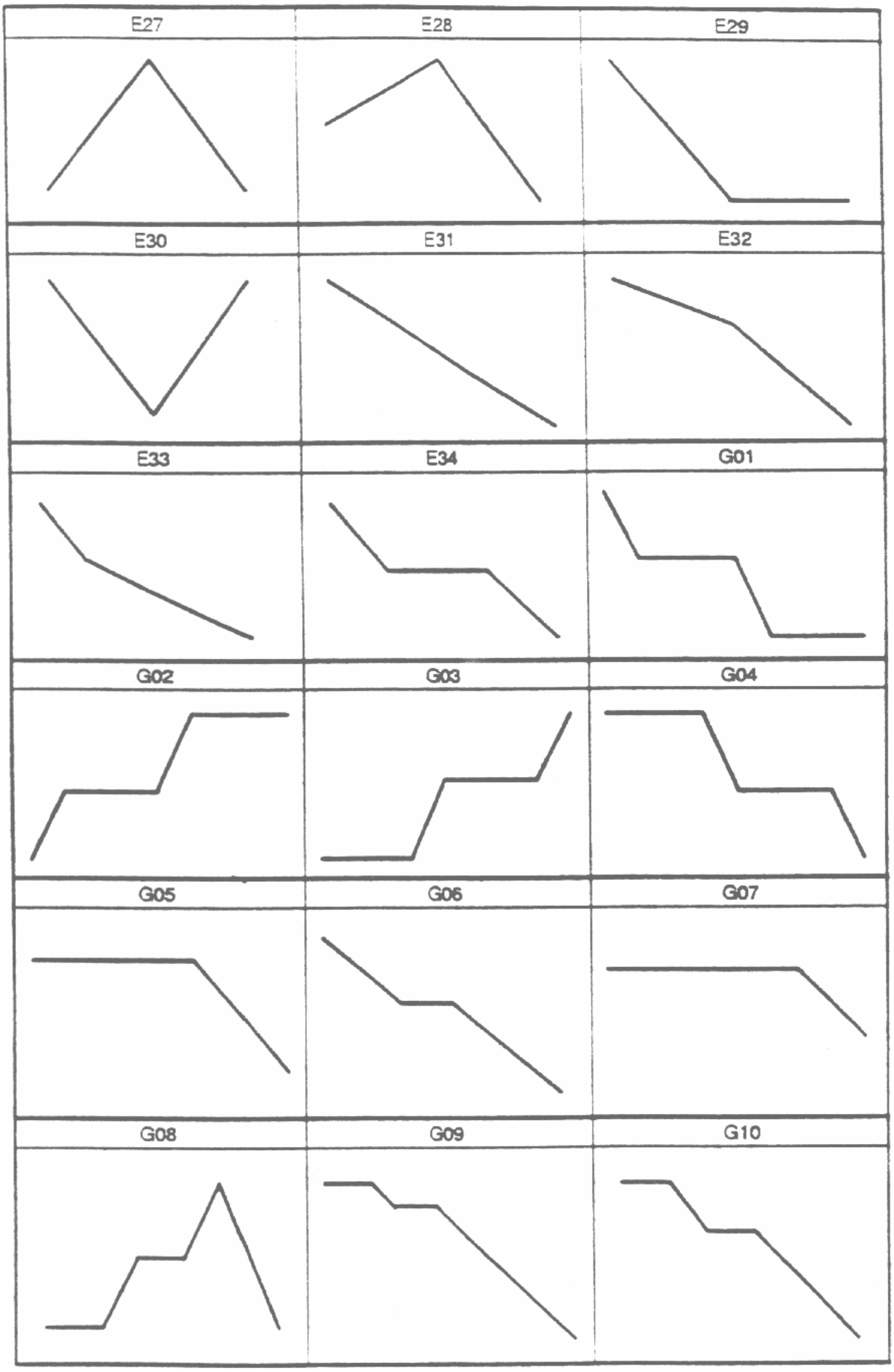


Figure 1 *A sample of the Pitch Primitive Set*

```
E28   0,1,2,0,-2
E29   0,-1,-2,-2,-2
E30   0,-1,-2,-1,0
E31   0,-1,-2,-3,-4,-5
E32   0,-1,-2,-4,-6
E33   0,-2,-4,-5,-6
E34   0,-3,-3,-4,-5
G01   0,-1,-1,-1,-2,-2,-2
G02   0,1,1,1,2,2,2
G03   0,0,0,1,1,1,2
G04   0,0,0,-1,-1,-1,-2
G05   0,0,0,0,-1,-2,-3
G06   0,-1,-2,-2,-3,-4,-5
G07   0,0,0,0,0,-1,-2
G08   0,0,1,1,2,1,0
G09   0,0,-1,-1,-2,-3,-4
G10   0,0,-2,-2,-4,-5,-6
G11   0,0,-1,-2,-3,-4,-5
G12   0,0,-2,-4,-6,-7,-8
```

Figure 2 *Pitch Primitive Templates*

The complete set of pitch primitives is included in the appendix (Section 5.1)

3.3 Modelling with the Pitch Primitives

In modelling, the real waveform is examined from the start and the best fit shape is applied. A weighting is placed on fitting with the longer (ie 7-point) shapes to keep the used set of primitives to a minimum. An error function based on distance of the natural pitch contour from the postulated primitive is used in order to arrive at the choice of the best primitive. Each primitive is examined for shape and stretch to obtain the particular best fit for that shape. The primitive with the best fit at a particular stretch is retained. This process is moved forward to the next part of the natural contour. At present there is no overall best error fit, but only a 'running' best error fit. Each primitive is independent of the previous or following. The endpoint of the primitive is not constrained. The next primitive analysis starts from the next real pitch value trying to find the next best fit. Therefore errors are not cumulative though there can be local anomalies in the shape.

Figure 3 shows a natural and modelled intonation contour based on part of the Byzantine chant. The result is quite similar. As already mentioned any gross anomalies can always be rectified by editing the pitch primitive set. What is important is the fact that the modelled contour is known and defined in detail. Figure 4 gives a partial entry on the model for the Byzantine waveform. The entries refer to the primitive type, the stretch number, the initial real pitch, which for the purposes of the modelling would be the '0' position of the first pitch point in the primitive, and the start location, within the waveform in milliseconds. This data makes it relatively easy to obtain statistical information on the natural pitch contour based on the modelled contour.

Typically 60 seconds of a chant require approximately 450 concatenated primitives to make up the overall shape.

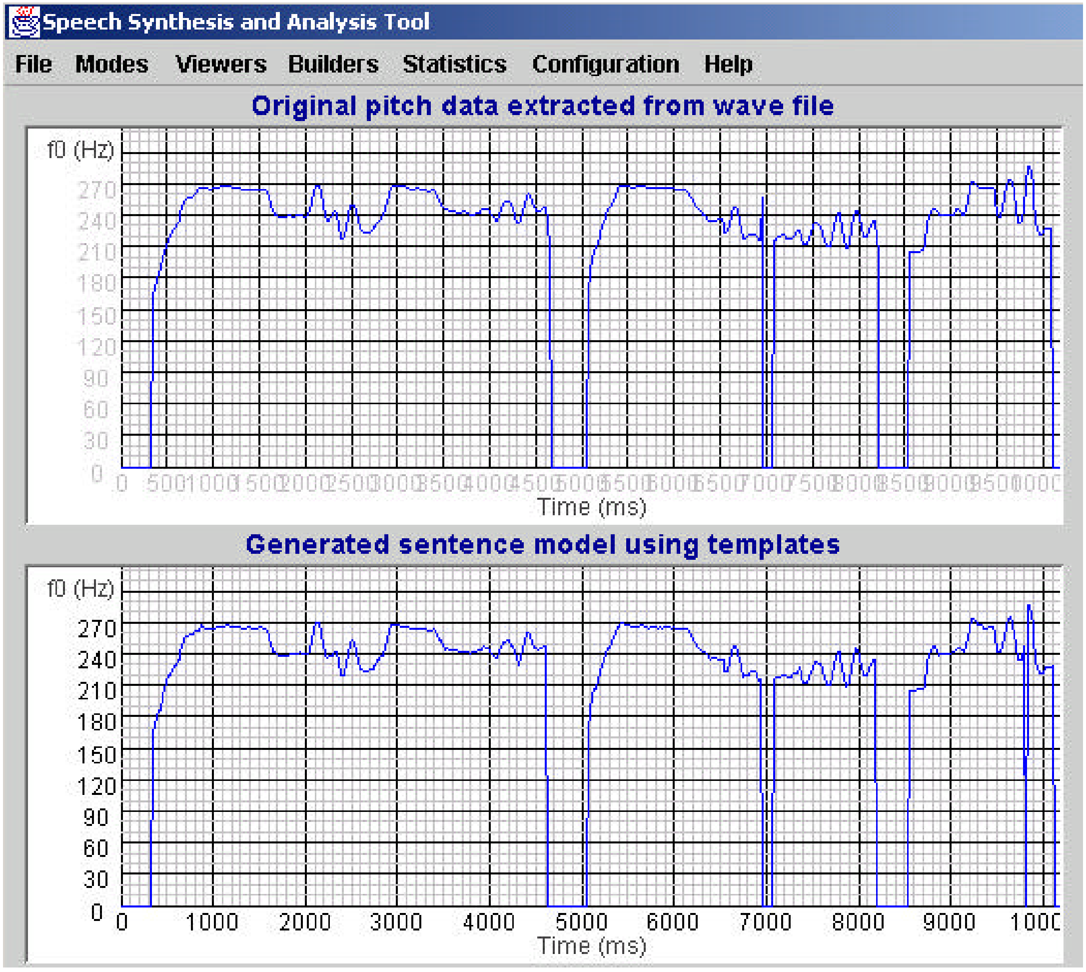


Figure 3 *Original pitch data and generated model for part of the Byzantine Solo Chant*

Appendix section 5.2 illustrates graphically the original pitch data of the Bahir Solo Chant extracted from the wav file and the corresponding generated waveform model using the pitch primitives.

E30	3	126.72	1690
G02	3	128.95	1790
G02	2	136.96	1930
E19	5	139.12	2070
E13	5	153.13	2170
E12	5	168.32	2270
E13	6	151.03	2370
E33	3	168.32	2470
G02	1	151.03	2570
G20	1	152.6	2710
G02	1	152.07	2850

Figure 4 *Sequence of primitive set models approximating a real intonation pattern*

The full sequence of models used for each of the solo chants are included in the CD.

3.4 Statistical Analysis

Figure 5 gives the raw statistics of the most used primitives for the Byzantine Chant and for the Bahir chant. Each primitive includes all the various stretch positions used by the shape. Figure 6 gives the detailed breakdown of one particular primitive with respect to the various stretch numbers used.

Byzantine Chant Primitive Contours

Primitive	Occurrences	% of total occurrences
G01	375	8.54
G02	345	7.86
E13	317	7.22
G03	287	6.54
E05	232	5.29
C08	206	4.69
G17	201	4.58
E19	156	3.55
E29	151	3.44
E12	149	3.39
G20	136	3.10
E06	131	2.98
C04	128	2.92
G07	108	2.46
G05	100	2.28
G04	89	2.03
G08	84	1.91

Bahir Chant Primitive Contours

Primitive	Occurrences	% of total occurrences
G01	219	10.43
G02	147	7.00
E13	137	6.53
G03	137	6.53
C08	132	6.29
G20	124	5.91
G04	95	4.53
C04	82	3.91
G05	60	2.86
E29	58	2.76
G17	58	2.76
E05	56	2.67
C03	55	2.62
E12	54	2.57
G07	53	2.53
E19	49	2.33
C01	41	1.95

Figure 5 *Sample of the statistics of the primitive templates used in the solo chants*

The most widely used primitives are the same in both cases. This is expected in that the basic pitch movements are dependent on the physical limits of phonation, on temporal limits of breathing and on preferred ranges both of pitch and of hearing. Notwithstanding, the exact agreement in the first four primitives is not only indicative of the reliability of the method, but may indicate some basic similarity in the two types of chants. The contours E05 and E12 are more prominent in the Byzantine. This indicates the wide variability in the pitch range and the higher rate of changes in the pitch than used in the Bahir chant.

Figure 6 shows the wide stretch variability for primitive E05 in both chants. Note that there is a much more consistent use of higher stretch numbers in the Byzantine than in the Bahir again indicating the wider use of higher pitch range changes.

Byzantine Chant

E05 Primitive

Stretch No.	Occurrences
1	1
2	5
3	10
4	23
5	31
6	36
7	31
8	25
9	16
10	23
11	11
12	6
13	9
14	3
15	1
18	1
	232

Bahir Chant

E05 Primitive

Stretch No.	Occurrences
2	1
3	3
4	15
5	10
6	10
7	6
8	5
9	4
10	1
12	1
	56

Figure 6 *Stretch variability for template E05 in the Byzantine and Bahir Anechoic Chants*

The partial statistical analysis of the solo chant anechoic waveforms is listed in Appendix section 5.3.

3.5 Conclusions

The intonation modelling tool can be used to look in detail at the components making up the chants, the pitch range and pitch preferred changes. This allowed detailed comparison of all the available Islamic and Byzantine chants. At the same time particular changes in chant can be automatically pinpointed in the acoustic waveform by reference to the primitive and its stretch number, and its position within the intonation model for the chant.

4 The Effective Duration of the Autocorrelation Function

4.1 Introduction

The work by Ando[1] on the Effective Duration of the Autocorrelation Function (ACF) was taken as a bases for this investigation. Various aspects of the ACF were developed further in this work. In particular a detailed analyses was conducted on the high values of the Effective Duration.

4.2 Tools used

A framework has been designed in order to facilitate the testing of the different mathematical formulae as well as the processing and the display of the data once the testing stage was over. Matlab 6 Release 12 was used as a base for the framework as it is very flexible, it offers a wide range of mathematical functions as well as the possibility to create a Graphical User Interface (GUI) in order to make the framework user friendly.

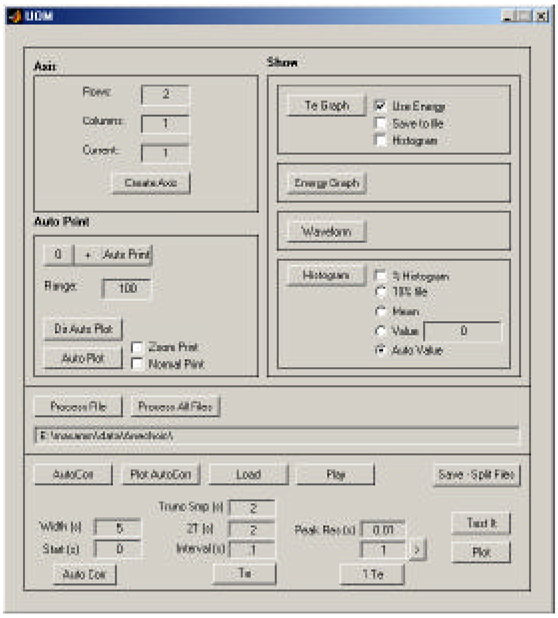


Figure 7 *A screenshot of the Framework*

[1] "Architectural Acoustics: Blending Sound Sources, Sound Fields, and Listeners (Modern Acoustics and Signal Processing)" by Yoichi Ando and R. Beyer – Section 3.1.3

4.3 Theoretical Introduction

4.3.1 The Autocorrelation Function

The short-time moving Autocorrelation Function (ACF) as a function of time t is calculated as[(1)]:

$$?_p(?) ? ?_p(? : t,T)$$

$$? \frac{? _p(? : t,T)}{[? _p(0 : t,T).? _p(0 : ? ? t,T)]^{\frac{1}{2}}}$$

where

$$? _p(? : t,T) ? \frac{1}{2T} \int_{t?T}^{t?T} p'(s)\, p'(s ? ?)\, ds$$

4.3.2 Definition of ?e

The effective duration (?e) is defined by the delay at which the envelope of the normalized ACF becomes –10 dB and represents the repetitive features or reverberation contained within a signal. This is calculated by extrapolating a linear approximation of the envelope of the ACF between 0 and –5 dB. An example is shown in Figure 8.

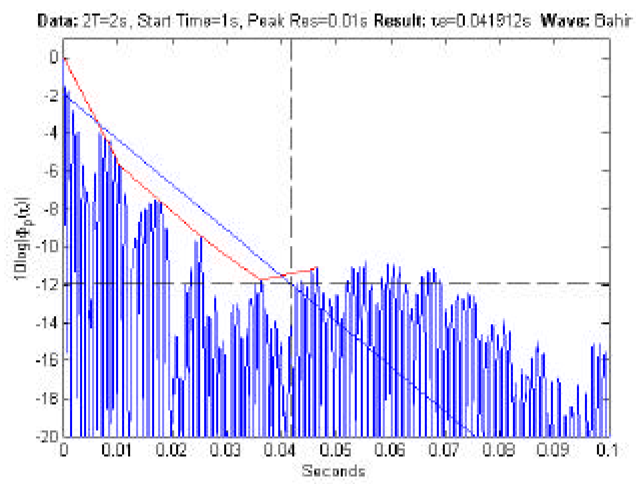


Figure 8 *An example of the calculation of the ?e*

4.4 Selecting the 2T window size.

Initially the window size parameter (2T) was investigated to obtain a measure of its influence on ?e. The 2T values used were **0.5s**, **1s**, **2s** and **5s**. The graphs obtained show too much ?e activity for the 0.5s graphs (a lot of instantaneous peaks) and too little activity for the 2s and 5s graphs. The graphs for the 1s showed to be a good compromise and thus a 2T value of 1s was used for the rest of the examination.

4.5 Problems in the interpretation of ?e values

4.5.1 Factors effecting ?e

The problem arises because apart from the repetitive features and reverberation there are other factors that influence the calculated values of ?e. These are:

?? **DC Values**: The auto correlation of DC segments is very high because the signal is obviously correlated. Thus the ?e values for DC segments are very high (over 4000ms in **Figure 9**).

?? **Uncorrelated Noise**: This yields a low value of ?e (**Figure 9**).

?? **DC Shift**: Similar signals but with a different DC shift have a similar ?e contour but the one with a higher positive DC shift has an overall higher ?e graph (**Figure 10** – a,b and c).

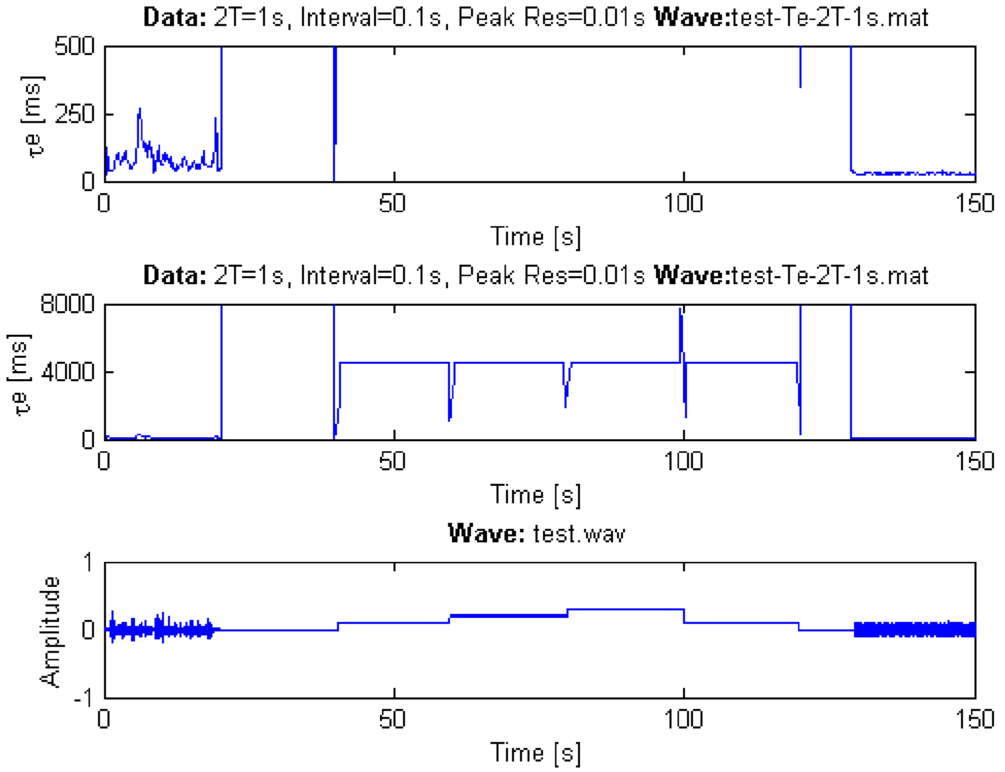


Figure 9 *Factors effecting ?e – DC Values and Uncorrelated Noise*

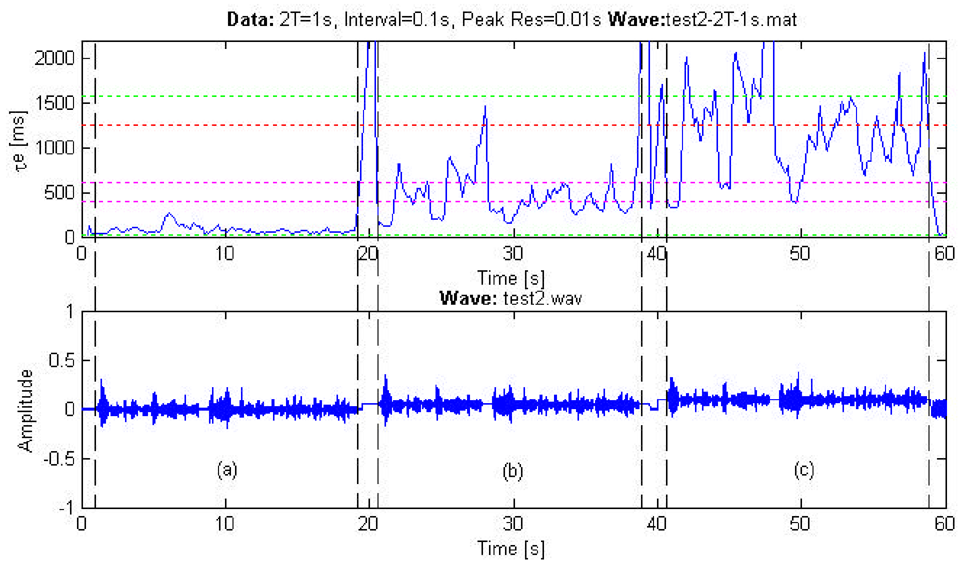


Figure 10 *Factors effecting ?e – DC Shift*

4.5.2 Silence (and Correlated Noise)

By visually comparing the ?e graphs of a particular sample and the sample itself it was noted that sections with silence (or pauses) have ?e values that are comparable to the ?e values in the rest of the signal (Figure 11 sections a, b and c).

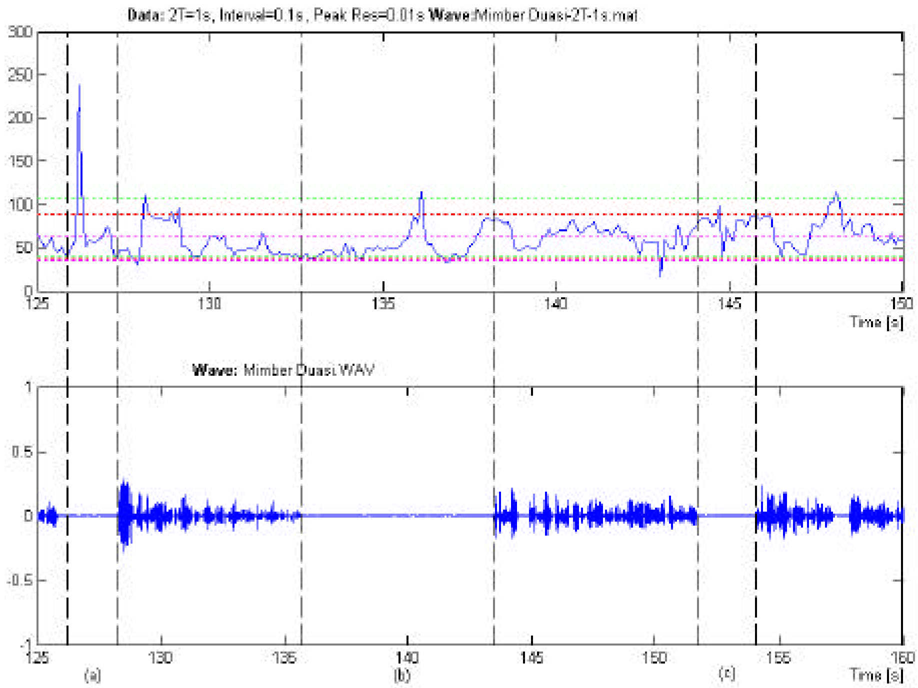


Figure 11 *Sections a,b and c of the waveform (bottom graph) consist of silence – The ?e values for these regions are comparable with the rest of the waveform.*

It seems that these ?e values are being calculated on the noise of the signal that, although being small, is correlated in such a way that it is giving the results obtained. Obviously, the ?e values of these sections of the sample are not relevant to the signal and thus a method to avoid this problem had to be found.

4.6 Solution to the problems

4.6.1 Extracting the 'silence' segments

In our case the noise issue was taken into account at the recording stage, any DC shifts that could be present would be similar in all the duration of the sample. The problem that remains is the effect of 'silence' and the correlated noise.

The method of calculating the ?e values does not distinguish between sections of the sample that contain the signal and the sections that contain the 'silence' (and the small correlated noise). Thus some other method must be used in order to distinguish between the parts of the sample that are relevant and the ones that are not.

It was found that using the energy of the signal at that particular point is a good method of distinguishing between these sections. Tests have shown that it is important to calculate the energy on a window rather then on the discrete points (this is a sort of averaging mechanism). The window size to be used is a compromise between selecting a small value and returning to the discrete point system and selecting a large value and not being able to detect the sections with 'silence' (due to the excessive averaging). It was found that using a window of 0.1s gives a good energy graph when compared visually (i.e. sections of 'silence' could be identified easily from the energy values using the 0.1s window).

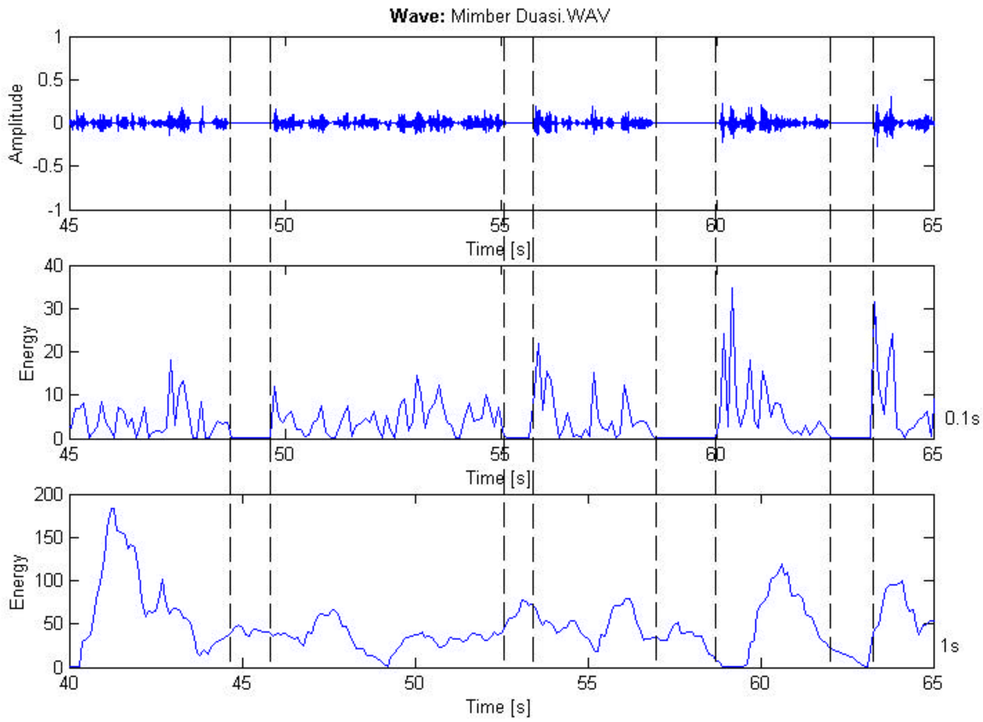


Figure 12 *(a) Waveform (part of the Mimber Duasi chant). (b) respective energy graph using a 0.1 second window. (c) respective energy graph using a 1 second window.*

4.6.2 Selecting the relevant ?e data

Once that a distinction between the relevant and the non relevant sections of the signal was made, the next step was to decide on how to alter the ?e values in the respective sections in order to arrange for this 'silence' issue.

Method 1:

Eliminate the ?e values for which the Energy falls below a certain value.

Method 2:

Scale the ?e value in relation to the Energy content of the signal.

The problem with Method 2 is that sections with relatively low ?e values and high Energy will be 'scaled' up to higher ?e values. Thus the elimination method (i.e. Method 1) was selected.

4.7 Extraction of the Data

4.7.1 The ?e Graphs

The ?e graphs were generated for all the anechoic and synthesised chants available these graphs are included in the CD. Moreover the CD also contains a zoomed version of all the graphs with a time range of 50s that can be used for a detailed analysis of the graphs. The zoomed graphs for the anechoic Bahir Solo Chant are also illustrated in the Appendix section 5.2.

Figure 13 and Figure 14 show a sample of the ?e and Waveform graphs of the Bahir chant systemised at SS Sergius Bacchus Church.

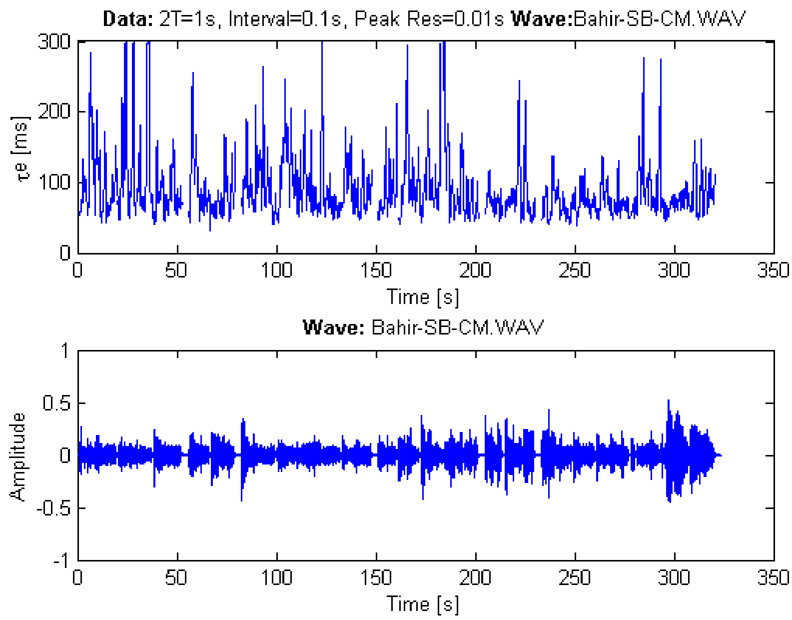


Figure 13 *?e and waveform graphs of the Bahir chant synthesised at SS Sergius Bacchus Church*

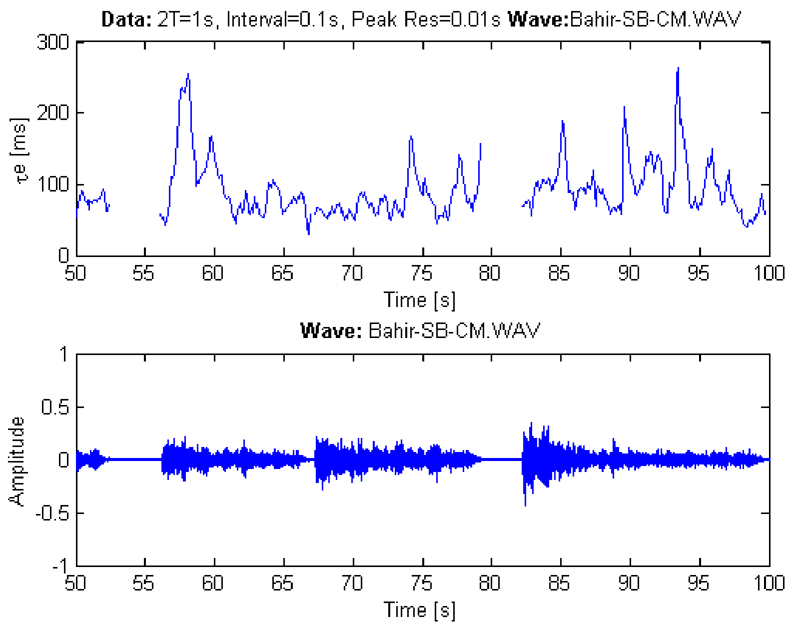


Figure 14 *A zoomed version of the graphs in Figure 13 with a Time range of 50s to 100s*

Comments on a visual analysis of the ?e graphs could be found in section 4.8.1.

4.7.2 ?e peak investigation

Given that the ?e represents the time taken for the autocorrelation to fall by 10 dB, meaning, that by that time the signal section in consideration would have died, high values of ?e mean that the signal is 'sustained' for a longer period and thus gives information regarding the repetitive features and the reverberation of the signals. Thus, in the context of the project, it is interesting to investigate further these high values of ?e, especially studying the effect of the Mosques and Byzantine Churches on these ?e values.

4.7.3 Statistical Data

The ?e graphs were analysed statistically and the following statistical data was extracted for each graph.

Values	**Description**
Mean	This is the mean value of the ?e data
S.D.	The standard deviation (S.D.) of the ?e data around the mean
5 %tile	The 5 percentile (%tile) is the level at which only 5% of the sorted list

10 %tile 90 %tile 95 %tile	of ?e values exceed this limit. (Note that, the 50 %tile (median) is not the same as the Mean value.)

As a further illustration, Figure 15 shows the same ?e and waveform graphs as in Figure 13 but with lines showing the positions of the Statistical Data.

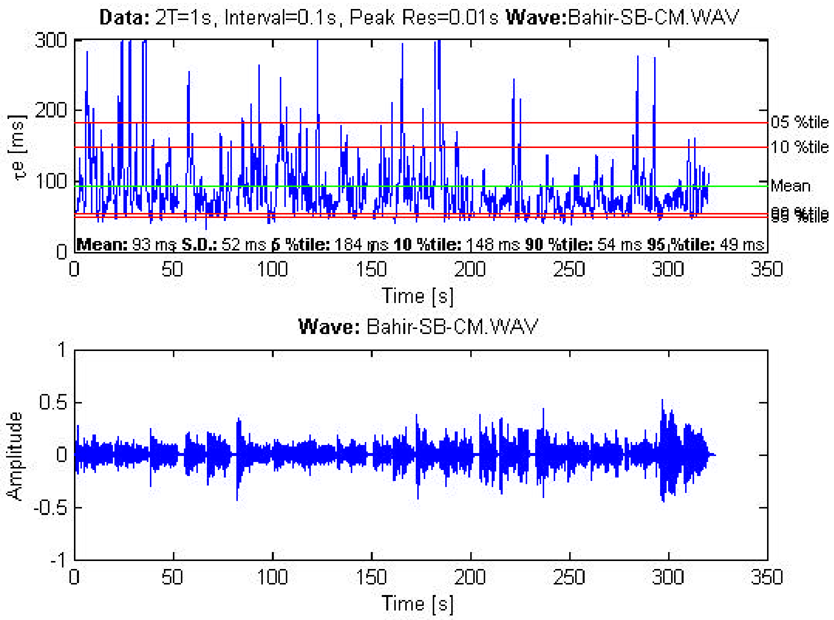


Figure 15 *?e and waveform graphs of the Bahir chant synthesised at SS Sergius Bacchus Church overlaid with the Statistical Data*

Moreover, Figure 15, shows, graphically, the relation of the higher percentiles (the 5 and the 10 %tiles) to the ?e peaks.

The bar charts depicting the Statistical Data obtained for the Anechoic Chants and the Chants Synthesised with the receiver positioned at the Centre of the Mosque (CM) can be found in the Appendix sections 5.4.1 and 5.4.2 respectively. The exact data values as well as the statistical data of the Chants Synthesised in the other receiver positions could be found on the CD.

4.7.4 Percentile Analyses

The Statistical Data can also be shown as the change in ?e with the change in the percentile from the 100 %tile to the 5 %tile.

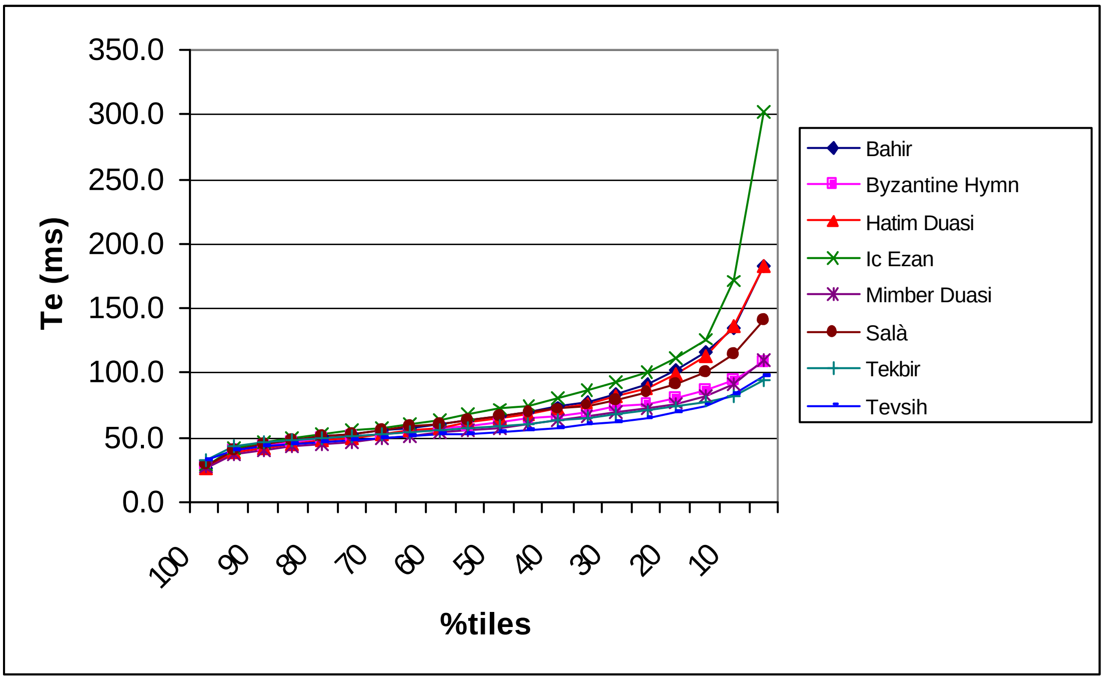


Figure 16 *Percentile Graph for the anechoic chants*

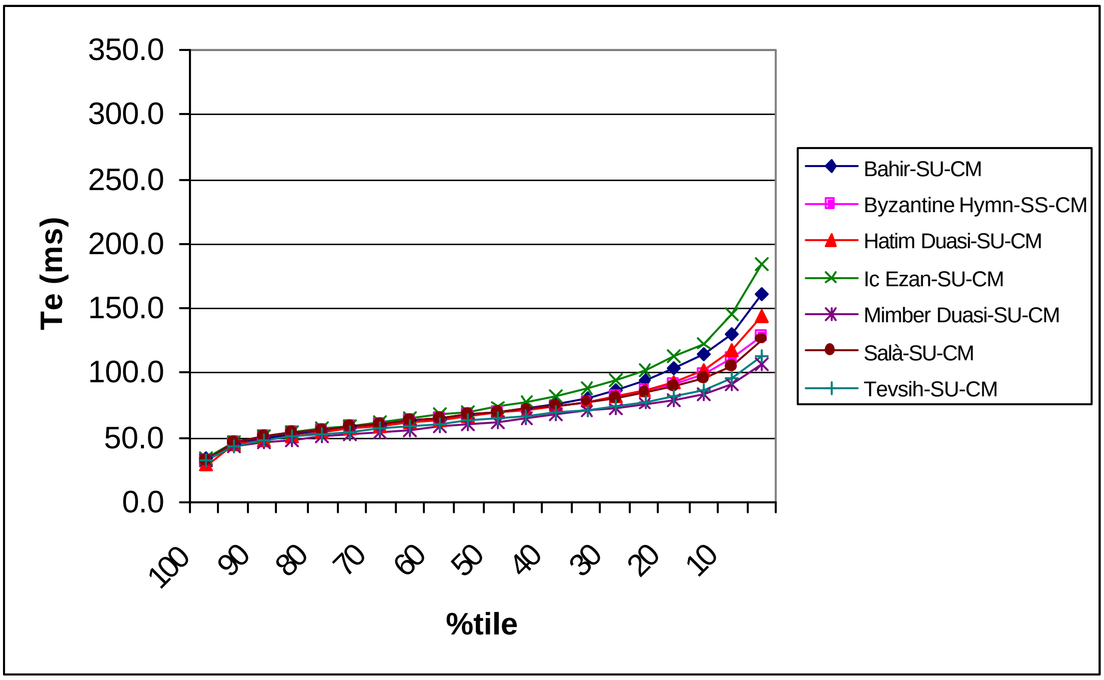


Figure 17 *Percentile Graph for the chants synthesised at Süleymaniye and St. Sophie*

Figure 16 and Figure 17 show the percentile values for the Anechoic and the Synthesised (at the Süleymaniye Mosque) chants.

The full set of Percentile Analyses figures is included in Appendix section 5.6.

4.7.5 Peak Distance Calculation

Due to the significant change in the range of the higher percentiles (of the ?e), between the anechoic and the synthesised chants, a further investigation was considered. This was to measure the distance between successive ?e peaks in order to investigate whether this distance is influenced by the space.

First of all the peaks had to be identified. Given that only the highest peaks were of interest, only peaks with a ?e value greater then the value of the 10 percentile were considered. To be able to compare results from the anechoic and synthesised waveforms the same threshold value was used. This was the 10 %tile of the anechoic version of the chant under consideration.

The values were subsequently smoothed so that very small variations within a distance of 0.5 s were eliminated and considered as one peak.

A histogram was then used to obtain a measure of the distribution of the spread of the distance between peaks of ?e in the various chants. Figure 18 shows an example of such a histogram with bins of 1s, the rest of the data is included in the CD.

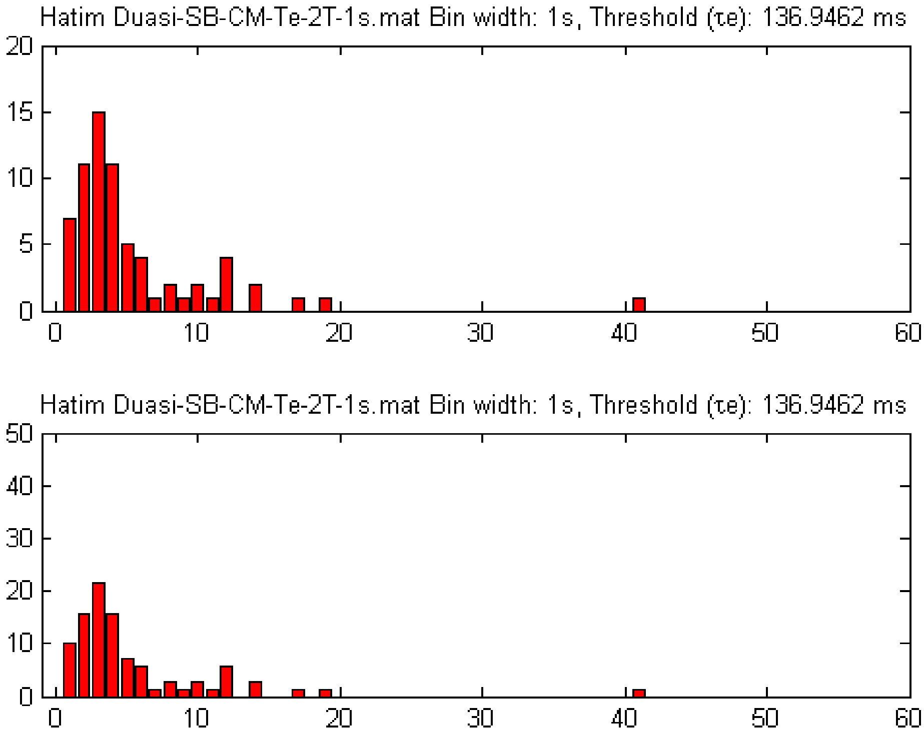


Figure 18 (a) *Histogram of the Peak Distances for the Hatim Duasi Chant syntesised at SS Sergius Bacchus Church and with the receiver at the center.* **(b)** *same histogam as in (a) but 100% normalised.*

4.8 Comments on Results

4.8.1 ?e Graphs

The ?e graphs of the Anechoic Islamic solo chant group (Bahir, Ic Ezan and Salà) and the Anechoic Islamic choir chant group (Tekbir & Tevsih) are visually quite consistent between the other chants of the same group.

The Islamic solo chants seem to have a distinct ?e graph compared to the ?e graph of the Byzantine solo chant. The Islamic samples have a greater spread of ?e values and much more instantaneous ?e peaks.

It was noted that the Islamic solo chants seem to have relatively long pauses between the verses of the chant (this is not found in the Islamic choir and Byzantine solo chants). It would be interesting to investigate if this pausing may be influenced by the structures.

The ?e graphs for the Islamic Choir Chants and the last choir part (approx. 26s) of the Bahir have much less ?e instantaneous peaks when compared to the Islamic solo chants.

They are much closer to the Byzantine solo chant but have a lesser spread and less instantaneous peaks.

4.8.2 Statistical Data

4.8.2.1 Anechoic

It is interesting to note that the value of ?e at the 95 %tile and 90 %tile is quite similar for the all the Anechoic chants (Reference Figure 19). This means that the 95 and 90 %tiles do not give information that can distinguish the various types of chants, such as the Solo Chants and the Choir Chants.

On the other hand the values for the 10 and 5 %tiles are quite distinct. It is also interesting to note that the Tekbir & Tevsih, which are both Choir Chants have a similar value.

The ?e and intonation contour for the Bahir Solo Chant in Appendix 5.2 also show a clear correlation between sustained pitch and high values of ?e.

4.8.2.2 Synthesised

From Figures 20 – 26, in Appendix section 5.4.2, the mean, 95 %tile and 90 %tile of the particular chants sung in the three Mosques are higher than the corresponding Anechoic parameters. This is to be expected, as the initial reflections will tend to sustain the original waveform. Moreover, the slight increase in the values is similar in all the three spaces.

As regards to the 5 %tile and 10 %tile parameters, they are quite dependent on the volume of the Mosques. Moreover, it seems that the different types of pieces (i.e. Solo or Choir Chants) are, in general, influenced in a different manner.

Apparently all the Solo Chants tend to decrease the 10 %tile and 5 %tile values as the volume of the worship space increases.

The effects of position in the worship spaces also follow a similar pattern. The values of the 95 and 90 %tile remain practically the same whatever the position of the receiver. However the values of the 10 and 5 %tile vary significantly (reference Statistical Data file on the CD)

4.8.3 Percentile Analyses

Form the Percentile Analyses Graphs in the Appendix section 5.6 it was noted that the percentiles with lower ?e values tend to increase when the chant is synthesised in the worship space while the percentiles with a high ?e value tend to decrease.

This may be due to the fact that in general the chant becomes more correlated because of the echoes introduced by the worship space which have the effect of making the chant more sustained (especially in the sections with silence and when the energy of the echo is greater or comparable to the energy of the chant at that instant).

On the other hand the higher values of ?e are decreasing in all the worship spaces. This could probably be due to the echo produced by the previous sections, which could be interfering negatively with the repetitive features of the section in question and thus reducing the correlation.

Thus the worship spaces tend to decrease the overall range of ?e from that of the anechoic record. This seems to imply that there is always loss in the dynamic range intrinsic in the Anechoic record when this is produced inside a volume.

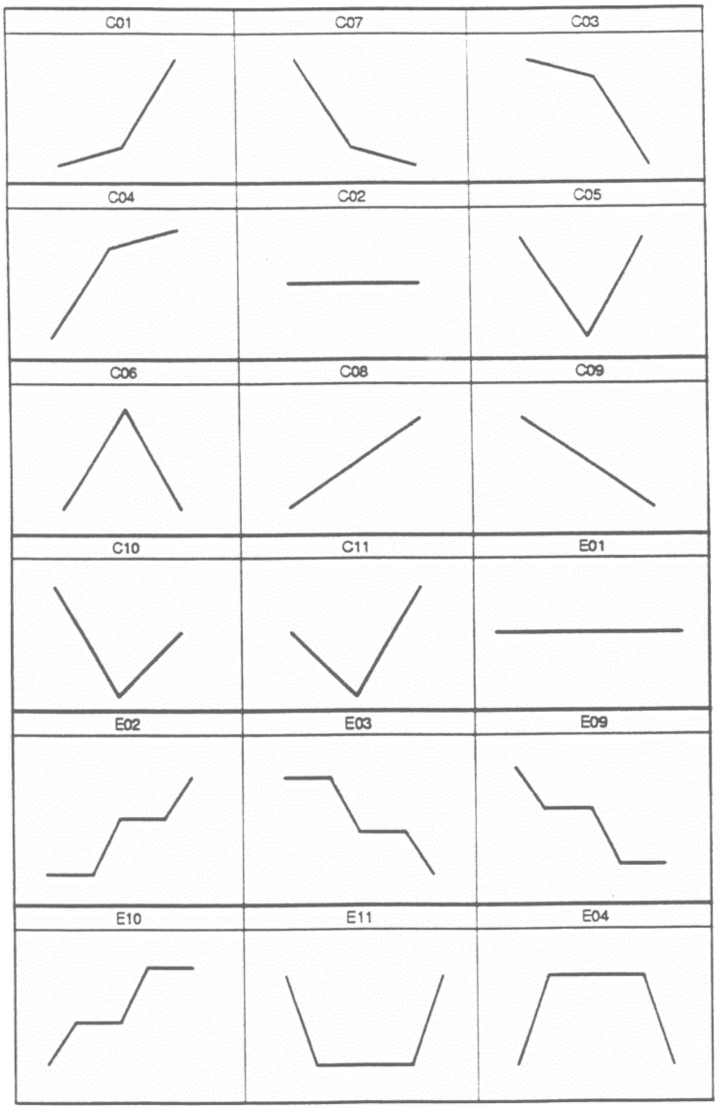
4.8.4 Peak Distance Analysis

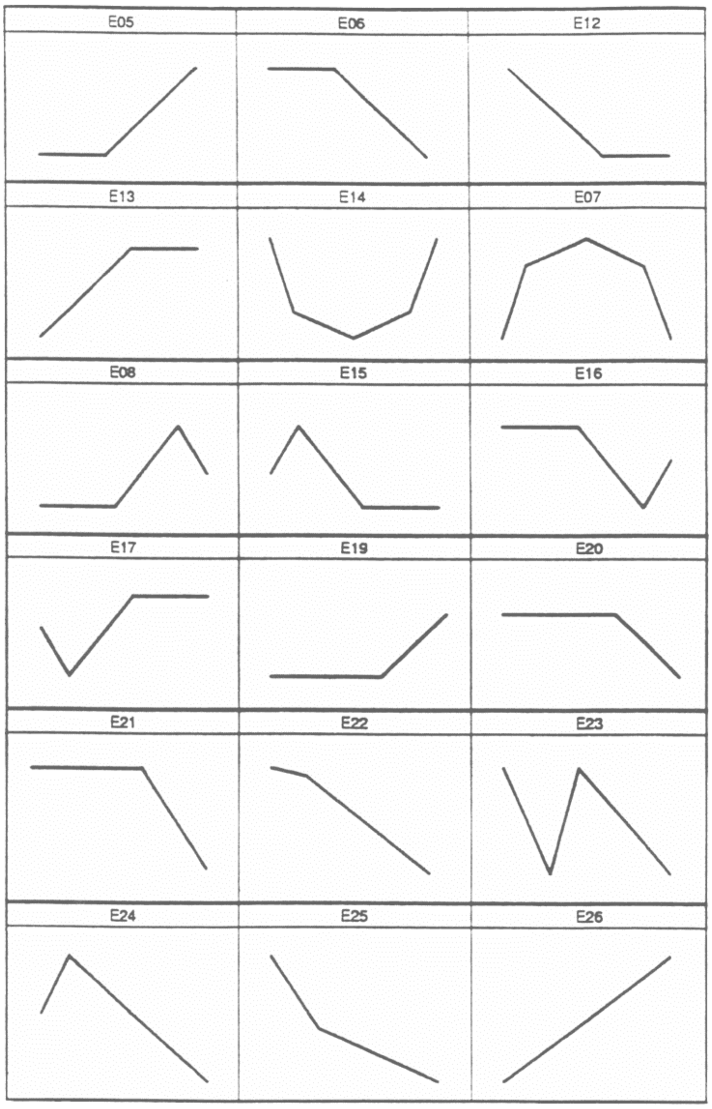
The histograms for the Anechoic Chants shows a distribution that has a general similar pattern fot Bahir Salà, and Hatim Duasi, and a slight variation from this pattern in the Mimber Duasi and the Byzantine Hymn. The change in the patterns is also similar in the larger volumes. There is a general tendency of a reduction in the number of occurrences of peak distances in the order of 2 to 4 seconds with a higher increase in distances of 1 second indicating that a number of distinct original peaks have been reduced with the appearance of other peaks in between due to the influence of the large volume.

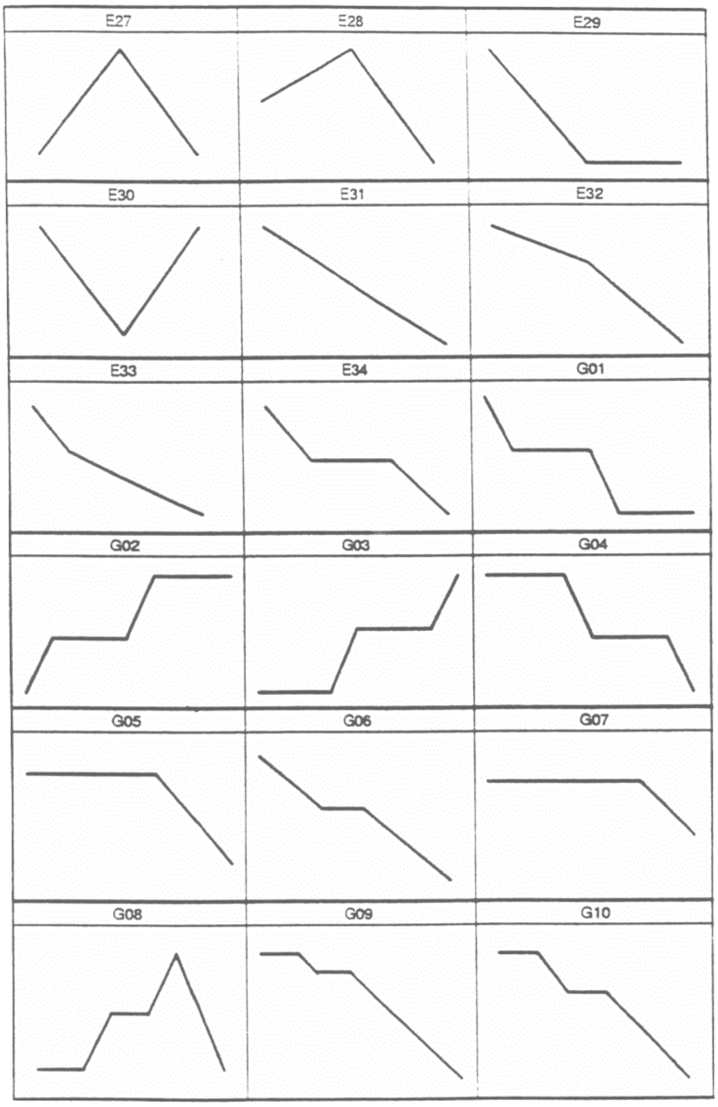
There is however large variability in the results and no general conclusions can be drawn on whether the worship spaces have a distinct influence on the time intervals between the peaks of high ?e.

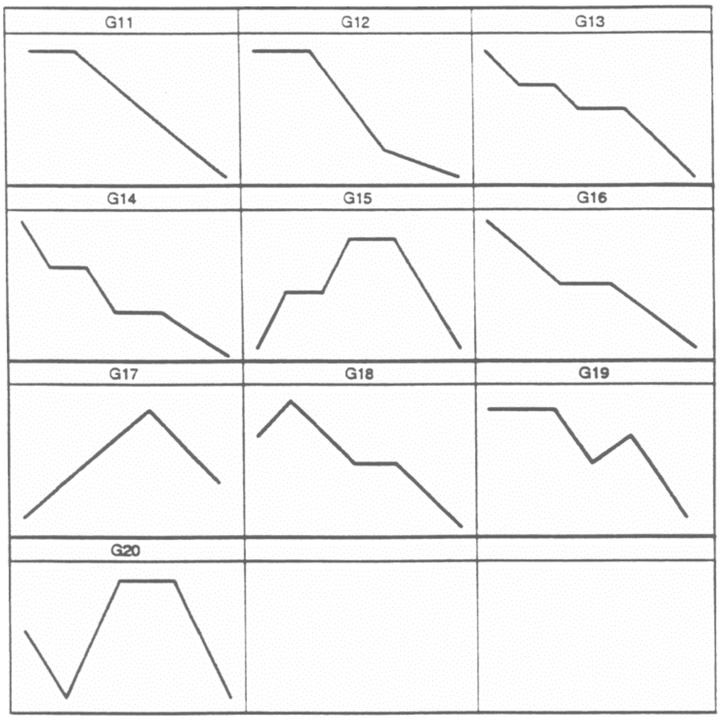
5 Appendices

5.1 Pitch Primitive Set

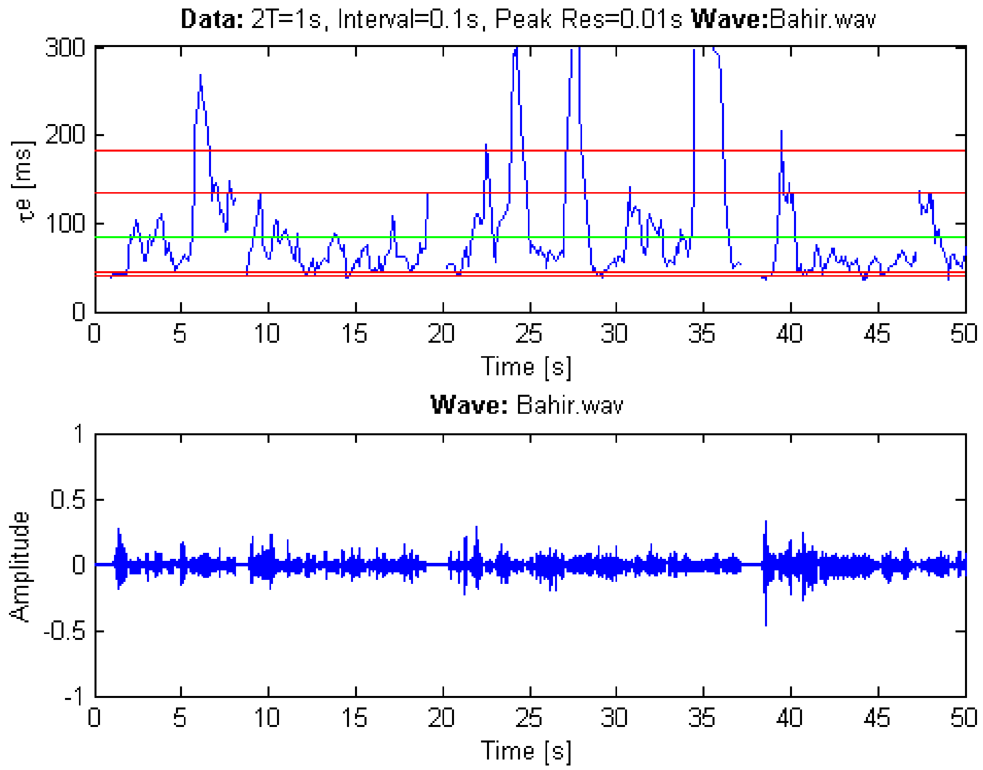


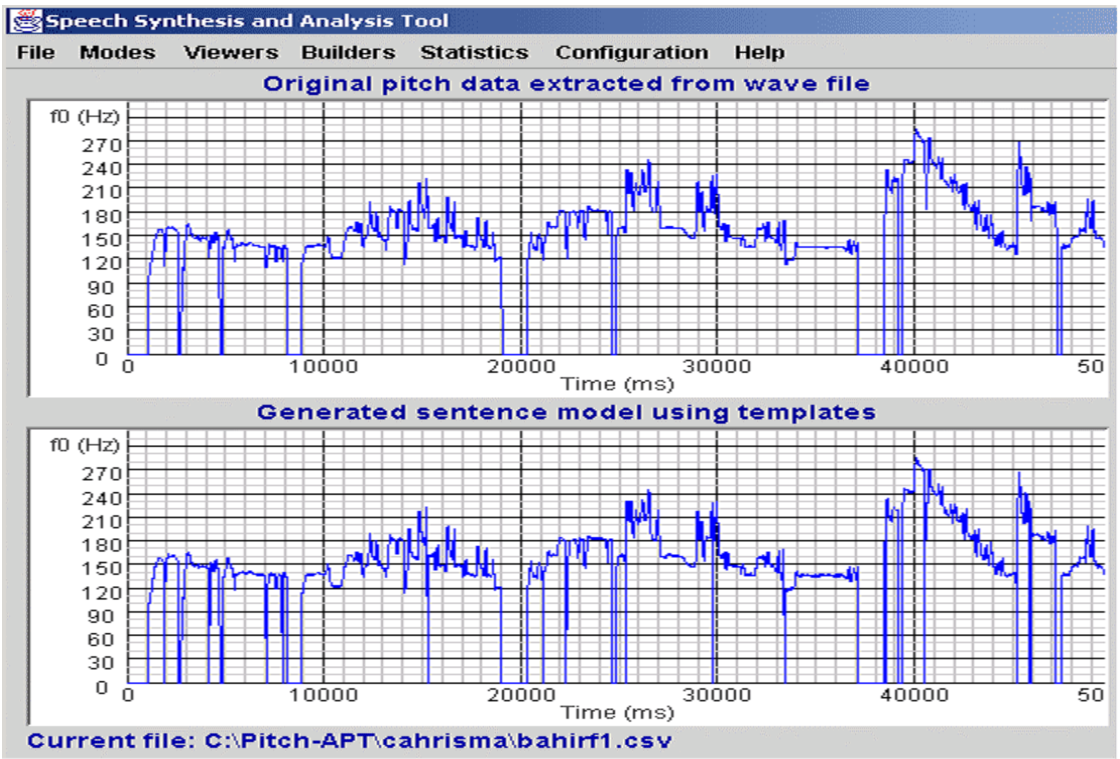

E05
E06
E12
E13
E14
E07
E08
E15
E16
E17
E19
E20
E21
E22
E23
E24
E25
E26

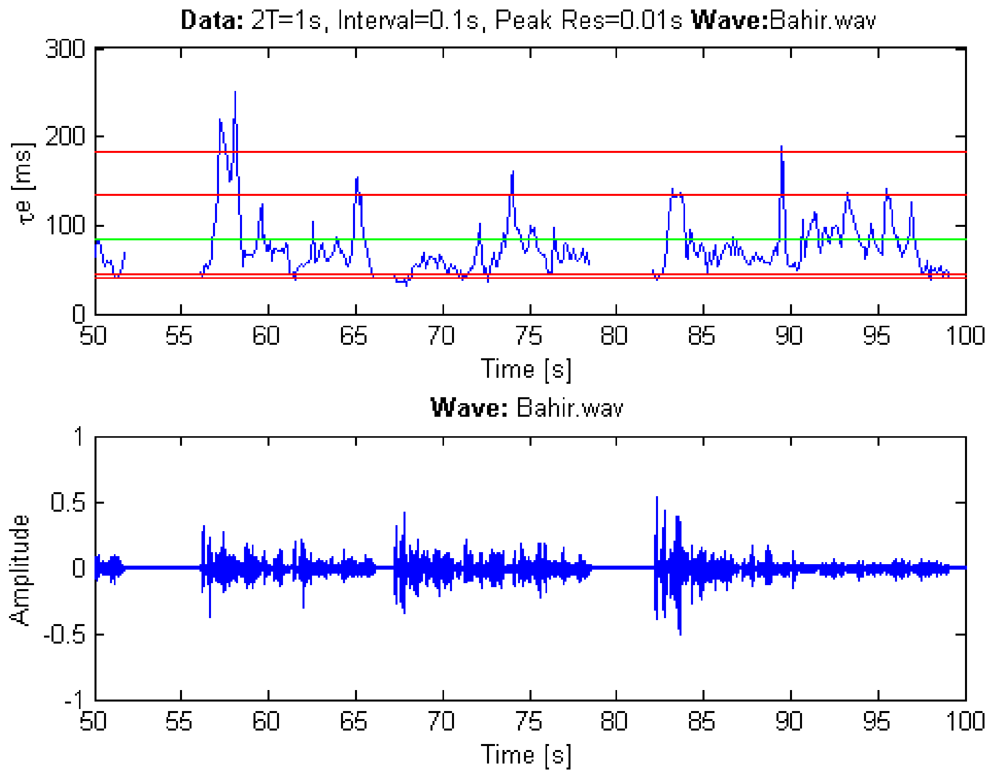

E27
E28
E29
E30
E31
E32
E33
E34
G01
G02
G03
G04
G05
G06
G07
G08
G09
G10

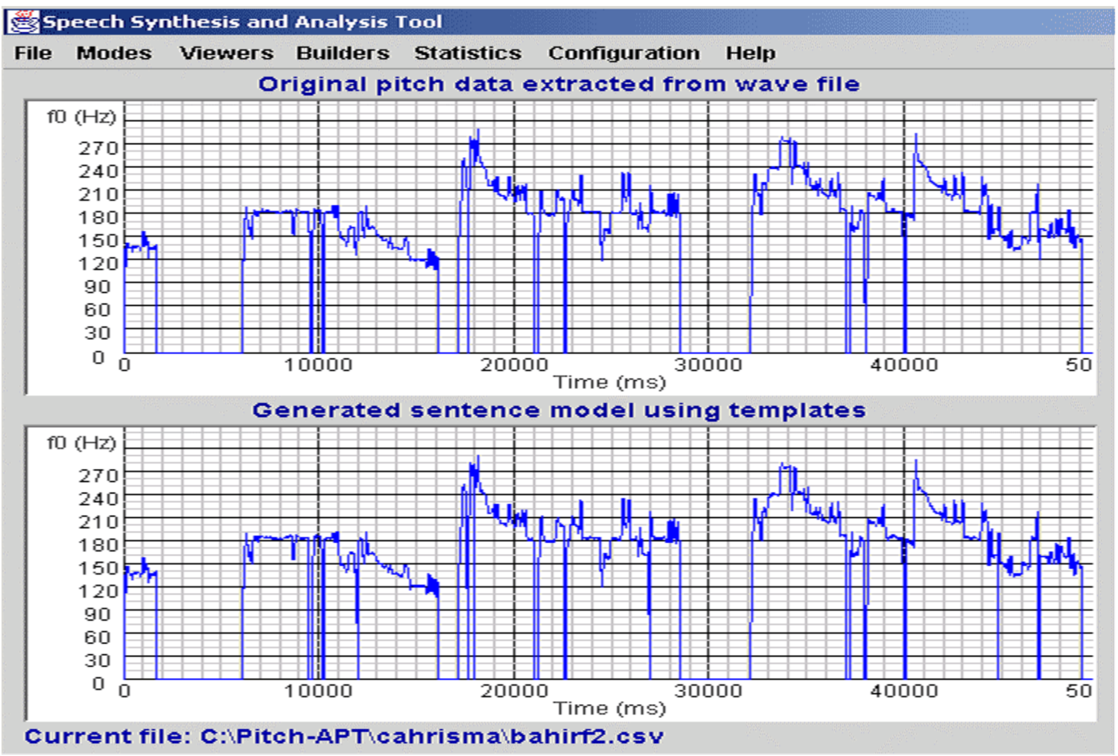

G11
G12
G13
G14
G15
G16
G17
G18
G19
G20

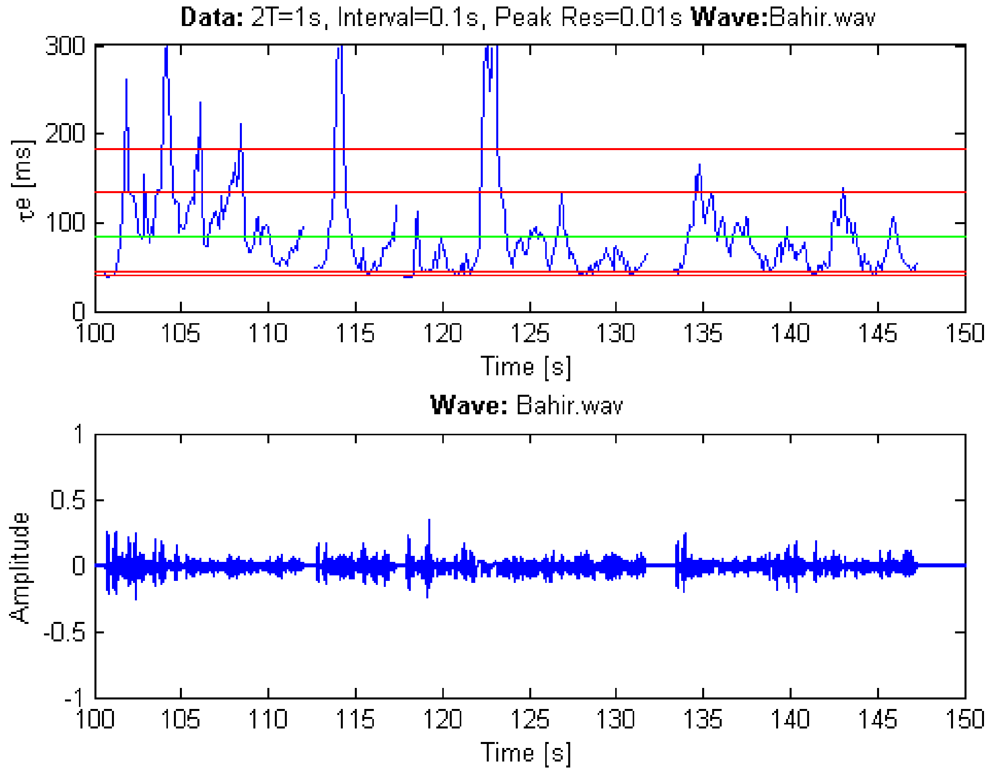
5.2 Bahir Solo Chant Analysis

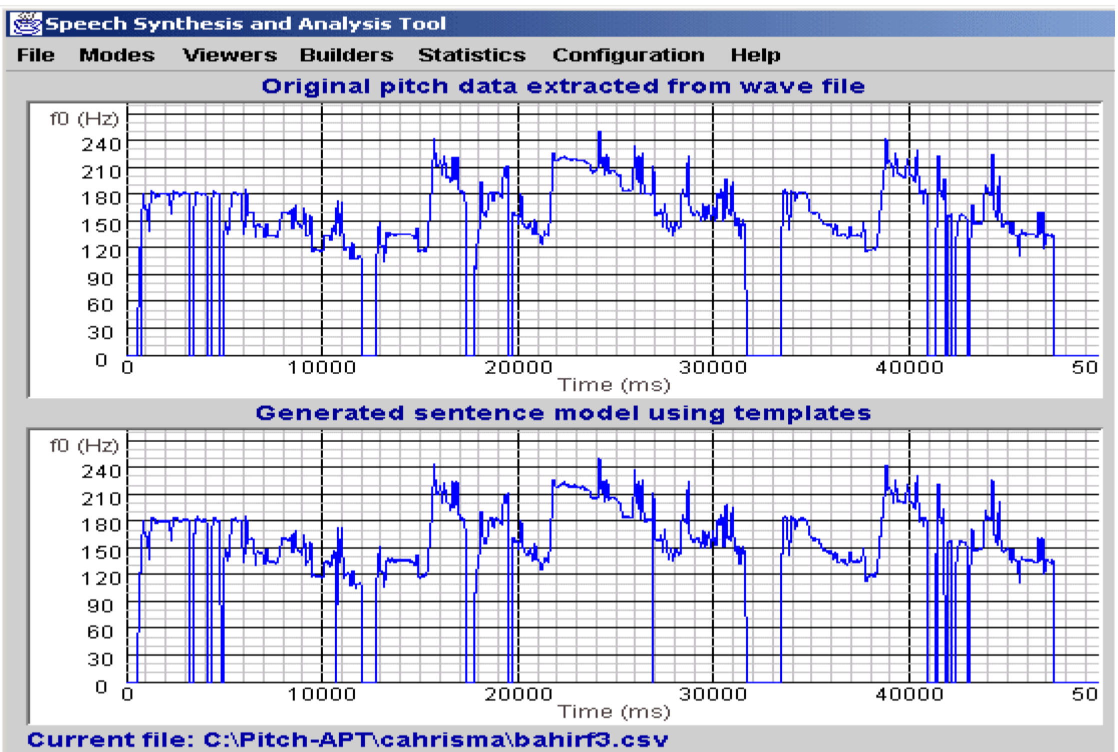


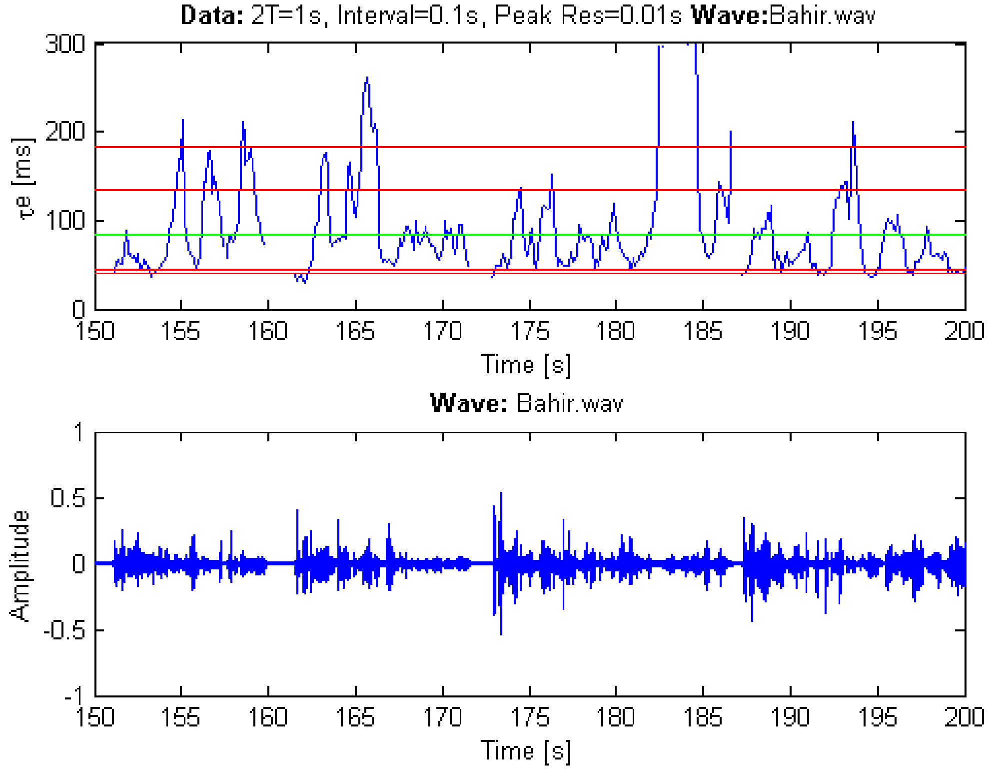


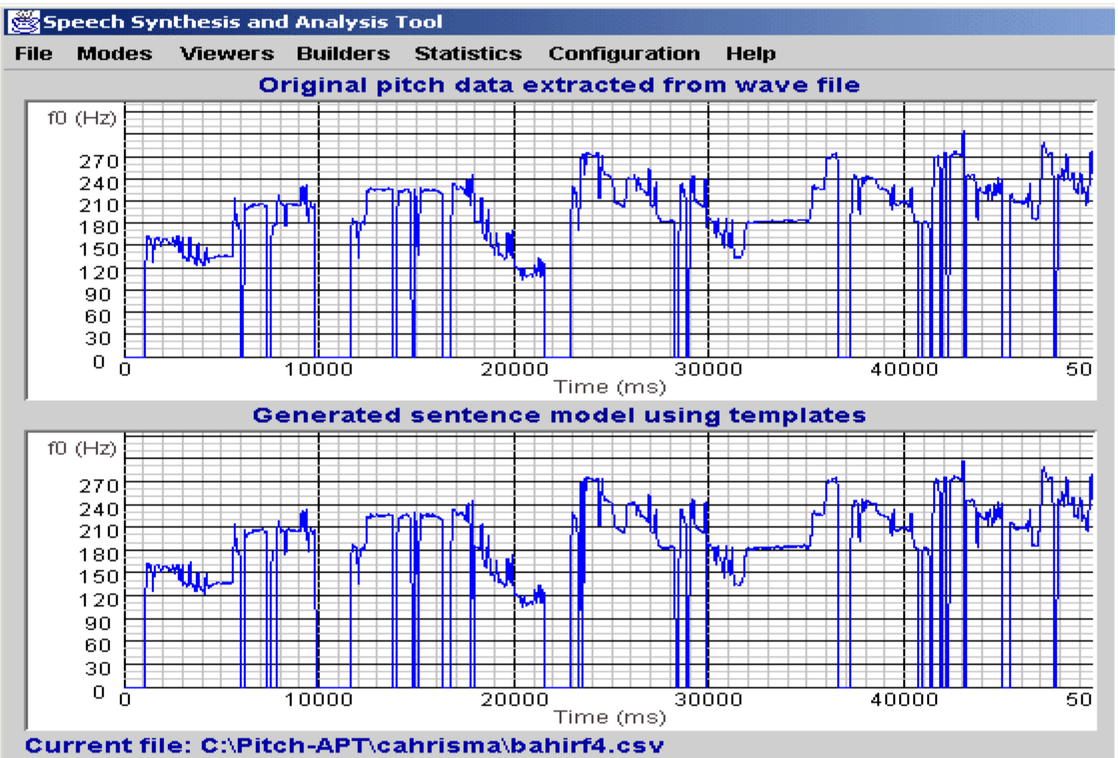

Data: 2T=1s, Interval=0.1s, Peak Res=0.01s Wave:Bahir.wav
τe [ms]
300
200
100
0
50 55 60 65 70 75 80 85 90 95 100
Time [s]
Wave: Bahir.wav
Amplitude
1
0.5
0
-0.5
-1
50 55 60 65 70 75 80 85 90 95 100
Time [s]

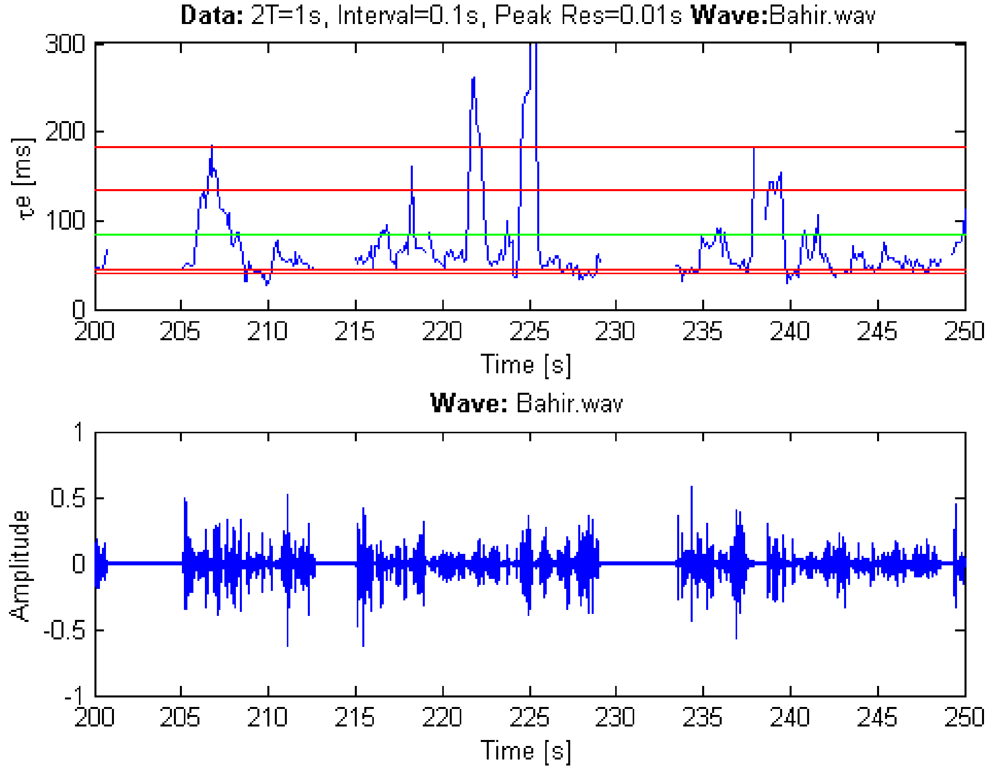

Speech Synthesis and Analysis Tool
File Modes Viewers Builders Statistics Configuration Help
Original pitch data extracted from wave file
f0 (Hz)
270 240 210 180 150 120 90 60 30 0
0 10000 20000 30000 40000 50
Time (ms)
Generated sentence model using templates
f0 (Hz)
270 240 210 180 150 120 90 60 30 0
0 10000 20000 30000 40000 50
Time (ms)
Current file: C:\Pitch-APT\cahrisma\bahirf2.csv

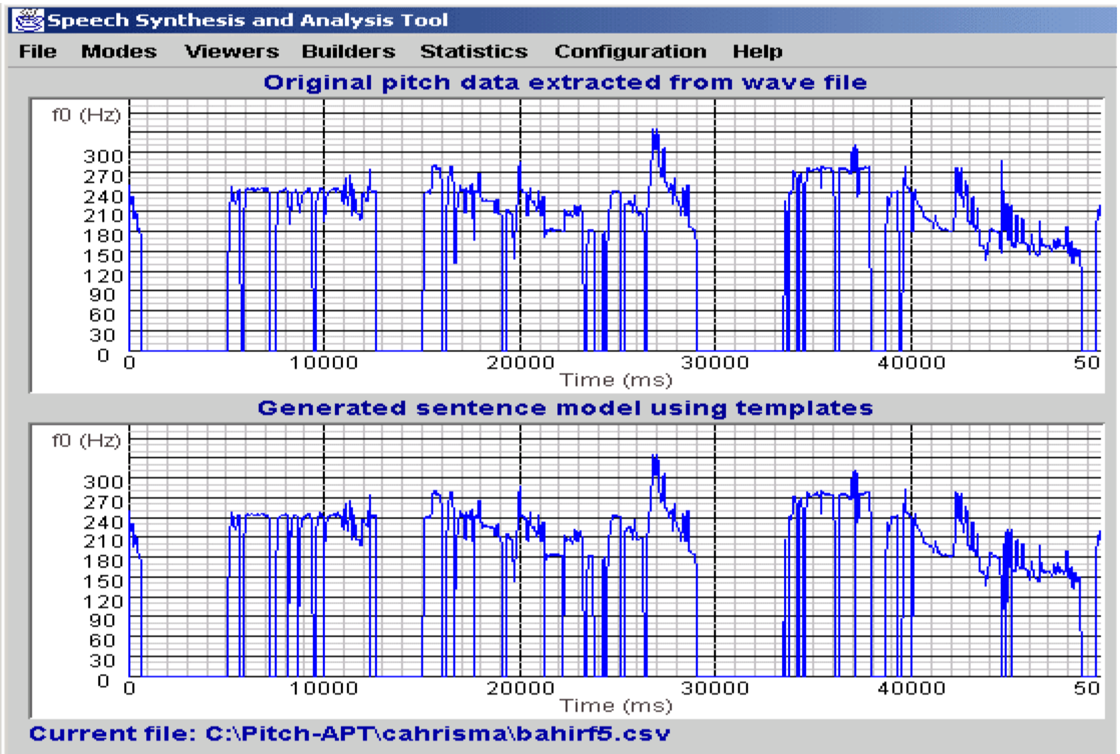

Data: 2T=1s, Interval=0.1s, Peak Res=0.01s Wave:Bahir.wav
τe [ms]
Time [s]
Wave: Bahir.wav
Amplitude
Time [s]

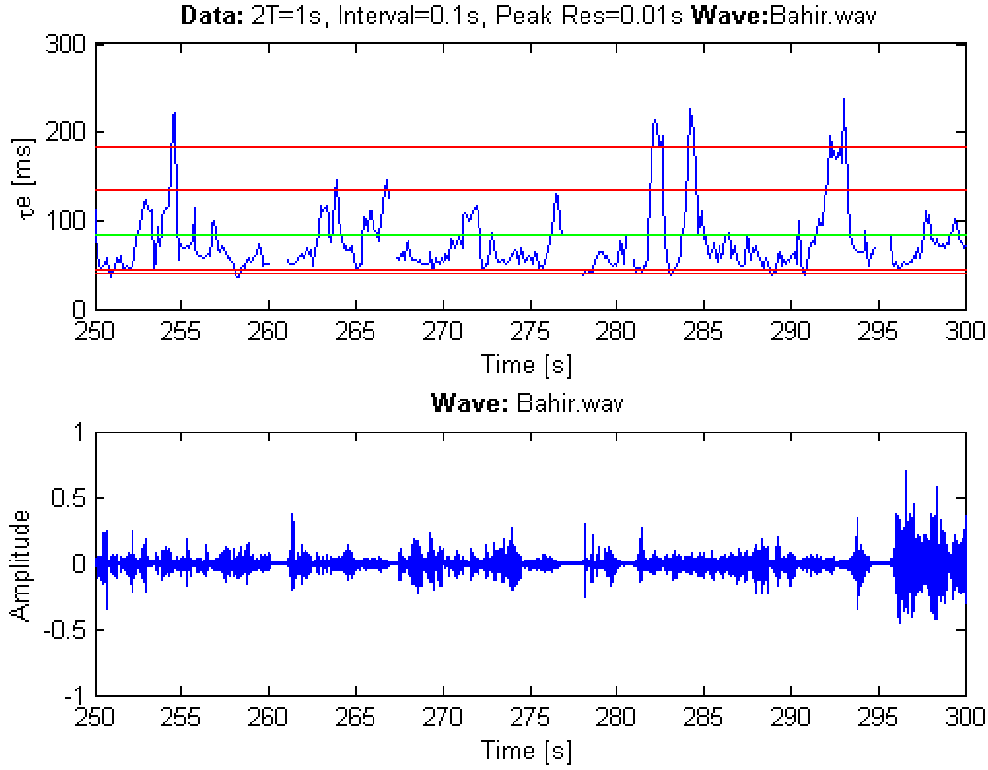

Speech Synthesis and Analysis Tool
File Modes Viewers Builders Statistics Configuration Help
Original pitch data extracted from wave file
f0 (Hz)
Time (ms)
Generated sentence model using templates
f0 (Hz)
Time (ms)
Current file: C:\Pitch-APT\cahrisma\bahirf3.csv

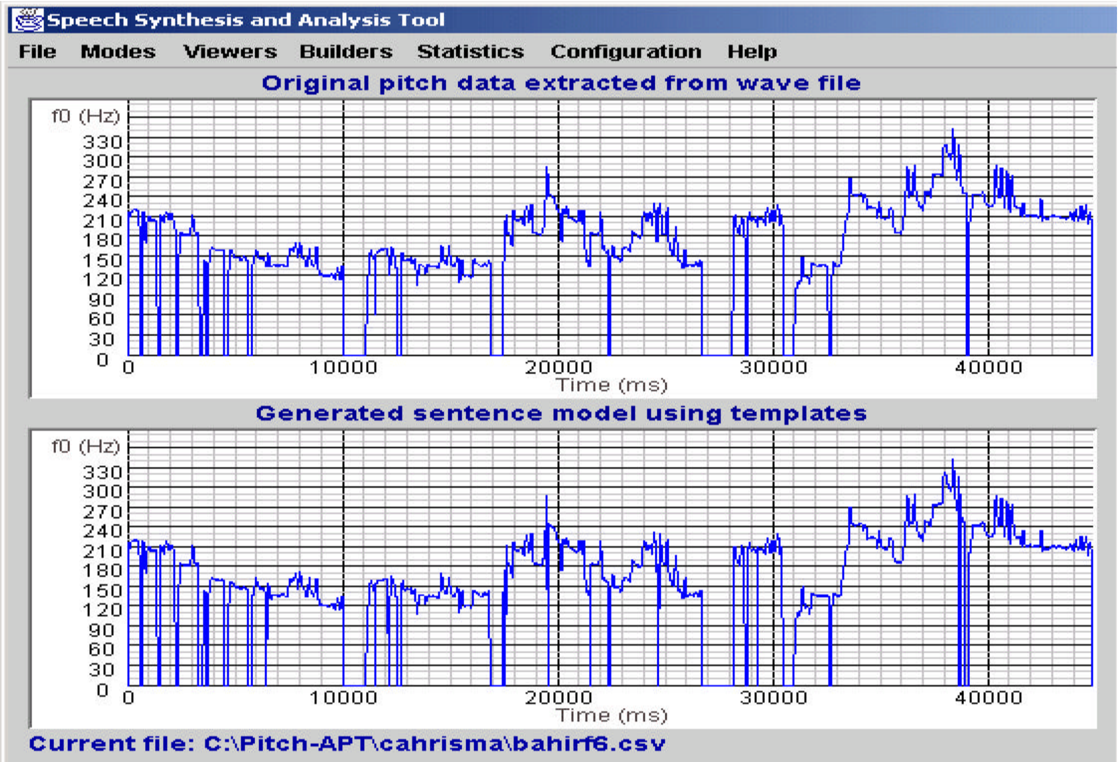

Data: 2T=1s, Interval=0.1s, Peak Res=0.01s Wave:Bahir.wav
τe [ms]
Time [s]
Wave: Bahir.wav
Amplitude
Time [s]

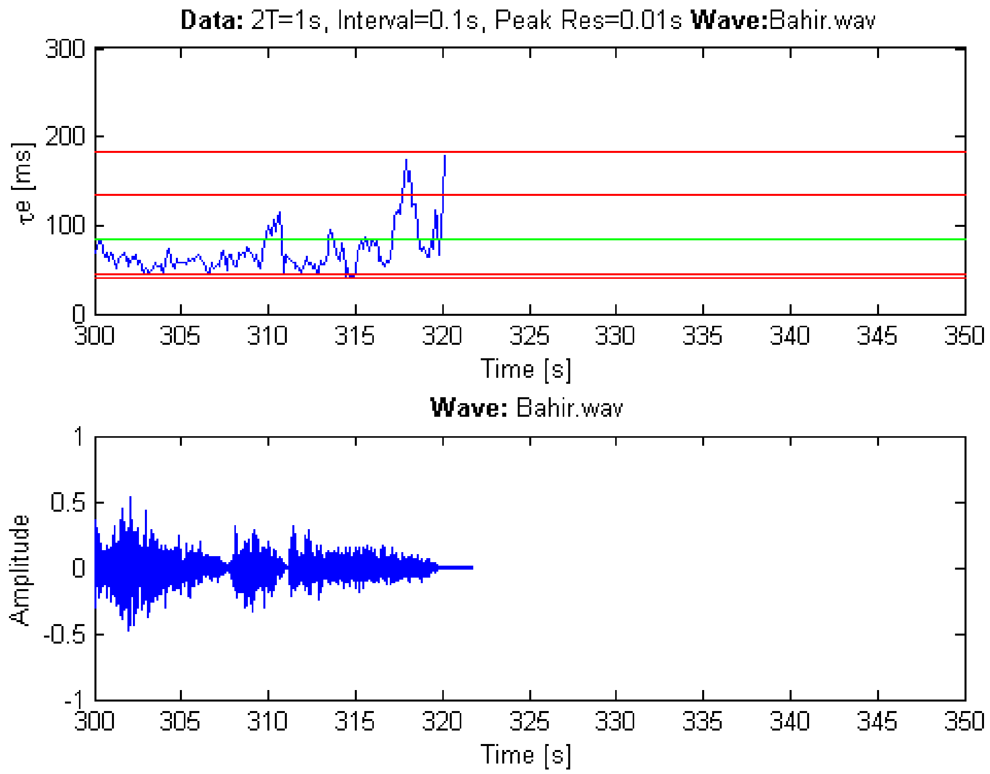

Speech Synthesis and Analysis Tool
File Modes Viewers Builders Statistics Configuration Help
Original pitch data extracted from wave file
f0 (Hz)
Time (ms)
Generated sentence model using templates
f0 (Hz)
Time (ms)
Current file: C:\Pitch-APT\cahrisma\bahirf4.csv


Data: 2T=1s, Interval=0.1s, Peak Res=0.01s Wave:Bahir.wav
τe [ms]
Time [s]
Wave: Bahir.wav
Amplitude
Time [s]


Speech Synthesis and Analysis Tool
File Modes Viewers Builders Statistics Configuration Help
Original pitch data extracted from wave file
f0 (Hz)
Time (ms)
Generated sentence model using templates
f0 (Hz)
Time (ms)
Current file: C:\Pitch-APT\cahrisma\bahirf5.csv


Data: 2T=1s, Interval=0.1s, Peak Res=0.01s Wave:Bahir.wav
τe [ms]
Time [s]
Wave: Bahir.wav
Amplitude
Time [s]


Speech Synthesis and Analysis Tool
File Modes Viewers Builders Statistics Configuration Help
Original pitch data extracted from wave file
f0 (Hz)
Time (ms)
Generated sentence model using templates
f0 (Hz)
Time (ms)
Current file: C:\Pitch-APT\cahrisma\bahirf6.csv



5.3 Statistical Analysis of the Solo Chant Anechoic waveforms

OVERALL SORTED PERCENTAGE OF TOTAL OCCURRENCES FOR ANECHOIC SOLO CHANTS

BAHIR		IC EZAN		SALA'		MIMBER DUASI		BYZANTINE	
Template	% Total	Template	%Total	Template	%Total	Template	%Total	Template	%Total
G01	10.40	G20	18.14	G20	13.60	G01	9.23	G01	8.54
G02	6.98	G01	10.67	G01	10.91	G02	6.21	G02	7.86
E13	6.51	G02	7.55	G02	6.58	E13	5.71	E13	7.22
G03	6.51	E13	4.95	C08	5.24	G20	4.71	G03	6.54
C08	6.32	C08	4.65	G03	4.46	C08	4.52	E05	5.29
G20	5.89	G04	4.27	G04	4.42	G03	4.46	C08	4.69
G04	4.51	G03	4.19	E13	3.77	G05	4.14	G17	4.58
C04	3.89	C04	3.20	E05	3.55	G04	3.95	E19	3.55
G05	2.90	E05	3.13	G05	3.51	G17	3.70	E29	3.44
E29	2.75	G05	2.67	G06	2.60	C04	3.33	E12	3.39
G17	2.75	E29	2.44	C04	2.56	G07	3.08	G20	3.10
E05	2.66	C03	2.21	E19	2.56	C09	3.01	E06	2.98

C03	2.61	E19	2.06	G17	2.51	E05	2.64	C04	2.92
E12	2.56	G17	2.06	E29	2.12	E20	2.26	G07	2.46
G07	2.52	E12	1.98	E12	1.99	E29	2.13	G05	2.28
E19	2.33	C01	1.91	C01	1.82	E12	2.07	G04	2.03
C01	1.95	E06	1.91	G12	1.65	E06	1.88	G08	1.91
C09	1.90	C09	1.68	E06	1.60	G15	1.88	G15	1.89
E04	1.57	G15	1.60	G16	1.60	G06	1.82	E04	1.85
G15	1.52	G11	1.37	E20	1.47	G11	1.76	C03	1.62
E06	1.47	G14	1.30	G11	1.47	E04	1.69	E11	1.62
G11	1.42	G06	1.14	G15	1.39	G09	1.69	C01	1.48
E20	1.33	G08	1.14	E04	1.34	C03	1.51	C07	1.41
G09	1.33	E02	1.07	G14	1.34	C01	1.44	C09	1.41
G08	1.23	E20	1.07	C09	1.30	E19	1.32	E20	1.32
G16	1.23	G07	1.07	G09	1.21	G08	1.32	G11	1.28
C07	1.19	G09	0.99	C03	1.17	G16	1.32	G12	1.28
E02	1.09	E10	0.91	G07	1.13	E11	1.26	E02	1.18
G12	1.04	E11	0.91	E10	1.08	G14	1.26	G16	1.16
G14	0.90	G16	0.91	E11	1.08	C02	1.19	G09	0.91
G06	0.85	C07	0.84	E02	1.04	E10	1.19	E28	0.89
E11	0.76	E04	0.84	C07	0.95	G12	1.13	E10	0.80
E28	0.71	G12	0.69	G08	0.87	G10	1.07	E32	0.80
E32	0.71	E01	0.46	G10	0.69	E02	1.00	C02	0.77
E33	0.66	E09	0.46	E28	0.61	E09	1.00	G14	0.66
G10	0.66	G13	0.46	E25	0.52	C07	0.88	E33	0.62
G13	0.66	C02	0.38	E32	0.52	C10	0.88	G06	0.62
E10	0.57	E22	0.38	C02	0.39	E03	0.75	E25	0.39
E25	0.47	G10	0.38	E33	0.39	E22	0.63	G10	0.39
E22	0.38	E25	0.30	G13	0.39	E28	0.63	C10	0.36
E01	0.33	E03	0.23	E34	0.35	G19	0.63	E01	0.36
C02	0.28	C05	0.15	C10	0.30	E32	0.56	G13	0.36
E17	0.28	C10	0.15	E09	0.30	E33	0.56	E09	0.27
G19	0.28	E17	0.15	E17	0.30	G13	0.56	E22	0.25
E03	0.24	E28	0.15	E01	0.26	E01	0.31	E17	0.23
C10	0.19	E32	0.15	E03	0.26	E08	0.25	E03	0.18
E09	0.14	E34	0.15	E22	0.26	E34	0.25	E16	0.18
E16	0.14	G19	0.15	C05	0.13	C05	0.19	E08	0.14
E30	0.14	C06	0.08	E16	0.13	E15	0.19	E30	0.14
E34	0.14	E16	0.08	E27	0.09	E17	0.19	C05	0.09
C05	0.05	E24	0.08	G19	0.09	E30	0.19	E34	0.09
E27	0.05	E30	0.08	C06	0.04	E16	0.13	G18	0.09
		E33	0.08	C11	0.04	E25	0.13	G19	0.05
				E08	0.04	G18	0.13	C06	0.02
						C06	0.06	E24	0.02
								E27	0.02

5.4 ?e Statistical Data

5.4.1 Anechoic

Figure 19 shows the Statistical Data for the Anechoic chants. The x-axes shows the value (in ?e (ms)) while the y-axes is divided into six sections, namely: Mean, S.D., 95 %tile, 90 %tile, 10 %tile and 5%tile. The bars are colour coded as (shown in the legend on the right). Thus for example the first bar in each y-axes group is the data for the anechoic Bahir.

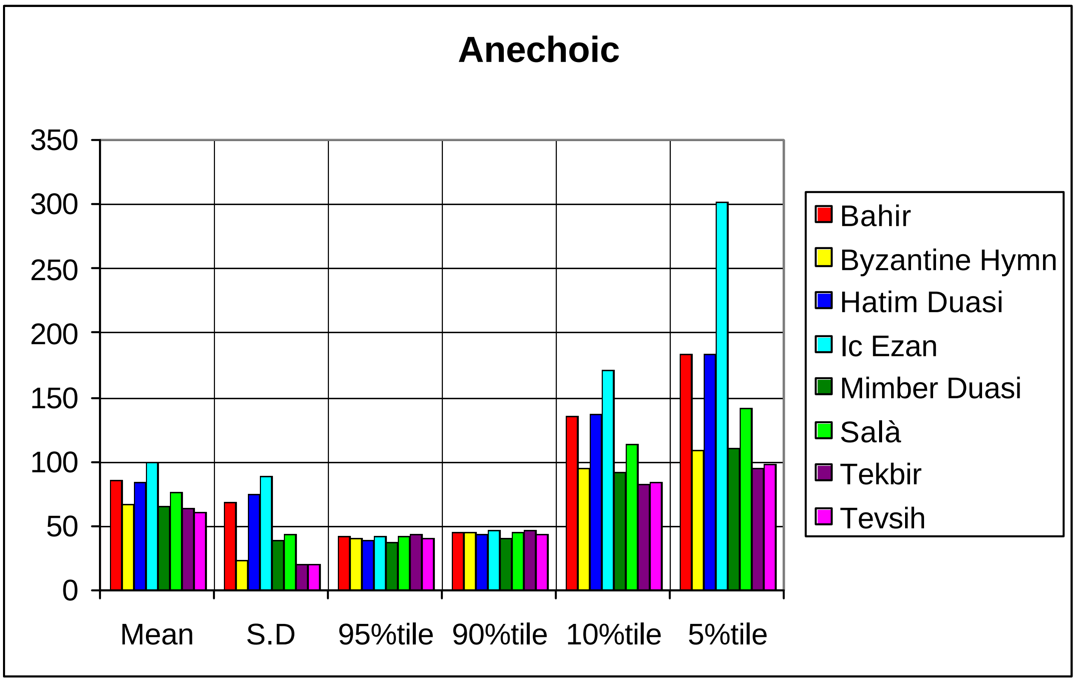


Figure 19 *Statistical Data for the Anechoic Chants*

5.4.2 Synthesised

The following are the results for the Statistical Data for all the Synthesised Chants available. Each chart shows the Statistical Data for the Anechoic version of the chant as well as the Synthesised versions (at the Centre of the Mosque (or Church)) in increasing volume order. Moreover, the x-axes and y-axes are the same as the ones used in Figure 19.

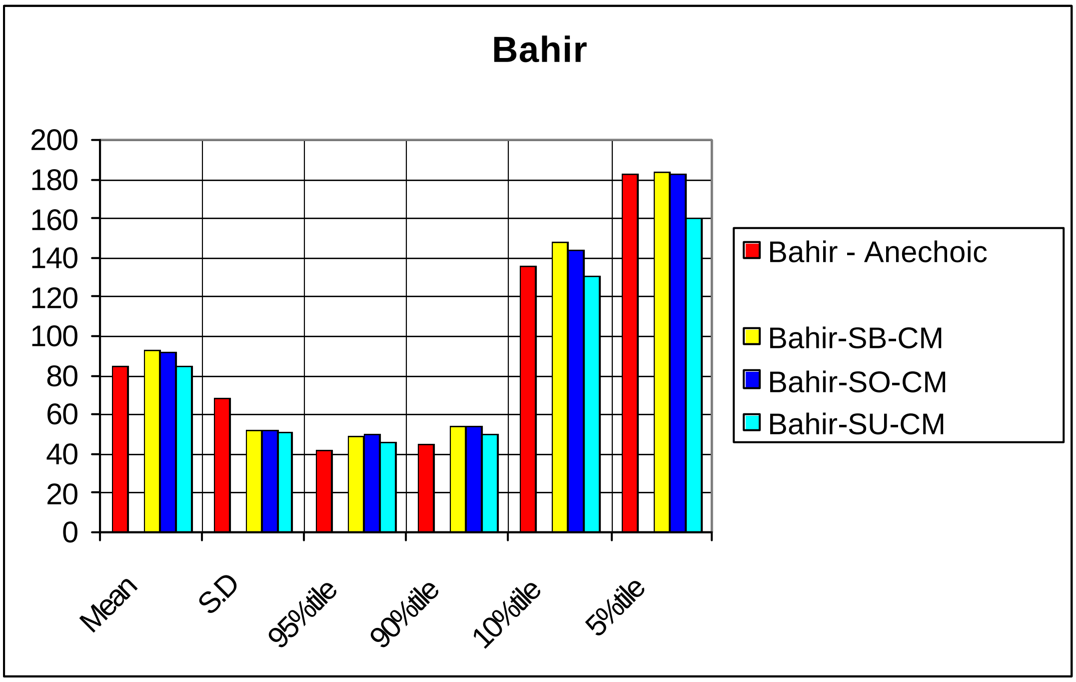


Figure 20 *Statistical Data for the Bahir Chant*

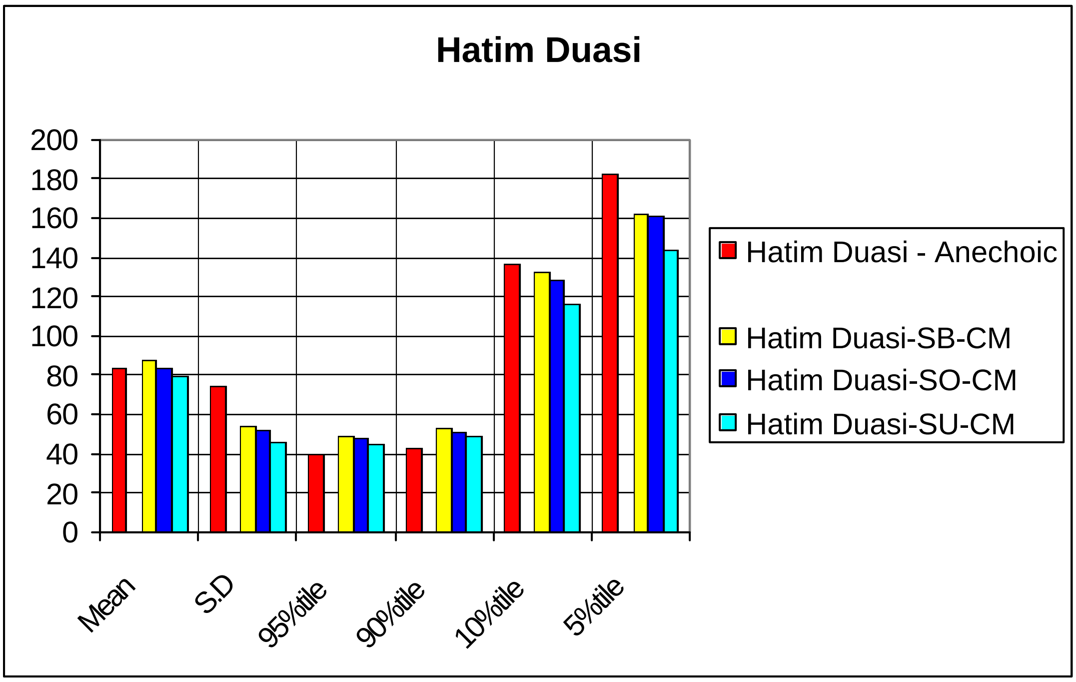


Figure 21 *Statistical Data for the Hatim Duasi Chant*

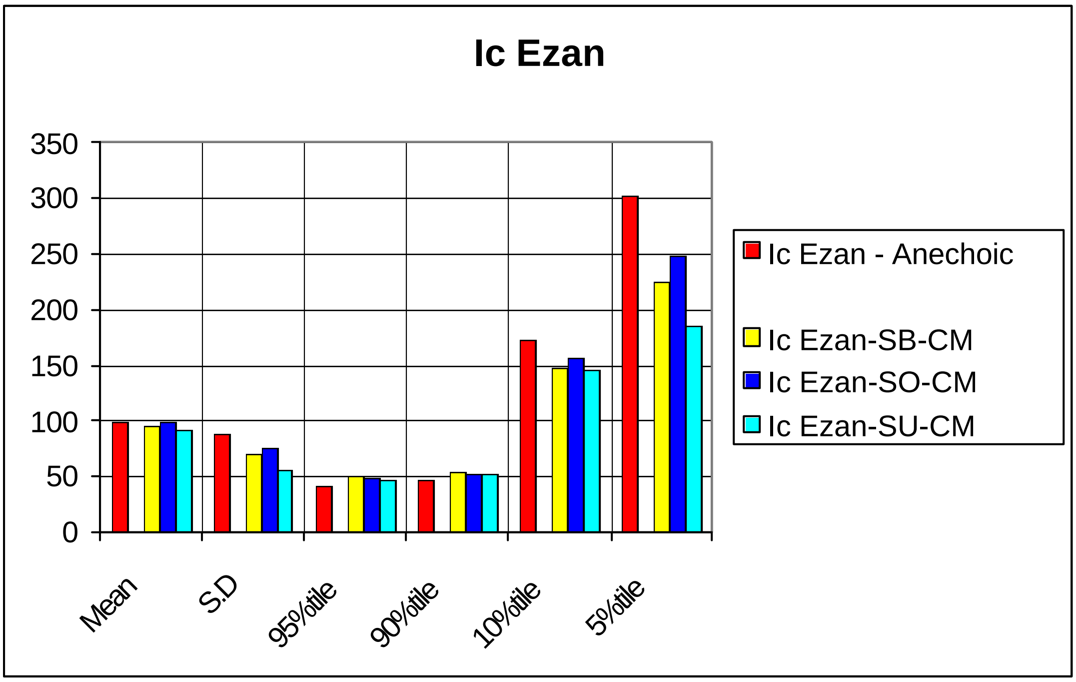


Figure 22 *Statistical Data for the Ic Ezan Chant*

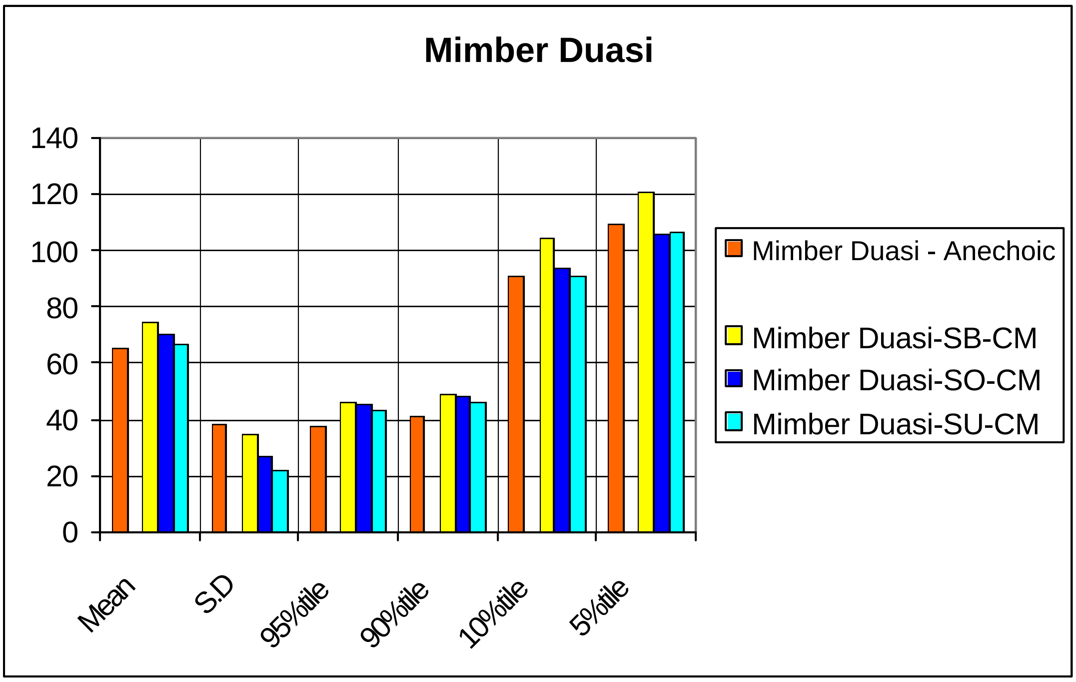


Figure 23 *Statistical Data for the Mimber Duasi Chant*

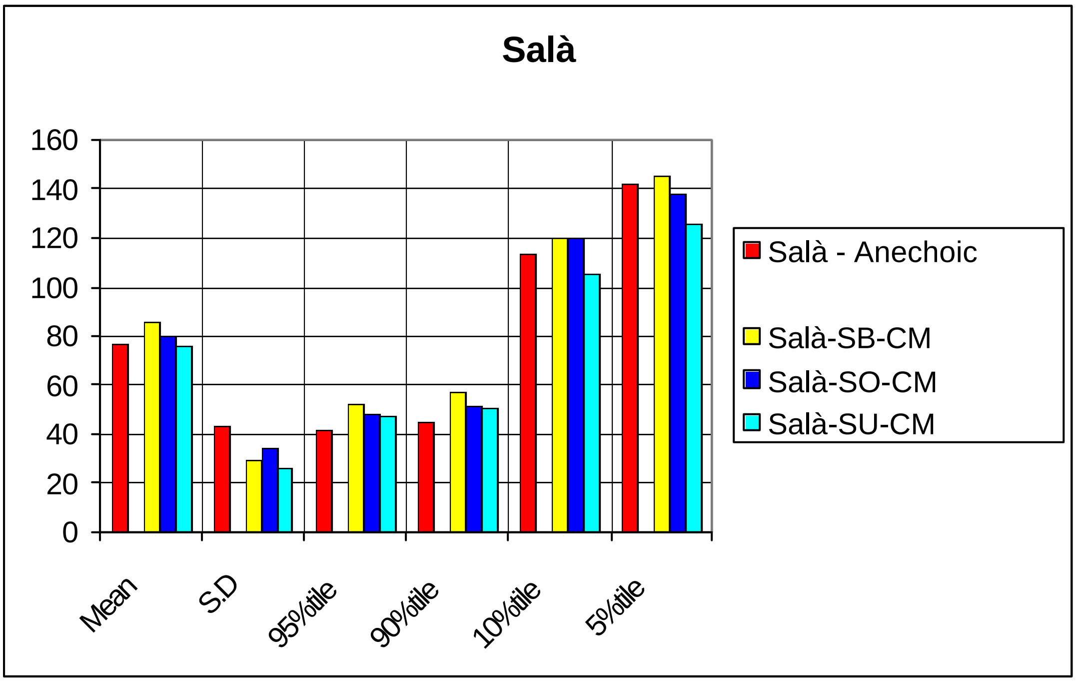


Figure 24 *Statistical Data for the Salà Chant*

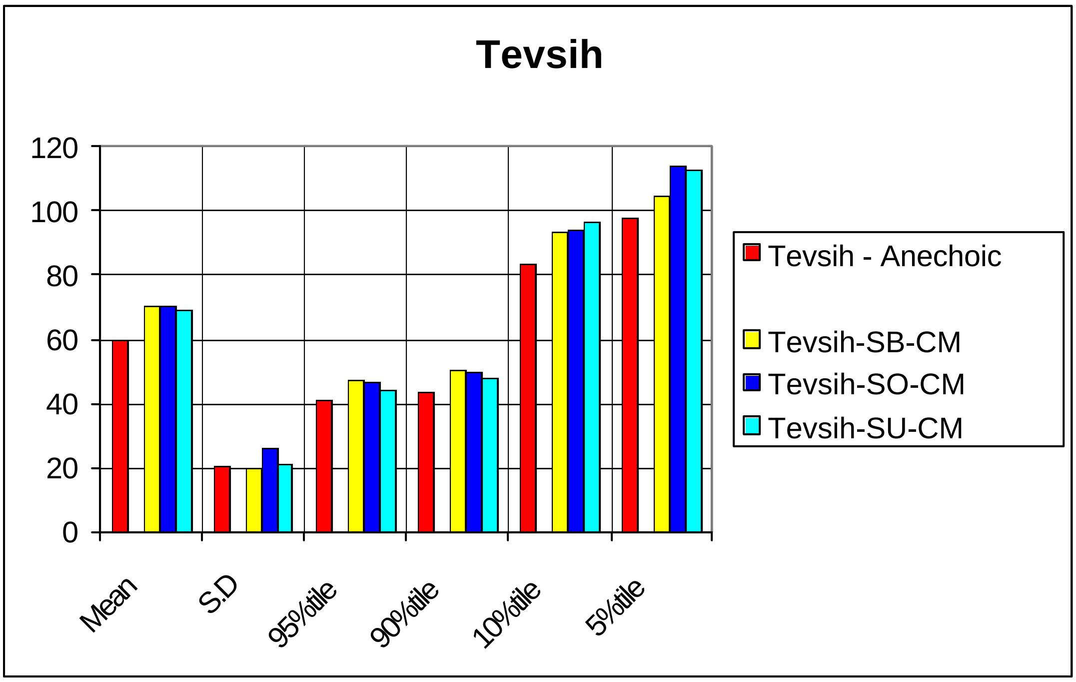


Figure 25 *Statistical Data for the Tevsih Chant*

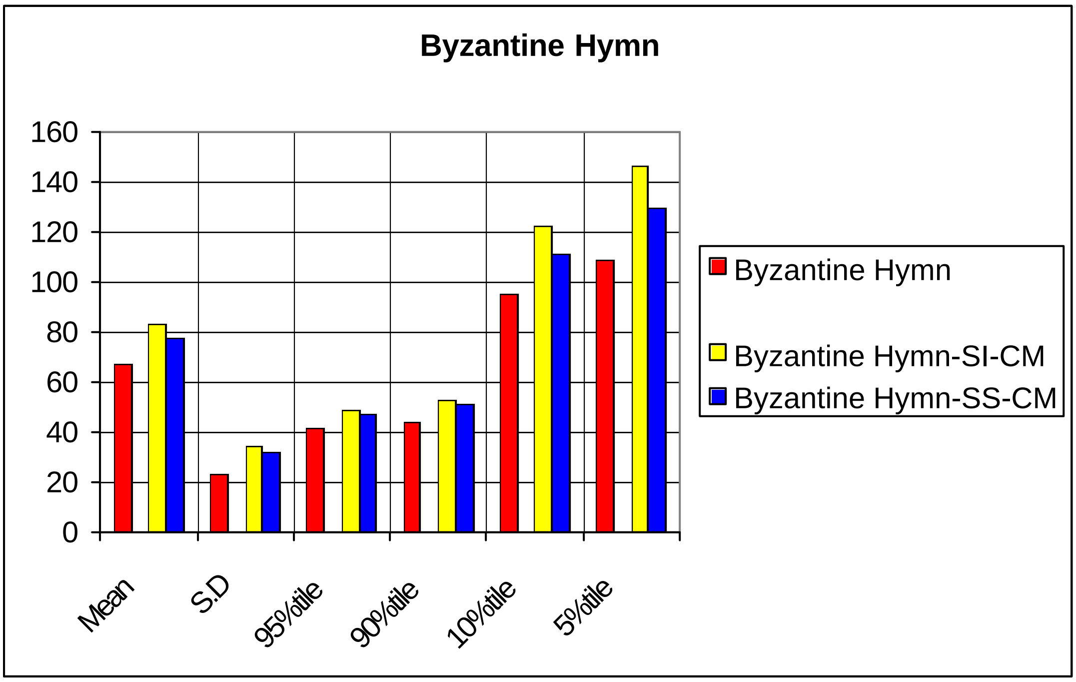
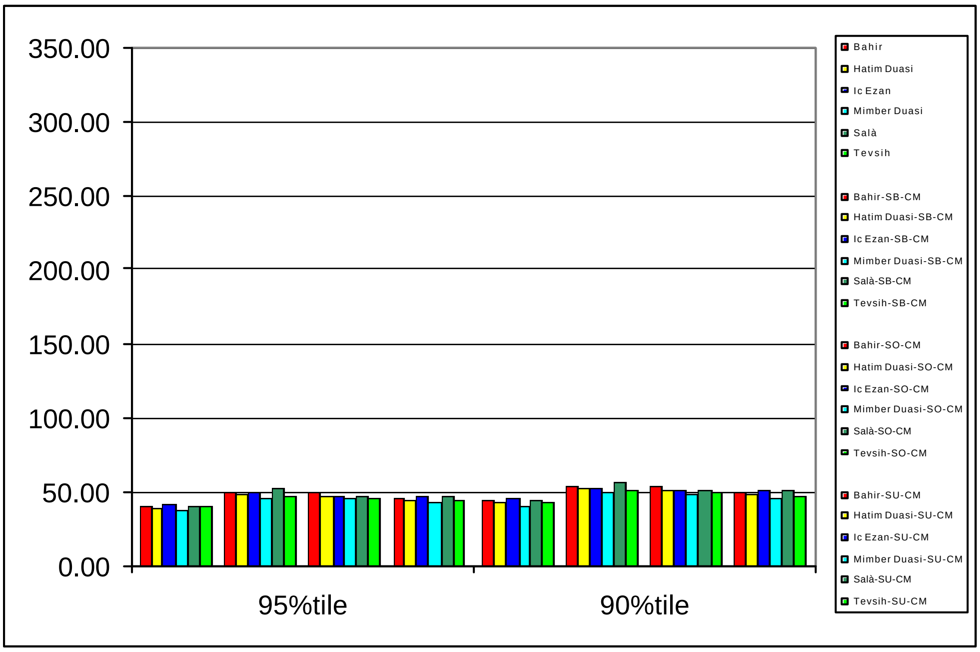


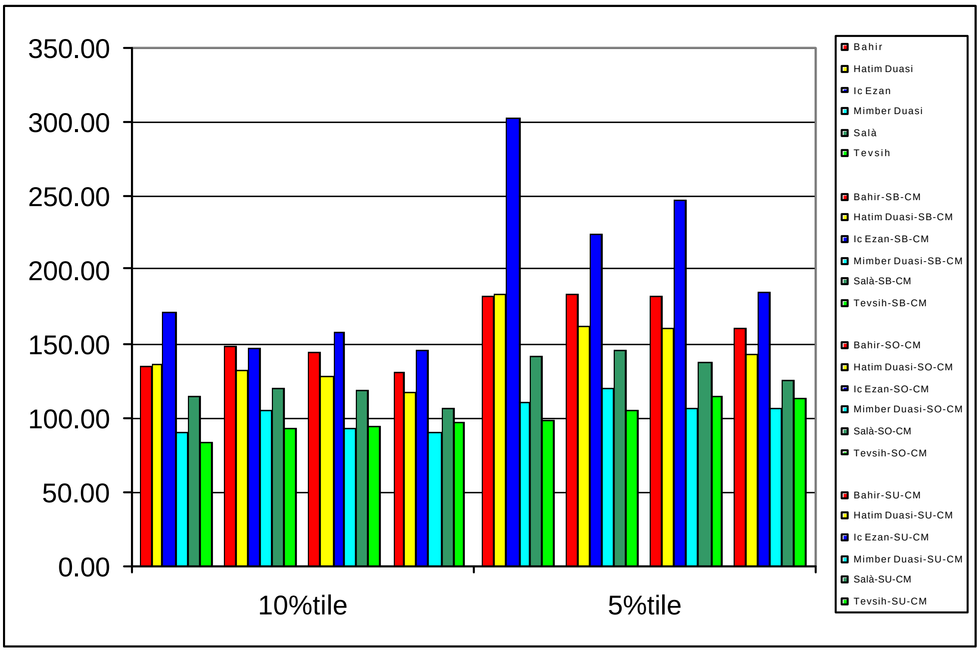
Figure 26 *Statistical Data for the Byzantine Hymn*

Appendix section 5.5 illustrates the data for the lower (95 and 90) and higher (10 and 5) percentiles for all the anechoic and synthesised (at the centre of Mosque) chants grouped together.

The Statistical Data for the chants systemised using other receiver positions is included in the CD.

5.5 Lower and Higher Percentile Statistical Data





5.6 Percentile Analyses Figures

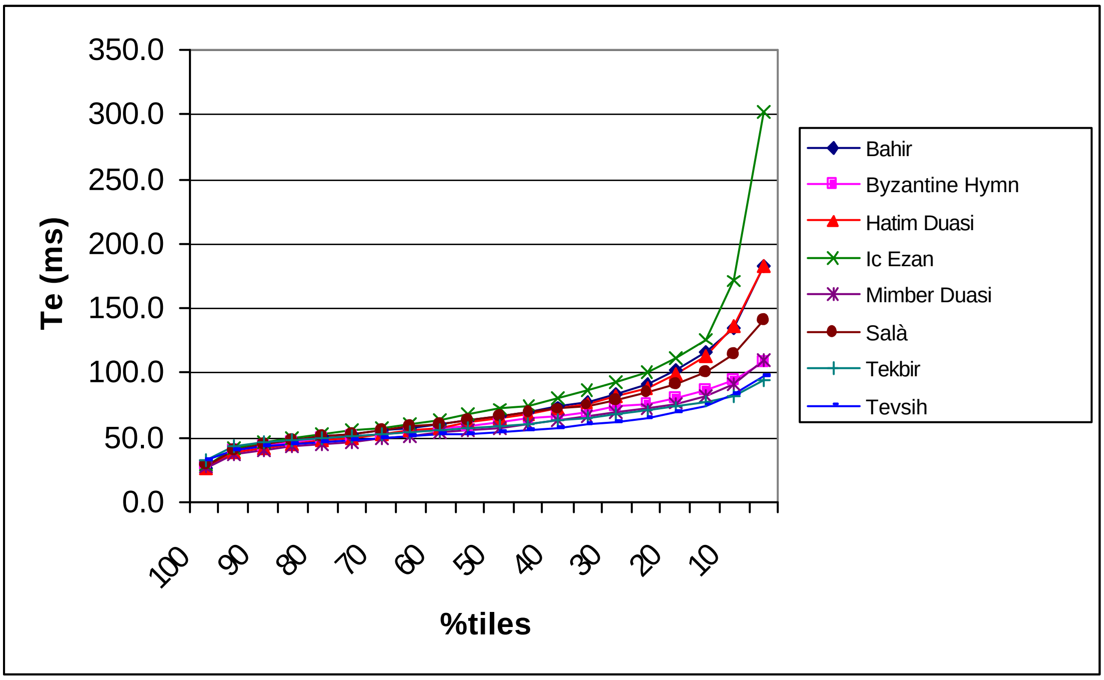


Figure 27 *Percentile Graph for the anechoic chants*

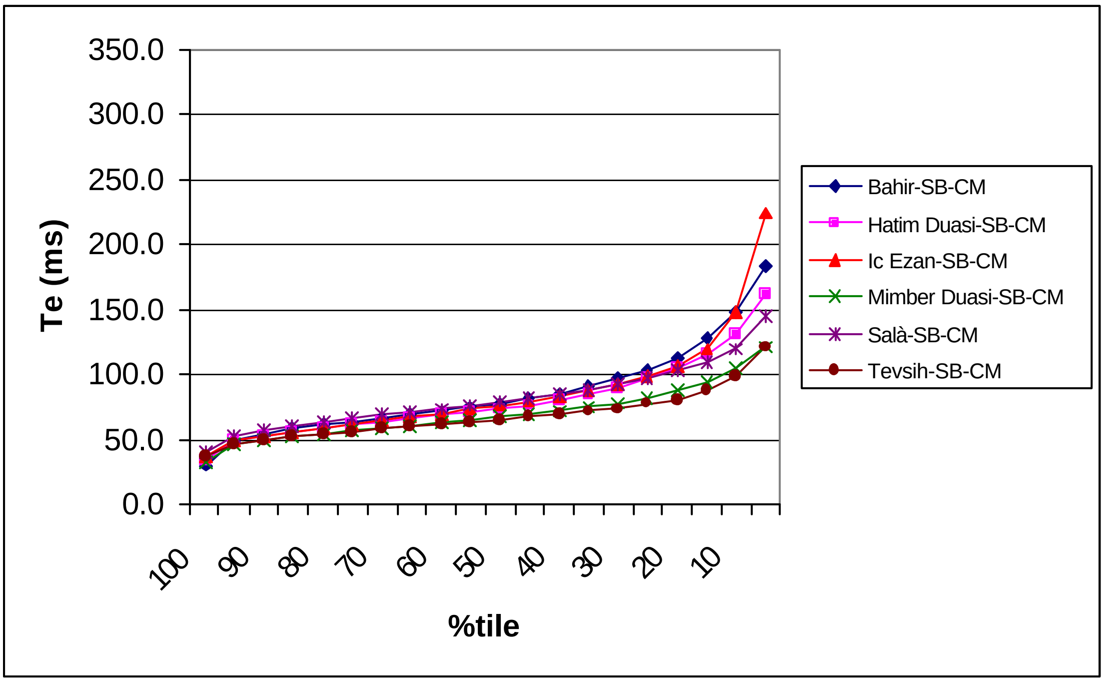


Figure 28 *Percentile Graph for the chants synthesised at Sergius Bacchus and St. Irene*

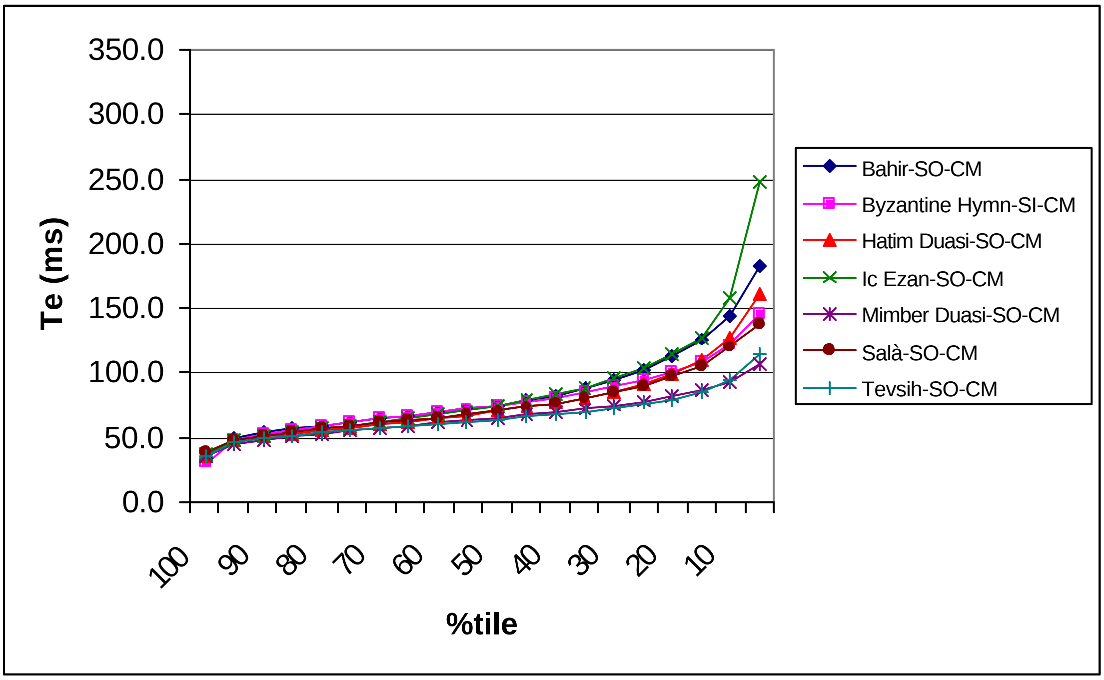


Figure 29 *Percentile Graph for the chants synthesised at Sokullu*

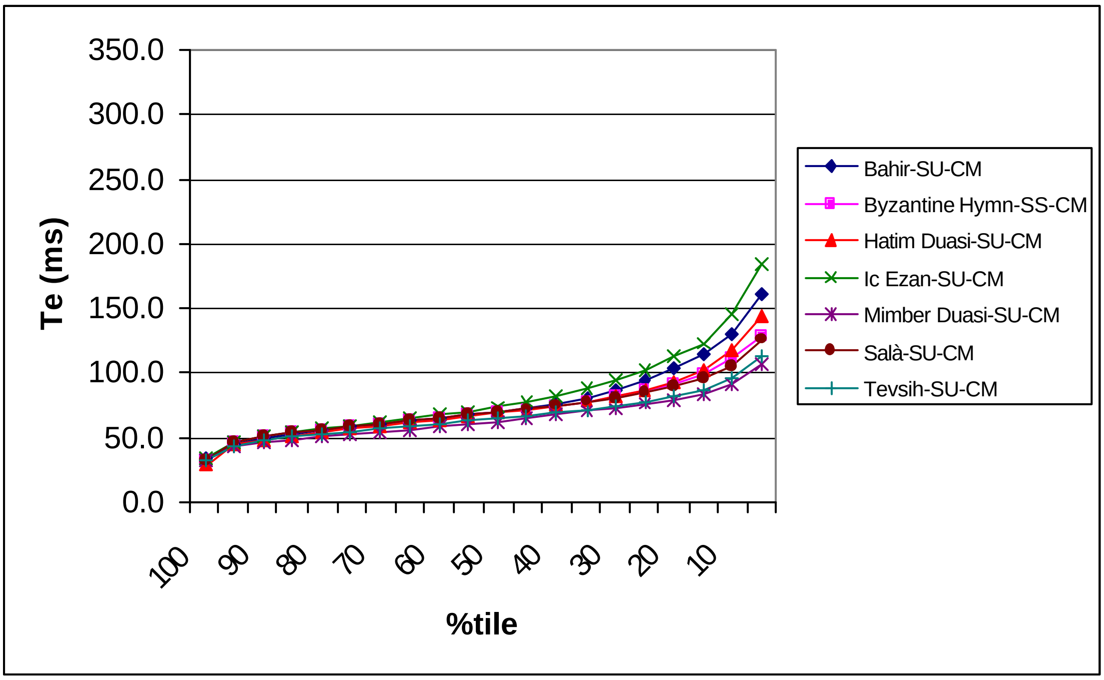


Figure 30 *Percentile Graph for the chants synthesised at Süleymaniye and St. Sophie*

5.7 CD

The CD has at the root this document and a contents file. The general structure consists of two main directories named Intonation and Te, with various subdirectories as explained in the contents file on the CD.