ANALYSIS OF TURKISH ART MUSIC SONGS VIA FRACTAL DIMENSION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ABDURRAHMAN TARİKCİ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
PHYSICS

FEBRUARY 2010

Approval of the thesis:

ANALYSIS OF TURKISH ART MUSIC SONGS VIA FRACTAL DIMENSION

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ABSTRACT

ANALYSIS OF TURKISH ART MUSIC SONGS VIA FRACTAL DIMENSION

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February 2010, 88 pages

Forty songs are randomly selected from four randomly selected maqams. Songs are restricted to be in sofyan usül (sofyan rhythmic form) to check the statistical significance. Next, fractal dimensions of the these songs are calculated by using two different method and two different scattering diagrams. In the first method, fractal dimensions are calculated via two different box sizes. As for second method, successively decreased box sizes are used. In addition, standard deviation and mean values of the fractal dimensions are calculated to check the relation between fractal dimension and maqam. T test and F test are applied to check the statistical significance. After these calculations, it is verified that fractal dimension can be used as an information source concerning the Turkish art music songs which are nonlinear dynamical systems. Moreover, it is showed that maqams can have their own fractal dimension for low resolutions. On the other hand, it is seen that for high resolutions all songs have almost same fractal dimension.

Keywords: Turkish Art Music, Fractal Dimension, Maqam, Usül, F test, T test

ÖZ

TÜRK SANAT MÜZİĞİ ŞARKILARININ FRAKTAL BOYUT İLE ANALİZİ

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Şubat 2010, 88 sayfa

Rastgele seçilmiş dört makamdan kırk Türk sanat müziği şarkısı rastgele seçildi. İstatiktiksel anlamlılığı kontrol etmek için şarkılar sofyan usulünde olanlarla sınırlandı. Daha sonra, bu şarkıların fraktal boyutları iki farklı yöntem ve iki farklı saçılma diyagramı kullanılarak hesaplandı. Birinci yöntemde, şarkıların fraktal boyutları iki farklı kutu büyüklüğü kullanılarak hesaplandı. İkinci yöntemde ise art arda küçülen kutu büyüklükleri kullanılmıştır. Ek olarak, fraktal boyutların standart sapma ve ortalama değerleri, fraktal boyut ile makam arasındaki ilişkiyi kontrol etmek için hesaplandı. Bu hesaplamalar sonrasında fraktal boyutun doğrusal olmayan dinamik sistemler olan Türk sanat müziği şarkıları hakkında bir bilgi kaynağı olabileceği doğrulandı. Ayrıca, düşük çözünürlüklerde her makamın kendine ait fraktal boyutu olabileceği gösterildi. Diğer taraftan, düşük çözünürlüklerde bütün şarkıların yaklaşık aynı fraktal boyuta sahip olduğu görüldü.

Anahtar Kelimeler: Türk Sanat Müziği, Fraktal Boyut, Makam, Usül, F testi, T testi

To my wife and parents

ACKNOWLEDGMENTS

I would like to thank my supervisor Prof. Dr. Ramazan Sever for his deserving support and guidance throughout the whole study. Also, I am profoundly indebted to Prof. Dr. Namık Kemal Pak and Prof. Dr. Atalay Karasu who were very generous with their time and knowledge and assisted me to complete this thesis. Special thanks reserved to my friends, Dr. Cenk Güray, Bilge Bakın, Yaprak Güleç Öğütcü, Özgür Kara, Filiz Ece Sağcan, Can Şahiner, Elif Turhan Özdemir, and Erman Togay.

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CHAPTER 1

INTRODUCTION

Anatolian traditional music is one of the untouched subjects by means of scientific tools. This broad subject can be analyzed from different perspectives. From musician's point of view, musicological perspective, theoretical perspective, compositional perspective, and similar ones are important. On the other hand, from scientist's point of view, perception, acoustics, dynamic systems approaches, and probabilistic approaches, are some possible avenues of research. Studies on music via scientific tools is one of the branches that have been growing in recent years. In fact, until the 17th century music was treated as a mathematic discipline [1].

First part of studies that uses scientific tools for musical analysis and creation is composition by using formalizable methods – algorithmic composition–[2]. In his book of *formalized music* I. Xenakis [3] states that music is defined as the organization of the elementary operations (such as union, intersection) between the sonic entities or between the functions of sonic entities. It is also underlined that order of sonic entities is lexicographic. Similarly, compositions using Markov models is another significant category in algorithmic composition. These compositions have started with the researches of H. F. Olson [4]. Some other examples can be found in [5,6,7,8]. In addition, generative grammars, transition networks (TN), genetic algorithms, cellular automata, and some similar tools are used for algorithmic composition [8,9,10,11,12,13,14,15,16,17,18].

Second part of studies that uses scientific tools for musical analysis and creation is based on cognition of the music, namely; auditory cognition, perception of rhythm, melody, and harmony. J. J. Bharucha and W. E. Menel [19] discussed two problems, which are self-organization of octave categories and pitch invariant pattern recognition. Similarly in the paper of N. P. M. Todd, D. J. O'Boyle and C. S. Lee, [20] a sensory-motor theory of rhythm, time perception and beat induction are developed. Later, E. Bigand and R. Parncutt [21] worked on perception of musical tension in long chord sequences by means of their experimental work. In that study, they try to predict perceived musical tension in long chord sequences by hierarchic and sequential models based on Lerdahl and Jackendoff's cognitive theories and Parncutt's sensory-psychoacoustical theory. As a main outcome, they found that musical events were perceived through a short perceptual window sliding from cadence to cadence along a sequence. Next, D. Povel and E. Jansen [22] worked on perceptual mechanisms in music processing. They worked on the cases in western tonal system in an experimental way. Another paper that can be included in the category of cognition of music was that of E. W. Large [23]. In that paper Large describes an approach to metrical structure focusing on its role as an active listening strategy. Additionally, it is stated that metrical structure is a self organized dynamic structure composed of self sustaining oscillations. Moreover, the emergence of this structural representation is modeled as a pattern formation process whose neural correlate is the formation of a spatiotemporal pattern of neural activity. Afterward, J. Pressing [24] states the computational and transcultural foundations of Black Atlantic rhythm. The Black Atlantic rhythmic features are mostly seen in western non-classical music like jazz, blues, reggae etc. Pressing states these rhythmic features by using them both in transcultural and perceptional ways. Similarly, J. London [25] presents a discussion on various studies on rhythmic perception and performance.

Another important branch which is one of the basic concepts of the thesis is chaos and dynamical systems. Chaos is an ancient word that means lack of order or form. Technically, it generally describes irregular and unpredictable nonlinear systems [26]. There are many researches that work on music via tools of chaos. J. P. Boon and O. Decroly [27] classified the western classical music by using *theory for music dynamics.* They considered music as a dynamical system since there is both vertical motion by means of harmony and horizontal motion by means of counterpoints. Later, D. S. Dabby [28] set the musical variations between the different styles by means of chaotic mapping. The technique is based on the idea that the change of the initial conditions changes the pitch sequences of the songs. To do this, musical pitch sequences are paired with the x-components of the Lorenz chaotic trajectory. Afterwards, another development was on the perception of the pitch of the complex sound by J. H. E. Cartwright, D. L. Gonzalez and O. Piro [29]. They applied the results from nonlinear dynamics to an old problem in acoustical physics: the mechanism of the perception of the pitch of sounds, especially the sounds known as complex tones.

In addition to the these works described above, chaos is also used in the algorithmic composition. J. Pressing [30] uses discrete nonlinear maps as a compositional tool. In this study, sound is generated by computer which determines its pitch, duration, and dynamics of it. In this process discrete nonlinear maps is the main tool of algorithm. Similarly, R. Bidlack [31] uses chaotic systems as a note generator. In this study, chaos is employed as a selector of pitch, rhythm or similar musical functions for composition. Later, there are J. Leach and J. Fitch used orbit of chaotic systems in their work on algorithmic composition [32]. Other researches on algorithmic composition using Genetic Algorithm and Chua's oscillator are given in [33,34].

Another method, which is used for quantitative analysis of music, is using fractals. In fact, fractal dimension is one of the main tools for this thesis. Historically, the use of the fractal geometry starts with the work of Hsü and Hsü [1]. In that work, some Bach songs have been investigated by using fractal geometry. They have concluded that the analogy between the frequency ratios of the notes and fractal dimension gives some information about the investigated songs. Later, M. Bigerelle and A. Iost [35] did the classification of the music by using fractal dimension. First they set the fractal dimensions of some songs by using the analysis of variance method. Then results of fractal dimension calculations were used for discrimination of genre of music. Similarly, Z. Su and T. Wu [36] studied the fractal property of music by multifractal analysis. They described the music by set of points which is the transformation of the rhythm and melody. After that, they calculated the local Hölder exponent and the multifractal spectrum for the transformed music sequences according to the multifractal formalism. As a conclusion, it was found out that the shape and opening width of the multifractal spectrum plot can be used for distinguishing different styles of music. Z. Su and T. Wu in another study, converted songs to the one-variable music random walks (music walks)[37]. After the conversion, quantitative analysis of the music walk showed that it has similar features with the fractal Brownian motion (fBm).

Similar to the other tools of chaos, specifically, fractals is also used in the algorithmic composition. Firstly, these studies are based on selecting the pitches according to fractal objects. Secondly, the iterative processes of fractals used these compositions. Thirdly, self similarity of the fractals is used as an idea creator for compositions. Some examples of compositions using fractals can be found in [38,39,40].

Recently, G. Gündüz and U. Gündüz [41] worked on mathematical structure analysis of six Anatolian traditional music songs which constitutes the starting point of the thesis. In this work, analysis is based on (*i*) scattering diagram, (*ii*) spiral structure, (*iii*) graph theory and animal diagrams, and (*iv*) entropy and organization. In the first base, fractal dimensions and radius of gyration of each song are calculated and compared. The scattering diagrams are constructed by using note to next note distribution graphs.

In this thesis, analysis of the fractal dimensions of 40 songs is done by using their scattering diagrams, and some comparisons are made. To check statistical significance, songs are restricted to be in sofyan usul (sofyan rhythmic form) and selected randomly from four randomly chosen maqams (Acemaşiran, Mahur, Kürdi, and Hüzzam). Scattering diagrams are constructed in two ways including duration and without including duration. Different from the method used in [41], notes are placed in diagrams according to Turkish art music sound system. In order to be clear in presentation of the choice of the Turkish art music sound system, basics of Turkish art music and some historical concepts are covered. Moreover, fractal dimensions of songs are re–calculated by using more a complicated and accurate method compared to the study of G. Gündüz and U. Gündüz. By using results of these fractal dimension calculations, it is checked whether these songs have fractal properties or not. In addition, it is controlled whether each maqam has its own fractal properties or not. Next, statistical significance of the results is also checked via T test and F test. These calculations showed that selected songs show fractal properties. However, all of the songs have almost same fractal dimension when the resolution used for computing fractal dimension is reduced. Similarly, for low resolution there are differences between the fractal properties of the maqams. On the other hand, for high resolution, these differences disappeared.

The organization of the thesis are as follows: In chapter 2, some necessary basic concepts of the Turkish Art Music (TAM) are given. In chapter 3, scales in western music and Turkish music can be found. In chapter 4, fractal geometry and fractal dimension are introduced. Furthermore, methods used for the calculation of fractal dimension are presented. Tools used to check the statistical significance of the results are also included in chapter 4. In chapter 5, results are given; and finally, in the last chapter, discussion of the results is presented.

CHAPTER 2

TURKISH ART MUSIC

Traditional Anatolian music can be divided into two main categories. They are called Turkish folk music (TFM) Turkish art music (TAM). Sometimes, instead of art music, the term *classical music* is used [42]. In this thesis, Turkish art music genre is selected because of its larger number of academic sources compared to Turkish folk music.

Turkish art music is very rich in melodic and rhythmic structure. Also, this genre has deep historical roots. In fact, there are thousands of pieces in this genre. Moreover, it is possible to state that repertoire of art music stretches back at least to the sixteenth century [43].

Similar to the other branches of art, dividing the music into genres is very problematic. Therefore, determining which piece is in classical music is not easy. Hence, the question of which properties should exist in the art music arises. If European music is taken into account, the term art or classical can have the following properties as listed in [43]:

- enduring
- balanced, restrained
- notated
- theorized about
- serious
- professional

- passively received
- non-folk
- elite

K. Signell states that these nine items exist in Turkish art music [43].

As for history of Turkish art music, it can be divided into two parts: Art music in Ottoman Empire and Turkish Republic. Before the foundation of the Turkish Republic, evolution of Turkish art music had mostly taken place in İstanbul, the capital city of the Ottoman Empire. Musicians of that genre are supported by the Ottoman Sultans [45]. Although there were some compositions before, it can be stated that establishment of the original music tradition had been done in the sixteenth century [46]. In addition, compositions that can be included in the independent repertoire of the Turkish art music started to be built in the sixteenth century.

Different from the other cultural branches of the Ottomans, teaching and learning in music and transmission of this culture hade been done orally. The process of oral teaching is called *meşk* and had taken place in *meşkhane*s [47]. In this process, teaching of the new songs, techniques of playing and singing, practicing, and performance was included.

After the foundation of the Turkish Republic, some reforms on Turkish music were also carried out. These reforms based on the *imposed synthesis* idea of ideologue Ziya Gökalp. Gökalp divided Turkish music into three categories: Eastern, western, and folk. He described the eastern music as the music of the elite pre-Republican era; which takes its roots from the Byzantine. He supported this idea by showing some analogies from ancient Greek music. However, according to Gökalp, music of civil western have taken its form by correcting the mistakes of the Greek music. He also described the eastern music as depressingly monotonous, artificial and ill. On the other hand, he claims that, folk music is the national music of the Turks, and civilization of Turkish music can be done by using the folk songs which should be re-arranged by western music tools. Thus, the eastern music of Turks which mostly refers to the art music should be discarded [48].

There have been various developments based on this policy. For example, The Palace Symphony Orchestra (Saray Senfoni Orkestrası) was replaced with Presidential Music Band (Riyaseti Cumhur Orkestrası); schools based on the eastern music closed down, new ones, whose curriculum was based on the western music had been established in 1927. In 1926, places for religious rituals called, *tekke*, was closed which caused the development and the performance of the tekke music to slow down. This list can be expanded. Detailed information and some critics on music reform of Turkey can be found in [49].

On the other hand, there are very important works on Turkish art music both in the last period of the Ottoman Empire and in the period of Turkish Republic. Some of the works have maintained their effect up to present. For example, the work of H. S. Arel is still one of the most frequently applied theoretical models for Turkish art music [50], although the sound system that he suggested is controversial [51,52,53,54] which will be covered in the coming sections.

2.1 Maqam

Turkish art music is a kind of modal music and these modes are called *maqam*. In fact, the word maqam not only corresponds to the musical scales or modes in TAM, but also, it covers a very large and multicultural area [55,56,57]. The word maqam has different pronunciations in different geographical regions. For example, in Turkey *makam*, in Azerbaijan *mugam*, in Uzbekistan *shash-maqom*, in Iran *dastgah*, and in the Arab world *maqam* is used [55].

There are some different approaches to the definition of maqam. Suphi Ezgi [58] defines maqam as the performance of the melodies called as *durak* or *karar* (similar to the *tonic* note in western music, will be explained in details below) and *güçlü* (analog of the *dominant*, will be explained in details below) with the other pitches of the sequence of that maqam according to the relations in mind. He also states that durak and güçlü are the most important notes of the maqams and they attract the other notes to the themselves. Moreover, Ezgi categorizes maqams into two: Maqams with tone levels moving upwards, and maqams with tone levels moving downwards. He also states that maqam has a beginning, seyir (melodic direction), and karar.

The second work on definition of maqam is done by R. Yekta [59]. He states that maqam is the most important part of the Turkish art music theory because of its effect on human emotions. In fact, he defines maqam as style of becoming, the special shape of the musical intervals and ratios. In his point of view, necessary conditions to compose a maqam is listed as given below:

- Factors of formation: Pentachords and tetrachords to form maqam.
- *Ambitus* - Wideness: It is corresponds to the pitches from low to high which are used to construct maqam.
- Beginning: Description of the beginning of the song for each maqam.
- Güçlü: In general, it is the perfect fifth of the karar note of the maqam.
- Karar: Specific note of the maqam.
- Seyir, and tam karar: Characteristic melodic movements of the maqams are called seyir, specific form of seyir which causes the feelings of relaxation called tam karar (which is similar to the cadence).

Thirdly, description of maqam based on the thoughts of K. Uz [60] can be covered. His definition of maqam is based on seyir. He states that one or more types of melodic movements (seyir) are necessary and sufficient conditions for describing maqam.

Perspective of C. Behar [61] to the Turkish art music is different from the ones described above. He thinks that the maqam gives freedom to the composer, in contrast to the general understanding. He also states that maqam is a field for the composers, and that field is unlimited and widens continuously. C. Behar also states that definition of maqam is not a pitch sequence. He defines maqam as the type of melodic movements which can use the pitches, and those pithces do not have to be in the sequence of the maqam. According to him, maqam is defined and characterized by seyir (melodic movements), pitch sequence formed by this seyir, and little melodical sentences.

Although there is no agreement in the definition of the maqam and the sound system, in this work the Arel-Ezgi system will be used since it is the contemporary prevailing system in Turkish conservatories [57] and in literature [62]. As mentioned before, sound system is important for this thesis, since it is used for the description of the melodic movements of the songs.

In this manner, we define Turkish art music as a kind of modal music and these modes are called maqam. In addition to scaling of the pitches by specific combinations of tetrachords (dörtlü) and pentachords (beşli), melodic direction and order of the melodic phrases, called as *seyir* (path), are important, and well-defined in maqams [62].

Maqams can be divided into three types:

- Simple,
- Transposed,
- Combinatory,

A simple maqam has the following properties:

- It has to be a combination of one tetrachord and one pentachord or vice a versa,
- Perfect tetrachord and pentachord have to be used
- Güçlü note (will be explained below) should be at the connection of the tetrachord and pentachord
- It should be an eight note sequence, and that sequence has to show all the properties of the maqam.

As for transposed maqam, it is obtained by simple transposition as in western music. However, sometimes transposition of maqam to all notes in Turkish art music is not possible, since the pitch system of the Turkish art music does not have symmetric intervals [39]. There are 13 simple maqams in Turkish art music and their names are: Çargah, Buselik, Kürdi, Rast, Uşşak, Neva, Hümayun, Hicaz, Uzzal, Zirgüleli Hicaz, Karcığar, Simple Suz'nak, and Hüseyni. Thirdly, a combinatory maqam is simply a combination of two maqams[63].

In Turkish art music, each degree of the a maqam has special name and function. These names and functions can be listed as below [63]:

- First degree: It is called *durak*, which is the most important note of the maqam. All of the pieces end at this note without any exception.

- Second degree: It has the name *duraküstü* which is important only for some special cases.

- Third degree: It is called *orta perde* or *ortalı perde*. It has an importance for some special cases

- Fourth degree: There are two cases for this degree. If the maqam is composed of tetrachords + pentachords, it is called as *güçlü*, and it is the second most important note in maqam. Otherwise, it has a name *güçlü altı* and has no importance.

- Fifth degree: Similar to the fourth degree, there are two alternatives. If the maqam is composed of pentachords + tetrachords, it is called *güçlü* and it is the second most important note in a maqam. Otherwise, it is called *güçlü üstü* and has no such importance.

- Sixth degree: There is no special name for this degree, and no special role.

- Seventh degree: Its name is *yeden*. When it is used it has an effect such that it pushes the notes to the eighth degree of the sequence which is called as *tiz durak*. However, actual yeden is one octave below the seventh degree.

Different from the western music, in Turkish art music every pitch has a special name. The name of the notes and corresponding western music notes is given in Table 2.1.

In this thesis, randomly chosen four maqams are used. Namely, Kürdi, Acem Aşiran, Hüzzam, and Mahur.

2.1.1 Kürdi Maqam

Kürdi maqam is the first maqam used in this thesis. Furthermore, it is one of the simple maqams. Its karar (or durak) is Dugah pitch. Seyir of the Kürdi maqam is mostly upwards, but sometimes it has the form of upwards-downwards. It is composed of the Kürdi tetrachord in its place (means starting from dügah), and Buselik pentachord

Table 2.1: Pitch Names in Turkish Art Music

Kaba Çargah	do
kaba Nim Hicaz	
Kaba Hicaz	
Kaba Dik Hicaz	
YEGAH	re
Kaba Nim Hisar	
Kaba Hisar	
Kaba Dik Hisar	
HÜSEYNİ AŞİRAN	mi
ACEM AŞİRAN	fa
Dik Acem Aşiran	
Irak	
Geveşt	
Dik Geveşet	
RAST	sol
Nim Zirgüle	
Zirgüle	
Dik Zirgüle	
DÜGAH	la
Kürdi	
Dik Kürdi	
Segah	
BUSELİK	Si
Dik Buselik	
ÇARGAH	do
Nim Hicaz	
Hicaz	
Dik Hicaz	
NEVA	re
Nim Hisar	
Hisar	
Dik Hisar	
HÜSEYNİ	mi
ACEM	fa
Dik Acem	
Eviç	
Mahur	
Dik Mahur	
GERDANİYE	sol
Nim Şehnaz	
Şehnaz	
Dik Şehnaz	
MUHAYYER	la
Sünbüle	
Dik Sünbüle	
Tiz Segah	
Tiz BUSELİK	si
Tiz Dik Buselik	

starting from the pitch neva (Sometimes Kürdi scale is formed from the combination of Kürdi tetrachord in its place and Buselik pentachord in the fourth degree or Kürdi pentachord and Kürdi tetrachord). Güçlü note of Kürdi maqam is the fifth degree, neva at the combination note of the tetrachord and pentachord. Yeden of the maqam is rast, which is at seventh degree of the scale.

Seyir of the Kürdi pieces, in general, starts with güçlü or durak. After some melodic movements at the scale, music sentence is finished at neva pitch. Such music sentence ends are called *asma karar* in Turkish art music. Indeed, asma karar does not show the end of the piece, but it shows the end of the melodic part. After such movements, there can be some new melodies formed at the higher pitches than the tiz durak. At last, the song finishes at the dügah pitch with the Kürdi *çeşni*. Çeşni is composed of short melodies that show the characteristics of the specific maqam [40].

Transposition of Kürdi maqam to some notes is not possible. That is to say, it can not be transposed to kaba dik hicaz (or dik hicaz), kaba dik hisar (or dik hisar), dik acem aşiran (or dik acem), dik geveşt (or dik mahur), dik zirgüle (or dik şehnaz), and dik buselik pitches due to the inappropriateness of the intervals.

In summary, scale of Kürdi maqam is shown in Figure 2.1, sample seyir is shown in Figure 2.2 and sample songs can be found in [64].

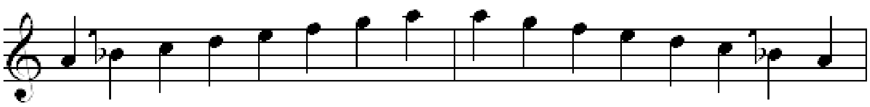


Figure 2.1: Scale of Kürdi Maqam

2.1.2 Acem Aşiran Maqam

The second maqam used in this thesis is Acem Aşiran. It is one of the transposed maqams. Namely, it is the transposition of the Çargah maqam to the acem aşiran pitch. Additionally, it has a downward seyir, and its scale is made from the çargah pentachord at the acem aşiran pitch and çargah tetrachord at the çargah pitch.

Figure 2.2: Seyir of Kürdi Maqam

The first important feature that can be mentioned is that there are two güçlü pitches of the Acem Aşiran maqam. The first order güçlü is tiz durak acem pitch which is used with the çargah çeşni. In general, çargah çeşni ends with half karar at acem pitch. Second order güçlü is the çargah pitch as expected since it is the connection note of the tetrachord and pentachord. Its usage is similar to the first order güçlü. In other words, it uses the çargah çeşni with asma karar at çargah.

Another important feature of the Acem Aşiran maqam can be noted by using the equality of the Acem Aşiran scale and Fa major scale. This property gives the chance to do modulation to the Re minor scale which is equal to the Buselik scale transposed to the pitch neva. Thus, neva becomes an asma karar pitch and nim hicaz pitch becomes yeden of it. In addition, if there is no modulation in maqam, or in general, the yeden of the maqam is hüseyni aşiran pitch.

Generally, seyir of the Acem Aşiran maqam starts with tiz durak acem pitch because of the downward character of the pitch sequence. To construct melodies in this high-pitched region, çargah pentachord is modulated to the acem pitch. After that, seyir progresses with the use of second order güçlü as mentioned above. Next to these melodic phrases, some other movements at the scale can be done and melody goes to the kaba çargah. Finally, seyir finishes at acem aşiran pitch via çargah çeşni.

Briefly, scale of Acem Aşiran maqam is shown in Figure 2.3, sample melody to show seyir given in Figure 2.4 and sample songs can be found in [64].

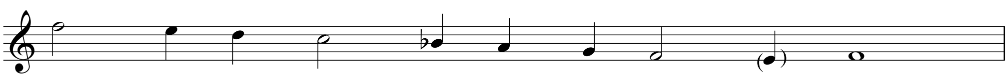


Figure 2.3: Scale of Acem Aşiran Maqam

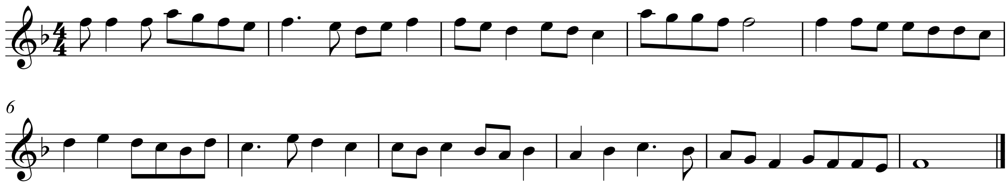


Figure 2.4: Seyir of Acem Aşiran Maqam

2.1.3 Hüzzam Maqam

The third maqam included in this thesis is the Hüzzam maqam which has a durak at segah. Moreover, it is made from the combination of hüzzam pentachord in its place and hicaz tetrachord at eviç pitch. Güçlü of the maqam is neva pitch.

Differently, all of çeşnis that compose the Hüzzam maqam have their own asma karar. From high to low pitches, that situation can be shown as follows:

- Gerdaniye pitch with buselik çeşni,
- Eviç pitch with hicaz or segah çeşni,
- Dik hisar pitch with nikriz çeşni,
- Neva pitch with uşşak çeşni,
- Çargah pitch with nikriz çeşni,
- Rast pitch with rast çeşni,
- Dugah pitch with uşşak çeşni,

- Segah pitch with segah çeşni,

As far as seyir of the Hüzzam maqam is concerned, it starts either with güçlü or durak pitch. After some melodies using some çeşnis with asma karar at neva, seyir finishes at segah with hüzzam pentachord.

As a summary, scale of Hüzzam maqam is shown in Figure 2.5, sample seyir is shown in Figure 2.6 and sample songs can be found in [64].

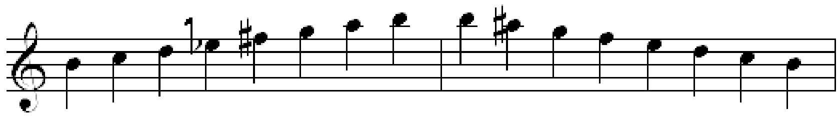


Figure 2.5: Scale of Hüzzam Maqam

Figure 2.6: Seyir of Hüzzam Maqam

2.1.4 Mahur Maqam

The last maqam used in this thesis is Mahur maqam which is transposition of the Çargah maqam to the rast pitch with downward scale. That is, it is the composition of çargah pentachord at rast pitch and çargah tetrachord at neva pitch. Its yeden is geveşt pitch.

Because the Mahur maqam has a downward scale, its first order güçlü is gerdaniye pitch. Second order güçlü of the Mahur maqam is neva. In fact, neva is at the connection of the tetrachord and pentachord.

Another property of the Mahur maqam comes from the fact that the mahur scale is just the same as the Sol major scale of the western music. Due to this similarity, it is possible to make modulations to the Do major which corresponds to Çargah maqam. When this modulation is done, çargah pitch becomes asma karar. In addition to modulation to Çargah maqam, due to the same reason, it is possible to make modulation to Mi minor which corresponds to Buselik maqam at the hüseyni pitch which uses hüseyni pitch as asma karar.

Next important feature of Mahur maqam that should be mentioned is seyir which starts with tiz durak gerdaniye pitch. After ending at asma karar with çargah çeşni, melody goes downwards and makes asma karar at neva pitch. Finally, seyir ends at rast pitch with çargah çeşni.

In short, scale of Mahur maqam is shown in Figure 2.7, sample seyir is shown in Figure 2.8 and sample songs can be found in [64].

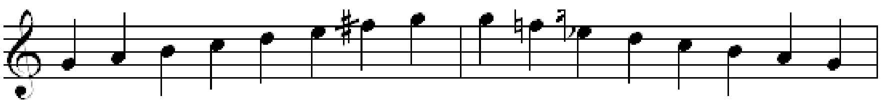


Figure 2.7: Scale of Mahur Maqam

2.2 Usul

Usul composes the rhythmic form of the Turkish art music. It can be defined as the combination of forced, half–forced and weak beats which do not have to have the same duration. It should be noted that all of the songs in Turkish art music have an usul, and there can be more than one usul for a song, however, at any time of the song only one usul can exist. That means, if there are more than one usul in the song, these

Figure 2.8: Seyir of Mahur Maqam

occur at different places of the song [63].

There are more than 40 usuls in the TAM, and each have a specific name. In addition, usuls can be divided into two according to their forms:

- *Simple Usuls*: These kind of usuls do not include any other usul in its components. There are only two usuls in this class, which are nim sofyan and semai.
- *Combined Usuls*: These usuls are the composition of at least two kinds of usuls.

Another categorization of usul can be made according to its size as follows:

- *Small Usuls*: This group includes the usuls from two beats to fifteen beats. Nim sofyan, semai, sofyan, Türk aksağı, yürük semai, mürekkeb nim sofyan, devr-i hindi, devr-i turan are some of the examples of the small usuls.
- *Big Usuls*: This set of usuls includes the beats bigger than sixteen. Çifte düyek, fer, nim berefşan, nim hafif, Türki darb (darb-ı Türki), nim devir, fahte, durak evferi are some examples to this group.

In this thesis, sofyan usul is selected in order to check the statistical significance. Also, understanding and using sofyan is easier than the others. To define sofyan usul, firstly nim sofyan usul has to be covered, since sofyan is composed from nim sofyan.

2.2.1 Nim Sofyan Usul

Nim sofyan usul is the simplest and the smallest usul of the Turkish art music and can be described as below:

- It is two beats usul.
- It is simple usul, which means it is not includes any other usul in its components.
- It can be used for time signatures 2/8, 2/4, or 2/2 but mostly 2/4 time signature is used.
- It is mostly used in musical forms similar to the sirto, longa.
- In this usul the first beat is forced, and the second is weak.
- It is written and played as given in Figure 2.9.

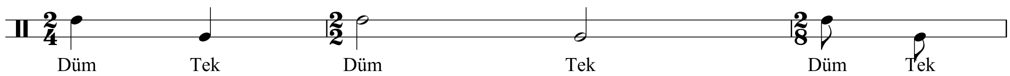


Figure 2.9: Nim Sofyan Usul

2.2.2 Sofyan Usul

Sofyan is one of the basic forms of the Turkish art music. Furthermore, because of its uncomplicated structure, it is easy to find songs using this rhythmic form.

In order to define and understand sofyan, its properties can be listed as follows:

- It is four beats usul.
- It is the composition of two nim sofyans or twice of two beats usuls.
- It can be used for time signatures 4/8 and 4/4 but mostly 4/4 time signature is used
- It is widely used in almost all forms of Turkish art music
- In this usul, first beat is forced, second beat is half-forced and third beat is weak.

- It is written and played as given in Figure 2.10, kudüm velveleli form is given in Figure 2.11.

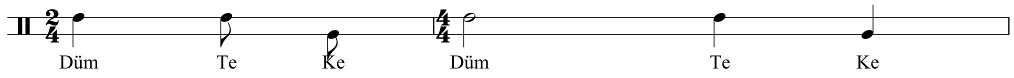


Figure 2.10: Sofyan Usul

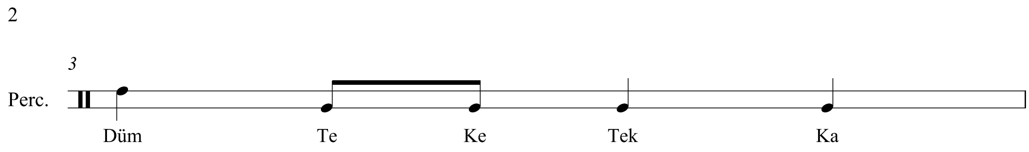


Figure 2.11: Sofyan Usul with Kudüm Velvele

CHAPTER 3

SCALES IN MUSIC

In this chapter, western and Turkish art music scales will be covered. In addition, some important concepts will be examined such as *koma*. In fact, sound system of Turkish art music is a very problematic issue. Officially, 24–keys Arel system is accepted, however, there are disagreements on this model.

Therefore, to be clear in what is used in the calculations, scales in western music and traditional Turkish music will be covered.

3.1 Scales in Western Music

Scales can be defined as the model of dividing pitch continuum. Additionally, they make music easy to understand and write [65]. Also, intervals and tones are the basic materials of the music. In other words, any musical idea gets its form in terms of tones and intervals [66].

Another definition of scale can be done by using cultural perspective. For instance, C. Güray defines pitch system as structures of sound materials used for developing own music of a culture [67].

Scales used today are not the same as the scales used in the past. In the coming subsections, some historically important scales will be covered. These historical scales have affected both western music and Turkish art music.

3.1.1 Pythagorean Scale

When any instrument plays a note, a pitch with frequency ν sounds, and that can be composed to sine waves with frequency integer multiples of ν. The component of the pitch with frequency ν which is called the *fundamental*. The other components of the note with frequency $m\nu$ are called the mth *harmonic*. As an example, harmonics of the note C below the middle C is shown in Figure 3.1

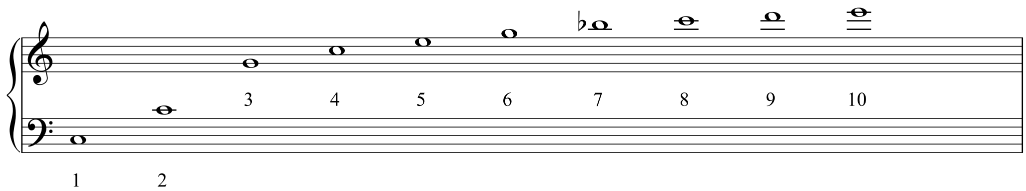


Figure 3.1: Harmonics of note C

In general, musical intervals are shown by the ratios of the frequencies. Pythagoras discovered that the pitch of one half of the string gives the one octave higher note when it played in its original length. Hence, the interval between the fundamental and the first harmonic is called the octave, and the ratio of the octave is 2 : 1. Similarly, he discovered the ratio of the perfect fifth as 3 : 2. By using these two ratios Pythagoras developed his scale as described below.

First, if the ratio of the perfect fifth used twice, we get the the ratio 9 : 4. Next, one octave below of that ratio is taken, and it gives us the ratio for the whole tone as 9 : 8. By using these ratios, frequency ratios of the Pythagorean major scale can be found as shown in Table 3.1.

Table 3.1: Frequency Ratios for Pythagorean C Major Scale

note	**ratio**
do	1:1
re	9:8
mi	81:64
fa	4:3
sol	3:2
la	27:16
ti	243:128
do	2:1

Similarly, minor semitone can be found by using octave and perfect fifth as following:

$$256 : 243 = 2^8 : 3^5 \tag{3.1}$$

If the half of the whole tone and minor semitone are compared, it can be realized that ratios of these two are not equal. Indeed, two minor semitones give the ratio $2^{16} : 3^{10}$ different from the $9 : 8$. To get rid of this inequality Pythagoras assumed that

$$2^{16} : 3^{10} \approx 9 : 8 \tag{3.2}$$

in other words

$$2^{19} \approx 3^{12} \tag{3.3}$$

or

$$524288 \approx 531441 \tag{3.4}$$

The difference between the two minor semitones and half of the whole tone in Pythagorean scale is called as the *Pythagorean comma* and has the value

$$3^{12}/2^{19} = 531441/524288 = 1.013643265 \tag{3.5}$$

which is almost equal to the one ninth of the whole tone [68].

Another important concept that should be included in the musical scales is the *cent* which is frequently used in modern literature [69]. Basically, cent is a tool for comparing the size of the intervals [66]. In fact, concept of a cent is based on the logarithmic character of the musical intervals which corresponds to the multiplying frequency ratios. As for the definition, it starts with dividing an octave interval to 1200 equal intervals and each one is called as cent. Furthermore, we can convert the Pythagorean scale in units of cents by starting with the conversion of the whole tone.

$$1200 \log_2(\frac{9}{8}) = 1200 \ln(\frac{9}{8})/\ln(2) \approx 203.910 \tag{3.6}$$

With similar calculations, frequency ratios and corresponding cent values can be found as given in Table 3.2.

Table 3.2: Cent Values for Pythagorean C Major Scale

note	ratio	cents
do	1:1	0.000
re	9:8	203.910
mi	81:64	407.820
fa	4:3	498.045
sol	3:2	701.955
la	27:16	905.865
ti	243:128	1109.775
do	2:1	1200.000

Because of the advantages of the melodical structure, Pythagoras scale has a wide application area in different musical cultures. In old Chinese and Greek music, pentatonic and heptatonic melodies based on the Pythagorean scale can be found. Also, 12-tone Pythagoras scale in Europe and 17-tone Pythagoras scale in Islamic world were used at the end of the middle age. In addition, western music violin players use the Pythagorean system for intonation. Furthermore and most importantly, the Arel system which is used in this thesis, is widely accepted today in traditional Turkish art music, which is a 24-tone Pythagorean scale [70].

3.1.2 Just Intonation

As a second scale used, just intonation can be covered. Beginning of the construction of this scale is based on arguments on consonance and dissonance.

Although, consonance and dissonance are two critical concept in music since they include some subjective sensations, these two words can be explained physically. Without going into detail, it can be set that musical intervals which have the ratios of small integers are more consonant than the ratios with big integers [69]. For example, the most consonant interval, unison, has the ratio $1:1$; secondly, octave comes with ratio $2:1$. On the other hand, the whole tone, known as the dissonant interval, has the ratio $9:8$.

The idea of just intonation scale is based on the better approximation to the consonant thirds. In Pythagorean scale, the major third has a ratio $81:64$ which is seen to be dissonant, although it is consonant. So, new ratios which can be constructed by using the harmonics of the sound are needed to eliminate this problem. For example, the fifth, tenth, etc harmonic of any pitch has a frequency ratio 5 : 4 which is more consonant than the major third of the Pythagorean scale. Beginning with this ratio, we can construct the just intonation major scale with the cents as given in Table 3.3.

Table 3.3: Frequency Ratios and Corresponding Cents of Just Intonation C Major Scale

note	**ratio**	**cents**
do	1:1	0.000
re	9:8	203.910
mi	5:4	386.314
fa	4:3	498.045
sol	3:2	701.955
la	5:3	884.359
ti	15:8	1.088.269
do	2:1	1.200.000

One of the important concepts that can be accessed from the difference between the Pythagorean major third and the just intonation major third is *syntonic comma* and has a ratio 81 : 80. Sometimes this ratio called as comma of Didymus, Ptolemaic comma, or ordinary comma [69].

3.1.3 Meantone Scale

As a third scale, meantone scale can be studied. This scale makes adjustments to play two notes by various commas. In other words, meantone scale aims to achieve perfect thirds and acceptable triads [68]. In fact, meantone scales are the tempered scales constructed by doing adjustments of syntonic comma in order to get better major thirds [69].

There are various meantone scales. The most commonly used one has the name *classical meantone* or *quarter-comma meantone* scale. In this scale, major third has the ratio 5 : 4, and the other notes are interpolated equally. In table 3.4, frequency ratios and cents of the classical meantone are given.

Secondly, comparison of tuning of 12-tone Pythagorean scale and three different meantone scale is given in Figure 3.2. -1 shows the Pythagorean comma. It should be noted that the perfect fifth intervals in meantone scales are no longer perfect.

Table 3.4: Frequency Ratios and Corresponding Cents of Classical Meantone C Major Scale

note	ratio	cents
do	1:1	0.000
re	$\sqrt{5}$:2	193.157
mi	5:4	386.314
fa	2:$5^{\frac{1}{4}}$	503.422
sol	$5^{\frac{1}{4}}$:1	696.579
la	$5^{\frac{3}{4}}$:2	889.735
ti	$5^{\frac{5}{4}}$:4	1.082.892
do	2:1	1.200.000

3.2 Scales in Turkish Art Music

In this section, two important scales of Turkish art music will be covered. Firstly, 17-keys Urmevi system, secondly, 24-keys Arel system which is used in this thesis will be presented.

3.2.1 17-keys Urmevi System

17-keys Urmevi system can be considered to be the first system that includes pitches in Turkish art music. The music theorists in Ottoman Empire took this system as a mathematical base for both pitch scale and melodic design [44].

Safiyüddin Urmevi, who developed the 17-keys system for Turkish art music, is the founder of the school called as *sistemci* (systematist). The most important reason to get this name comes from the fact that he developed his maqam theory systematically by using mostly the works of Farabi and İbn-i Sina [67].

Roots of the 17-keys system can be found in the Sasani term (A. D. 226-651) of the Persian, and it is developed by using the Pythagorean fifths [71]. The pitches of this scale is constructed by applying the Pythagorean perfect fifth ratio sixteen times. Starting from the pitch dik yegah, we get the pitch scale as given Figure 3.3.

If we put these notes in an order we get the scale given in Tabel 3.5.

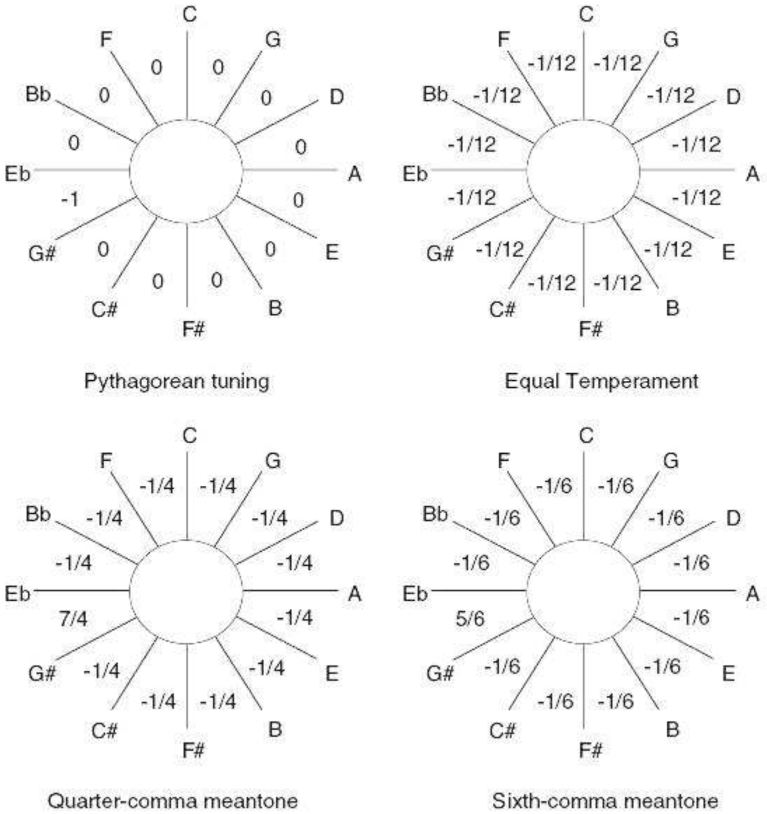


Figure 3.2: Comparison of Tunings

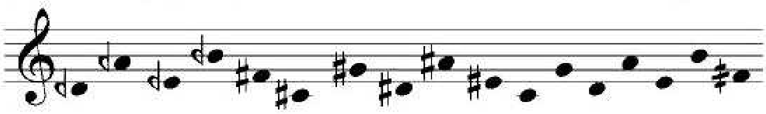


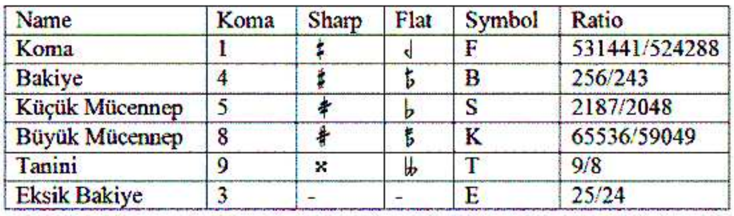
Figure 3.3: Application of Fifths and 17-keys System

3.2.2 24-keys Arel System

The 24-keys scale system is developed by H. S. Arel (1880-1955) [50], S. Ezgi (1869-1962)[58], and S. M. Uzdilek (1891-1967)[49]; and this system is based on the works of Rauf Yekta Bey (1871-1935) [59]. Because, the contribution of the Arel is more than the others, this system is mostly called as Arel-Ezgi-Uzdilek system or Arel system [73]. There are six intervals in whole tone, named as koma, eksik bakiye, kücük münecceb, büyük münecceb and tanini. In order to build these intervals, firstly whole tone is divided into nine equal pieces, and each is called *koma* which is equal to the Pythagorean comma [63]. After that, intervals are produced by using some integer multiples of the koma. Properties of these intervals are given in Figure 3.4.

Table 3.5: 17-keys Scale from Yegah to Neva with Cents

note	**cents**
Yegah	0.00
Pest Nim Hisar	90.22
Pest Hisar	180.45
Hüseyni Aşiran	303.91
Acem Aşiran	294.13
Irak	384.96
Geveşt	407.82
Rast	498.04
Nim Zengule	588.27
Dik Zengule	678.49
Dügah	701.96
Kürdi	792.18
Segah	882.40
Buselik	905.87
Çargah	996.09
Nim Hicaz	1086.31
Dik Hicaz	1176.54
Neva	1200.00



Name	Koma	Sharp	Flat	Symbol	Ratio
Koma	1	[illegible]	[illegible]	F	531441/524288
Bakiye	4	[illegible]	[illegible]	B	256/243
Küçük Mücennep	5	[illegible]	♭	S	2187/2048
Büyük Mücennep	8	[illegible]	[illegible]	K	65536/59049
Tanini	9	×	𝄫	T	9/8
Eksik Bakiye	3	-	-	E	25/24

Figure 3.4: Intervals in Whole Tone in 24-keys System

According to Uzdilek, construction of the scale should be started from kaba çargah note by using eleven perfect fifth and twelve perfect forth intervals[72]. After this procedure is applied, 24-keys system pitches, their frequency ratios and other values can be found as given in Figure 3.5 and Table 3.6.

In spite of its well–acceptance, there are some negative arguments on Arel system. M. C. Can states that four of the pitches, dik buselik, dik geveşt, dik acem aşiran and dik hicaz (and octaves of these), have not been used in any pieces [74]. In addition İ. H. Özkan states that 1 and 8 koma flat or sharp is used mostly in theoretical

Table 3.6: Frequency Ratios and Corresponding Cents of 24-keys Scale in TAM

note	**ratio**	**cents**
Kaba Çargah	1:1	00.000
kaba Nim Hicaz	256:243	90.225
Kaba Hicaz	2187:2048	113.685
Kaba Dik Hicaz	65536:59049	180.450
YEGAH	9:8	203.910
Kaba Nim Hisar	32:27	294.135
Kaba Hisar	19683:16384	317.595
Kaba Dik Hisar	8192:6561	384.360
HÜSEYNİ AŞİRAN	81:64	407.820
ACEM AŞİRAN	4:3	498.045
Dik Acem Aşiran	177148:131072	521.505
Irak	1024:729	588.270
Geveşt	729:512	611.730
Dik Geveşet	262144:177147	678.495
RAST	3:2	701.955
Nim Zirgüle	128:81	792.180
Zirgüle	6561:4096	815.640
Dik Zirgüle	32768:19683	882.405
DÜGAH	27:16	905.865
Kürdi	16:9	996.090
Dik Kürdi	59049:32768	1019.550
Segah	4096:2187	1086.315
BUSELİK	243:128	1109.775
Dik Buselik	1048576:532441	1176.540
ÇARGAH	2:1	1200.000

Figure 3.5: Pitches of 24-keys System

considerations. Also in some cases, these notes can take 2 komas instead of 1 which means there are some mismatches between theory and practice [63]. A recent congress was dedicated to just on this mismatch (Theory-application mismatch for Turkish Music: Problems and Solutions, organized by Istanbul Technical University, State Conservatory for Turkish Music, $3-6$ March 2008, İstanbul).

CHAPTER 4

METHOD

In this chapter, concept of fractal dimension is introduced. Moreover, the methods of calculations which are used in this thesis are presented. Furthermore, the way used to model songs, and the tools used to check statistical significance are given.

4.1 Fractal Geometry

Fractals can be defined as the more irregular geometrical objects compared to the ordinary geometrical objects. B. Mandelbrot is often accepted as the father of the fractal geometry, and the term fractal is first used by him [75]. In addition to B. Mandelbrot, previous studies of G. Cantor, G. Peano, D. Hilbert, H. Koch, W. Sierpinski, G. Julia, and F. Hausdorff are important steps in the development of the fractal geometry.

The idea behind the fractals roots from the problem that the nature is not formed from the squares, triangles, or any other shapes from the Euclidean geometry. On the other hand, B. Mandelbrot recognized that features of the shapes of natural objects mostly exist in the fractals [75].

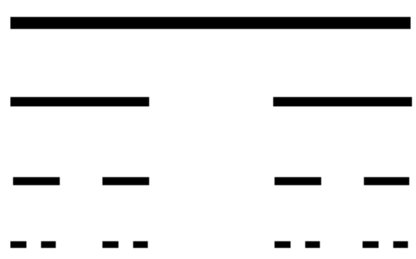


Figure 4.1: Construction of middle third Cantor set

To demonstrate fractals, it is useful to start with examples from the so called classical fractals such as Cantor set, Sierpinski carpet and Koch curve. The first example that will be covered is Cantor set whose features exist in many fractals.

Cantor set was first discovered in 1883 [76] by the German mathematician G. Cantor (1845-1918), who had contributed a lot in the set theory. Furthermore, Cantor set is not only important for the fractal geometry, but also it is important for chaotic dynamical systems. In addition, it is the model behind most of the fractals such as Julia Sets [77].

Cantor set is constructed by removing recursively middle third of the unit interval $E_0 = [0, 1]$ as shown in Figure 4.1. After the first deletion, we have

$$[0, 1/3] \cup [2/3, 1] \tag{4.1}$$

which is called as set E_1. Removing the middle thirds of that gives union of four intervals as given below

$$[0, 1/9] \cup [2/9, 1/3] \cup [2/3, 7/9] \cup [8/9, 1] \tag{4.2}$$

and it is called as E_2. As a result of this iterative process, Cantor set is obtained as the union of the sets E_k, which have 2^k intervals, and each of them has a length 3^{-k} as k goes to infinity.

Initially, one of the most important properties of the fractals is self similarity which can be understood by using Cantor set. Self similarity is closely related to the concept of geometric similarity which can be defined as follows: Two geometric objects are said to be similar if their line segments are proportional with the same factor of proportionality, and if the corresponding angles are the same. One further step is similarity transformation which is the combination of scaling, rotation, and transformation.

In addition to similarity transformation, nonproportional growth could be included in the concept of similarity. It can be said that nonproportional growth is at the heart of the fractal geometry [77]. In fact, it is description of the similarity between the grown and the young living since this kind of similarity is different from the geometric similarity.

Self similarity of fractals involves both nonproportional growth and geometric similarity and sometimes more. When the fractal is invariant under ordinary geometric similarity, it is called self similar [75]. When the small copies of the object have little variations, then it is called statistical self similarity; and when the copies are distorted some other way it is called self affinity[77]. It is clear from the definition of the Cantor set that it is a self similar set. That is, in any step, if we multiply the set with 3 or 1/3 we get exactly the same set since the iteration continues up to the infinity.

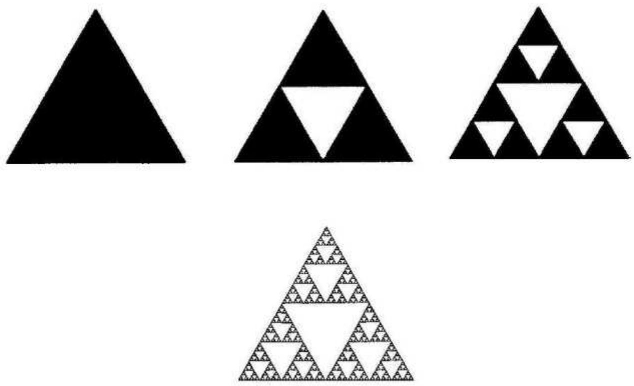


Figure 4.2: Construction of Sierpinski gasket

The second example will be covered is Sierpinski gasket which was found by Polish mathematician W. Sierpinski [78,79]. It is constructed by repeatedly removing the 1/3 of the equilateral triangles from the previous ones as shown in Figure 4.2. Namely, when the construction is carried out infinitely often, the set of points remains at the plane is a Sierpinski gasket. The self similarity of a Sierpinski gasket can be seen from the fact that iterations give the scaled down form of the previous one with a scaling factor 2.

Thirdly, Koch curve will be discussed as an example to fractal objects. Koch curve was first introduced by Swedish mathematician H. Koch in 1904. [80,81]. Similar to the construction of a Cantor set, Koch curve construction starts with a straight line as an initiator. Then, middle third of the line is removed and raise an equilateral triangle as shown in Figure 4.3. Repeating this process up to infinity gives the real Koch curve.

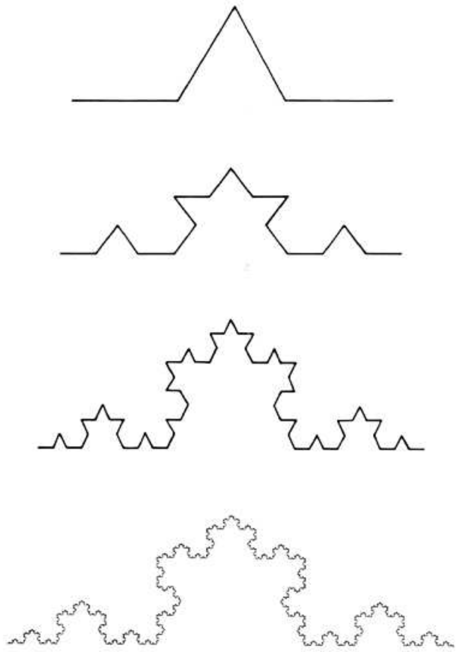


Figure 4.3: Construction of Koch curve

Some properties of Koch curve have an a special importance for B. Mandelbrot [75], and therefore, for fractal geometry. First, it is continuous but not differentiable. Second, its shape is similar to the natural coastlines which was one of the starting points of B. Mandelbrot. Third, it is self similar curve, namely, k^{th} step is a scaled down version of $(k-1)^{th}$ step with scaling factor 3.

In the fourth place Peano curve, whose construction can be seen in Figure 4.4, will be examined as an example to fractals [82]. It is obvious from the construction that the curve is self similar with scaling factor 3. This curve has a distinction from the other fractal examples from its space-filling property. In other words, that one-dimensional curve fills a two-dimensional plane.

The examples of fractals given above called classical fractals and these are very efficient tools for getting the fundamentals of fractals. .

From all of the demonstrations of fractals some common properties can be gathered and listed as follows:

- Self Similarity: Fractals have self similar structure.

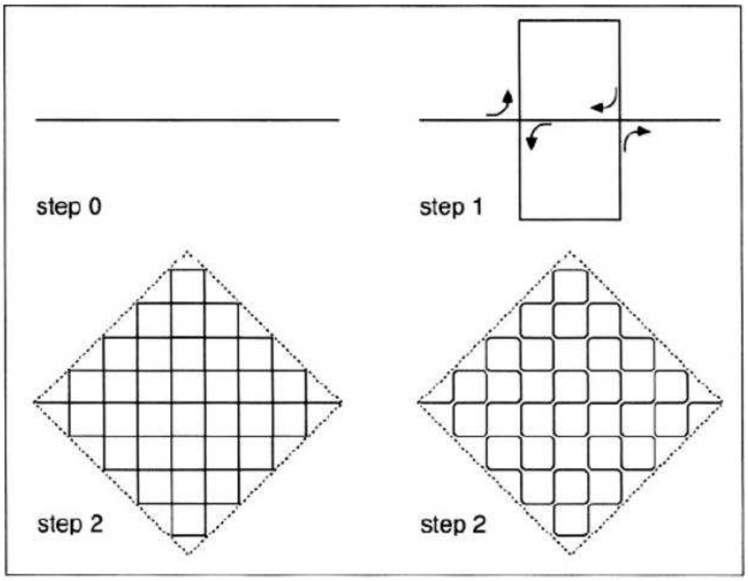


Figure 4.4: Construction of Peano curve

- Fine Structure: Even in small scales, there is detailed structure since there are infinitely long construction processes.
- Recursive Development: Fractals are generally obtained from recursive relations.
- Simple Definition: In contrast to the fine structure, construction of fractals are very straightforward.
- Difficulty in Local Descriptions: It is hard to describe local geometry fractals because of the large number of gaps and lines with different lengths.
- Difficulty in Measure: Setting the size of this uncountable infinite set with usual measures – such as length or surface – is difficult.

From the list of features given above, it can be concluded that description of the fractals with the classical tools are not so easy. Therefore, new tools are necessary to get rid of these difficulties. One of the new tools that is one of the main tools of the thesis is the fractal dimension.

4.1.1 Fractal Dimension

Existence of the space filling curve caused studying on the concept of dimension since, although it is a one dimensional object, it has a space filling property. From these studies, new definitions of dimension have been developed. Topological dimension, Euclidean dimension (it is the number of co-ordinates required to specify the object), and Hausdorff dimension are some examples of the dimension types.

Similar to the general dimension considerations, there are different types of fractal dimensions. Indeed, types of fractal dimensions which are the special forms of the Hausdorff dimension, developed by F. Hausdorff [84], uses the method described in [83]. More detailed information on this subject can be found in [85,86,87].

Before going into details of the fractal dimensions, it is useful to cover briefly the concept of topological dimension. Detailed information about dimension theory and topology can be found in [88] and [99].

4.1.2 Topological Dimension

Topology is a branch of mathematics and simply deals with the forms and shapes. Furthermore, topological dimension is one of the basic tools that is used for discriminating the shapes.

Among the many forms of the topologically invariant dimension, *covering dimension* is the mostly used one. Although it is possible to explain the covering dimension by set theory, it can be simply be described in the following way. If an object has a covering dimension n, that shape can be covered with disks of small radius so that there are at most $n + 1$ pairs of disks with nonempty intersection.

By using the covering dimension, it can be stated that all kinds of curves, including Koch curve and Peano curve, have a topological dimension 1. Moreover, square, circle, triangle, and Koch island are topologically invariant and has a dimension 2. In general, intersection of lines and holes are invariant in topology.

4.1.3 Types of Fractal Dimension

Measurement and dimension are two interconnecting concepts in geometry. This interconnection is also the beginning of the research of the fractal dimension. The most classical example of that situation is the length of the coast of Britain[90]. Measuring the length of such curves is very difficult; however, it is possible to define a dimension which is between the topological dimension and Euclidean dimension[new ref2-10]. Nowadays, some new studies on the coast of Britain can be seen [91]

In general, there are many definitions of fractal dimension such as *compass dimension*, (also called divider dimension), *self-similarity dimension*, *box-counting dimension*[92]. In this thesis, self-similarity dimension and box-counting dimension will be covered.

4.1.3.1 Self-Similarity Dimension

Dimension and self similarity are closely related to the concept for both fractal and non-fractal objects. This relation can be shown for the non-fractal objects as following:

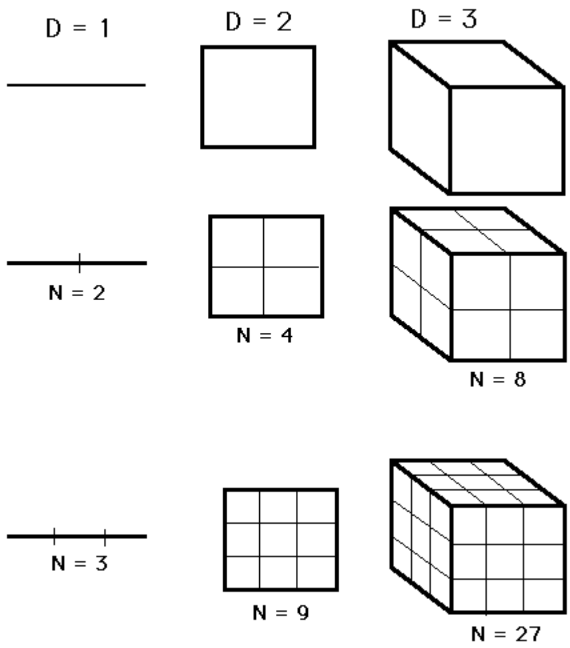


Figure 4.5: Dimension and scaling

Assume a line of length l. If it is scaled down with a scaling factor 1/3, its length becomes $l/3$. Similarly, for a square with side length l, if it is scaled down with a factor $l/3$, its area becomes $l^2/9$. The same operation and calculation can be done for cube as shown in Figure 2.5 and the results can be grouped as follows:
From the table the following identity can be set:

$$N = \frac{1}{s^{D_s}} \tag{4.3}$$

Table 4.1: Scaling and Measure

Object	Number of Pieces	Scaling
line	1	1
line	2	1/2
line	3	1/3
square	$1 = 1^2$	1
square	$4 = 2^2$	1/2
square	$9 = 3^2$	1/3
cube	$1 = 1^3$	1
cube	$8 = 2^3$	1/2
cube	$27 = 3^3$	1/3

where N is number of pieces, s is a scaling factor and D_s is self-similarity dimension. Using logarithms gives

$$D_s = \frac{\log N}{\log(1/s)}. \tag{4.4}$$

When we apply the Eq. (4.4) to some of the regular fractal shapes, we get the following results:

- For the middle third Cantor set $s = 1/3$ and $N = 2$ so we have

$$D_s = \frac{\log 2}{\log 3} \approx 0.631. \tag{4.5}$$

- For the Koch curve $s = 1/3$ and $N = 4$ so we have

$$D_s = \frac{\log 4}{\log 3} \approx 1.262. \tag{4.6}$$

- For the Sierpinski gasket $s = 1/2$ and $N = 3$ so we have

$$D_s = \frac{\log 3}{\log 2} \approx 1.585. \tag{4.7}$$

- For the Peano curve $s = 1/3$ and $N = 9$ so we have

$$D_s = \frac{\log 9}{\log 3} = 2. \tag{4.8}$$

From the above results, some properties of the fractal dimension can be gathered. First, it can take non-integer value which is between the Euclidean dimension and topological dimension. Second, it is the measure of space filling of the fractal object. Third, it gives information about the irregularity of the shape of the object.

4.1.3.2 Box Counting Dimension

Box counting dimension is a widely used type of fractal dimensions due to its ease of computation. Instead of the term box counting dimension, some authors use other names, such as Kolmogorov entropy, entropy dimension, capacity dimension, metric dimension, logarithmic density and information dimension. In this study, box counting dimension will be used.

Consider a one dimensional object with length L. This object can be covered with a $N(\epsilon)$ number of boxes of side ϵ. The length L of the object can be expressed as

$$L = \frac{N(\epsilon)}{1/\epsilon}. \tag{4.9}$$

If a similar procedure is applied for the two-dimensional object, we get

$$L^2 = \frac{N(\epsilon)}{(1/\epsilon)^2}. \tag{4.10}$$

For D-dimensional object we have

$$L^D = \frac{N(\epsilon)}{(1/\epsilon)^D}. \tag{4.11}$$

Taking the logarithm gives

$$D = \frac{\log N(\epsilon)}{\log L + \log(1/\epsilon)}. \tag{4.12}$$

Taking the limit when ϵ goes to zero gives the expression for box counting dimension as given below:

$$D_b = \lim_{\epsilon \to 0} \frac{\log N(\epsilon)}{\log(1/\epsilon)}. \tag{4.13}$$

In the applications of the box counting dimensions, some simplified forms can be seen. Two of them are used in this thesis. First one is the method used in the work of G. Gündüz and U. Gündüz [41].

According to G. Gündüz and U. Gündüz, fractal dimension of the song can be calculated by using the phase portrait (or scattering diagram) of the song which can be obtained by plotting the note versus next note graph. By using two different box sizes or graph resolutions fractal dimension of the song can be found from the following identity:

$$D_{ab} = (\ln(s_b)/(s_a))/(\ln(S_b)/(S_a)) \tag{4.14}$$

In this equation D_{ab} is the fractal dimension, s_b and s_a are the number of boxes that enclose(s) points, S_b and S_a are the number of boxes, and indices a and b denote the resolution of the diagrams; b has the higher resolution. Because of the use of the scattering of the notes, we have given the name for this kind of fractal dimension as *scattering fractal dimension.*

In addition to the scattering fractal dimension, second type of phase diagrams used in this thesis is formed by plotting the note versus duration graph. Fractal dimensions of these graphs is calculated again by using Eq. (4.14) and will be called as *melody fractal dimension* of the songs.

Second method used for calculation of the box counting fractal dimension is used in some other works [93, 94, 95, 96, 97]. According to this method, first, sizes of the covering boxes is decreased successively. Then, the slope of the linear fit of the results of the Eq. (4.15) gives the box counting dimensions of the object.

$$D_b = -\lim_{\epsilon \to \infty} \frac{\log N(\epsilon)}{\log \epsilon}. \tag{4.15}$$

In the thesis, this method is applied only for the note versus duration graphs, since it includes more musical features, since it contains time.

4.2 Modeling Songs

To find a fractal dimension of the song, it should have a shape that can be used for calculation. As mentioned, although there are different ways to do it, we will use two different methods similar to the model used in [41] due to its ease in calculation and ability to show musical motion compared to other ways.

In order to model songs, first, Turkish art music pitch height, which is compatible with Arel system, is developed similar to pitch height of the Shepard [98]. Next, kaba

Table 4.2: First Octave of Turkish Art Music Pitch Height and Corresponding Western Music (WM) Notes

NAME in WM	NAME in TAM	KOMA	NAME in WM
C1	KABA ÇARGAH	0	do
C#1b	Kaba Nim Hicaz	4	
C#1c	Kaba Hicaz	5	
C#1d	Kaba Dik Hicaz	8	
D	YEGAH	9	re
D#1b	Kaba Nim Hisar	13	
D#1c	Kaba Hisar	14	
D#1d	Kaba Dik Hisar	17	
E	HÜSEYNİ AŞİRAN	18	mi
F	ACEM AŞİRAN	22	fa
F#1a	Dik Acem Aşiran	23	
F#1b	Irak	26	
F#1c	Gevşet	27	
F#1d	Dik Geveşet	30	
G1	RAST	31	sol
G#1b	Nim Zirgüle	35	
G#1c	Zirgüle	36	
G#1d	Dik Zirgüle	39	
A1	DÜGAH	40	la
A#1b	Kürdi	44	
A#1c	Dik Kürdi	45	
A#1d	Segah	48	
B1	BUSELİK	49	si
B#1b	Dik Buselik	52	
C2	ÇARGAH	53	do

çargah note is taken as origin, and then, other notes take their places according to their distance from kaba çargah as shown in the Table 4.7.

Second, to show time in music, quarter note is taken as one unit and the others take their values accordingly. Furthermore, distance for rests are assigned as -1. An example song is given in Figure 4.6 and coding is given in Table 4.8.

4.3 Music Data and Statistical Analysis

One of the purposes of this study is checking whether maqams have their own fractal dimension or not. In order to get the result, after calculating the fractal dimensions, some statistical analysis are necessary.

Figure 4.6: Kürdi Song Hayal Kadın

Table 4.3: First part of Kürdi Song Hayal Kadın

OCTAVE	**TIME**	**DISTANCE**
1	0.5	-1
0	0.25	40
0	0.25	40
0	0.5	40
0	0.5	40
1	2	71
1	0.5	-1
1	0.25	62
1	0.25	62
1	0.5	62
1	0.5	62
1	2	53
0	0.5	-1
0	0.25	44
0	0.25	44
0	0.5	44
0	0.5	44
0	2	40
1	0.5	-1
0	0.25	22
0	0.25	22
0	0.5	22
0	0.5	31
1	1	53
0	1	40

In statistics, there are different ways to use data that can describe a situation, event or some other thing. Thus, data type should be checked before making statistical work. In this thesis, the notes are assumed as position in the musical motion. However, the zero in the notes does not correspond to zero as in IQ or temperature. Therefore, our data can be classified as the interval-level data. Similarly, it can be stated that fractal dimension values are also interval-level data [99].

Another important point is the discovery of the significance of the differences of the results. The first method used to understand this difference is *T test*, which is used for evaluation of differences of means of two groups. Theoretically, this test is applicable to small size data even if the number of samples is smaller than ten [99, 100].

Second statistical test used in this thesis is *F test* which is used to compare variances of two or more means. The F test can only show whether or not significant difference exists in means, but it can not set where the difference is. In order to find the difference, least significant difference test, abbreviated as *LSD test*, is used.

Both T test and F test use the null hypothesis that all of the means are the same, namely

$$H_o : \mu_1 = \mu_2 \leftrightarrow \mu_1 - \mu_2 = 0. \tag{4.16}$$

Alternative hypothesis of the null hypothesis is

$$H_1 : \mu_1 \neq \mu_2 \leftrightarrow \mu_1 - \mu_2 \neq 0. \tag{4.17}$$

In the above equations, μ_n corresponds to the mean value of the fractal dimension of the maqam n. Both T test and F test is used to understand which one of the hypothesis is correct.

T test calculations start with calculation of test statistic as given in Eq. 4.10.

$$t = \frac{(\bar{y_1} - \bar{y_2}) - 0}{SE_{(\bar{y_1} - \bar{y_2})}} \tag{4.18}$$

where $SE_{(\bar{y_1} - \bar{y_2})}$ is the standard error of the mean, and $\bar{y_n}$ is the mean value of the sample songs of maqam n. Next step is getting the *P value* which is defined as the probability, computed with the assumption that the null hypothesis is true, of the test statistic being at least as extreme as the value of the test statistic that was actually obtained [54]. The third step is setting an α value which is the measure of nonconfidence. As a last step, P value and the value of α will be compared to make a conclusion. If P is smaller than the α, our null hypothesis will be rejected [99].

On the other hand, procedure for calculation of F test starts with mean and variance of each sample. Then, grand mean denoted by $\bar{X}_{GM}$, mean of all values in the samples, should be calculated. Third step is calculation of between-group variance abbreviated as s_B^2 as given in Eq. 4.11.

$$s_B^2 = \frac{\sum n_i(\bar{X}_i - \bar{X}_{GM})}{k-1} \tag{4.19}$$

where $\bar{X}_i$ is mean of sample i, n_i is size of the sample i, and k is the number of maqams. Next step is calculation of within-group variance using Eq. 4.12.

$$s_W^2 = \frac{\sum (n_i - 1)s_i^2}{\sum (n_i - 1)} \tag{4.20}$$

where s_W^2 is within-group variance, s_i^2 variance of sample i, and n_i is again size of the sample i. Finally, F test value can be found via Eq. 4.13.

$$F = \frac{s_B^2}{s_W^2} \tag{4.21}$$

To make the decision value of F and critical value which can be obtained according to sample size and number of groups from the tables in [99,100], is compared.

CHAPTER 5

RESULTS

In this chapter, results of calculation of box counting fractal dimensions of the songs are given. Results of calculations are grouped according to the method used– method used by Gündüz [41] or linear fit. Then, comparative analysis of the results are presented. Lastly, results of statistical tests are given.

In the calculations, forty randomly chosen Turkish art music songs are used. In fact, these songs are selected from the Turkish Radio and Television (TRT) archive scores. Moreover, they are in one of four maqams, Kürdi, Acem Aşiran, Hüzzam, or Mahur, which are randomly selected also. Furthermore, there are ten songs for each maqam.

It should be noted that, from the 20112 songs in the TRT archive, 2498 of them are in the rhythmic form sofyan. In fact, 34 of them are in Kürdi maqam, 85 of them are in Mahur maqam, 115 of them are in Hüzzam maqam, and 48 of them are in Acem Aşiran maqam. Thus, the number of songs in sofyan usul is great enough for statistical work.

5.1 Results of Fractal Dimension Calculations with the Method of Gündüz

In the work of Gündüz, six Anatolian traditional songs are studied [41]. In fact, four of these songs are from the Turkish art music repertoire and other two are from the folk music repertoire. Moreover, notes are presented with sequential natural numbers which are not related to any of the sound systems of Turkish music. On the other hand, in this thesis, there are forty songs as described. Furthermore, notes are presented with a pitch height which is compatible with the Arel pitch scale.

5.1.1 Scattering Fractal Dimension

Firstly, fractal dimensions of these forty songs are calculated via scattering diagrams, and following results are found.

We begin with demonstration of the results of calculations of scattering fractal dimensions of ten Kürdi songs, as given in Table 5.1. Their mean and standard deviation values are calculated as 0.667, and 0.293 respectively.

Table 5.1: Kürdi Songs Scattering Fractal Dimensions Found with a Method in [16]

Song No	Song Name	Scat. Frac. Dim.
2992	Hayal Kadın	0.607
6462	Hiç Tatmadım Böyle Duyguyu	0.580
11973	Ne Aşk Kaldı Ne De Bir İz	0.963
13062	Gel Bahardan Zevk Alalım	0.118
13451	Bulut Bulut Geçer İnsan	0.557
17479	Sever misin	0.747
17637	Ben Onu Gördüm Yıllardan Sonra	0.940
18691	Özür Dilerim	1.094
19250	Gül Goncası Nazende	0.710
19384	Ne Giden Aşklara Sor Gururun Bittiğini	0.355

Secondly, the results of dimension computations of the songs of Acem Aşiran maqam are represented in Table 5.2. In this case, standard deviation and the mean values are 0.142 and 0.617.

Table 5.2: Acem Aşiran Songs Scattering Fractal Dimensions Found with a Method in [16]

Song No	Song Name	Scat. Frac. Dim.
614	Aşık Oldum	0.855
1132	Bakma Sakın Benden Yana	0.674
2846	Coşkun Deniz	0.580
5986	Hani Nerde Beni Öpen Dudaklar	0.607
10235	Söz Verdim Adına Gelecek Diye	0.690
10507	Seviyorum Seni Güzel İstanbul	0.630
12969	Bir Anda Doldun İçime	0.756
13478	Şu Samsun'un Güzel Kızı	0.500
13889	Birtanem	0.500
18367	Rüyada Gibiyim	0.355

Thirdly, scattering fractal dimension values of Hüzzam songs are given in Table 5.3. Here, mean value of the scattering fractal dimensions of Hüzzam songs is 0.503, and 0.187 is the standard deviation of them.

Table 5.3: Hüzzam Songs Scattering Fractal Dimensions Found with a Method in [16]

Song No	Song Name	Scat. Frac. Dim.
4858	Eskisi Gibi	0.355
8427	O Kara Gözlerine Güzelim Dalıyorum	0.190
11870	Çiçek Açmaz Dallardayım	0.355
12185	Bu Ne Sevgi	0.440
12515	Tutuşurken Dalında Gül	0.599
12639	Gözlerin Karanlık Geceler Gibi	0.545
15898	Mutluluk Ve Keder	0.690
17687	Gözlerin Sevgi Dolu	0.500
18667	Sen Gideli Dile Düştüm	0.855
18781	Varsın Karlar Yağsın Şakaklarıma	0.500

Lastly, scattering fractal dimensions of the ten Mahur songs are given in Table 5.4. Mean and the standard deviation of the scattering fractal dimensions of the songs are 0.493 and 0.107 respectively.

Table 5.4: Mahur Songs Fractal Dimensions Found with a Method in [16]

Song No	Song Name	Scat. Frac. Dim.
314	Al Bu Geceyi Vur Ötekine	0.297
413	Aman Aman Bağdatlı	0.500
1936	Mahur Şarkı	0.453
5242	Gönüller Tutuşup Alev Alınca	0.500
5302	Gördüm Bugün	0.674
6731	İstanbul'lu Akşamlar	0.430
6734	İstanbul'un Koynunda	0.430
11902	Herkes Birini Sever	0.607
12210	Kaybolan Hayallerim Gözlerinde Her Gece	0.462
17846	Mahur Beste Çalınsa	0.580

It can be computed via the values of scattering fractal dimensions that standard deviation of all the songs is 0.142, and mean is 0.569. Additionally, comparison of the mean values of the scattering fractal dimensions is given in Fig. 5.1.

Furthermore, from the results of the computations, it can be stated that Kürdi songs

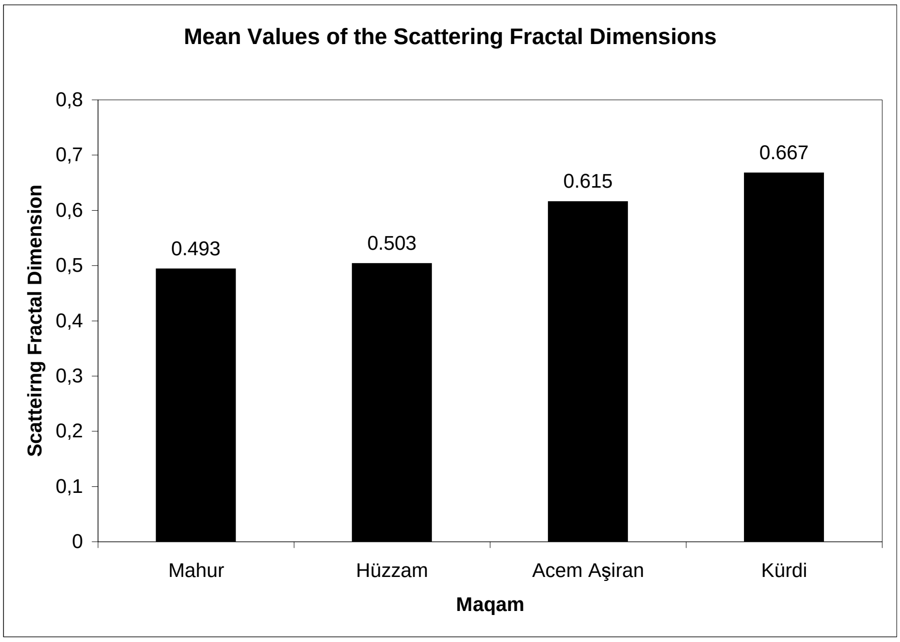
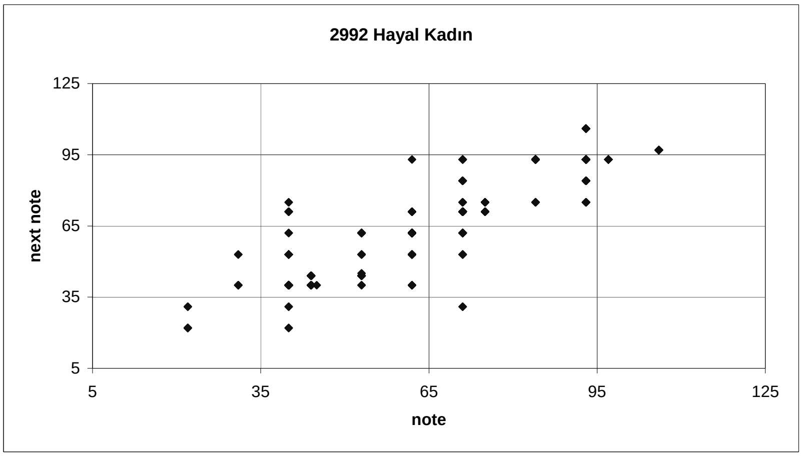


Figure 5.1: Mean Values of the Scattering Fractal Dimensions of the Maqams

show different irregularities, since the biggest range and standard deviation are found in this maqam. Moreover, Kürdi maqam has the biggest mean fractal dimension hence, the most irregular songs are in this maqam. In addition, song 2992 has the nearest scattering fractal dimension value to the mean of Kürdi songs, therefore we can say that it shows the irregularity characteristics of the maqam. Scattering diagram of song 2992 is given Fig. 5.2.

Another Kürdi song that has a conspicuous fractal dimension among the others is song 13062 whose scattering diagram is given in Fig. 5.3. This song has the minimum scattering fractal dimension, and if it is investigated in musical ways, it can be noted that musical phrases of the song are short (mostly made from two measures), easily understandable, and mostly includes second intervals. Also, melody of the song as a whole is narrow in range.

The third Kürdi song that should be examined is song 18691 which has the biggest scattering fractal dimension. As expected, it has a complicated melodic structure, long musical sentences, variety in use of the intervals, and wide pitch range. Scattering diagram of song 18691 is shown in Fig. 5.4.



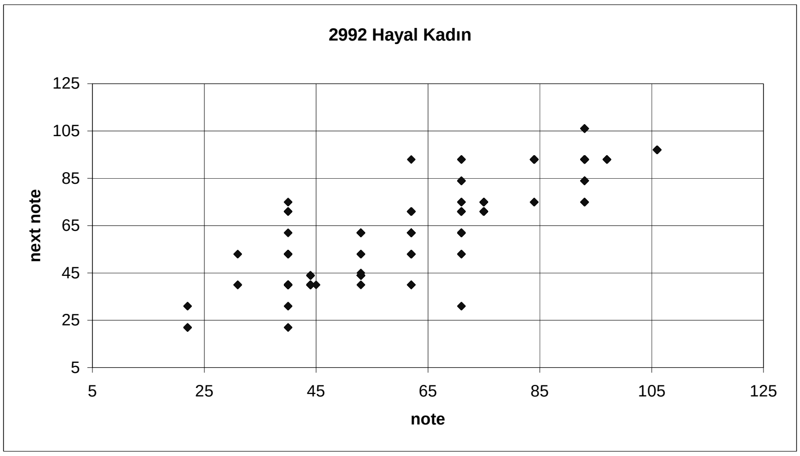
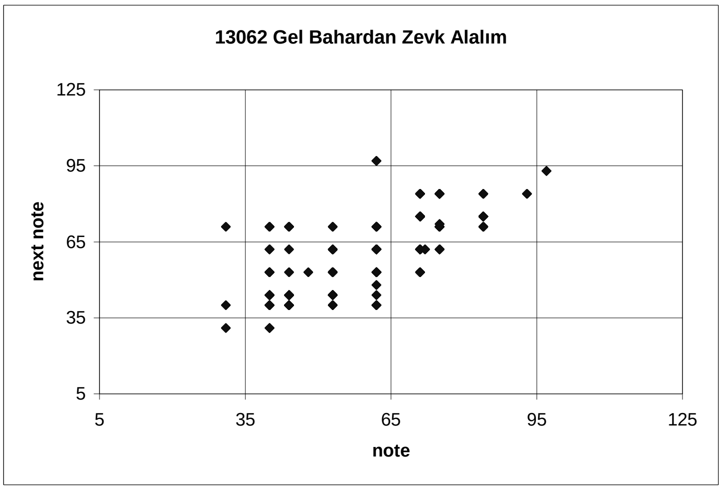


Figure 5.2: Scattering Diagram of Kürdi Song - Hayal Kadın



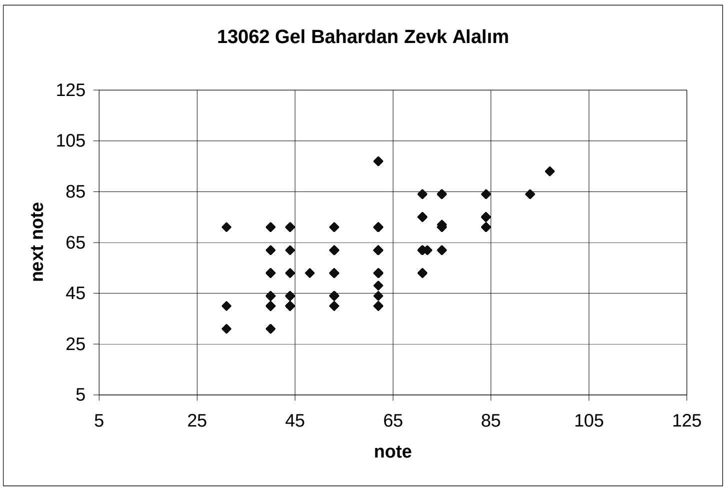


Figure 5.3: Scattering Diagram of Kürdi Song - Gel Bahardan Zevk Alalım

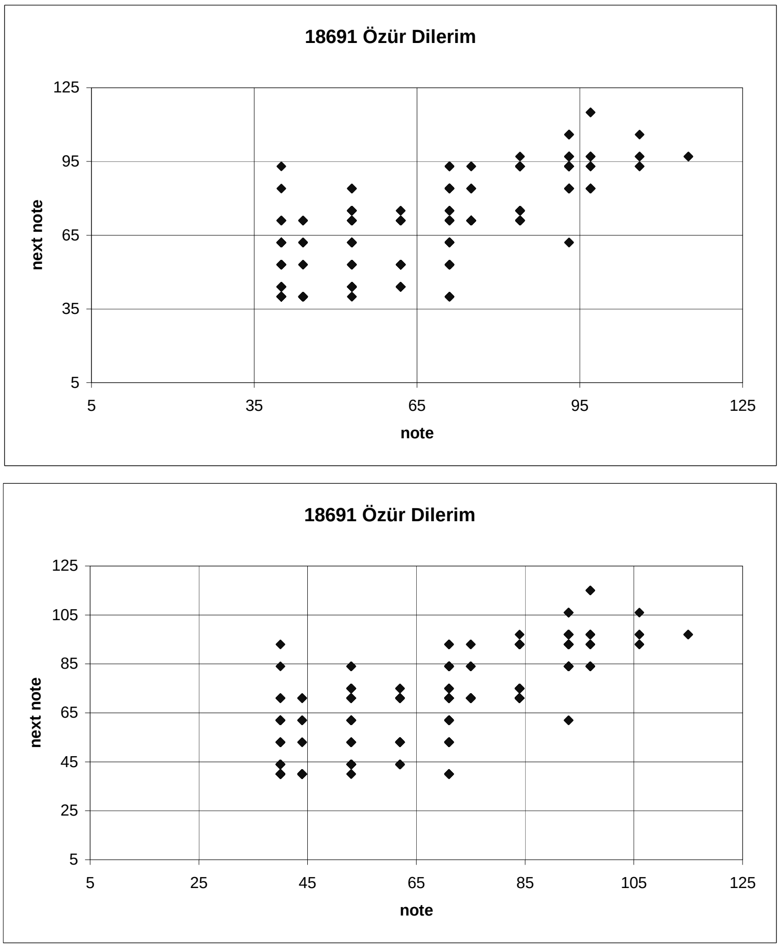


Figure 5.4: Scattering Diagram of Kürdi Song - Özür Dilerim

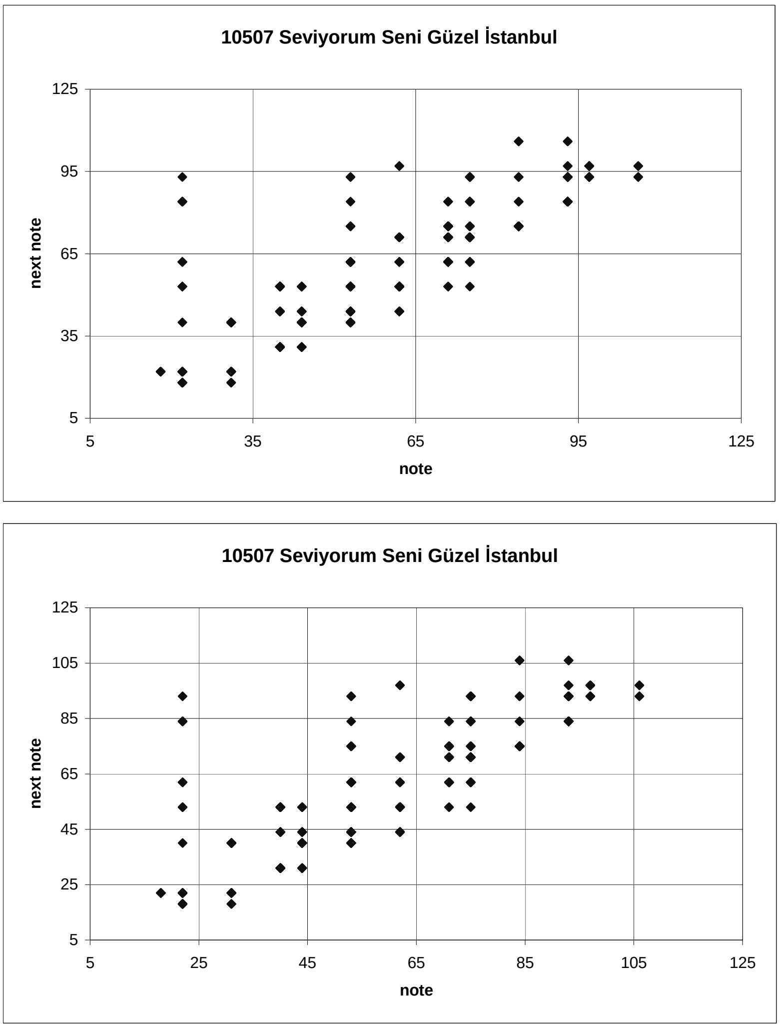


Figure 5.5: Scattering Diagram of Acem Aşiran Song - Seviyorum Seni Güzel İstanbul

Next maqam, according to the mean scattering fractal dimension values, is Acem Aşiran. Among the ten songs studied, song 10507, shown in Fig. 5.5, has the closest value to the mean scattering fractal dimension.

Hüzzam maqam is the third one according to the order of mean scattering fractal dimension values. In this maqam, the song 18781 has the dimension value nearest to mean scattering fractal dimension value of Hüzzam. Scattering diagram of this song is given in Fig. 5.6.

The last maqam which has the smallest mean scattering fractal dimension value is

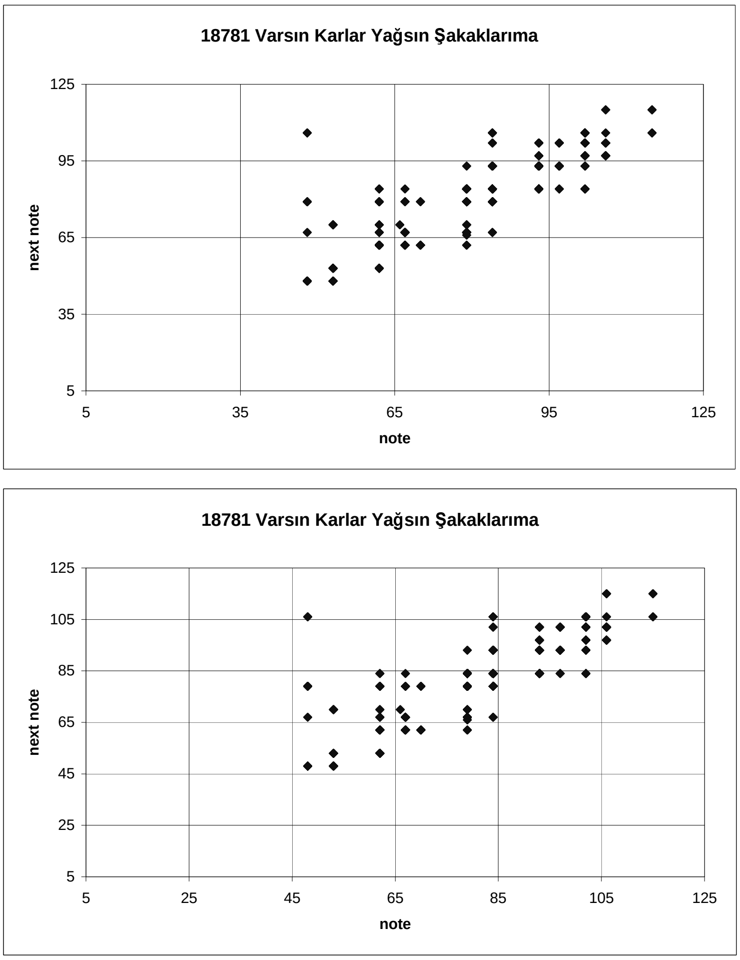


Figure 5.6: Scattering Diagram of Hüzzam Song - Varsın Karlar Yağsın Şakaklarıma

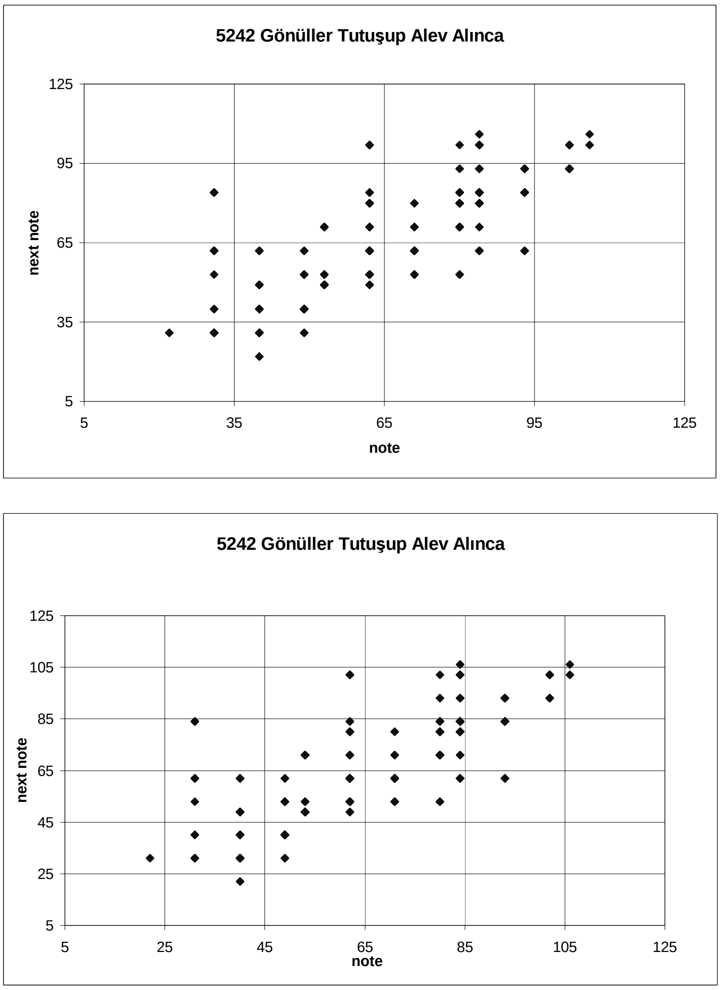


Figure 5.7: Scattering Diagram of Mahur Song - Gönüller Tutuşup Alev Alınca

Mahur. The fractal dimension of the song 5242 has the nearest value to the mean fractal dimension, and it is shown in Fig. 5.7.

5.1.2 Melody Fractal Dimension

In this section, melody fractal dimension calculations will be presented and compared with the scattering fractal dimension values. Melody fractal dimension is computed by using scattering diagram of the type containing duration of the notes.

In the first place, melody fractal dimensions and scattering fractal dimensions of Kürdi songs are given in Table 5.5. It can be found from the data that mean and standard

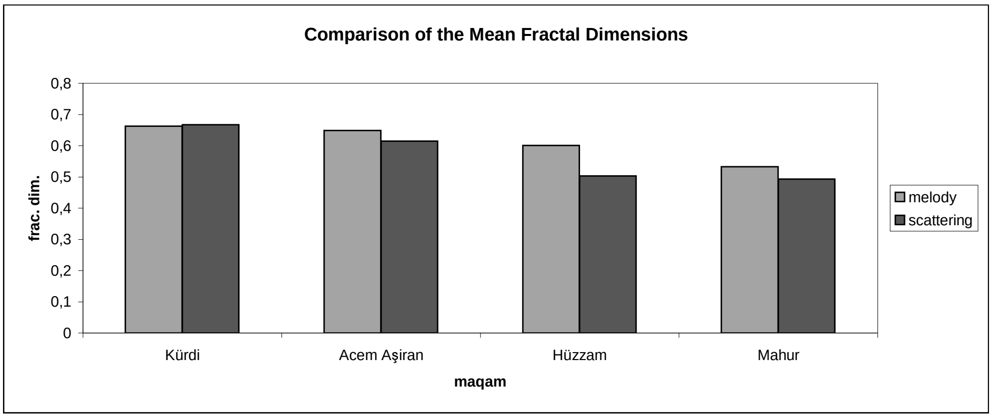


Figure 5.8: Comparison of the Mean Values of the Fractal Dimensions of the Maqams

deviation values of the melody fractal dimensions are 0.663, and 0.078 respectively.

Table 5.5: Kürdi Songs Fractal Dimensions Found with a Method in [41]

Song No	**Song Name**	**Scat.–Mel. Frac. Dim.**
2992	Hayal Kadın	0.607 – 0.597
6462	Hiç Tatmadım Böyle Duyguyu	0.580 – 0.691
11973	Ne Aşk Kaldı Ne De Bir İz	0.963 – 0.683
13062	Gel Bahardan Zevk Alalım	0.118 – 0.570
13451	Bulut Bulut Geçer İnsan	0.557 – 0.725
17479	Sever misin	0.747 – 0.789
17637	Ben Onu Gördüm Yıllardan Sonra	0.940 – 0.618
18691	Özür Dilerim	1.094 – 0.764
19250	Gül Goncası Nazende	0.71 – 0.615
19384	Ne Giden Aşklara Sor Gururun Bittiğini	0.355 – 0.582

As mentioned above, Kürdi maqam has the biggest scattering fractal dimension. On the other hand, the mean value of the melody fractal dimensions of the Kürdi maqam is low compared to the mean value of the scattering fractal dimensions. In fact, this difference is very small as can be seen from the values which are 0.663 and 0.667. Comparison of the mean values and standard deviations of the fractal dimensions are given in Fig. 5.8 and Fig. 5.9.

It can be distinguished from Table 5.5, that song 11973 shows the average Kürdi melody property. Phase diagram of this song is shown in Fig. 5.10.

Moreover, from these results, it is observed that the second maqam in the order

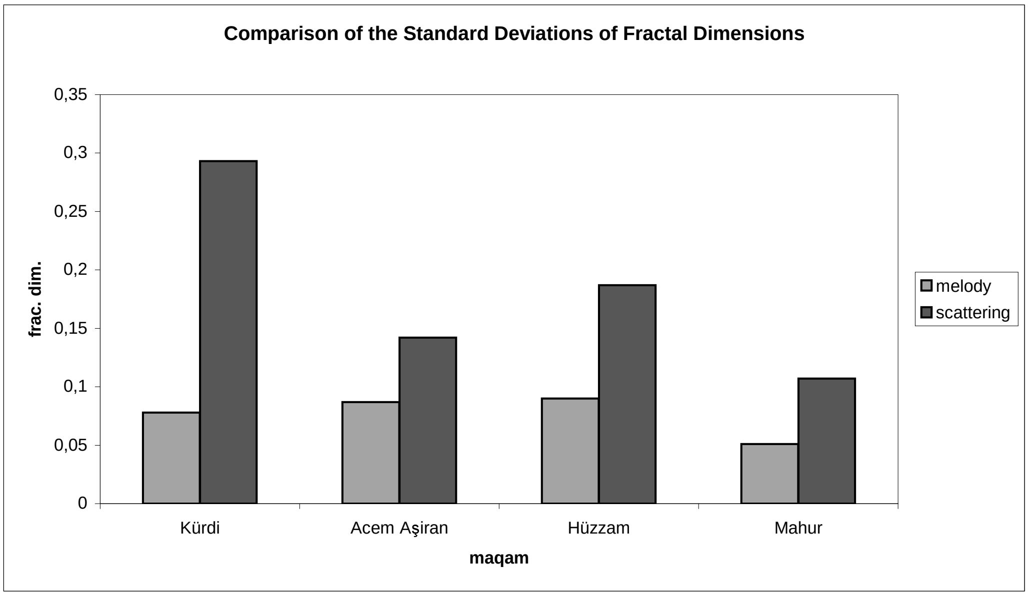


Figure 5.9: Comparison of the Standard Deviation Values of the Fractal Dimensions of the Maqams

of the maqams according to their mean melody fractal dimensions is Acem Aşiran. That is, maqam has a mean fractal dimension value 0.649, higher than the mean scattering fractal dimension value 0.615. Table 5.6 shows melody fractal dimensions and scattering fractal dimensions of Acem Aşiran songs.

Table 5.6: Acem Aşiran Songs Fractal Dimensions Found with a Method in [41]

Song No	**Song Name**	**Scat.–Mel. Frac. Dim.**
614	Aşık Oldum	0.855 – 0.738
1132	Bakma Sakın Benden Yana	0.674 – 0.724
2846	Coşkun Deniz	0.580 – 0.761
5986	Hani Nerde Beni Öpen Dudaklar	0.607 – 0.687
10235	Söz Verdim Adına Gelecek Diye	0.690 – 0.647
10507	Seviyorum Seni Güzel İstanbul	0.630 – 0.648
12969	Bir Anda Doldun İçime	0.756 – 0.593
13478	Şu Samsun'un Güzel Kızı	0.500 – 0.665
13889	Birtanem	0.500 – 0.538
18367	Rüyada Gibiyim	0.355 – 0.490

As can be seen from Table 5.6, song 10507 has the nearest melody fractal dimension to the mean of Acem Aşiran maqam whose melody scattering diagram is shown in Fig. 5.11.

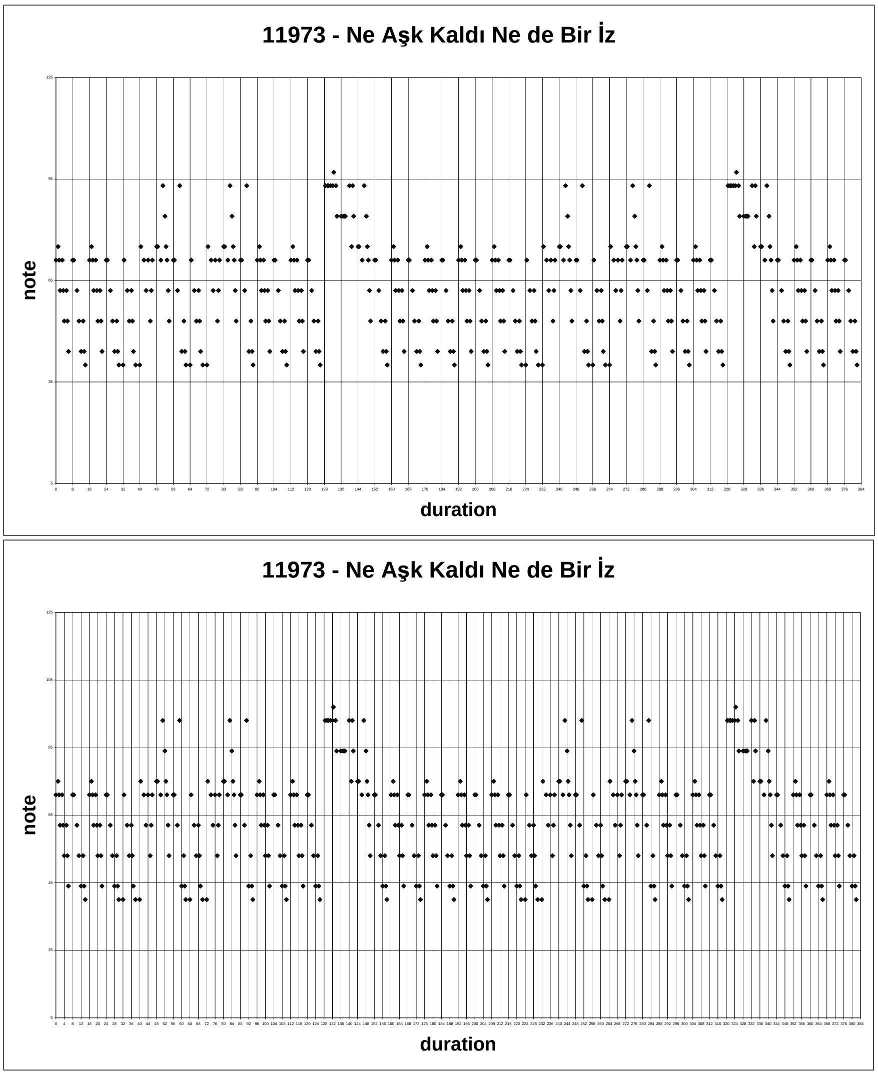


Figure 5.10: Kürdi Song - Ne Aşk Kaldı Ne De Bir İz.

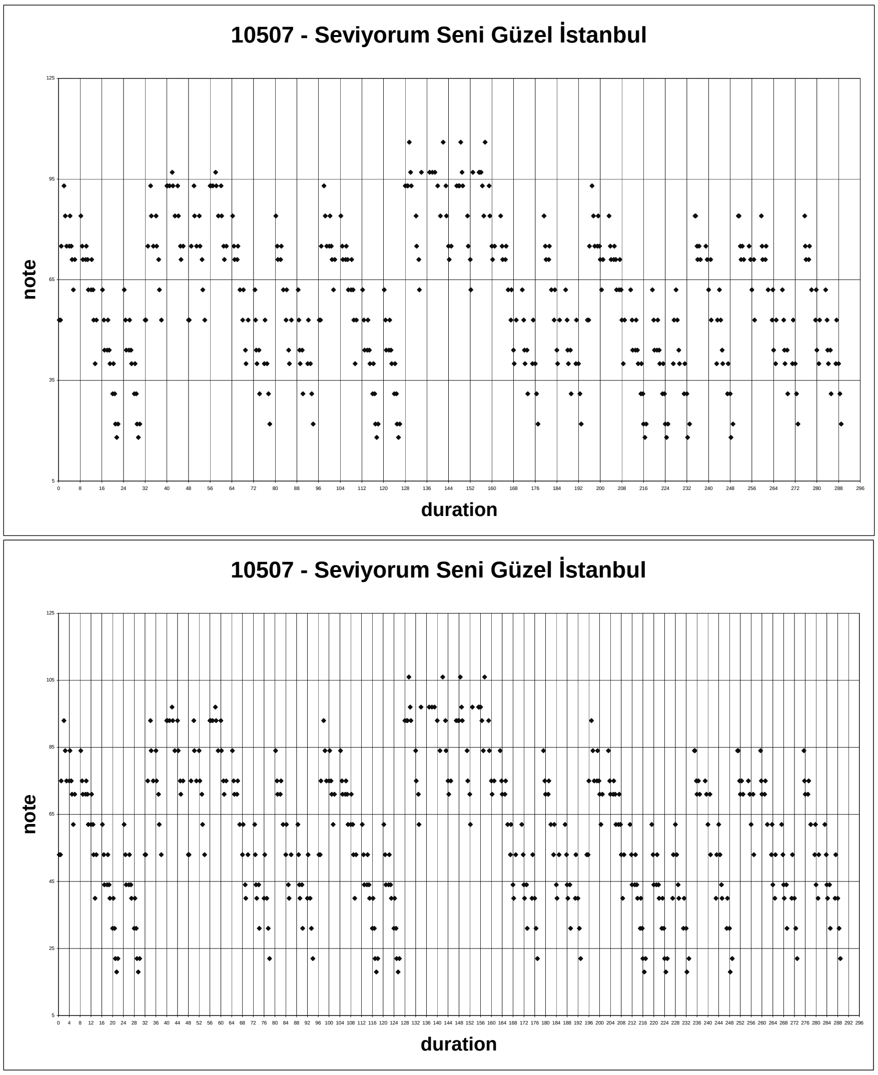


Figure 5.11: Acem Aşiran Song - Seviyorum Seni Güzel İstanbul.

Next, Hüzzam maqam will be examined. It has a bigger mean melody fractal dimension compared to the scattering one as can be seen from the fractal dimension values given in Table 5.7.

Table 5.7: Hüzzam Songs Fractal Dimensions Found with a Method in [41]

Song No	**Song Name**	**Scat.–Mel. Frac. Dim.**
4858	Eskisi Gibi	0.355 – 0.575
8427	O Kara Gözlerine Güzelim Dalıyorum	0.190 – 0.549
11870	Çiçek Açmaz Dallardayım	0.355 – 0.620
12185	Bu Ne Sevgi	0.440 – 0.684
12515	Tutuşurken Dalında Gül	0.599 – 0.555
12639	Gözlerin Karanlık Geceler Gibi	0.545 – 0.447
15898	Mutluluk Ve Keder	0.690 – 0.723
17687	Gözlerin Sevgi Dolu	0.500 – 0.552
18667	Sen Gideli Dile Düştüm	0.855 – 0.738
18781	Varsın Karlar Yağsın Şakaklarıma	0.500 – 0.568

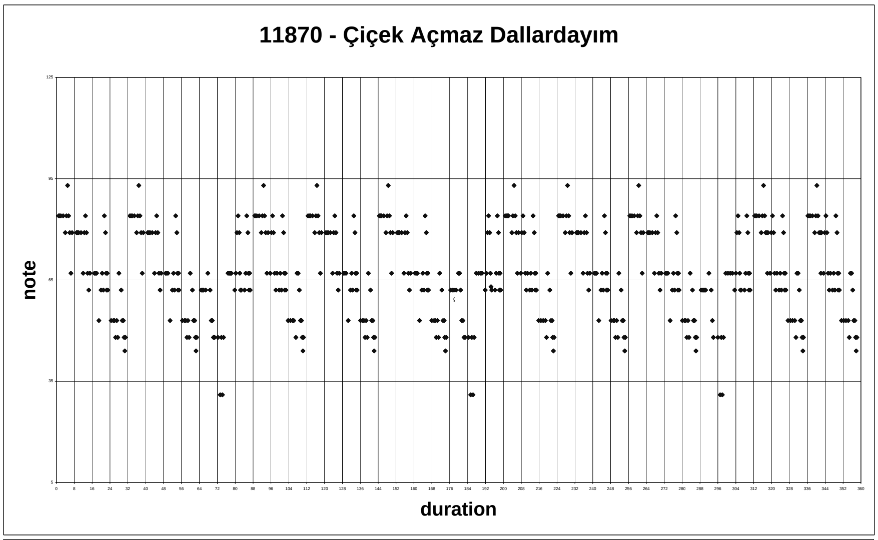
From Table 5.7, it can be distinguished that characteristic song whose melody fractal dimension close to the mean of melody fractal dimension of the Hüzzam maqam is song 11870. Melody scattering diagram of this song is shown in Fig. 5.12.

The last maqam covered in this section is Mahur which has the smallest mean melody fractal dimension value. In Table 5.8 fractal dimension values of the Mahur maqam can be seen.

Table 5.8: Mahur Songs Fractal Dimensions Found with a Method in [41]

Song No	**Song Name**	**Scat.–Mel. Frac. Dim.**
314	Al Bu Geceyi Vur Ötekine	0.297 – 0.524
413	Aman Aman Bağdatlı	0.500 – 0.57
1936	Mahur Şarkı	0.453 – 0.497
5242	Gönüller Tutuşup Alev Alınca	0.500 – 0.503
5302	Gördüm Bugün	0.674 – 0.662
6731	İstanbul'lu Akşamlar	0.430 – 0.537
6734	İstanbul'un Koynunda	0.430 – 0.532
11902	Herkes Birini Sever	0.607 – 0.506
12210	Kaybolan Hayallerim Gözlerinde Her Gece	0.462 – 0.483
17846	Mahur Beste Çalınsa	0.580 – 0.517

From Table 5.8, it can be stated that the song 6734 has the nearest value to the mean



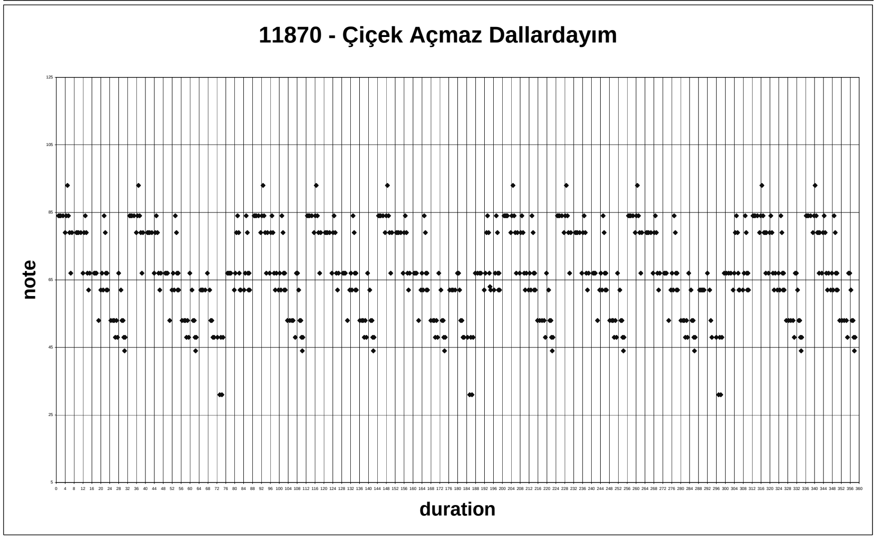


Figure 5.12: Hüzzam Song - Çiçek Açmaz Dallardayım.

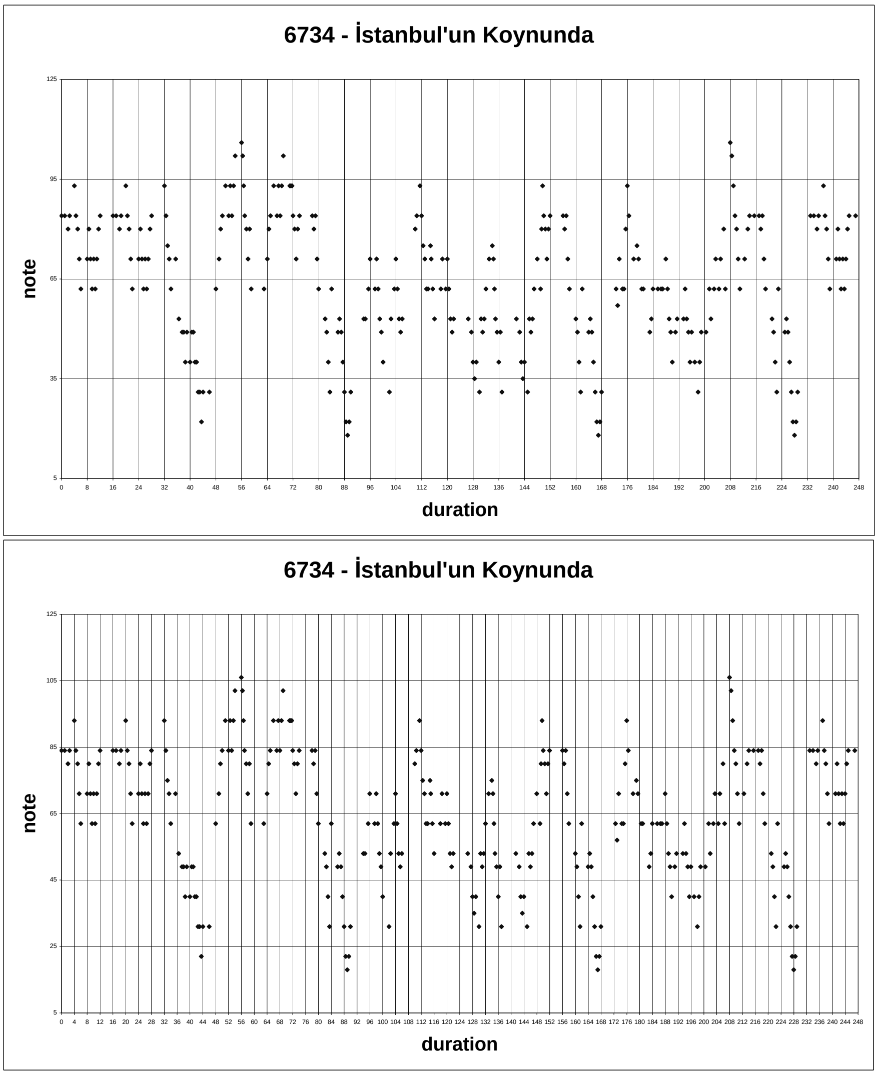
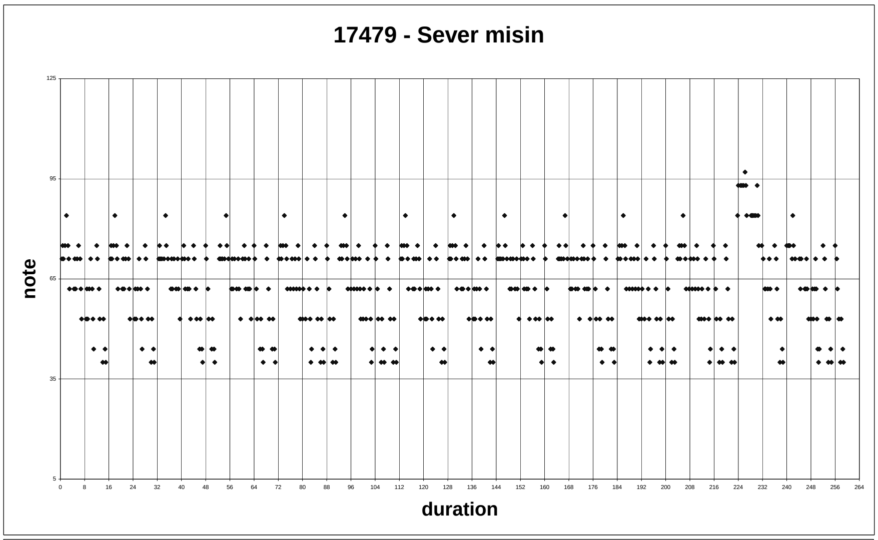


Figure 5.13: Mahur Song - İstanbul'un Koynunda.

melody fractal dimension of Mahur, and its phase portrait is given in Fig 5.13.

If all of the data are analyzed, it could be investigated that the order of the mean values of the fractal dimensions of the maqams is just the same with that of scattering fractal dimension. Moreover, if we look at the values of the melody fractal dimension, we see that the Kürdi song 17479 has the biggest value whose phase portraits are given in Fig. 5.14. Additionally, Mahur song 12210, whose melody scattering diagram is shown in Fig. 5.15 has the minimum melody fractal dimension value.



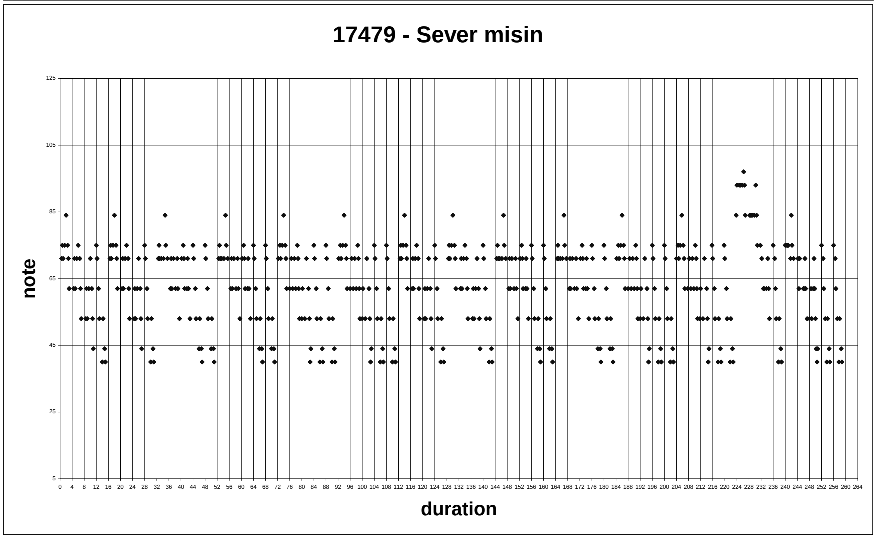


Figure 5.14: Kürdi Song - Sever misin.

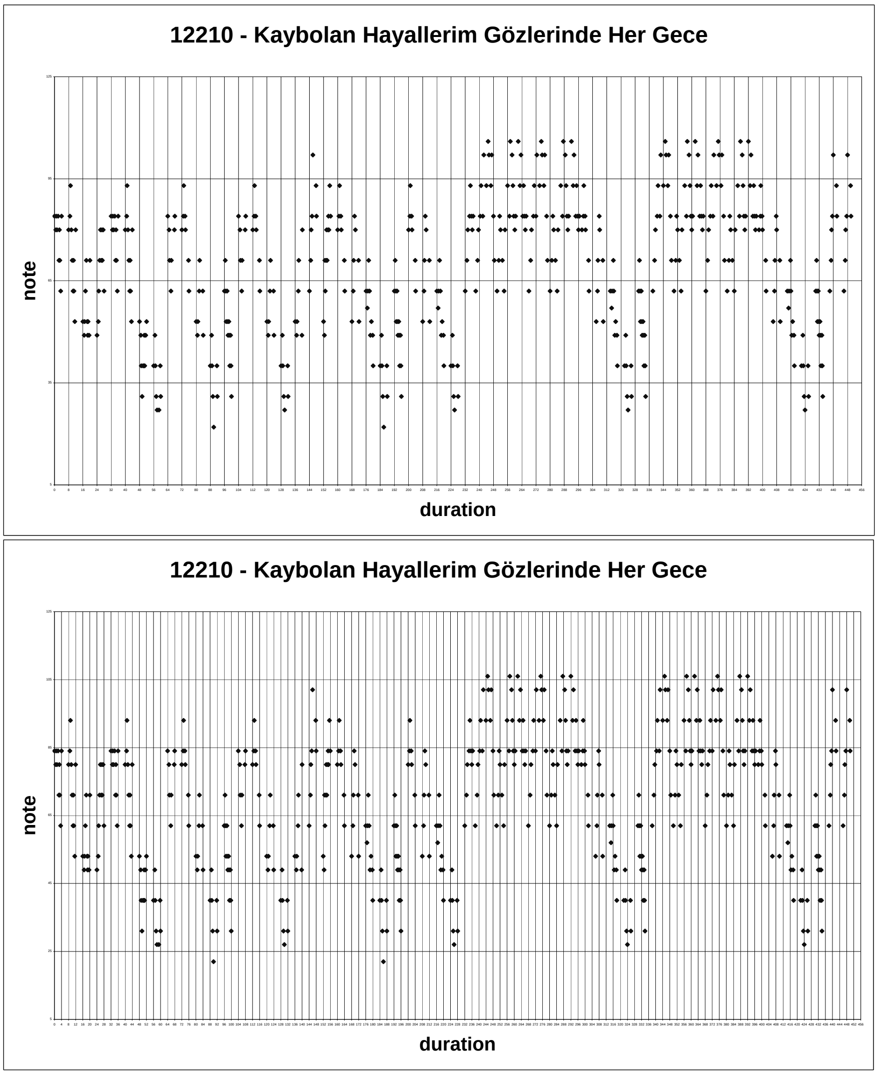


Figure 5.15: Mahur Song - Kaybolan Hayallerim Gözlerinde Her Gece.

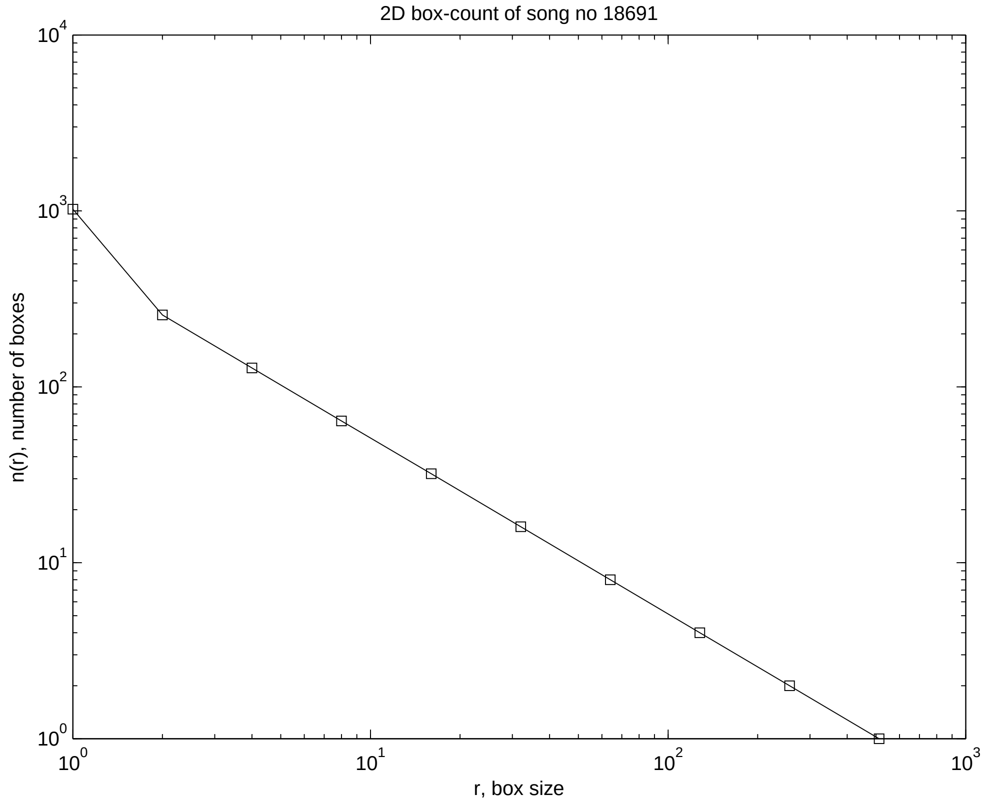


Figure 5.16: Graph Used for Calculation of Box Counting Dimension of the Song No:18691

5.2 Results of Fractal Dimension Calculations with the Linear Fit Method

In this section, fractal dimensions of the songs are calculated via the method used in [93, 94, 95, 96, 97]. There are some differences between the method used above and this method. First, in the linear fit method, as a result of using different box sizes, calculations become more accurate. Second, small box sizes give chance to check the details of the object. Another point about the usage of the method is that only melody scattering diagrams are used in calculations, since they include more musical features. To illustrate the process, graphs used for linear fit of the four songs are given in Fig. 5.16 to Fig. 5.19.

It is useful to follow the same order for presentation of the results of computation. Therefore, Kürdi songs will be covered firstly. The results of melody fractal dimensions of Kürdi songs calculated via linear fit are presented in Table 5.9. As can be seen from

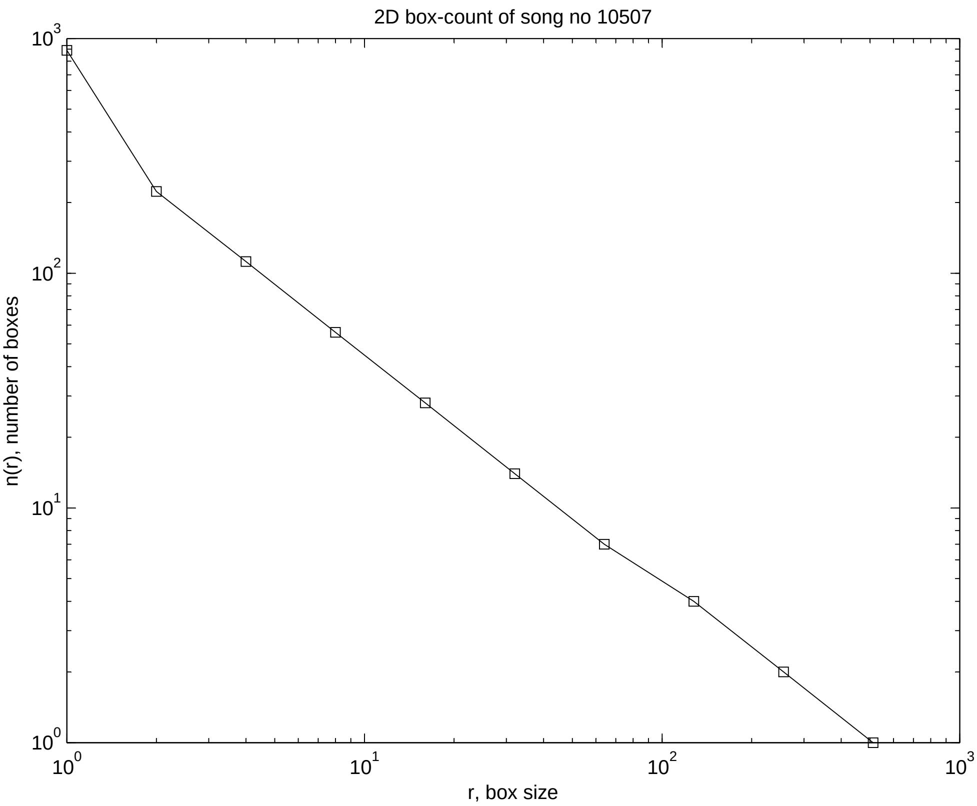


Figure 5.17: Graph Used for Calculation of Box Counting Dimension of the Song No:10507

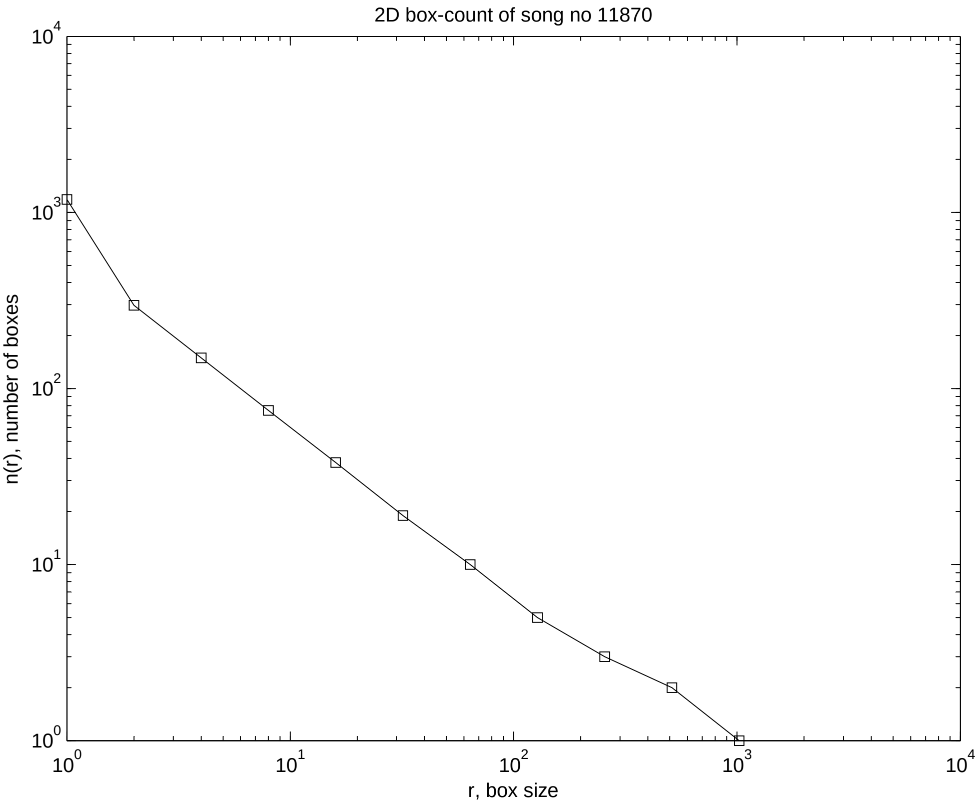


Figure 5.18: Graph Used for Calculation of Box Counting Dimension of the Song No:11870

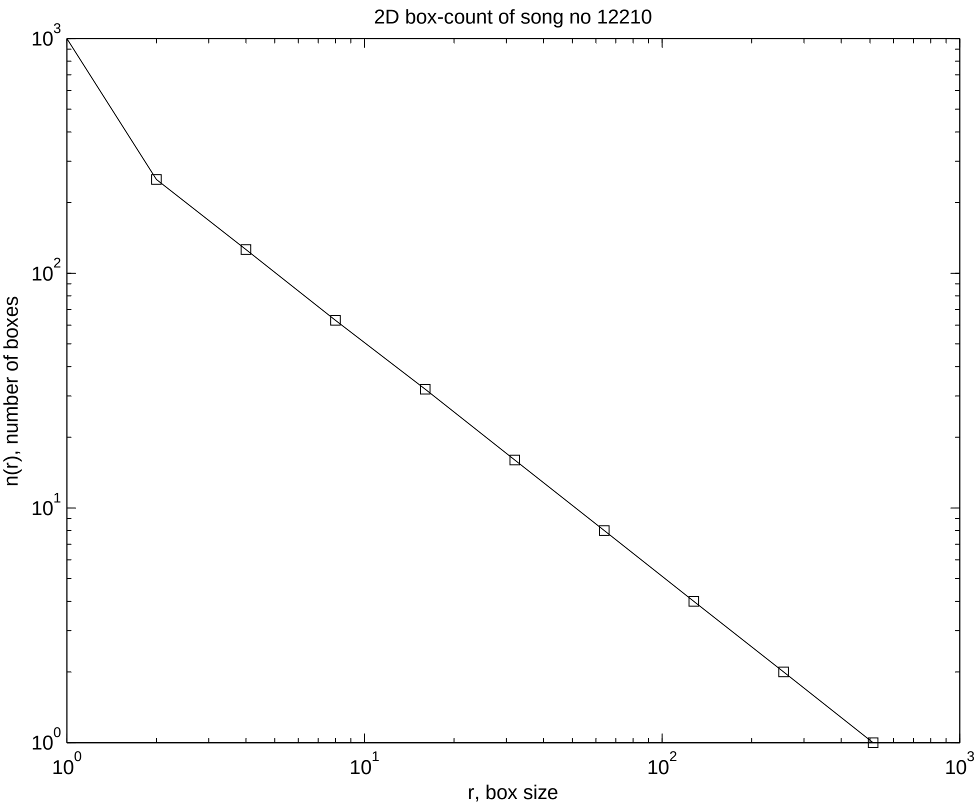


Figure 5.19: Graph Used for Calculation of Box Counting Dimension of the Song No:12210

the data, values of the dimensions are close to each other. In fact, the mean of the data is 0.303, and standard deviation is 0.011.

Table 5.9: Kürdi Songs Melody Fractal Dimensions Found with a Linear Fit Method

Song No	**Song Name**	**Mel. Frac. Dim.**
2992	Hayal Kadın	0.301
6462	Hiç Tatmadım Böyle Duyguyu	0.302
11973	Ne Aşk Kaldı Ne De Bir İz	0.305
13062	Gel Bahardan Zevk Alalım	0.287
13451	Bulut Bulut Geçer İnsan	0.317
17479	Sever misin	0.290
17637	Ben Onu Gördüm Yıllardan Sonra	0.304
18691	Özür Dilerim	0.317
19250	Gül Goncası Nazende	0.314
19384	Ne Giden Aşklara Sor Gururun Bittiğini	0.293

Secondly, Acem Aşiran maqam will be shown. Similarly, results of calculation are tabulated and shown in Table 5.10. Analogous to the results of Kürdi maqam, dimension values are close to each other. Furthermore, after the descriptive statistical analysis, mean is found as 0.305, and standard deviation of data found as 0.012.

Table 5.10: Acem Aşiran Songs Melody Fractal Dimensions Found with a Linear Fit Method

Song No	**Song Name**	**Mel. Frac. Dim.**
614	Aşık Oldum	0.315
1132	Bakma Sakın Benden Yana	0.312
2846	Coşkun Deniz	0.284
5986	Hani Nerde Beni Öpen Dudaklar	0.302
10235	Söz Verdim Adına Gelecek Diye	0.284
10507	Seviyorum Seni Güzel İstanbul	0.310
12969	Bir Anda Doldun İçime	0.312
13478	Şu Samsun'un Güzel Kızı	0.314
13889	Birtanem	0.298
18367	Rüyada Gibiyim	0.315

Thirdly, Hüzzam maqam is studied. At the end of the same procedure, we get the results which are given in Table 5.11. Again, we faced with a similar situation. Namely, mean value of the data is 0.303, and standard deviation is 0.007.

Lastly, fractal dimension values of the Mahur maqam are presented in Table 5.12.

Table 5.11: Hüzzam Songs Melody Fractal Dimensions Found with a Linear Fit Method

Song No	Song Name	Mel. Frac. Dim.
4858	Eskisi Gibi	0.298
8427	O Kara Gözlerine Güzelim Dalıyorum	0.298
11870	Çiçek Açmaz Dallardayım	0.292
12185	Bu Ne Sevgi	0.300
12515	Tutuşurken Dalında Gül	0.309
12639	Gözlerin Karanlık Geceler Gibi	0.299
15898	Mutluluk Ve Keder	0.316
17687	Gözlerin Sevgi Dolu	0.307
18667	Sen Gideli Dile Düştüm	0.302
18781	Varsın Karlar Yağsın Şakaklarıma	0.307

Similar to the other maqams, dimension values of the Mahur songs are close to each other. That is, mean value of the data is 0.307, and standard deviation is 0.013.

Table 5.12: Mahur Songs Melody Fractal Dimensions Found with a Linear Fit Method

Song No	Song Name	Scat. Frac. Dim.
314	Al Bu Geceyi Vur Ötekine	0.313
413	Aman Aman Bağdatlı	0.320
1936	Mahur Şarkı	0.320
5242	Gönüller Tutuşup Alev Alınca	0.313
5302	Gördüm Bugün	0.289
6731	İstanbul'lu Akşamlar	0.289
6734	İstanbul'un Koynunda	0.294
11902	Herkes Birini Sever	0.296
12210	Kaybolan Hayallerim Gözlerinde Her Gece	0.316
17846	Mahur Beste Çalınsa	0.317

5.3 Comparative Analysis

In the first place, comparison of the results of scattering fractal dimensions and melody fractal dimensions calculated by using the method described in [41] will be given. From the Tables 5.5 to Table 5.8, it is seen that the values of melody fractal dimension and scattering fractal dimension are compatible. On the other hand, the maximum values and standard deviation of the melody fractal dimension are lower than that of the scattering fractal dimension.

In addition to the these determinations, there are some important differences between the fractal dimension values of the songs. For example, the Kürdi song Özür Dilerim has the biggest scattering fractal dimension; however, its melody fractal dimension value is nearly equal to the average value. Similarly, Gel Bahardan Zevk Alalım song has the lowest scattering fractal dimension. On the other hand, there is no such situation in its melody fractal dimension.

Some other important points can be seen in the Hüzzam Songs. For example, fractal dimension values of Varsın Karlar Yağsın Şakaklarıma are nearest to the mean ones. On the other hand, we can not see such a consistence in the the song Çiçek Açmaz Dallardayım.

After the analysis of computations carried out by using the method in [41], the values of melody fractal dimensions of songs calculated by using both of the methods will be compared. This comparison can be demonstrated using tables from 5.13 to 5.16.

The first and the most important consequence is that, there is no correlation between the two group of data. Secondly, range of the values of the first method is very large compared to the linear fit method. Thirdly, there is a considerable decrease in the values of fractal dimension when linear fit is used. Finally, there is no relation found between the extremum values of these two groups of data.

Table 5.13: Comparison of Melody Fractal Dimension Calculations of Kürdi Maqam

Song No	**Song Name**	**Gündüz**	**Linear Fit**
2992	Hayal Kadın	0.597	0.301
6462	Hiç Tatmadım Böyle Duyguyu	0.691	0.302
11973	Ne Aşk Kaldı Ne De Bir İz	0.683	0.305
13062	Gel Bahardan Zevk Alalım	0.570	0.287
13451	Bulut Bulut Geçer İnsan	0.725	0.317
17479	Sever misin	0.789	0.290
17637	Ben Onu Gördüm Yıllardan Sonra	0.618	0.304
18691	Özür Dilerim	0.764	0.317
19250	Gül Goncası Nazende	0.615	0.314
19384	Ne Giden Aşklara Sor Gururun Bittiğini	0.582	0.293

Table 5.14: Comparison of Melody Fractal Dimension Calculations of Acem Aşiran Maqam

Song No	**Song Name**	**Gündüz**	**Linear Fit**
614	Aşık Oldum	0.738	0.315
1132	Bakma Sakın Benden Yana	0.724	0.312
2846	Coşkun Deniz	0.761	0.284
5986	Hani Nerde Beni Öpen Dudaklar	0.687	0.302
10235	Söz Verdim Adına Gelecek Diye	0.647	0.284
10507	Seviyorum Seni Güzel İstanbul	0.648	0.310
12969	Bir Anda Doldun İçime	0.593	0.312
13478	Şu Samsun'un Güzel Kızı	0.665	0.314
13889	Birtanem	0.538	0.298
18367	Rüyada Gibiyim	0.490	0.315

Table 5.15: Comparison of Melody Fractal Dimension Calculations of Hüzzam Maqam

Song No	**Song Name**	**Gündüz**	**Linear Fit**
4858	Eskisi Gibi	0.575	0.298
8427	O Kara Gözlerine Güzelim Dalıyorum	0.549	0.298
11870	Çiçek Açmaz Dallardayım	0.620	0.292
12185	Bu Ne Sevgi	0.684	0.300
12515	Tutuşurken Dalında Gül	0.555	0.309
12639	Gözlerin Karanlık Geceler Gibi	0.447	0.299
15898	Mutluluk Ve Keder	0.723	0.316
17687	Gözlerin Sevgi Dolu	0.552	0.307
18667	Sen Gideli Dile Düştüm	0.738	0.302
18781	Varsın Karlar Yağsın Şakaklarıma	0.568	0.307

Table 5.16: Comparison of Melody Fractal Dimension Calculations of Mahur Maqam

Song No	**Song Name**	**Gündüz**	**Linear Fit**
314	Al Bu Geceyi Vur Ötekine	0.524	0.313
413	Aman Aman Bağdatlı	0,570	0.320
1936	Mahur Şarkı	0.497	0.320
5242	Gönüller Tutuşup Alev Alınca	0.503	0.313
5302	Gördüm Bugün	0.662	0.289
6731	İstanbul'lu Akşamlar	0.537	0.289
6734	İstanbul'un Koynunda	0.532	0.294
11902	Herkes Birini Sever	0.506	0.296
12210	Kaybolan Hayallerim Gözlerinde Her Gece	0.483	0.316
17846	Mahur Beste Çalınsa	0.517	0.317

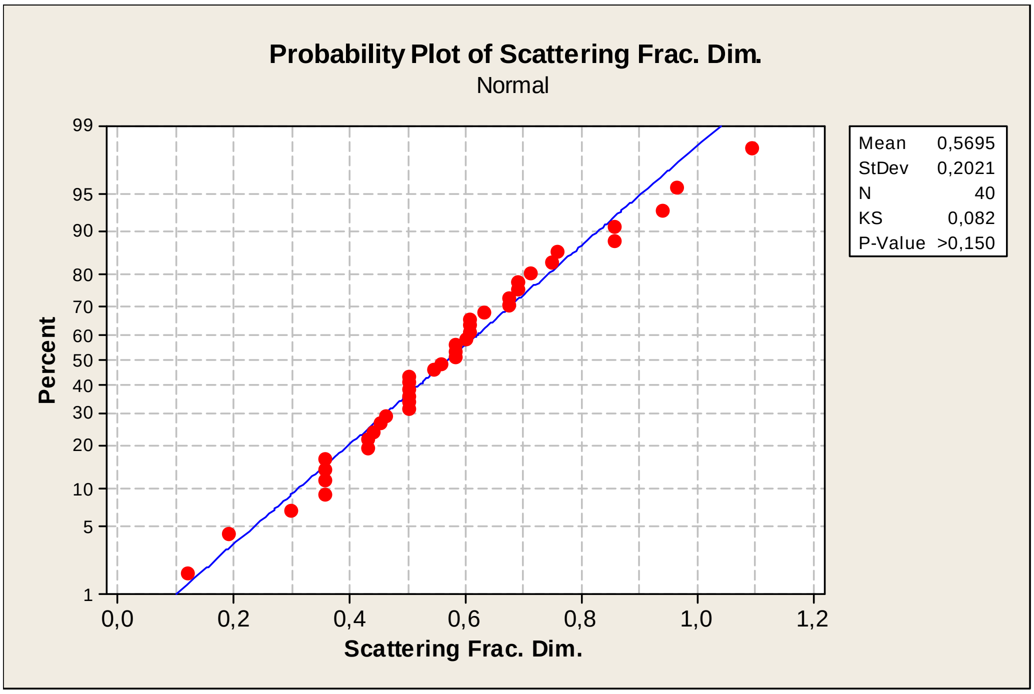


Figure 5.20: Distribution of the Data of Scat. Frac. Dim. Calculated with the Method Used in [41]

5.4 Statistical Tests

In this part, statistical test results will be presented. Both T test and F test require the data to be normally distributed as in our sets shown in Fig. 5.20, Fig. 5.21, and Fig. 5.22.

In the first place, results of statistical tests are applied to the box counting dimensions of songs which are calculated by using the method used in [41] will be given. To begin, outcomes of T test, which is used for determining the statistical significance of the scattering fractal dimension values, are demonstrated. In fact, we have taken $\alpha = 0.1$ for T test. This means that our results have ninety percent consistency. In Table 5.17, T test scores of the scattering fractal dimension are given. From the table, it can be stated that only the Acem Aşiran – Mahur and Kürdi – Mahur P values are smaller than our α value. Therefore, a statistically significant difference occurs only in these two cases.

Next, results of F test which is applied to the melody fractal dimension values are given. In this case, we have used $\alpha = 0.05$. The summary of the results is given in

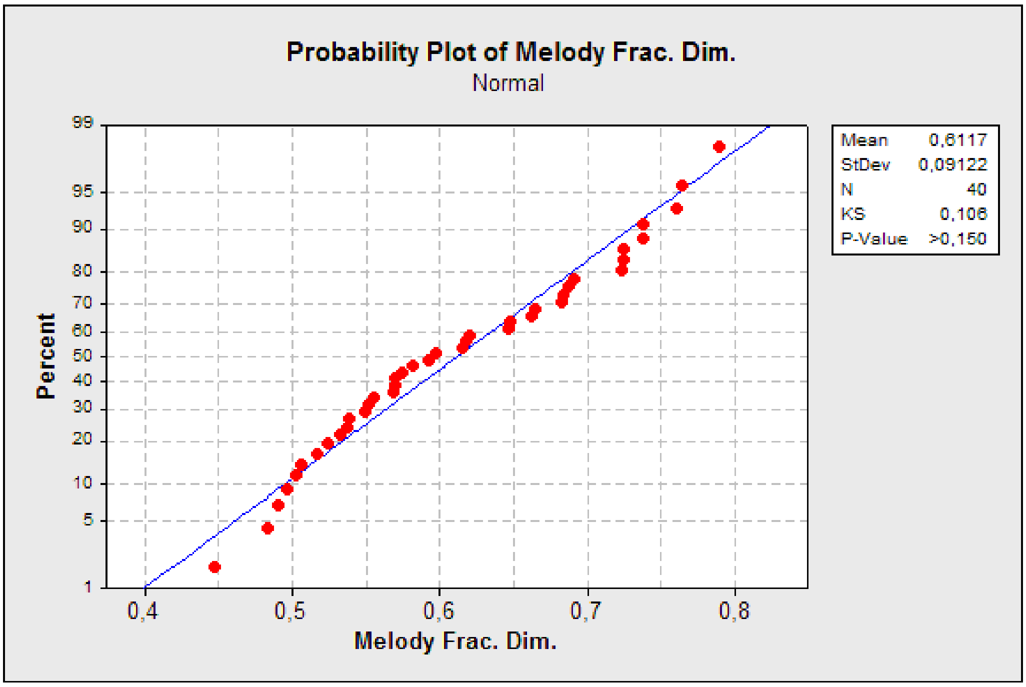


Figure 5.21: Distribution of the Data of Mel. Frac. Dim. Calculated with the Method Used in [41]

Table 5.17: Results of Two Sample T Tests Applied to Scat. Frac. Dim.

	N	**Mean**	**SE Mean**
Acem Aşiran	10	0.615	0.045
Kürdi	10	0.667	0.093
P–Value = 0.617			
Acem Aşiran	10	0.615	0.045
Mahur	10	0.493	0.034
P–Value = 0.045			
Acem Aşiran	10	0.615	0.045
Hüzzam	10	0.503	0.059
P–Value = 0.150			
Kürdi	10	0.667	0.093
Mahur	10	0.493	0.034
P–Value = 0.095			
Kürdi	10	0.667	0.093
Hüzzam	10	0.503	0.059
P–Value = 0.153			
Mahur	10	0.493	0.034
Hüzzam	10	0.503	0.059
P–Value = 0.890			

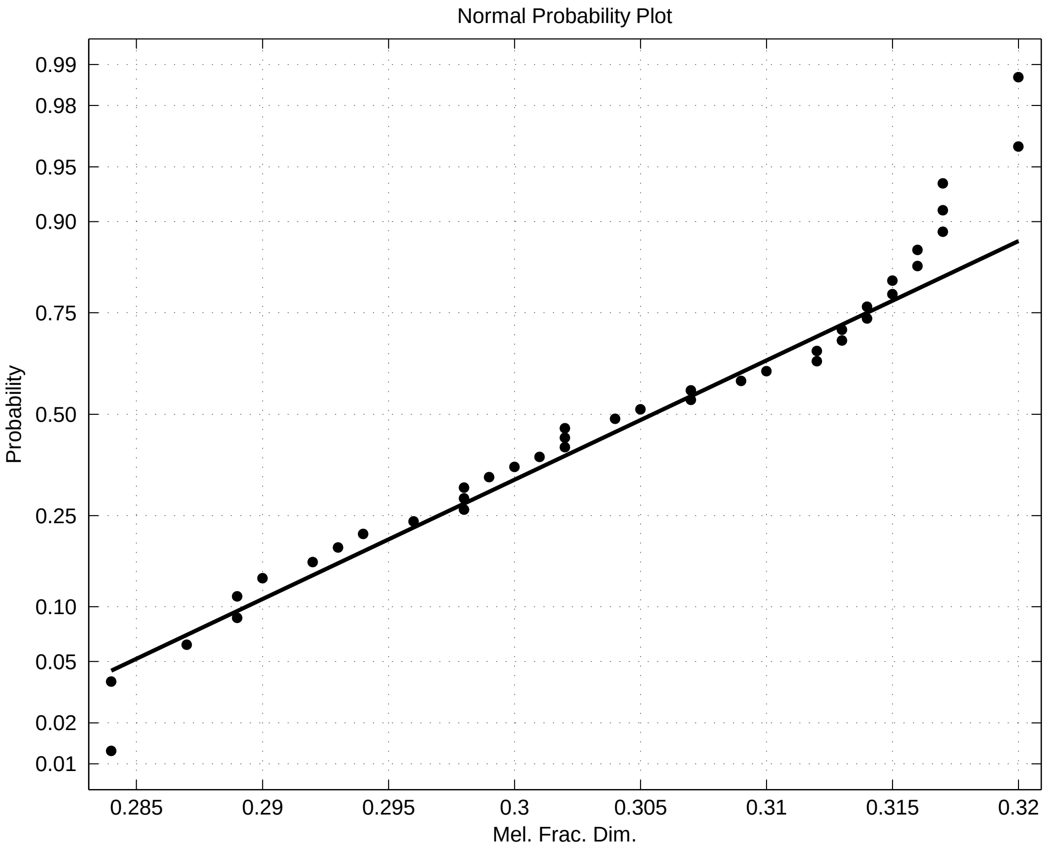


Figure 5.22: Distribution of the Data of Mel. Frac. Dim. Calculated with Linear Fit Method

Table 5.18, where we can see that P value is smaller than our $\alpha = 0.05$ value which means that there is significant difference between the maqams when it is examined by using melody fractal dimension.

Table 5.18: Results of F Test Applied to Mel. Frac. Dim. Calculated Via Method in [41]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0,10362	3	0,03454	5,628315	0,002865	2,866266
Within Groups	0,220925	36	0,006137			
Total	0,324545	39				

Following these studies, statistical test scores of the melody fractal dimension values which are found by using the linear fit method are given. Both T test and F test are applied to these data but no significant statistical difference could be found. To illustrate, results of F test are presented in Table 5.19.

Table 5.19: Results of F Test Applied to Mel. Frac. Dim. Calculated Via Linear Fit Method

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9,79E-05	3	3,26E-05	0,26987	0,846688	2,866266
Within Groups	0,004352	36	0,000121			
Total	0,00445	39				

Table 5.20: Results of Descriptive Statistics Applied to Mel. Frac. Dim. Calculated Via Linear Fit Method

MEL. FRAC. DIM.	
Mean	0,304275
Standard Error	0,001689
Median	0,3045
Mode	0,302
Standard Deviation	0,010682
Sample Variance	0,000114
Range	0,036
Minimum	0,284
Maximum	0,32
Sum	12,171
Count	40
Confidence Level(99,5%)	0,005026

On the other hand, when descriptive statistical tools are applied to all of the linear fit data, we get a very consistent result which is given in Table 5.20.

CHAPTER 6

CONCLUSION

In this thesis, fractal dimensions of forty songs are calculated by using two different box counting methods. The first method is also used by Gündüz in [41]. In the paper of Gündüz, fractal dimensions of the songs are found by using scattering diagrams which can be constructed by drawing a graph of note versus next note. In that work, they find the fractal dimension of the songs by using two different resolutions of these graphs. In this thesis, a modified version of this method is used.

First of all, notes are described according to their positions in one of the Turkish art music sound systems – 24 keys Arel system –. Secondly, a new form of a scattering diagram is introduced and called melody phase diagram. Differently, this diagram includes the duration of the notes which is one of the most important features of the songs. In fact, this diagram is the graph of duration versus note. Results of calculations by using these diagrams are called melody fractal dimensions. Thirdly, forty songs are selected randomly from the Turkish Radio Television (TRT) archives. In addition, these songs are restricted to be in one of the four maqams which are randomly chosen. Moreover, rhythmic forms of the songs are restricted to the sofyan usul to reduce the number of parameters included and to check the statistical significance. Fourthly, statistical tests are applied to the results of calculations to check whether there are statistical differences between the fractal dimension values of the maqams.

In addition to these modifications, the second form of box counting method is used to calculate the fractal dimensions. In order to use this formalism, we used the coding of the songs as used in melody fractal dimension. After that, successively decreasing the sizes of the boxes and following the method described in Chapter 4 gives the fractal dimensions of the songs. Then, statistical tests are used to control the statistical significance.

By doing these calculations, we try to find the answers to the following questions:

- Can we use a fractal dimension as an information source concerning the songs which are nonlinear dynamical systems?
- Is there a special fractal dimension for the maqam(s)?
- What are the differences between methods of calculation of box counting dimension?

After the computations, two kinds of results are obtained. First kind of results are obtained from the calculations of fractal dimension via the first method. According to these results, maqams can have their special fractal dimensions. Indeed, we can say that there could be a mean fractal dimension value for these maqams. Moreover, mean value of fractal dimension gives information about the irregularity of a maqam. It can also be said that fractal dimension can be a source of information about the irregularity of the melody of the song. In fact, it is possible to state that if the fractal dimension of the song is high, it has a high irregularity. Furthermore, from the order of the mean fractal dimensions, it can be concluded that the Kürdi and Acem Aşiran maqams exhibit more irregular patterns.

Another important point that can be gathered from these results is the observation of the importance of time in music. It is an obvious fact that music can not be thought without the duration of the notes. This is proved by the decrease in the standard deviation values of the melody fractal dimensions. Furthermore, it can be concluded that more musical features are included in geometry of the songs when melody fractal dimension is used. Moreover, it can be set that melodic properties of the maqams, especially effect of the seyir (path), can be better understood by considering melody fractal dimension since it includes the duration of the notes.

Final result of the first part is that although Acem Aşiran and Mahur are both transpositions of the Çargah maqam, T test analysis of the first part of the results showed that Mahur exhibits a statistically significant difference from Acem Aşiran and Kürdi.

The second part of results are obtained from the outcomes of calculations of fractal dimensions via linear fit method. In contrast to previous conclusions, maqams do not have theis own fractal dimension. Namely, results of the statistical tests showed that there is significant difference between the maqams. However, descriptive statistics show that geometry of all the songs resemble each other. That is, we have a narrow range and small standard deviation. Therefore, it can be stated that all of the songs have similar fractal properties.

One of the most important purposes of this thesis is setting the difference of the two methods of calculations. In fact, the first method is a simplified version of the second one. Thus, the purpose can be restated as following: Checking whether this simplification causes loss of information.

There are different ways to see this situation. From the musician's point of view, there should be some limit for the resolution of the duration; otherwise, the song as a whole, can not be understood. Therefore, simplification can be useful. In other words, we can get musical information from the first part of the computations. On the other hand, from the scientist's point of view, results of the calculations state that there is a huge difference between the two groups of data. Thus, the first method can be taken as oversimplified.

However, we think that these kinds of issues can not be decided by using only one perspective. Music, as explained, is a complicated phenomena; and in order to study on it, interdisciplinary approaches are necessary. From this point of view, we can conclude that both of the methods are useful.

There are many topics that can be thought for a further study in the future. Basically, this work can be extended to other maqams and songs. This will give the chance to check the validity of the results. By doing such a work, comparison of these two methods will also be possible.

Another tool that can be used to get fractal properties of the songs is the time series analysis. In fact, such a research can be done by using the coding of the song as introduced in this thesis. Moreover, this tool can be used for examining the actual performance in audio files. In addition, it is also possible to check the fractal properties of instrument, style, sound, or similar musical features by using this sort of a time series tool. Such a tool working in matlab can be found in [101].

Another problem that can be studied is the problem of mismatch of theoretical sound system and applications. To solve this problem, it is possible to make an experimental study. Process can be designed as follows: First, sufficient number of professional fretless instrument players will play the selected songs. After collecting enough amount of data, a statistical study will give the result.

Furthermore, to combine methods of musical analysis and kind of methods used in this thesis, comparative study can be done including, for example, fractional analysis used in music and fractal geometry.

In summary, it can be concluded that Turkish art music songs show a fractal behavior. Moreover, from general perspective, maqams can have fractal properties; but as the resolution becomes higher, this property disappears. Finally, in order to get more accurate results, more data concerning studies of the other maqams are necessary.

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