Pitch Patterns of Cypriot Folk Music between Byzantine and Ottoman Influence

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Abstract

Music of Cyprus has received influence from other music traditions due to geographical and historical reasons. This thesis focuses on an investigation of Byzantine and Ottoman music influence as observed from the underlying *pitch patterns*. The notion of pitch patterns in this context comprises the tuning of the scale, the use of intervals and the prominence of scale degrees.

A computational comparative analysis was applied on sung melodies of Cypriot music and mainly religious Byzantine and Ottoman music. This was an innovative approach in the analysis of Cypriot folk tunes as well as the empirical study of the tuning of Byzantine scales and its relations with Ottoman music.

The proposed methodology was based on the use of pitch class profiles, specifically designed to integrate the particularities of these music traditions. Novel algorithms were particularly employed for the tasks of pitch histogram computation, smoothing and alignment and the challenges of scale note extraction. A combination of similarity measures was further proposed.

Results revealed that the use of intervals in Cypriot music was rather equally similar to both traditions whereas the prominence of scale degrees shared some tendencies with Byzantine music. On the other hand, influence in the tuning of the scales showed more similarity with Byzantine music. Integration of Byzantine-Ottoman inter-dependencies in their relation to Cypriot music is left for future work.

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1 Introduction

1.1 Background

Being an island in the Mediterranean Sea and a connecting point between Europe, Asia and Africa, Cyprus has always been an attractive destination of many occupiers [Encyclopaedia Britannica, 2011]. Cyprus kept changing sovereigns, from Romans (58 BC) to Byzantines (395 AD) to Arabs (688 AD) and again to Byzantines (965 AD), and then from King Richard I of England (1191 AD) to Guy of Lusignan (1192 AD) and Venetians (1489 AD). In 1570, Cyprus became an Ottoman possession and thousands of Muslims settled on the island. In 1878, the Cyprus Convention between Britain and Turkey provided that British government should administer Cyprus, while Cyprus is under the Turkish sovereignty. This changed in 1914 when Cyprus became officially a crown colony, a fact that was welcomed by the Greek-Cypriots who, opposed to the Turkish-Cypriots, demanded union with Greece.

The republic of Cyprus was eventually established in 1960 although the long-standing conflict between the Greek-Cypriot and the Turkish-Cypriot populations was not solved. This culminated with the partition of the island to the northern third inhabited by Turkish Cypriots and the southern two-thirds by Greek Cypriots after the Turkish invasion in 1974 [BBC News, 2011].

As a consequence of this long-term history of occupiers, the multiculturalism of Cyprus is evident today in many aspects of the Cypriot daily life, let alone entertainment and especially, music. Cypriot music[1] has a special character built upon all these years of cultural exchanges. Out of all, we focus on elements of particularly the Greek and Turkish traditions that have been interacting with Cypriot culture for the geographical reasons and historical reasons described above.

In the music world, Greek and Turkish characteristics are reflected, amongst others, in Ottoman music (*makam* modal system) and Byzantine music (*echos* modal system). Ottoman music is defined as the music of the Ottoman Empire (1389–1918) dominating in areas such as Istanbul, Izmir and south-east Anatolia cities where Turkish was the language of the Muslim population (redefined also as "Turkish classical music" after the Republic of Turkey in 1923) [Feldman, 2011]. Byzantine music is the liturgical rite of the Christian Roman Empire since the establishment of Constantinople (as was named during the Byzantine Empire and Istanbul as was renamed afterwards by the Ottomans) that is still practiced today by the Eastern Orthodox Christians (Greeks, Russians, Romanians etc.) whose native or liturgical language is Greek [Levy et al., 2011]. These two music traditions have a long history, influencing but also being influenced by the countries belonging to the two empires and its neighbours.

Initial hypothesis is that Byzantine and Ottoman music influence has also reached Cyprus, for the historical and geographical reasons explained above. With the present

[1] With the present study we refer to *Cypriot* music as what today is Greek Cypriot folk music. However, the Cypriot music collection we analyse in this study includes recordings dated before 1974 that originated in both parts of the island but were mainly practiced by the Greek speaking population.

research we aim to study the characteristics of traditional music of Cyprus and track any possible similarities with Ottoman and Byzantine music. Bearing in mind that Cypriot, Ottoman and Byzantine music belong to the orally transmitted and mainly monophonic music traditions, we restrict our study to the melodic and tonal features as summarised in the notion of a pitch pattern.

1.2 Motivation

Research in the Cypriot music started just at the end of the 19th century, initially focusing on the text of the songs and eventually on the musical structure. The most important studies on Cypriot music appeared in the 20th c. with independent musicians/musicologists publishing collections of Cypriot songs transcribed in Byzantine and/or Western notation. It was at this point that Cypriot music experts started suggesting strong influence from Byzantine and Ancient Greek music. Influence from Turkish music on the other hand, was rarely mentioned or in case of [Zarmas, 1993] would only be admitted if scientific methods proved it existed.

Tools for empirical investigation of stylistic similarity are available today due to the advances of the multidisciplinary field of Music Information Retrieval (MIR). Incorporating musicology, signal processing and statistical modelling, a variety of ideas, algorithms and systems have been proposed to organize, understand and search large collections of music.

The study of ethnic or traditional music styles falls in the concept of *Computational Ethnomusicology,* a recently introduced branch of MIR which refers to the use of computational methods to assist in ethnomusicology research [Tzanetakis et al., 2007]. The term “Ethnomusicology” in this content defines the “study of all world’s music without implying particular methodology” and distinction from “Musicology” can be seen in aspects as the ones summarised in the table below.

Discipline	Musicology	Ethnomusicology
Music studied	Notated music of Western cultural elites	Everything else
How it is transmitted	Notation	Oral transmission
Methodology	Analysis of scores and other documents	Fieldwork, ethnography

Table 1.1: Some of the distinctions between Musicology and Ethnomusicology [Tzanetakis et al., 2007].

This concept is particularly useful for the study of orally transmitted music traditions such as the ones considered in this study, since manual annotations might be subjective or erroneous if generated from people with different criteria and musical backgrounds [Toiviainen et al. 2006], in particular with respect to subtle nuances in intonation or temperament. Second, manual analysis of scores and recordings is a time consuming task, thus restricting the study on relatively small music collections.

However, for a long time MIR research has been focused on the analysis of mainly "Western" music and has neglected music from not so popular traditions, i.e. the "non-Western" music. The characteristics of non-Western music and their distinction from Western often require the improvement and/or implementation of new MIR tools. In the table below we list some of the differences between Western and non-Western music as stated in [Leonidas 2010, Gomez & Herrera 2008]. Note however that these features are not incorporated in all non-Western music or not all properties apply at the same time.

Feature	Western	Non-Western
Octave deviation	Equal temperament	Non tempered
Tuning	Standard diapason	No standard tuning
Number of used intervals per octave	12 possibilities	More than 12 possibilities
Practice Vs. Theory	Can be studied both ways as theory defines the actual practice.	Lack of ground truth due to oral transmission. Theory is descriptive.

Table 1.2: Some of the differences between Western and non-Western music

In the past years, a significant amount of researchers have experimented with the application of (new) MIR tools in the analysis of non-Western music. Naming here a few:

- Pitch analysis of Turkish Maqam music, [Bozkurt et al. 2009, Bozkurt 2008, Gedik & Bozkurt 2010] and development of the Makam Toolbox2
- Exploration of the African tone scales [Moelants et al. 2009] and development of the Tarsos3 platform [Six & Cornelis et al. 2011].
- Melodic analysis [Cabrera et al. 2008] and similarity [Mora et al. 2010] of A Capella Flamenco Cantes
- Raag recognition [Chordia & Rae 2007] and ornaments in North Indian Classical music [Pratyush 2010]
- Study of the art music traditions in India (Hindustani and Carnatic), Turkey (Ottoman), North Africa (Andalusian), and China (Han) as part of the compMusic project4 [Serra 2011].

More details on the relevant research ideas are provided in the state-of-the-art methods of pitch pattern analysis.

[2] ftp://ftp.iyte.edu.tr/share/ktm-nota/TuningMeasurement.html
[3] http://tarsos.0110.be/
[4] http://compmusic.upf.edu/

1.3 Objectives

Tracking influence of different musical traditions requires a multi-approach analysis as similarities can be observed in various aspects. The problem takes actually more than one dimension; it is not adequate to study the way different musical parameters behave but is also essential to analyse the way their use changes within each music tradition, where music tradition in this case implies both the theoretical definitions and actual practice.

First, let us note that the musical parameters considered in this approach are derived from the notion of a *pitch pattern*. These comprise the tuning of the scale, the relative and absolute size of the underlying intervals, the prominence of scale notes and the variability of scale note frequency. The main tool to base our analysis on will be a pitch class profile with a high bin resolution, extracted from audio recordings [Tzanetakis 2002]. The main idea behind a pitch class profile is measuring the intensity of different pitches and is obtained by quantizing the frequencies of the spectrum to a fixed number of bins (the different pitch classes).

In order to achieve an overall comparison of the pitch patterns of each music tradition, the following tasks should be completed:

1. **Initial analysis of Cypriot pitch patterns:** understand and summarize the particularities of Cypriot music.
2. **Analysis of Byzantine and Turkish pitch patterns:** Before deciding whether Cypriot music has or not and at what degree been influenced by Byzantine or Turkish music, an anticipated study of the latter needs to be performed. This includes a thorough study of Byzantine and Turkish pitch patterns alone, the way they are defined in theory and the way they are actually used in practice.
3. **Study the relations between Byzantine and Turkish music:** Similarities of these two music traditions in theory and practice should be analysed separately before any comparison with Cypriot music. Ignoring their correlations can lead to erroneous conclusions regarding possible influence origins.
4. **Investigate influence in the use of intervals:** Compare the intervals used in Cypriot, Byzantine and Turkish music extracted by consecutive scale notes. Study which intervals are most frequently used, how many different intervals exist (in theory and practice) and which are consistently used or not.
5. **Investigate influence in the prominence of scale notes:** For pitch class profiles of all three music traditions compare the intensity of the scale notes. Study which scale notes are often most prominent, how many and/or which are significantly stronger than the rest.
6. **Investigate influence in the scales:**
    a. **Based on the overall shape of the pitch class profile:** Compare pitch class profiles of the different traditions and determine which Byzantine and Turkish scales (represented by the corresponding pitch class profiles) can best describe the underlying Cypriot scale. In this comparison the prominence of scale notes and the variability of scale note frequency will be the main factor of the similarity measure.

b. **Based on the scale notes:** Extract scale notes from the pitch class profiles and determine the Cypriot scale based on greatest similarity with Byzantine and Turkish scale notes. In this comparison the position of scale notes will play the main role in the similarity measure.

All the above are to be considered just as a preliminary study on the influences that possibly exist in Cypriot music. The approach will be constrained by the particularities of the chosen music material and the inaccuracy of the analysis tools. Nevertheless, the ultimate goal is to build a basis for a system that could be extended in a multi-dimensional comparison of pitch patterns and even more musical parameters that particularly characterize non-Western music of other cultures.

1.4 Organisation of the Thesis

The goals set above are further analysed by first providing the essential musicological background of the three music traditions followed by the state-of-the-art computational approaches in the analysis of pitch patterns of this kind of music. Moreover, the proposed methodology and designed system is explained and finally the results are presented and discussed.

The chapters of this thesis are therefrom structured in the following way:

1. Detailed description of Cypriot music; its particularities and the state-of-the-art research
2. Overview of Byzantine and Turkish music with focus on the scales and the similarities between them
3. Overview of the state-of-the-art approaches in computational analysis of pitch patterns.
4. Collection of music material and reasoning
5. Analytical description of the proposed methodology
6. Set of experiments and presentation of results
7. Discussion of results
8. Conclusions and future work

2 Musicological Background

2.1 Cypriot Music

Music from Cyprus belongs to the musical cultures of the East Mediterranean that are particularly characterized by their monophonic nature, high degree of ornamentation and specific scales/modes with frequent use of microtonal intervals. As summarized in [8], "*Folk songs of Cyprus are modal in structure and monophonic. Diatonic or chromatic with syllabic or melismatic melodies are sung in the natural and not the temperate scale".*

Research in the Cypriot music started at the end of the 19th century by educated people, usually schoolteachers, and was initially focused on the text of the songs. This research was very often part of broad musicological studies on regions of Greek culture, carried out and published by Greek folkloric foundations such as the Peloponnesian Folkloric Foundation [PFF LP VII. 1989]. In the beginning of the 20th century the first musical transcriptions appeared by Charalambos Papadopoulos (1908), Christos Apostolides (1903) and Kleovoulos Artemides (1902). Following their path, Theodoulos Kallinikos in 1951, Swzos Tombolis in 1966 and Gewrgios Averof in 1978 published their own collections of transcribed Cypriot melodies. The music was manually transcribed in Byzantine and/or Western notation.

In the 21st c. particularly important are the publications of the Cyprus Research Centre[5] with an analytical study on the religious songs of Cyprus [Cyprus Research Centre 2004] and the research carried out at the Ethnomusicology Research Program[6] with a preliminary analysis of the modes used in the Cypriot folk tunes [Giorgoudes 2011a].

[5] http://www.moec.gov.cy/kee/
[6] http://www2.ucy.ac.cy/research/ethno/

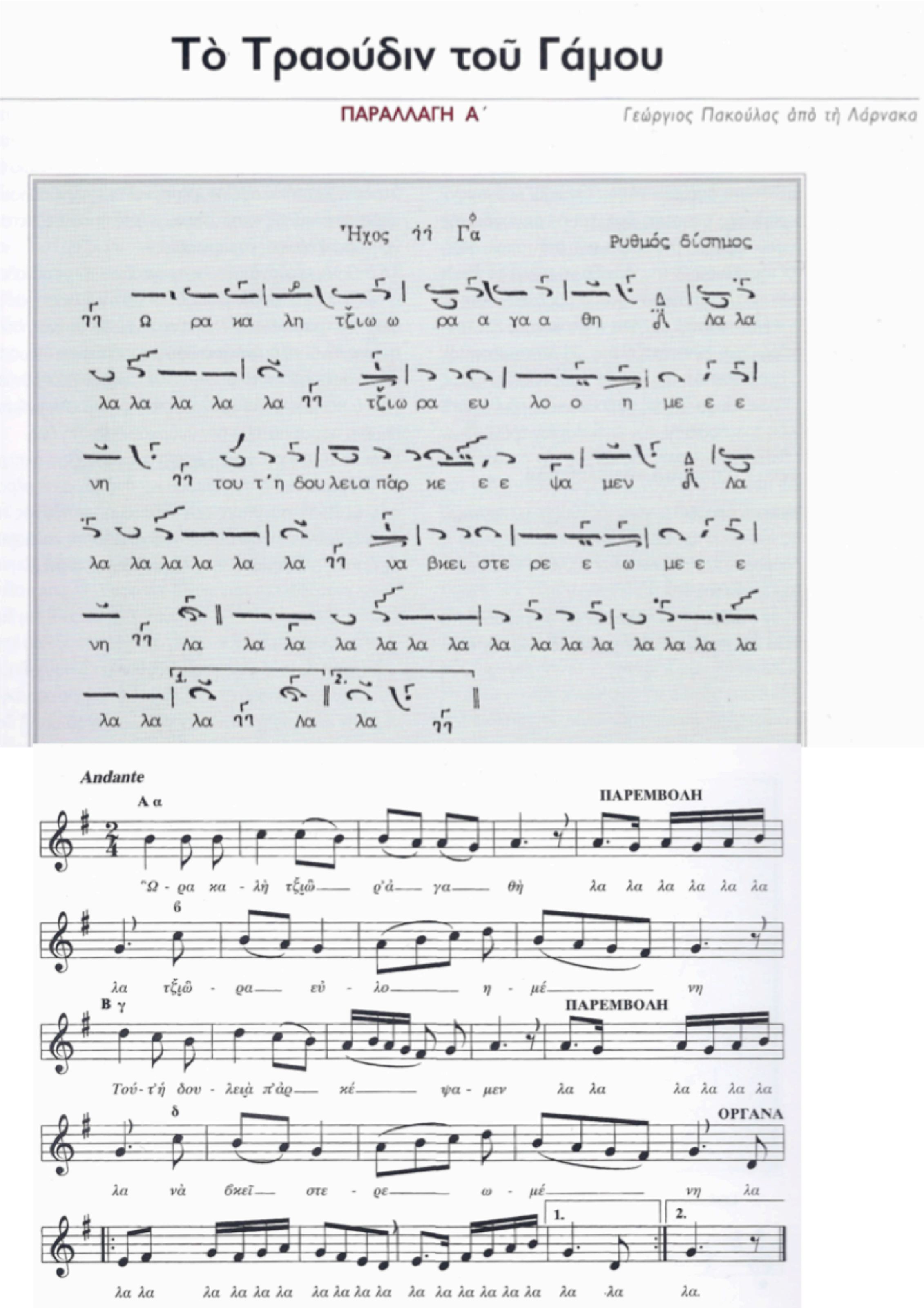

Figure 2.1: Transcription of the Cypriot tune "Το τραγούδι του γάμου" (the Wedding song) in Byzantine notation (top) and Western (bottom) by [Tombolis, 2002].

2.1.1 Musical Instruments

There are five musical instruments that have been widely used in Cypriot music from the past to today. However, it should be noted that there were more instruments used in Cypriot music at some point [Averof 1989, Zarmas 1993]. Among these are the clarinet, santur, tambouras, bouzouki, lyre, guitar, and accordion. However, these instruments were either played by foreign musicians in the big band orchestras or incorporated in Cypriot music for just a short period of time so that their use has not survived today. The five most popular instruments and their role in Cypriot music are further analysed in the paragraphs below.

As Cypriot music is mainly monophonic, one of the most common instruments traced back a long time ago is the singing voice [Averof 1989]. As happens in the roots of most musical traditions, people used to improvise simple melodies and then add lyrics (or vice versa) expressing their feelings poetically, be it pain, love, nostalgia, melancholy, or happiness. Musical melodies accompanied the people singing during their daily activities.

It was not until later, that the violin was introduced into Cypriot music, accompanying or sometimes even replacing the singing voice. Averof in [1989] refers to a violinist from Serbia, who moved to Cyprus in the 19^{th} century and soon mastered all Cypriot folk tunes, possibly being the first one to introduce the instrument to the island. Being a legend or not, violin was absorbed in Cypriot music and violin players became highly respected amongst Cypriots who even until today, speak with wonder for the old-time violin masters.

Accompanying the violin at the rhythmical songs, usually the dance songs, initially there was the *tamboutsa*, a special kind of tambourine. This instrument was played either with the two hands (using both palm and fingers) or with two wooden sticks. Its purpose was to enhance the rhythm of the melody.

However, the use of tamboutsa for keeping the rhythm was gradually taken over by the lute, which despite its melodic capabilities was mainly used as an accompaniment instrument. Respecting the monophonic character of the Cypriot music, the lute was used to play simple chords only, usually just drones of the tonic. Although at some point, violin, lute and tamboutsa were played together, today violin and lute is the most common duo whereas tamboutsa is rarely played.

Figure 2.2: Musical instruments in Cypriot music; violin and lute (left), tamboutsa (right).

2.1.1.1 The Pithkiavli Instrument

a) The instrument

The last instrument in practice in Cypriot music is the *pithkiavli*, a special kind of wind instrument very similar to the recorder or the Greek instrument *souravli.* It is a reed (rarely wood) instrument, made and played by the shepherds during the endless hours of tending the flock [PFF LP VIII-XIV1989]. Apart of its mainly solo role, the instrument is also occasionally played at ceremonies such as weddings and festivals, where it is often accompanied by voice or a percussion instrument such as a tambourine. Unfortunately today, the use of pithkiavli is becoming increasingly rare.

The melodies usually played by a pithkiavli are free improvisations or well-known folk tunes especially from the music style of Fones (cf. Section 2.1.2 [Giorgoudes, 2011b]).

An important characteristic of the pithkiavli melodies is the wide use of ornamentations such as glissandi, trills, turns, mordents etc. The use of a glissando and trill are marked in the pithkiavli melody[7] shown in the figure below.

[7] The melody representation is based on frequency estimations extracted from the Yin algorithm (cf. Section 5.3).

Figure 2.3: Pithkiavli melody with glissando and trill ornamentations.

b) The *two-pithkiavli* technique

Another common practice of the pithkiavli performers is the technique of two pithkiavli held at a sharp angle between the lips and played simultaneously. The two pithkiavli usually played the same melody and this technique was mainly used for increasing the volume of the sound. However, skilful players would efficiently use the second pithkiavli to embellish the melody with dronings, discords and other ornaments [PFF LP VIII-XIV 1989].

Figure 2.4: The two-pithkiavli technique [PFF LP VIII-XIV 1989].

The technique of the two-pithkiavli is quite limited not only because of its advanced performance level but also for two rather practical issues, as stated by two pithkiavli players interviewed for the purpose of this research [8]. First, is hard to find two pithkiavli instruments perfectly in-tune that could be played simultaneously without producing undesired dissonances. Second, the two-pithkiavli technique restricts the number of notes that can be produced as each instrument can be played with only four fingers. Therefore the repertoire for this technique is limited to melodies with a relatively short tessitura.

We tried to further justify the first reason by briefly analysing the tuning of this instrument. For this purpose, two different pithkiavli instruments were recorded while playing the same melody. Although the two performances are not completely identical, some significant differences in tuning can still be observed.

[8] The pithkiavli players were Giannis Ttikis interviewed on 26th April 2011 and Andreas Christakkos interviewed on 27th April 2011.

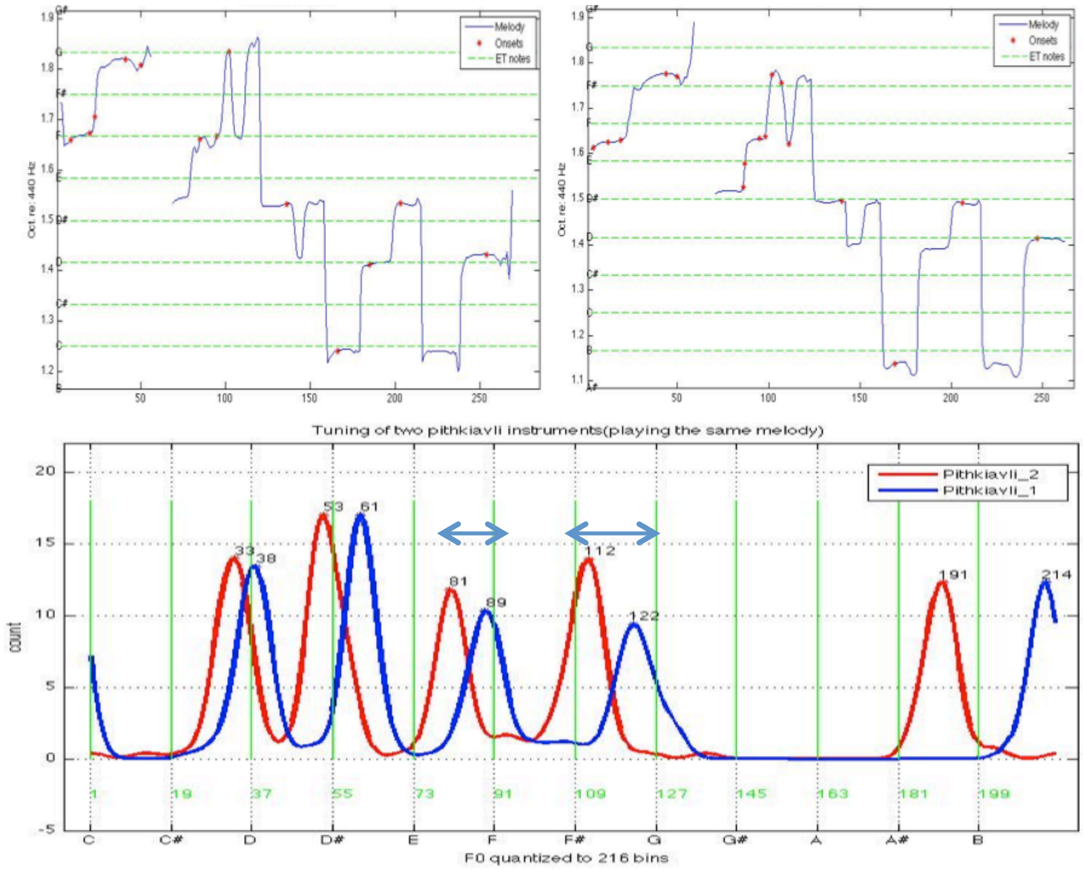

Figure 2.5: Melody played by two different pithkiavli instruments (top plots) and their corresponding tuning (bottom plot). The arrows in the bottom plot correspond to the tuning differences.

A straightforward observation from the figure above is that the pitch of the first note differs by approximately half a semitone; Pithkiavli_1 starts with the F note whereas Pithkiavli_2 starts with a note between F and E. However this cannot be considered as a kind of transposition because we see that the difference of the rest of the notes of the two melodies is not constant. For example, the arrows drawn on the pitch histograms correspond to a tuning difference of 8 bins between E and F notes and a difference of 10 bins between F# and G.

c) How to make and tune the pithkiavli

For the purpose of this research, Andreas Christakkos, one of the few pithkiavli masters today, was filmed[9] on the 27th April 2011, while making a pithkiavli instrument. It's noteworthy mentioning here that Andreas Christakkos is an authentic pithkiavli player; he is a shepherd and making and playing pithkiavli instruments is one of his favourite hobbies. In the paragraphs below we summarize the information regarding the characteristics of this instrument and the way it is made and tuned.

The pithkiavli is normally made of reed and rarely of wood. Its length varies between 25-30 cm depending also on the width of the reed piece; a thick reed normally needs to be longer than a thin one. The length must ensure adequate space for the six finger holes and whether this is the case it is specified by the position of the first finger hole. The latter should be placed at the centre of balance of the reed piece. Therefore, before positioning the first hole the pithkiavli maker balances the piece of reed on his finger to find the appropriate point. Once the first finger hole is fixed, adjusting the rest of the fingers at a convenient spacing along the reed, gives a good estimation of the appropriate length of the reed piece. The distance of the finger holes according to Andreas Christakkos should differ by approximately a "thumb" of the pithkiavli player. However, the distance should be gradually reduced as we approach the bottom finger holes [10].

Figure 2.1.6: Pithkiavli performance by Andreas Christakkos (27/04/2011)

[9] Part of this video is attached in the additional material of this thesis.
[10] Other theorists like Zarmas in [7] state that the finger holes should be equidistant and lying approximately "two fingers" from each other.

The mouthpiece is usually made of rhododendron that is resistant to corrosion and breakage. Special care is then taken at shaping the mouthpiece in the right dimensions. This is gradually formed upon trial and effort of the sound produced. The pithkiavli maker/player keeps modifying the mouthpiece shape until the sound reaches a satisfactory[11] quality level. Some shepherds may also further tune the pithkiavli to the bell sounds of their flock by appropriately adjusting the length, diameter and pitch holes of the instrument [PFF LP VIII-XIV 1989]. However, this doesn't apply for Andreas Christakkos's method, the shepherd who was filmed in this case.

[11] This often depends on criteria such as a relatively high-pitched sound with reduced breathiness.

2.1.2 Musical Styles - Fones

A common practice in Cypriot folk music is fitting an improvised poetic text to a given melodic phrase familiar to the singer and/or the instrument players. The poetic texts were inspired by aspects and concerns of everyday life and comprised a variety of themes such as religion, love stories, historical facts, work life, festivals, weddings, and other ceremonies. This tradition was -and still is- widely used for poetic contests between two or more singers. In these contests, the singers agree in advance on the theme and then improvise verses in turn. The loser is the one who is either slow to respond to his opponent's last provocative verse, or whose response is out of subject, rhyme or rhythm [12].

Due to this tendency, in a big collection of Cypriot folk music one often finds many songs of different text content sharing the same, or at least a very similar, melody. This incident is strongly related with the rise of the term *Fones* assigned to a particular group of songs. As often suggested, the different types of Fones are normally named after the region in which they are predominantly sung. The Greek word Fones literally means *Voices* (singular *Foni*). Cypriot music researchers have broadly used the term to describe a vocal folk music genre, relating to the melodic models on which many and different verses can be adapted [Giorgoudes 2011b].

However, recent research argues the ambiguity of this definition that has led to a confusion regarding which songs belong to the *Fones* 'genre'. The reasons for this confusion as stated in [Demetriou 2006] are partly due to the urbanization and modernization procedures of folk music and the inefficiency of past research methods. The latter, based mainly upon the ignorance of the views of performers in past research, who have been using the term to identify not just songs of a given group but virtually any song.

For the purpose of the thesis we do not aim to argue which songs belong or not to *Fones.* We rather base our analysis on those songs that represent the most typical Fones examples as found in the literature [Averof 1989, Zarmas 1993, Kallinikos 1951, PFF LP VII 1989, Tombolis 1966] and in the available music material. These Fones are:

1. Pafitissa
2. Aukoritissa
3. Akathkiotissa
4. Karpasitissa
5. Mesaritissa
6. Tillirkotissa
7. Isia
8. Poiitariki

The use of Fones is often referred to as the most typical tradition in music of Cyprus [Averof 1989, Giorgoudes 2011b]. These researchers also suggest that the practice of fitting a poetic text to a given melodic phrase adheres to an old Greek but also Byzantine musical practice. However, the same tradition appears as well in Turkish folk

[12] A brief illustration of these contests can be found in the corresponding video attached with the additional material of this thesis.

music with the “Türkü” singers adapting new verses to the songs they usually sing in different celebrations [Erdener 1995].

This topic on its own could be another interesting area to track the influence of Byzantine and Turkish incorporated in Cypriot music. For this, a *complete* (melody, harmony, rhythm etc.) comparative analysis of the songs should be exploit that goes beyond the scopes of the current research. However, the Byzantine/Turkish influence in these songs is still partly considered in this study, in terms of the pitch pattern comparison.

2.1.2.1 Characteristics of Fones

Some of the musical features that characterize the Fones (and a large number of other Cypriot folk songs) are listed below. Features 1-7 were obtained from a semi-automatic analysis of a subset of Fones melodies (cf. 6.2) although some of these had been already implied in the literature (i.e. the use of microtonal intervals, 7th point). The rest were summarised from [Zarmas 1993, Tombolis 1966, Karagiorgis 2010].

1. **The pitch range** of the melody is usually limited to a perfect fifth or sometimes a major sixth interval.
2. **Successive melodic steps** usually do not exceed a major 3rd, with semitones being used often.
3. **The main part** of the melodic phrase is characterised by the insistence on the fourth or fifth scale degrees and those contiguous notes.
4. **At the beginning and the end of the phrase** the melody ascends or descends in usually four or five consecutive steps, (a “tetra/penta-chordal” movement).
5. **The initial note** is usually the third (especially when interjection words occur) or the fourth. With interjections, we often observe a short ascending glissando just before introducing the starting note of the melody.
6. **Last note** of the melodic phrase is (usually) the tonic**.**
7. **Intervals other than equal-tempered** are used and are particularly emphasised in the embellishments of specific notes such as the highest note or the last note of the phrase.
8. **Musical form** can be either AA’ or AB
9. **Phrase structure** consists of a 15-syllable verse of two sentences; the beginning sentence of 8-syllable length and the ending sentence of 7-syllable length (8+7).
10. **Variations** of the 15-syllable verse can be of the structure:
    a. 8+8+7 (addition of a beginning sentence)
    b. 8+7+7 (repetition of the ending sentence)
    c. 8+8+7+7 (addition of a beginning sentence and repetition of the ending sentence)
11. **Beginning with an interjection** for the majority of the fones. This is usually an “Ee” or “Oo” and reminds the hesitation expression of someone who doesn’t know what to say next. Note that fones melodies were used for verse improvisation and that could be the reason of the presence of these interjections. In addition, the interjection “Ai” can also be observed in some cases and its role is rather to express pain. Whenever this appears it lasts longer than the other interjections and it thoroughly consists of ornamentation, especially melismas.

Figure 2.7: Manual transcription of Aukoritissa Foni by Evagoras Karagiorgis [Karagiorgis 2010]

2.1.3 The scales

In order to describe the scales of the Cypriot tunes, one needs to go beyond the Western scales. Zarmas in [1993] and Tombolis in [1966] indicate scale analysis of Cypriot tunes in terms of ancient Greek and Byzantine music theory. Giorgoudes in [2011b] states that "Cypriot music is traditionally based on the scales known as tropos ('mode')" and that there is clearly some correspondence to the eight Byzantine modes. However, some of the Cypriot tunes are performed in Western major and minor scales. But as he argues, these tunes are rather a few that have most probably been imported and absorbed in Cypriot music.

From the above, it is implied that Cypriot music was built upon Byzantine and ancient Greek musical models. Therefore in an investigation of influence in Cypriot music as this study, priority should be given to the Byzantine/Greek influence. It is inarguably clear that the Byzantine culture have had a strong impact not only in music of Cyprus but also in language, religion and other customs. However, it is the 343 years of relatively recent Ottoman rule that makes it plausible to assume a significant influence from that tradition too.

As a next step, we proceed with a thorough study of the theory of these two musical traditions. Emphasis is given on the scales used in each tradition, as it will be the main approach in describing the underlying pitch patterns.

2.2 Byzantine and Turkish Music

2.2.1 Music theory outline

The Byzantine and Turkish musical traditions share a lot of similarities firstly because of their geographical regions of practice; Byzantine music originating in Byzantium (Istanbul as named under the Byzantine empire) and practiced by the Greek-speaking Orthodox population and Turkish music originating in the Turkish, south-east Anatolia regions practiced by mainly the Turkish-speaking Muslim population. Secondly because of the great interaction of Byzantine and Ottoman empires history that unavoidably influenced the music.

Figure 2.8: Regions of practice of Byzantine and Turkish music regarding both geographical and historical impact.

Musically speaking, both these traditions are *modal* in structure. Unlike to the Western music, we refer to the meaning of mode as a sequence of notes with fixed characteristic intervals (usually within an octave) the use of which defines also a specific melodic behaviour. We cite the definition of mode as stated in Winnington-Ingram's *Mode in Ancient Greek Music* [Winnington-Ingram, 1936]: "Mode is essentially a question of the internal relationships of notes within a scale, especially of the predominance of one of them over the others as a tonic, its predominance being established in any or all of a number of ways: e.g., frequent recurrence, its appearance in a prominent position as the first note or the last, the delaying of its expected occurrence by some kind of embellishment".

Therefore the Byzantine *echos* and the Turkish *makam* rules comprise the intervallic distances of a note sequence and additionally the direction (ascending/descending) of melody, the particular function of scale tones, the use of characteristic musical patterns, specific scales and possible modulations of these. Both echos and makam are based on tri-/tetra-/penta-chordal entities that are combined together to construct scales. These are not defined in an absolute but rather in a relative way with the form of intervals that add up to (usually) the range of an octave.

Belonging to the orally transmitted music traditions, annotating this music has been and still is a great challenge. Several competing theoretical models have been suggested to describe and standardize these music traditions. However, as Zannos [1990] argues, '*…None of them offers a perfect solution; even more, none of them can be said to correspond with contemporary empirical study…*' Today, some theoretical models have been officially recognised as the ones to best describe the music but as these imply a certain degree of simplification we appreciate some distinction of the underlying theory and the music in practice.

2.2.2 Theory of Byzantine *echos*

The Byzantine music is characterised by the modes called *echos* (plural *echoi*). Experts of Byzantine music define in total eight basic echoi, a system also referred to as "octaechos" (eight-mode) [Levy & Troelsgard 2011]. In Byzantine notation, these eight modes are categorised into four *authentic* modes and their corresponding four *plagal* modes, namely the: *First authentic, Second authentic, Third authentic, Fourth authentic, First plagal, Second plagal, Grave*[13]*, Fourth Plagal.*

The main difference between authentic and plagal modes is that the plagal mode has a different reference tone, usually a fourth lower than its corresponding authentic mode. The scale intervals however are common for both authentic and plagal as long as no exceptions apply. Therefore, as specified by the theory, key elements for distinguishing authentic and plagal modes lie in melodic information such as the predominant scale tones and the use of characteristic melodic patterns also referred to as *musical formulae* particularly emphasized at the beginning and ending of a musical phrase.

Efforts for annotating the Byzantine music started very early [Levy & Troelsgard 2011]. The Paleo-Byzantine method dates back in the 10th c., which was followed by the Middle-Byzantine (*Round* notation) around the mid-12th century until the 1820s when the New Method (*Reformed* or *Chrisanthine* notation) was established. The latter evolved from 'the three teachers' namely, Chrysanthos of Madytos, Chourmouzios the Archivist and Gregorios the Protopsaltes and although it was subject to another reform in 1880s it is the official model used today for the Greek Orthodox Church music.

In the 20th century the Greek musicologist Simon Karas suggests an alternative Byzantine notation by re-introducing some old (paleographic) qualitative signs, reconstructing the interval structure and revising the classification of the modes. His theory however, was as much supported as opposed by the Byzantine music scholars and performers [Angelopoulos 1986].

For the purpose of this research we focus on the officially accepted model, the Chrysanthine theory. According to that, the octave in the Byzantine music is divided in 72 equal partitions, *commas* as they are also called. Awhole tone (*mizon* in Greek) consists of 12 such commas and a semitone of 6. Apart from the whole tone and half tone, which are the most typical intervals in the tempered scale, Byzantine music makes frequent use of the *minor* tone (*elasson*) of 10 commas and the *minimal* tone (*elachistos*) of 8 commas, which are respectively slightly shorter than the whole tone and slightly bigger than the half tone [Dontsios].

[13] The *Grave* echos is considered equivalent to the third plagal echos but because it starts on the same reference tone as the third authentic and not a fourth lower as every other plagal mode it is rather named differently.

For example, the First echos is defined with the following interval sequence that, if calculated, adds up to a total of 72 commas:

Scale Intervals (in commas)	**10**	**8**	**12**	**12**	**10**	**8**	**12**	**= 72**

There are a few important remarks to be noted at this point.

1. The Byzantine echos consists of seven intervals (eight tones considering a full octave). In the simplest form, the eight tones represent two identical tetrachords (three consecutive intervals) linked together by an interval of a whole tone. In the example above, the tetrachord is defined by the sequence of intervals 10-8-12 (green colour) which is repeated after the whole tone interval 12 (red colour) that lies in the middle of the scale.
2. The definition of an echos with just its interval sequence (as in the table above) is incomplete. According to [Mavroeidis 1999, Thoukididi 2003], echoi are defined by 5 basic elements: the scale intervals, predominant scale tones, a short introductory phrase that specifies also the reference tone, the different cadences in the middle and end of a phrase, and the modulations applied to particular scale notes depending on the melodic direction being ascending or descending (also called laws of attraction-gravity). A brief justification that the interval sequence cannot stand on its own can be found at the definitions of Third and Grave echoi. These echoi share by definition the same scale intervals but have, among other different elements, distinct predominant scale tones (cf. Table 2.1).
3. It should be also noted that the most predominant scale tones as defined in the theory of the different echoi are usually two or three scale degrees out of which the first-third and first-fourth scale degrees are the most reoccurring pairs [Thoukididi 2003].
4. The scale definition of an echos is also subject to modulations according to some secondary characteristics. One of the most important is the type of chant. Chants are categorised to:
    a. ***Eirmologika*** (singular *eirmologikon*): chants sung in a relatively fast tempo with each note corresponding to a new syllable.
    b. **Stoichirarika** (singular *stoichirarikon*): chants sung in a medium tempo with more than one notes corresponding to the same syllable (a sort of melisma ornamentation).
    c. **Papadika** (singular *papadikon*): chants sung in a slow tempo with a phrase of notes corresponding to one syllable.

    Therefore some of the echoi such as the Grave, if used in an eirmologikon chant have a different underlying scale than if used in a stoichirarikon or a papadikon chant (cf. Table 2.1)

Echos/ Elements	Third							Grave						
Chants Category	Eirmologika													
Scale Intervals	12	12	6	12	12	12	6	12	12	6	12	12	12	6
Predominant Scale Tones	First			Third		Sixth		First			Second		Fourth	
Chants Category	Papadika													
Scale Intervals	12	12	6	12	12	12	6	8	12	10	12	8	16	6
Predominant Scale Tones	First			Third		Sixth		First			Third		Sixth	

Table 2.1: Differences in the definition of the echos depending on its primary and secondary elements (the continuous and dashed circles refer to the second and third remark respectively).

Along with the previous remarks, should be clarified that the scale intervals of each echos that we define and analyse in this study are the default or simplest ones. Should not be discounted though the fact that these interval sequences can be subject to a lot more modulations depending on the melodic behaviour of a chant or other theory exceptions not stated here. For further details the reader is referred to the Byzantine music literature [Mavroeidis 1999, Thoukididi 2003].

That being said, the scale intervals of the eight echoi are listed in the table below.

Echos	Chants Type	Scale Intervals						
First	All chants	10	8	12	12	10	8	12
First Plagal	All chants	10	8	12	12	10	8	12
Second	All chants	8	14	8	12	8	14	8
Second Plagal	All chants	6	20	4	12	6	20	4
Third	All chants	12	12	6	12	12	12	6
Grave[14]	Eirmologika Stoichirarika	12	12	6	12	12	12	6
	Papadika	8	12	10	12	8	16	6
Fourth[15]	Eirmologika	8	12	12	10	8	12	10
	Stoichirarika	10	8	12	12	10	8	12
	Papadika	12	10	8	12	10	8	12
Fourth Plagal	All chants	12	10	8	12	12	10	8

Table 2.2: Definitions of echoi in terms of interval sequences.

[14] The Grave echos of Papadika and Fourth of Eirmologika chants will be named from now on, Grave(P) and Fourth(E) respectively.

[15] The Fourth echos of Stoichirarika and Papadika are not considered for further analysis the former because of the tonic not presented at the end of the phrase (cf. discussion in Section 5.7) and the latter because no relevant music material was found.

2.2.3 Theory of Turkish *makam*

Turkish traditional music is built on the modal concept of *makam* that shares similarities with the Byzantine echos. Makam theory is found in musical cultures of the Arab world, East-Mediterranean and Middle East and consists of a set of rules for melodic composition and improvisation that vary from region to region.

A makam scale is constructed by combining two or more tetrachords/pentachords and it is named after the lowest or the most important one (cf. Figure 2.9). Each makam melody evolves by construction in specific tonal centres that are classified in the following way:

- Tonic note also known as *karar*: The starting note of the first tetra/penta-chord of the makam scale and the one that almost always concludes the makam melody.
- Predominant note also known as *güçlü*: This is usually the fifth or the fourth and occasionally the third scale degree and is given by the first note of the second tetra/penta-chord of the makam scale. This is used as an alternative tonic mainly in the middle of the piece.
- Leading note known as *yeden*: This is either the Western leading note or the subtonic of the makam scale and the penultimate note in the melody that resolves to the tonic.

The makams are often classified into three main categories: The simple makams also known as *Basit*, the transposed makams known as *Sed* and the combinatory makams known as *Birlesik* [Reinhard 2011]. The simple makam category consists of 12 makams namely the: Çargah, Buselik, Ussak, Neva, Hüseyni, Rast, Süznak, Hicaz, Humayun, Uzzal, Karcigar, Zirgüle.

Combinatory makams are the ones that combine different (basic or not) makams and hence are thought of as modulations of the simple ones (i.e. Suznak makam is a modulation of Rast makam). The transposed makams are the simple makams transposed to another tonic. This is similar to the *plagal* concept of Byzantine music notation only that now the name of the transposed makam might not be related to the name of the corresponding makam in its original position. For example, in Byzantine music we had the *First authentic* and its transposed *First plagal* mode whereas in Turkish music we can have the *Rahat El Arwah* makam (Turkish: Rahat'ül-Ervah) as a transposed version of *Huzzam* (Turkish: Hüzzam).

It's noteworthy mentioning here that unlike the singing voice, transposing to an instrument of Turkish music practice such as oud or qanoun, implies a limitation on the transposable tonic choices. The reason behind this is rather technical and lies in the fact that melodies sound much better when their tonics, fourth and fifth notes fall on open strings, because of the way these string instruments resonate ["The Arabic Maqam" 2011]. Therefore, makams are mostly taught and documented with the same starting note and are transposable only to a few other tonics, the names of which are usually stated in the makam title (eg. "Beyati on G" or "Beyati on " instead of the default "Beyati on D").

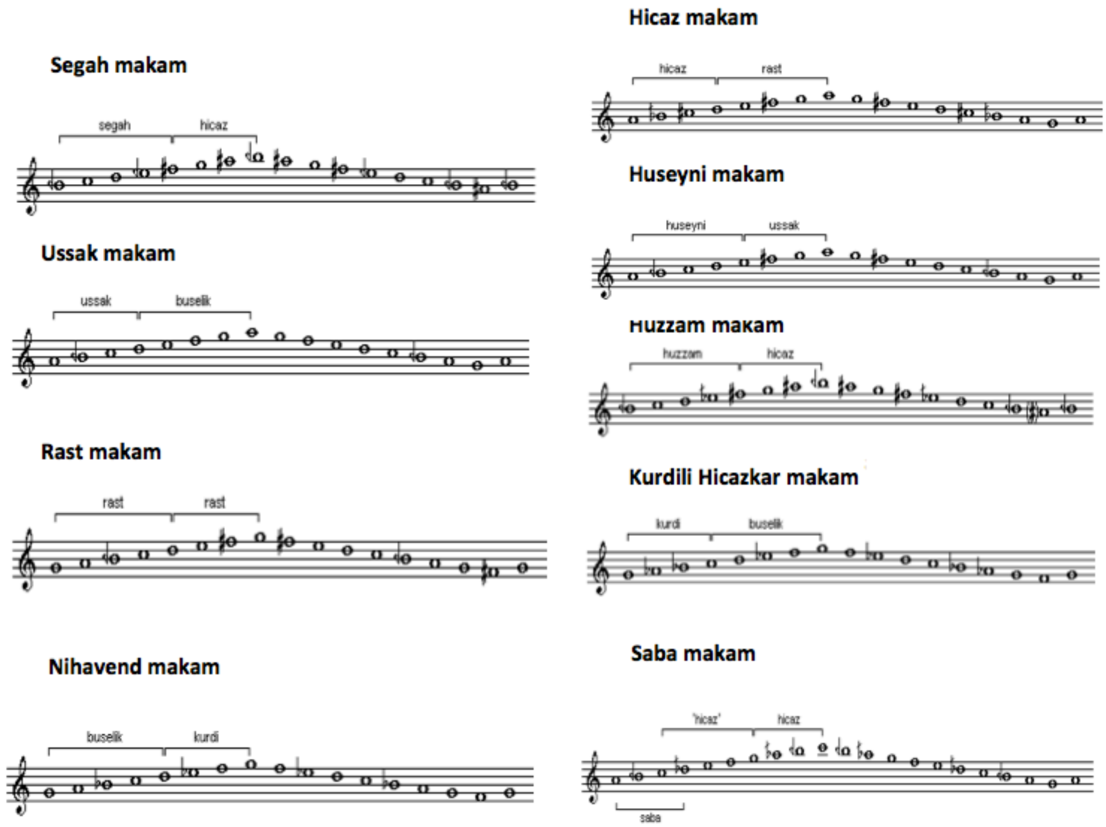

Figure 2.9: Makam construction from tetra/penta-chordal entities [Leonidas 2010]. The additional accidentals correspond to microtonal intervals [cf. Reinhard 2011].

Annotation of the makam tradition is also dated back in time with different theoretical models contradicting in the definition and amount of makams. Dimitrie Cantemir (17th c.) defines an amount of 27 makams whereas Arel (1993) defines 113 and Öztuna (2006) defines historically 600 makams out of which 333 survived today. Different theories regarding the temperament and possible scale note pitches are proposed, naming here a few:

1. Töre–Karadeniz theory (Karadeniz 1965/1983): based on a 41-tone subset out of 106 equal divisions of the octave
2. Yavuzoglu48 theory ((Yavuzoglu, 2008): based on logarithmically 48 equal divisions of the octave
3. Arel-Ezgi-Uzdilek (AEU) theory (Arel, 1930/1968; Ezgi, 1933): based on the 24-tone Pythagorean tuning of Yekta (1922/1986)
4. Ezgi-Arel (Arel) theory: based on logarithmically 53 equal divisions of the scale derived from the 24-tone Pythagorean tuning.

Further discussion on the different makam theories can be found in [Yarman 2007, 2008] and [Bozkurt 2009]. For the purpose of this research we'll focus only on the Arel theory as it is widely recognised.

According to Arel theory, the octave is divided in 53 equal partitions with a whole tone representing 9 such partitions, also known as the *Holdrian comma (Hc)*. Regular is also the use of the interval of 8 Holdiran commas (slightly shorter than the whole tone), 5 commas (slightly larger than semitone) and 4 (slightly shorter than semitone).

For example, the Hüseyni makam is defined with the following interval sequence that adds up to a total of 53 Holdrian commas:

Scale Intervals (in Hc)	**8**	**5**	**9**	**9**	**8**	**5**	**9**	**= 53**

As similarly discussed for the Byzantine echos, the definition of the makam comprises a lot more information than just the interval sequence. However, for this study we focus mainly on that as the basic characteristic of the makam. Moreover, out of the 113 makams defined in Arel theory we choose to focus on a subset of 15 makams, that were selected based on either the below:

- Makams that represent approximately the fifty percent of the current Turkish repertoire according to [Gedik & Bozkurt 2008], and,
- Makams that are -by definition- most similar to the Byzantine echoi (cf. Section 2.2.4)

These are listed in the table below.

Turkish makam	**Scale Intervals**						
Huseyni	8	5	9	9	8	5	9
Ussak	8	5	9	9	4	9	9
Buselik/ Nihavend	9	4	9	9	4	9	9
Hicazkar/ Sedaraban	5	12	5	9	5	12	5
Hicaz[16]	5	12	5	9	4/ 8	9/ 5	9
Suzidil	5	13	4	9	5	12	5
Mahur	9	9	4	9	9	9	5
Suzinak	9	8	5	9	5	12	5
Segah	5	9	8	9	5	9/ 13	8/ 4
Kurdilihicazkar	4	9	9	9	4	9	9
Rast	9	8	5	9	9	8	5
Saba[17]	8	5	5	13	4	9	5
Huzzam	5	9	5	9	5	13	4

Table 2.3: Makams definitions in terms of interval sequences.

[16] The fifth and sixth scale interval of Hicaz change according to the melodic direction being ascending or descending, thus the two alternatives. The same applies for the sixth and seventh intervals of Segah makam.
[17] The interval sequence of Saba lacks one more interval at the end that was omitted because if added the sequence would exceed the octave. Note that Saba is the only makam whose intervals don't add up to the octave (Saba: 8 + 5 + 5 + 13 + 4 + 9 + 5 **+ 12** = 61 Holdrian commas).

2.2.4 Similarities of Byzantine echos and Turkish makam

As previously explained, Byzantine and Turkish music unavoidably share some basic characteristics. Mavroeidis in [1999] undertakes a thorough study in the similarities of Byzantine echoi, Turkish and Arabic makams in terms of the scale intervals but also the melodic behaviour of each. Zannos in [1990] carries out a comparative study of the Greek Orthodox Church music (Byzantine as defined in this research) and the Ottoman music, focusing particularly on their intonation.

The two traditions clearly differ in the definition of the intervals that have been explicitly explained before. However, considering the relative rather than absolute size of the underlying intervals reveals a strong similarity of the two - Chrisanthine and Arel- theoretical models. That is, categorising the intervals in groups of approximately whole, 1/4, 1/2, 3/4 and 3/2 tone, a certain degree of equivalence of the two occur. To better illustrate this we form five interval classes, namely, ‘smallest’, ‘small’, ‘medium’, ‘large’, ‘largest’, that correspond respectively to the above interval groups and likewise we merge the theoretical Byzantine and Turkish intervals (cf. Table 2.4).

Interval Size/ Music	Smallest	Small	Medium	Large	Largest[18]
Byzantine (octave = 72 c.)	4	6, 8	10	12	14, 16, 20
Turkish (octave = 53 c.)	4	5	8	9	12, 13

Table 2.4: Categorisation of Byzantine and Turkish theoretical intervals in relative-size classes.

Regarding the above categorisation, the First echos and Huseyni makam can be considered ‘equivalent’ in their relative-size interval sequences.

First echos (octave = 72 c.)	10	8	12	12	10	8	12
Huseyni makam (octave = 53 c.)	8	5	9	9	8	5	9
Intervals in relative size	Medium	Small	Large	Large	Medium	Small	Large

In a similar way we list the equivalent echos-makam pairs in the table below. Note however that the equivalence suggested in some cases is not absolutely followed as in the above example. For instance, the pair Third echos – Mahur makam replaces a small Byzantine interval (6 commas) with the smallest Turkish interval (4 commas), where small and smallest correspond to the previous interval categorisation. Nevertheless,

[18] If melodic modulations are considered, the *largest* scale intervals found in Byzantine music include also the intervals of 18 and 22 commas (out of the total of 72 commas in the Byzantine octave).

there's still a significant similarity in the two interval sequences in terms of the order of the relative size of the intervals.
Keeping that in mind, we further note that the echos-makam lying in the same row of the table correspond to a rather 'direct equivalence' of the two scales (eg. First echos and Huseyni makam). However, significant echos-makam similarity can be observed also in other makams, which are listed just below the row of direct equivalence (eg. First echos and Ussak makam). The similarity considered in these cases results from the fact that the echos-makam pair shares at least a common basic tetrachord (often this represents the first three scale intervals). Lastly, the Saba and Huzzam makam could not be matched with any of the proposed echos but are still included for further analysis as they are two of most used makams in the current Turkish repertoire [Gedik & Bozkurt 2008].

Byzantine echos								**Turkish makam**							
First/ First Plagal	10	8	12	12	10	8	12	Huseyni	8	5	9	9	8	5	9
								Ussak	8	5	9	9	4	9	9
								Buselik/ Nihavend	9	4	9	9	4	9	9
Second	8	14	8	12	8	14	8	Hicazkar/ Sedaraban	5	12	5	9	5	12	5
								Hicaz	5	12	5	9	4/ 8	9/ 5	9
Second Plagal	6	20	4	12	6	20	4	Suzidil	5	13	4	9	5	12	5
Third/ Grave	12	12	6	12	12	12	6	Mahur	9	9	4	9	9	9	5
								Suzinak	9	8	5	9	5	12	5
Grave(P)	8	12	10	12	8	16	6	Segah	5	9	8	9	5	9/ 13	8/ 4
Fourth(E)	8	12	12	10	8	12	10	Kurdilihicazkar	4	9	9	9	4	9	9
Fourth Plagal	12	10	8	12	12	10	8	Rast	9	8	5	9	9	8	5
								Saba	8	5	5	13	4	9	5
								Huzzam	5	9	5	9	5	13	4

Table 2.5: Echos-Makam similarity by definition of the scale intervals.

3 Scientific Background

In this section we make a brief review to the state-of-the-art literature on computational analysis of pitch patterns. The methods proposed in the various systems that are particularly relevant to the methodology of the present research are further explained in the Methodology chapter.

In general, the analysis of a pitch pattern, as the primary goal of this study, comprises a lot of challenges. Amongst the major are the following:

1. Pitch estimation
2. Pitch distribution
3. Tonic detection
4. Scale-notes/intervals extraction

These are often combined in the broad task of automatic scale recognition. Various approaches have been designed for estimating the scale in Western music, less though for scales in non-Western music. In the sections below we explain in more detail some of the systems developed to deal with the above tasks. We focus more on the non-Western music approaches, as the challenges they encounter are most likely integrated in the kind of music we analyse.

In the analysis of Western music, automatic scale recognition, from midi or score representations to musical audio files analysis, has already a long tradition. For the methods of fundamental frequency estimation and pitch distribution, a review can be found in [Gomez 2006]. As for key estimation, an accuracy of 90% has been achieved already from the year 2005 in the MIREX contest with the most successful algorithm proposed by [Ismirli 2005]. In the contest of 2005 the candidate systems made use of either pre-computed key templates based on modifications of the Krumhansl-Schmuckler and Temperley's pitch class profiles [Gomez 2005, Ismirli 2005] or data-driven key templates [Purwins et al. 2000].

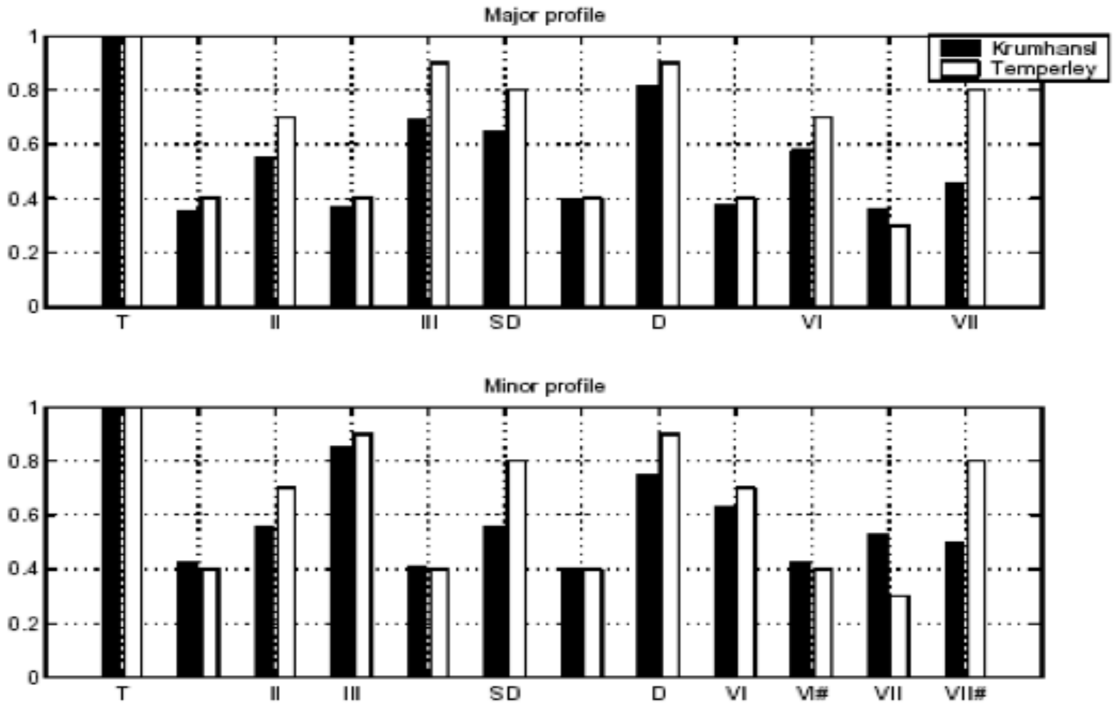

Figure 3.1: Krumhansl's and Temperley's pitch class profiles for major and minor scale [Temperley1999].

For the analysis of non-Western music, a series of papers by A. C. Gedik and B. Bozkurt deal with the problem of Makam recognition in Turkish music [Gedik & Bozkurt 2008, 2009, 2010]. Their method is based on pitch estimation by the Yin algorithm [de Cheveigné & Kawahara 2002] and post processing with filters specially designed for the characteristics of Turkish traditional art music. Pitch histograms are then computed with a bin resolution of 53 (number of Holdrian commas[19] in the Turkish octave). Tonic detection is performed via an automatic procedure that aligns histograms with makam templates represented as Gaussian curves centred at the theorised scale tones, and then finds the point of maximum correlation using the cross-correlation function [Bozkurt 2008]. Scale notes are extracted from histogram peaks that lie within a certain distance from the theorised tones of the corresponding makam template.

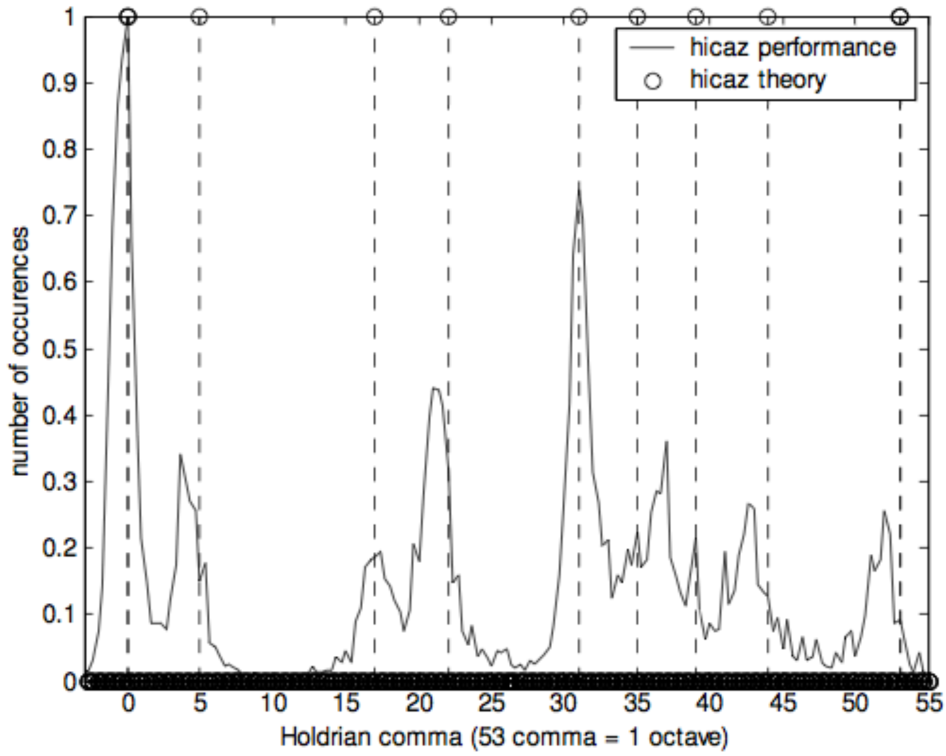

Figure 3.2: Pitch class profile of makam Hicaz [Gedik & Bozkurt 2008].

[19] A Holdrian comma is equivalent to 22.64 cents.

Another pitch histogram based approach for scale estimation is the research by [Moelants et al. 2009] in exploring the African tone scales. In this study, pitch was estimated through modifications of an automatic transcription algorithm for sung audio [Clarisse et al. 2002]. Pitch distribution was represented with histograms of 1200 bins and scale tones were extracted based on a peak detection algorithm tuned to certain parameter thresholds [cf. Moelants et al. 2009]. The histograms were then cross-correlated with each other in order to search for similar scales.

As for Indian music, P. Chordia and A. Rae research about Raag recognition [Chordia &Rae 2007, Chordia 2004]. In their approach, pitch estimation is performed using a version of the Harmonic Product Spectrum (HPS) algorithm [De La Cuadra et al. 2001]. Two pitch-class distributions are then considered; one from frame-based pitch and the other from onset-based pitch estimates. The combination of the two was good in the sense that erroneous pitch frame estimates included in the first distribution were on average overcome by the onset-based pitch distribution. On the other hand, notes that weren't clearly articulated (note attacked by sliding up or down to that pitch from a previous note) introduced erroneous pitch estimates to the onset-based pitch distribution that were overcome by the frame-based pitch distribution. Raag recognition was eventually obtained through classification methods applied on the two pitch-class distributions.

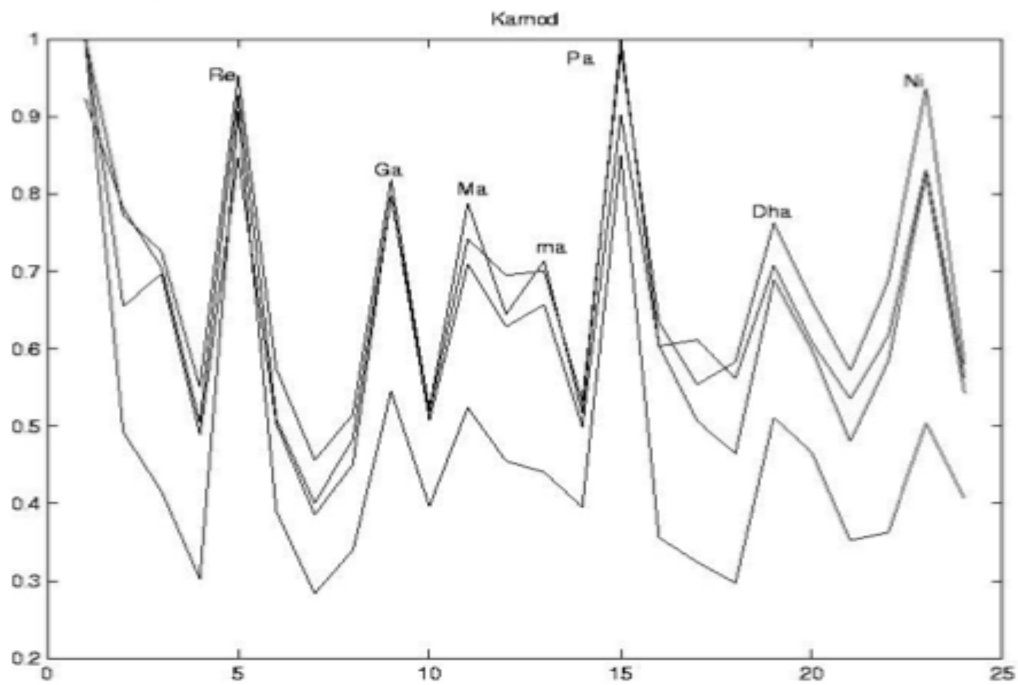

Figure 3.3: Pitch class profile of raag Kamod [Chordia 2004].

A different study on Indian music is a series of papers by Krishnaswamy that deal with the discourse of the pitch inflexions used in South Indian classical music (Carnatic) [Krishnaswamy 2003a & 2004]. Pitch analysis in this research does not utilize histograms but is rather based on pitch variations in time. The Short-Time Fourier transform (STFT) and Autocorrelation based pitch trackers (ACPT) are used for estimating the pitch whereas pitch analysis is then base on manual note segmentations [Krishnaswamy 2003b].

All the above approaches were particularly considered as possible ways of dealing with the objectives of the current research. The methodology was decided based on the ideas presented above, some being more inspiring than other, that were further developed to improve efficiency. In the methodology chapter, a detailed description of the most relevant approaches is provided.

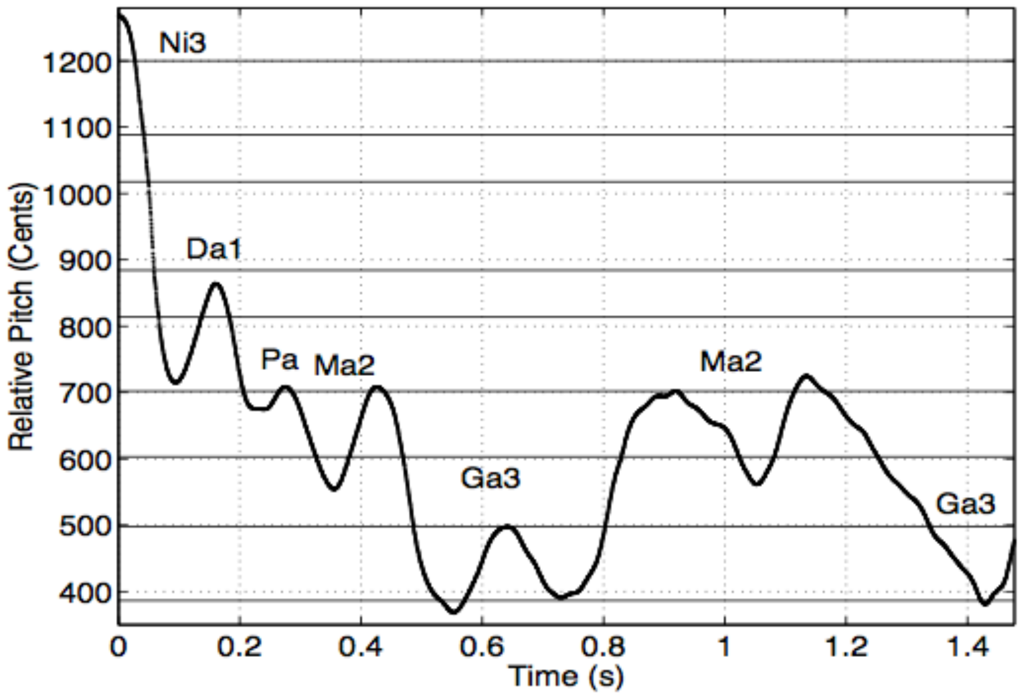

Figure 3.4: Pitch analysis of Indian music in time [Krishnaswamy 2003b].

4 Music Material

In a comparative analysis, like the one this thesis aims for, the collection of the music material is a critical issue. We try to construct music databases that represent 'fairly' the music traditions we analyse, in order not to bias the results of this study. The challenges considered in this 'fair' representation and the way each affected the choice of the music material, are further explained below.

Firstly, we choose to focus on vocal recordings for a couple of reasons:

1. The singing voice can accurately express the microtonal intervals defined in theory, in contrast to some equal-tempered instruments that are often used in the audio recordings (e.g. the lute instrument in some Cypriot recordings).
2. As musical instruments are forbidden in orthodox ecclesiastic music to this day, the available material of Byzantine music consists mainly[20] of recordings of the singing voice. Therefore the singing voice was considered as the main instrument of comparison for also Cypriot and Turkish music.
3. Since the Byzantine music material is limited to vocal recordings, we restrict our study to the particularities of the singing voice only. Besides, characteristics of the underlying music, such as the use of specific melodic embellishments, are differently emphasised if performed on other instruments. Therefore, Turkish or Cypriot instruments other than the singing voice were excluded from the music material.

Secondly, respecting the monophonic character of Cypriot music we prefer to focus mainly on monophonic material. However, polyphonic material was also included in the music database assuming that the leading melody was dominant enough or, at least, could be efficiently extracted by the algorithms employed (cf. Chapter 5). In the case of polyphonic material, some additional mixing was applied to the audio signal before further processing; this included the manual removal of the instrumental solos between the pauses of the singing voice in order not to be considered part of the leading melody.

What is more, the excerpts segmented were mostly extracted from the end of the piece. These were, on average, 40 to 60 seconds long, a time within which the underlying musical phrase could be presented twice or three times. The choice of the excerpts being extracted from the end of the piece lies in that the pitch of the last note of the phrase (or even better of the whole piece) was important for further use by the tonic detection algorithm (cf. Section 5.7). Therefore, we had to ensure that this note was also the last note played in the segmented excerpt.

Overall, we tried to find music recorded early in time to avoid the possibilities of the music characteristics being 'Westernised' as for example was the case for the recent recordings of African music in [Moelants et al. 2009]. In addition, we focus the selection on recordings from musicians referred to as 'the great masters' in the literature.

[20] In some cases, a synthesizer playing the *ison* or drone is also recorded to accompany the liturgical singing for teaching purposes.

For Cypriot music, the material consists mainly of recordings from:

1. The music collection in [PFF LP VIII-XIV 1989]
2. The religious music collection in [Cyprus Research Centre 2004]
3. Selected tracks from albums of the modern virtuosos *Michalis Tterlikas* and *Christos Sikkis*
4. Songs performed by the Cypriot musicians[21] *Christos Tziallis, Costas Karpasitis, Xenis Panteli, Giannis Ttikkis* and *Andreas Christakkos* recorded by the author in April 2011 for particular tasks of this research.

Music material from the first two collections was recorded in the 1960s and before, in the scope of extensive research in the music of Cyprus. The combination of the two collections provides a good representation of, on one hand, all musical styles of Cypriot music, and on the other, the religious music of Cyprus. The selected tracks from the recent artists were chosen as a complementary to the Fones songs and the different melodic variations that exist. From the recorded material, songs performed by the former three artists were mainly used for Fones analysis whereas songs from the latter two musicians were employed[22] for the analysis of the pithkiavli characteristics as presented in Section 2.1.2.

Note that more songs were selected from the religious and Fones music for two basic reasons. The former because the Byzantine and (hence) Turkish music we are comparing with is mainly religious, and the latter because Fones are considered very typical in the Cypriot music tradition (cf. Section 2.1). Moreover, another category that has also many instances is the *historical* style, where belong the songs that describe a historical story. There was a significant amount of these types of songs in the two big music collections we referred to. It should be noted though that many of these historical songs are actually using melodies of Fones, so one could also classify them under the Fones group.

Musical Style	**Count**	**Percentage (%)**
Fones	16	22.2
Religious	22	30.6
Historical	13	18.1
Laments	4	5.6
Lullabies	6	8.3
Wedding songs	5	6.9
Christmas/Easter songs	5	6.9
Other	3	4.2
Total	**74**	
Pithkiavli melodies	15	--

Figure 4.1: Distribution of the collected Cypriot recordings among different musical styles.

[21] In the tracks recorded the contribution of each musician was: Christos Tziallis – violin and singing, Costas Karpasitis – violin, Xenis Panteli – singing, Giannis Ttikkis – pithkiavli (two-pithkiavli technique) and singing, Andreas Christakkos – pithkiavli and singing.

[22] These melodies were not further considered in the comparison with Byzantine/Turkish music.

As for Byzantine music, the liturgical rites are rather fixed. Selection was therefore based on the proficiency of the chanter, the *Protopsaltis* as is often called a skilful Byzantine musician, and the echoi we focus on in this study. The chants in the Byzantine music database were selected from the albums of Protopsaltis Georgios Kakoulides and the Protopsaltis Georgios Spanos. Information regarding how many chants were selected for each echos can be found in Table 4.1.

For Turkish music, focus was given on religious music. The Turkish music database was then based on recordings of the masters Kani Karaca and Bekir Sıdkı Sezgin. The choices of the specific makam families were explained in the previous chapter. The distribution of songs among the different makams can be found in the table below.

Echos	**Count**	**Makam**	**Count**
First	7	Huseyni	5
First Plagal	8	Ussak	5
		Buselik	6
		Nihavend	4
Second	11	Hicazkar	5
		Sedaraban	3
		Hicaz	7
Second Plagal	3	Suzidil	3
Third	14	Mahur	3
Grave	5	Suzinak	5
Grave(P)	2	Segah	3
Fourth(E)	6	Kurdilihicazkar	6
Fourth Plagal	11	Rast	4
		Saba	6
		Huzzam	4
Total	**67**	**Total**	**69**

Table 4.1: Distribution of Byzantine and Turkish recordings among the different echoi/makams.

5 Methodology

5.1 Overview

The primary objective of this research is to compare the Cypriot pitch patterns with Turkish and Byzantine ones and detect their similarities and differences. Pitch histograms are used as the main analysis tool. Information of the different aspects of the pitch pattern, such as the scale, the intervals and the most prominent scale tones, is then directly derived from the histogram representation. This information is further analysed with the set up of specific experiments (cf. Chapter 6).

However, for all experiments there is a common underlying methodology. This includes the procedure of pitch extraction from a collection of recordings, the suitable post processing, histogram computation, histogram alignment and similarity measure. The steps are summarized in Figure 5.1 and further explained in the sections below.

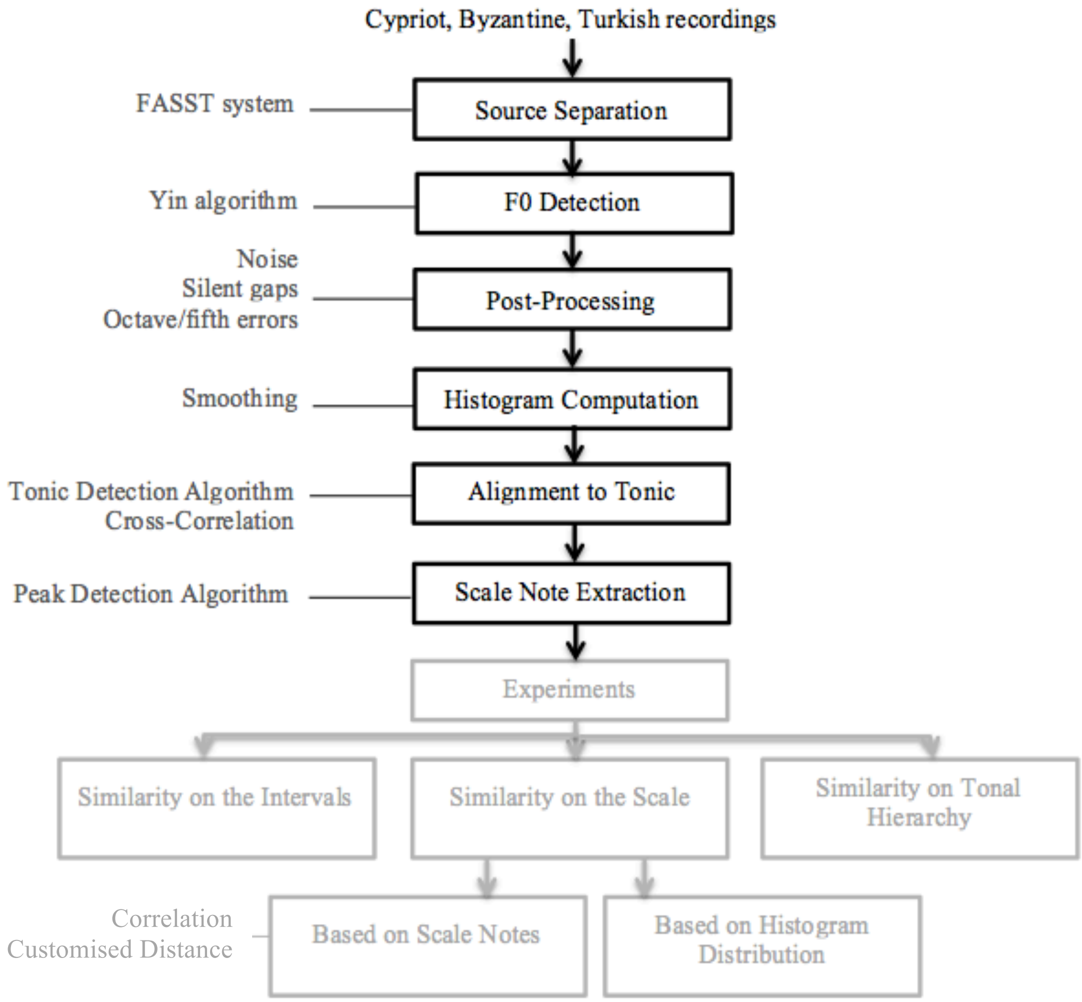

Figure 5.1: The underlying methodology for comparing Cypriot with Byzantine/Turkish pitch patterns based on pitch histogram representation.

5.2 Source Separation

In order to reduce possibility of frequency estimations that do not correspond to the leading melody, polyphonic recordings were further processed with the Flexible Audio Source Separation Toolbox[23] (FASST). FASST generalises the existing source separation methods by enabling incorporation of prior knowledge of each source via user-specifiable constraints [Ozerov et al. 2010]. From a mixture of music signals, separation to the following sources can be done:

1. Drums
2. Bass
3. Melody (singing voice or leading instrument)
4. Remaining sounds

The melody was the signal to be further processed. It should be noted that the estimated melody from source separation was not always accurately extracted. Most frequent confusion was between the singing voice and the lute/ud[24] instruments that for some songs were not efficiently separated. Yet, in the estimated melody the singing voice was more prominent than the other instruments and thus was still good for further processing with Yin algorithm (see below).

Overall, the source separation tool had satisfactory results and enabled the processing of complex audio signals that could not be dealt with if the Yin algorithm was directly applied.

5.3 F0 detection (YIN)

Algorithmic pitch estimation is usually done assuming a close relationship of the perceived pitch and the fundamental frequency (f_0) of the signal. In the current study we use the f_0 estimation algorithm developed by Cheveigne and Kawahara, called the Yin algorithm [Cheveigne et al, 2002]. The algorithm is based on the autocorrelation method [Rabiner 1977] with a number of modifications that improve its performance.

Yin estimates are still not completely free of errors. The error rate varies depending on the acoustic characteristics. Thus, special post-filtering methods are often applied to correct some of these errors. Considering the melodic characteristics of the music we analyse as well as the particularities of the singing voice, the following post processing filters were designed.

[23] http://bass-db.gforge.inria.fr/fasst/

[24] String instrument used often in Turkish recordings (also spelled oud), http://www.britannica.com/EBchecked/topic/612394/ud

5.4 Post Processing

a) Noise

As noise does not have defined pitch, frequency estimations by Yin are often erroneous at the noisy parts of a recording. To eliminate these we apply an aperiodicity threshold that acts as a noise filter.

b) Silent Gaps

Frequency estimates corresponding to silent and/or quiet parts should not be considered for further processing. Therefore we apply a loudness threshold to remove the frequencies falling in these gaps.

c) Octave/fifth errors

One of the major problems of any frequency detection algorithm is the wrong octave detection, also referred to as *octave errors*. That is, the fundamental frequency is often confused with its multiples and/or other harmonics. Considering pitch, these false harmonics represent either the correct note in the wrong octave (for actual pitch of 110, 220, 440, 880 Hz), or the note a fifth higher or lower than the fundamental (165, 330, 660 Hz). In the Yin algorithm octave/fifth errors are more likely to occur at the regions of high aperiodicity. To compensate with this we apply an octave/fifth correction algorithm as stated below.

First let us note that Yin estimates are scaled in an octave correspondence of integer multiples centred at 0, the reference frequency normally tuned at 440Hz. Therefore, a Yin output of 1 represents an octave higher than 0 (i.e. 880Hz) and a Yin output of -1 represents an octave lower (i.e. 220Hz). In a similar way, integer halves represent fifth intervals such as 0.5, which is equivalent to 660 Hz, and -0.5, which equals 330 Hz. Therefore, in the Octave/Fifth correction algorithm a jump of integer length correspond to an octave jump whereas a jump of integer-half corresponds to a fifth/octave+fifth jump.

Assumptions:

1. No pitch jumps of fifths, octaves, octaves+fifth occur between two consecutive pitch analysis frames
2. Consecutive frames with pitch higher than a fifth from the average melody pitch are not likely to occur in the music we analyse (characterised by short melodic pitch range).
3. A pitch candidate for the average human voice cannot be estimated beyond the range of the eight (piano) octaves i.e. Valid Yin output between [-4,4].

Steps:

Let $x = x_1, \dots, x_n$ be the input pitch sequence from YIN

Initialize corrected pitches $(x'_{i-t}, \dots, x'_{i-1})$ for a window of length *t*. These should not be a fifth or more apart from the average frequency.

For pitch sample i:

Jump of sample is $\Delta = median(x'_{i-t}, \dots, x'_{i-1}) - x_i$

If $|\Delta| \geq 0.5$

Find the error jump choosing between fifths, octaves, octaves+fifths higher or lower:

$$e_i = \min_{e \in (\pm 3.5, \pm 3, \pm 2.5, \pm 2, \pm 1.5, \pm 1, \pm 0.5)} |\Delta + e|$$

Correct sample: $x'_i = x_i - e_i$

End

End

Output $(x'_1, \dots, x'_n)$

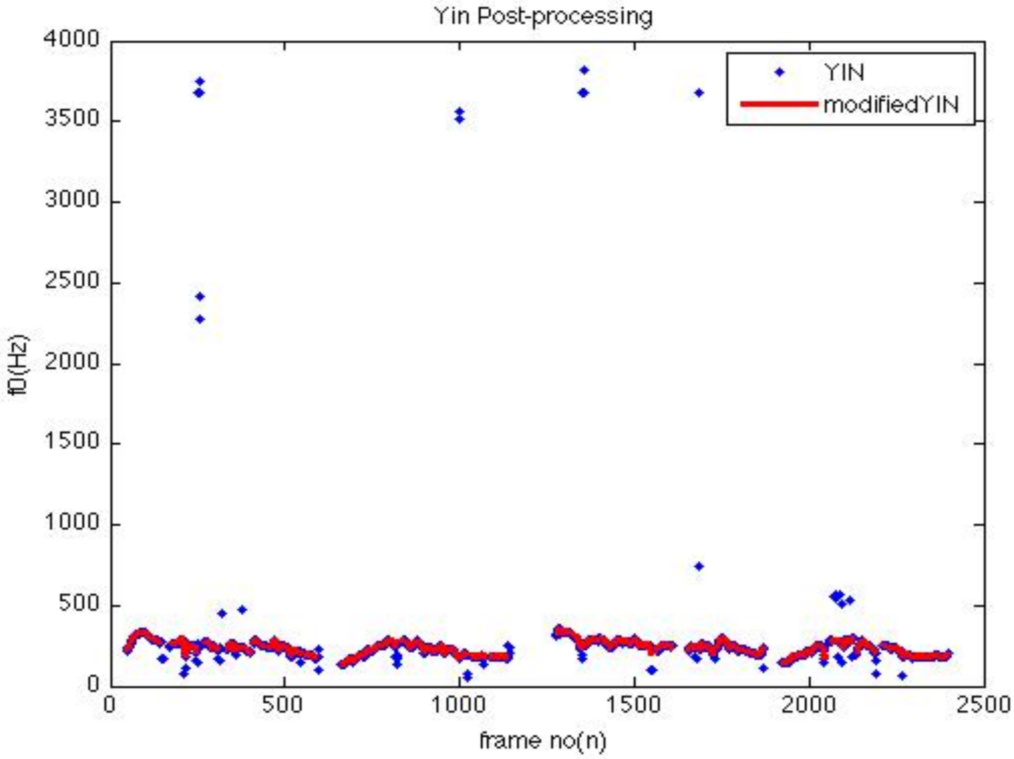

Figure 5.2: Octave/fifth error correction of the Yin f0 estimations. The corrected Yin line (red) is plot on top of the original one (blue). Therefore the blue regions remaining on the graph are the original Yin estimations that were afterwards corrected.

For the evaluation of the algorithm and the designed post processing filters we resynthesized the modified Yin estimates with the help of sinusoidal synthesis and compared with the original audio. Simultaneously playing the two could easily reveal the points where the improved frequency estimations still failed to match the original.

In a quantitative analysis of the vocal recordings in our music database, the modified algorithm is accurate for the majority of the recordings with some exceptions whenever the breathiness of the voice or the presence of noise is more emphasized in the recording than usual. However, the erroneous part is significantly small compared to the whole melodic contour of the recording and the total number of songs analysed that can be neglected.

5.5 Histogram Computation

The use of histograms for analysis of pitch frequencies is a common practice in scale estimation tasks [Akkoç C., 2002]. Ideally, the histogram peaks at the most frequently appearing notes of the melody, implicitly represent the tones of the scale. By definition, a histogram partitions the data $\boldsymbol{x}$ into distinct bins of width h_i and then counts the number K_i of observations of $\boldsymbol{x}$ falling in bin i. In the case of a pitch histogram, the vector $\boldsymbol{x}$ represents the f0 estimations usually reduced to the range of an octave and the bin widths h_i are the octave partitions often assumed to be equal so that $h_i = h$. Therefore the total number of f0 values lying in the bin i is given by:

$$K_i = \sum_{n=1}^{N} k\left(\frac{b_i - x_n}{h}\right)$$

where,

b_i is the centre of the bin i and

$k(u) = \begin{cases} 1 & |u| \leq \frac{1}{2} \\ 0 & otherwise \end{cases}$ is the *kernel function*.

The histogram values can be further normalised to a probability density function so that they add up to 1. This is achieved simply by dividing the count K_i for each bin by the bin's width h and the total number of observations N:

$$p_i = \frac{K_i}{Nh}$$

The bin resolution of the histogram is a critical decision and varies according to the characteristics of the analysed music and the processing purposes. For example, a piano music piece can be sufficiently analysed with a histogram bin resolution of 12 (octave partition in 12 equal parts, the so-called semitones)[25], as the piano cannot produce notes other than the fixed equally sized tones and their multiples. However, this is not enough for music with non-equal temperament or microtonal intervals where a higher bin resolution is required.

The Chrisanthine theory specifies an octave division of 72 equal partitions for Byzantine music analysis whereas Arel theory for Turkish music requires an octave division of 53 equal partitions. Therefore the ideal bin resolution for Byzantine and Turkish pitch histograms according to the chosen theoretical models is 72 and 53 respectively. Converting to cents (octave = 1200 cents) the above histogram resolutions are equivalent to cent precision of 16.67 and 22.64 for Byzantine and Turkish music respectively:

$$Byzantine: \frac{1200}{72} = \mathbf{16.67}$$

$$Turkish: \frac{1200}{53} = \mathbf{22.64}$$

[25] Due to spectral leakage, in practice, however 36 bins per octave are for pitch analysis of 12 tone equal temperament.

However, in the practice of these two music traditions we find intervals not agreeing with this equal-temperament division and especially when analysing vocal recordings. Therefore, we consider increasing the histogram resolution by a factor of three, for better precision and tuning robustness [Gedik & Bozkurt 2008, Gomez 2006]. This implies bin resolutions of 216 and 159 for Byzantine and Turkish music analysis respectively.

It is noteworthy mentioning here, that for purposes like measuring similarity of two or more histograms; the latter should have the same bin resolution (see for example Section 6.4). Therefore, for comparing histograms of Byzantine and Turkish recordings a common bin resolution had to be established. This was decided to be the least common multiple (lcm) of the two theoretical resolutions,

$$lcm(72, 53) = 3816.$$

This gives an equivalent cent precision of 0.31. The reason for the choice of this resolution size is that it respects the octave division of both Byzantine and Turkish music so that frequencies do not get rounded to bins other than the expected theoretical values.

Histogram smoothness is also improved with higher bin resolutions. This is very important in automatic histogram processing where peak detection is a basic operation as the smoother the histogram the more clearly pronounced the peaks are. However, the degree of smoothness is limited by the definition of the kernel function of the histogram. That is, the histogram will still suffer from artificial discontinuities at the boundaries of the bins. To overcome this problem we choose a smoother kernel function such as the Gaussian kernel.

The kernel density model then becomes:

$$p_{\boldsymbol{b}}(\boldsymbol{x}) = \frac{1}{N} \sum_{n=1}^{N} \frac{1}{\sqrt{2\pi h^2}} e^{\frac{-\|\boldsymbol{b_n} - x_n\|^2}{2h^2}}$$

where $\boldsymbol{b} = b_1, \dots b_N$ represents the centres of the N bins (the mean vector) and h the standard deviation of the Gaussian components.

In essence this model places a Gaussian at each data point and adds up the contributions over the whole dataset and normalizes then to [0, 1]. The parameter h is the smoothing factor and there is a trade off between noise sensitivity at small h and over-smoothing at large h values [Bishop 2006].

Experiments with automatically learning h gave overly smoothed curves [Sheather & Jones 1991]. The smoothing factor was therefore decided upon trial and error. Two smoothing factors were considered; less smoothing was applied for similarity experiments based on the histogram distribution whereas for scale note extraction based on histogram peak detection a bigger smoothing factor was employed. The idea behind these choices is that, a less smoothed histogram curve is better for histogram distribution similarity measure as it preserves more details of the recording's particularities such as singer's ornamentation. On the other hand, a higher degree of smoothing is required for scale tone picking as the more detailed the histogram curve is the more spurious peaks will be detected.

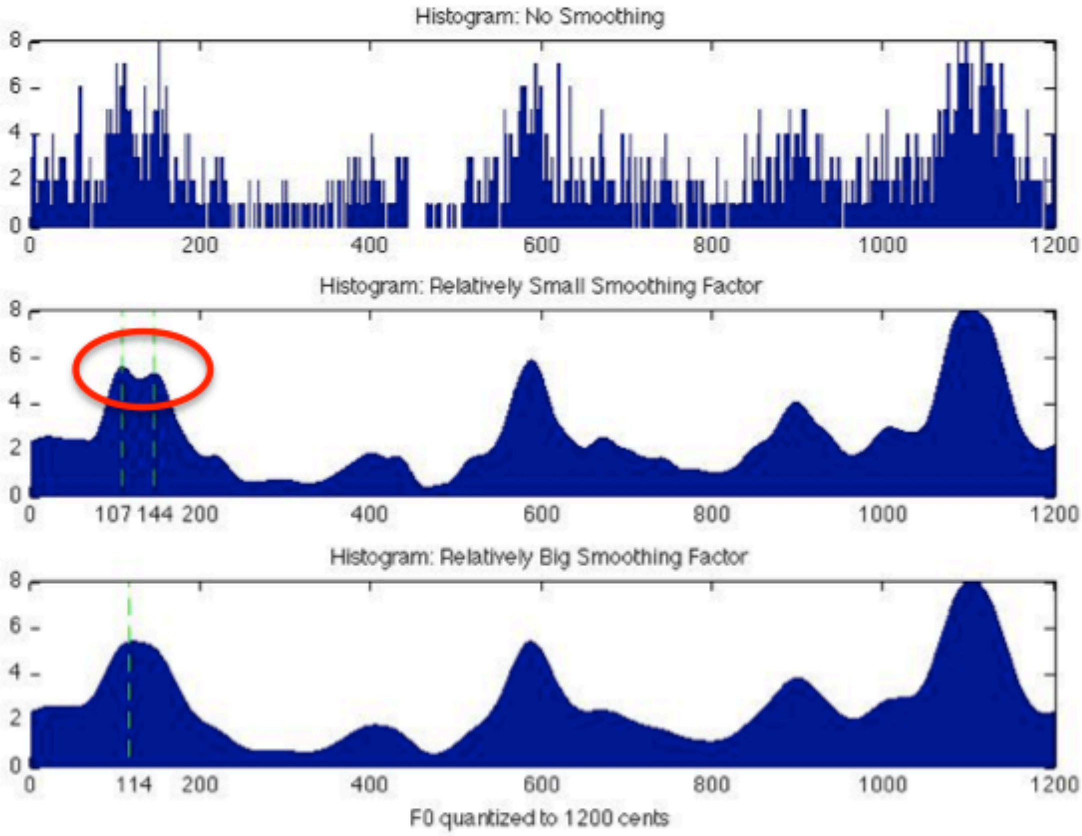

Figure 5.3: The smoothness of the Gaussian kernel density model; Histogram with no smoothing (top), with relatively small smoothing factor (middle) and relatively big smoothing factor (bottom). The circled peaks of the middle graph differ by less than a quartertone (less than 50 cents) and are merged in the bottom graph thus avoiding a fake scale-tone peak.

5.6 Peak extraction

A specifically designed peak-picking algorithm was used for the purpose of peak extraction from the histogram distribution. The algorithm peaks the *n* highest peaks in the given spectrum from the highest to the lowest. Three parameters are then given as input, namely the:

1. *Spectrum*: The histogram distribution in this case
2. *nPicks*: the number *(n)* of peaks to pick
3. *minspace*: the minimum space between two peaks

The peak-picking algorithm outputs the location and amplitude of the chosen peaks. If less than nPicks are found in the spectrum the algorithm outputs *0* for location and *-100* for amplitude. A threshold (*t*) was afterwards applied on the output amplitudes to select only those peaks that had significant amplitude in the spectrum. This threshold was set to 2 (when no normalisation is employed), implying that a peak is valid if the corresponding frequency bin is at least used twice in the total of frames of the whole excerpt[26]. Empirical tests showed that a low threshold like the one chosen is appropriate for the bin resolutions we are dealing with. Besides, some scale notes are rarely used in the whole piece and thus produce really low-amplitude peaks. Despite this, the location of these peaks is still important in the scale estimation, therefore a really low threshold was needed to make these peaks valid.

As for the number of peaks (nPicks) considered in further processing, parameter was tuned based on the characteristics of the music we analyse. That is, from the scales employed in the Byzantine and Turkish music theory we know that there are at least 7 scale notes for each echos and from 7-10 scale notes for the makams[27]. However, we consider the possibility of more than 7 peaks found in the histogram distribution due to relevant melodic modulations of the scales in theory and/or practice. Therefore the valid number of peaks was decided to be 12.

The minimum space (minspace) between two peaks was also decided upon the features of the underlying music theory. We know from Section 2.2 that smallest theoretical interval in Byzantine and Turkish music is 4/12 and 4/9 of the whole tone respectively. Both these intervals are bigger than a quartertone that was the distance threshold implied in minspace. Therefore peaks lying closer than a quartertone interval, even after the appropriate smoothing is applied, would not be both picked for further processing (only the highest amplitude peak would be chosen).

Lastly, to overcome the smoothing inaccuracies at the edges of the histogram, we copy the histogram 3 times, and paste it next to each other (the *three-histogram* method as will be named from now on), before applying smoothing. Then we smooth the whole with the smoothing factors explained in the previous section (remember that more smoothing is applied for the histogram used for peak extraction). From the three-

[26] The purpose of this threshold was also to filter out the -100 amplitude output values of false peaks.
[27] The echoi and makams chosen for further analysis (cf. Section 2.2.4) consist of 7 scale notes (in the majority) with the Saba makam only consisting of 8.

histogram copies the middle one is only considered for further processing. The idea is graphically illustrated in Figure 5.4.

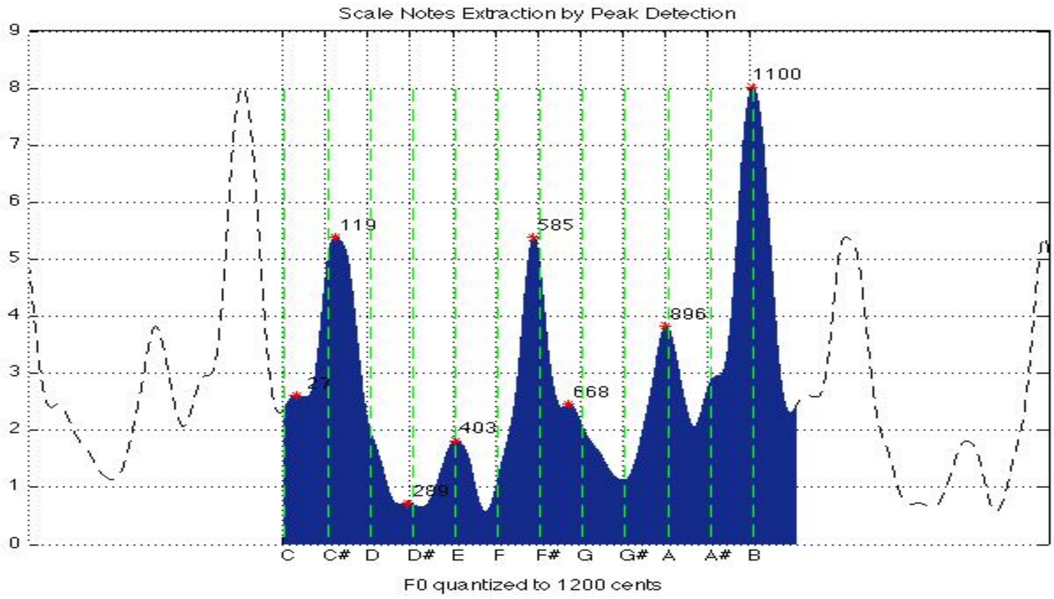

Figure 5.4: Peak detection applied to the three-histogram copies, where the middle part avoids the peak discontinuities at the edges of the original (single) histogram.

The peak detection algorithm works also with the three-histogram input, as in this way the peak disruption of the edges is avoided. Since the spectrum parameter contains therefrom the histogram distribution three times, the number of peaks to be picked (nPicks parameter) had also to be increased by a factor of three.

The parameters tuned for the peak extraction procedure as described above are summarised in Table 5.1.

Parameter	Definition	Value
Spectrum	Spectrum input	*Three-histogram* copies
nPicks	Number of peaks to pick	36 *(= 3 x 12)*
minspace	Minimum space between peaks	Quartertone *(Octave bins/4)*
t	Peak amplitude threshold	2

Table 5.1: Parameters tuned for the peak extraction task.

5.7 Tonic Detection

In the papers by Ali C. Gedik and B. Bozkurt the tonic is detected via an automated procedure that cross-correlates the recording's histogram with theoretical templates that represent the makam scale as the sum of Gaussian distributions. The Gaussian curves are centred at the theoretical pitch values as defined in Arel theory for each makam and have a fixed variance. This theoretical template is used as an initial step to detect the tonic by finding the highest cross-correlation between an Arel makam scale and the f0 histogram of a given recording. The theoretical scale template is then iteratively redrawn from lined up histograms of given recordings and alignment with all files is re-performed. A detailed explanation of this method can be found in [Bozkurt 2008, Bozkurt et al. 2009].

In [Bozkurt 2008] the tonic detection method was tested on 67 recordings and only 7% of these were problematic. One of the reasons of wrongly detected instances was the particularity of instruments such as the singing voice where its pitch instabilities add f0 regions that don't match exactly in histograms (Figure 5.5). In our study, where the music database is mainly built on vocal recordings, this tonic detection approach would be to a certain degree inefficient.

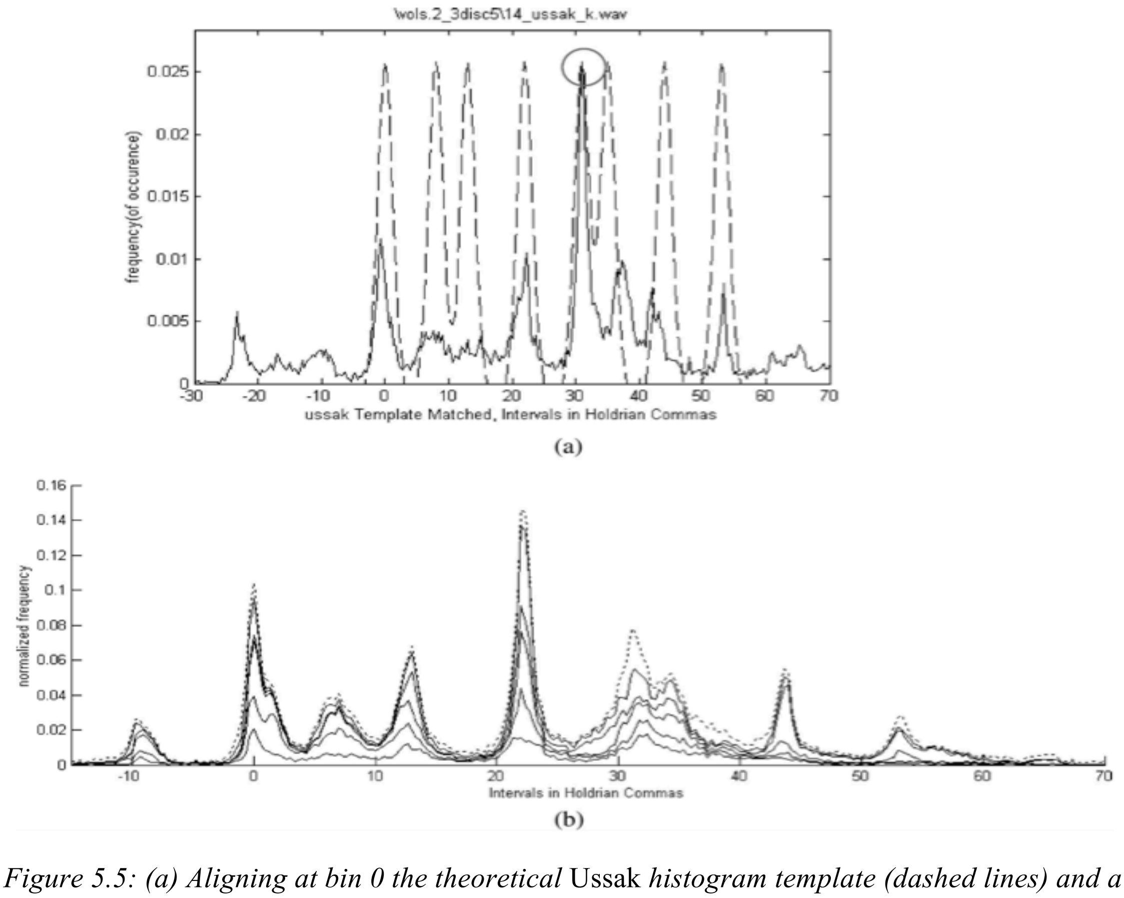

Figure 5.5: (a) Aligning at bin 0 the theoretical Ussak *histogram template (dashed lines) and a pitch histogram of an* Ussak *recording and (b) the theoretical template updated iteratively where the last contribution in dots come from the tonic misdetection of the histogram in (a) (correct tonic is circled). [Bozkurt, 2008].*

A different tonic detection approach was therefore considered and applied to Byzantine and Turkish music. As their music theory suggests, the tonic of a Byzantine echos or Turkish makam is usually[28] stated at the end of the phrase. We limited ourselves to the echoi and makams that this rule applies and designed a tonic detection algorithm that computes the pitch of the last phrase note from the onset and frequency information. This method was also implemented in [Bozkurt, 2008] but was rejected due to background noise sensitivity of Yin estimations, especially present in the old recordings. Considering this, we try to improve robustness of the tonic detected from the last phrase note by integrating appropriate assumptions and limitations (Section 5.7.1).

As for Cypriot music, empirical tests from a semi-automatic analysis of a subset of Cypriot melodies (cf. Section 6.2) revealed that the tonic is also usually the last note. However, we avoid taking this for granted and we instead align the Cypriot histograms to the bin of highest correlation with the Byzantine or Turkish histograms. This bin (being the tonic or not) was computed by the correlation coefficients method applied to the Cypriot and the most similar Byzantine/Turkish histogram. This is further illustrated in the figure below.

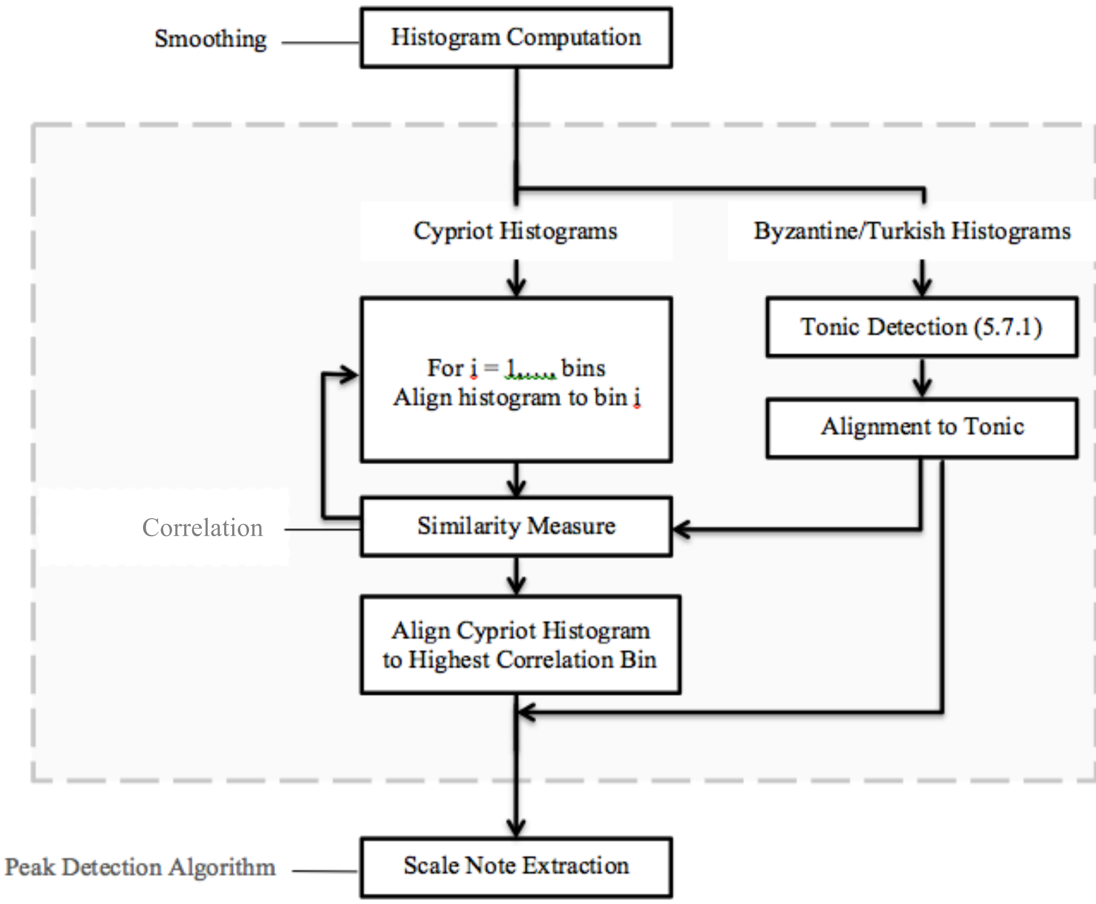

Figure 5.6: Alignment to tonic for Cypriot and Byzantine/Turkish histograms.

[28] There is one echos where the tonic is not presented at the end of the phrase and this is the Fourth echos for the Stoichirarika chants.

5.7.1 Algorithm for Tonic Detection from the Last Note

Assumptions:

1. The audio excerpts are segmented in such a way that the last note played is the last note of the ending phrase.
2. Due to the characteristics of religious music and the particularities of the singing voice as used in the music we analyse, the last note of all recordings lasts for at least half a second.

Limitations of the onsets detection algorithm:
The onset detection algorithm we use defines an onset whenever energy or pitch variations above certain thresholds occur between consecutive frames. The efficiency of the algorithm is however limited by the characteristics of the music we analyse and particularly the frequent use of vibrato of the last note. Usually, more than one onset is detected for the last note, due to strong energy and pitch variations.

Explicitly, false onsets occur because of the following reasons:

1. In the extreme cases vibrato ranges up to ±2 semitones and onsets due to pitch variation can then be detected on frames with instantaneous frequency that differs more than a semitone from the pitch of the last note.
2. Additionally, onsets due to energy-variation fail to detect the attack of the last note due to the high degree of melisma ornamentation. That is, the singer softly introduces the final note without changing the syllable and, energy-wise, without a noticeable energy variation.

Empirical tests showed that for our music collection an amount of three onsets is usually detected for the last note. The algorithm implemented takes into account this fact, and compensates with possibly false onsets by averaging the instantaneous frequencies of the last frames in the way described below.

Preprocessing

Detect the last three onsets
Get the three frame-wise frequency values they correspond to

Last note Detection

If all three frequencies lie within a semitone
    % Short vibrato range or no vibrato
    Tonic is the average of the instantaneous frequencies of the frames of the three inter-onset-intervals[29]
Elseif the last two frequencies lie within a semitone
    % Vibrato range bigger than a semitone or first of the three onsets is false
    Tonic is the average of the instantaneous frequencies of the frames of the last two inter-onset-intervals
Else
    % Vibrato range bigger than a semitone or first two onsets are false
    Tonic is the average of the instantaneous frequencies of the frames of the last half-second of the melody
End

Postprocessing

Detect scale tones from the histogram peaks (location and value)
Refine tonic to the closer scale tone according to location and value

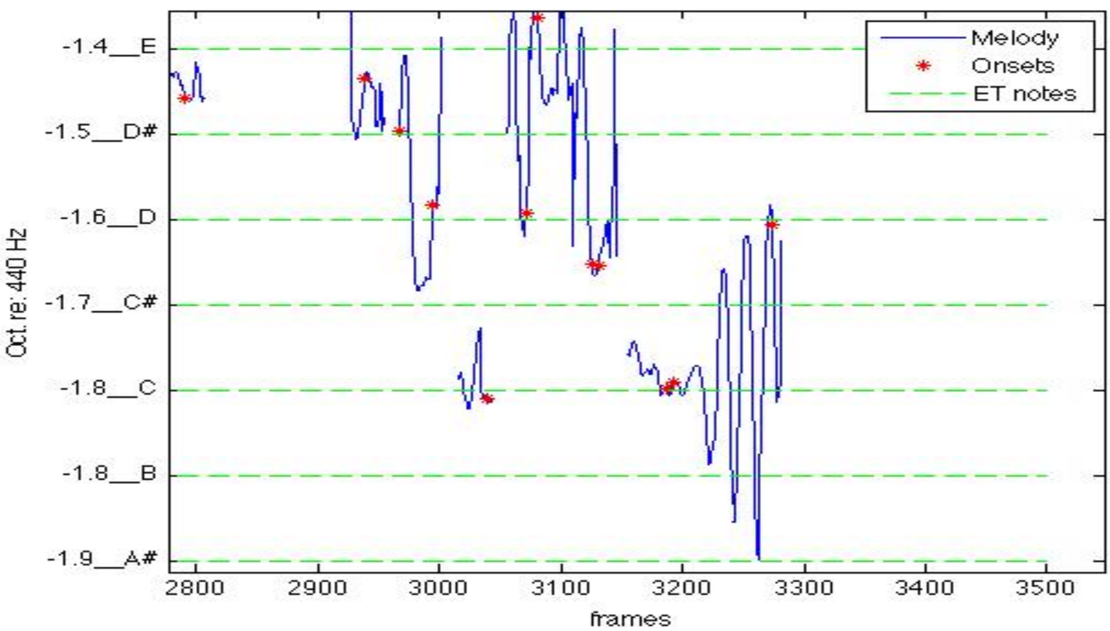

Figure 5.7: Onsets detected on the last note (frames 3150-3300). The first two detected onsets correspond to frame-wise frequencies around note C whereas the third corresponds to D due to a wide-range vibrato.

[29] The inter-onset-interval of the last onset is set to be the interval from the onset's frame to the last non-zero frequency of the piece.

5.8 Similarity Measures

A lot of distance measure methods are available for similarity purposes. In similar studies such as [Bozkurt 2008, Moelants et al. 2009], the cross-correlation function was preferred for measuring similarity of pitch histograms. There is however a variety of available similarity measures. We tested three of them and we chose the one with the relatively best results. Where best results in this sense imply the measure that best integrates the information of the histogram's peak locations, amplitudes and variances in the total similarity grade. The three methods are the correlation coefficients, the Euclidean distance and the Kullback-Leibler divergence measure of probability distributions.

The three techniques were tested against a similarity measure between the histograms of the different echoi. The best method was decided upon visualisation of the results on Distance Matrices. Ideally, the blocks for each echos lying on the diagonal of the matrix should be more correlated (more red coloured) as they correspond to histograms from the same echos. Moreover, the best similarity measure should reveal a rather balanced colour distribution in the corresponding Distance Matrix as on average, the histograms cannot be totally un-correlated neither totally correlated.

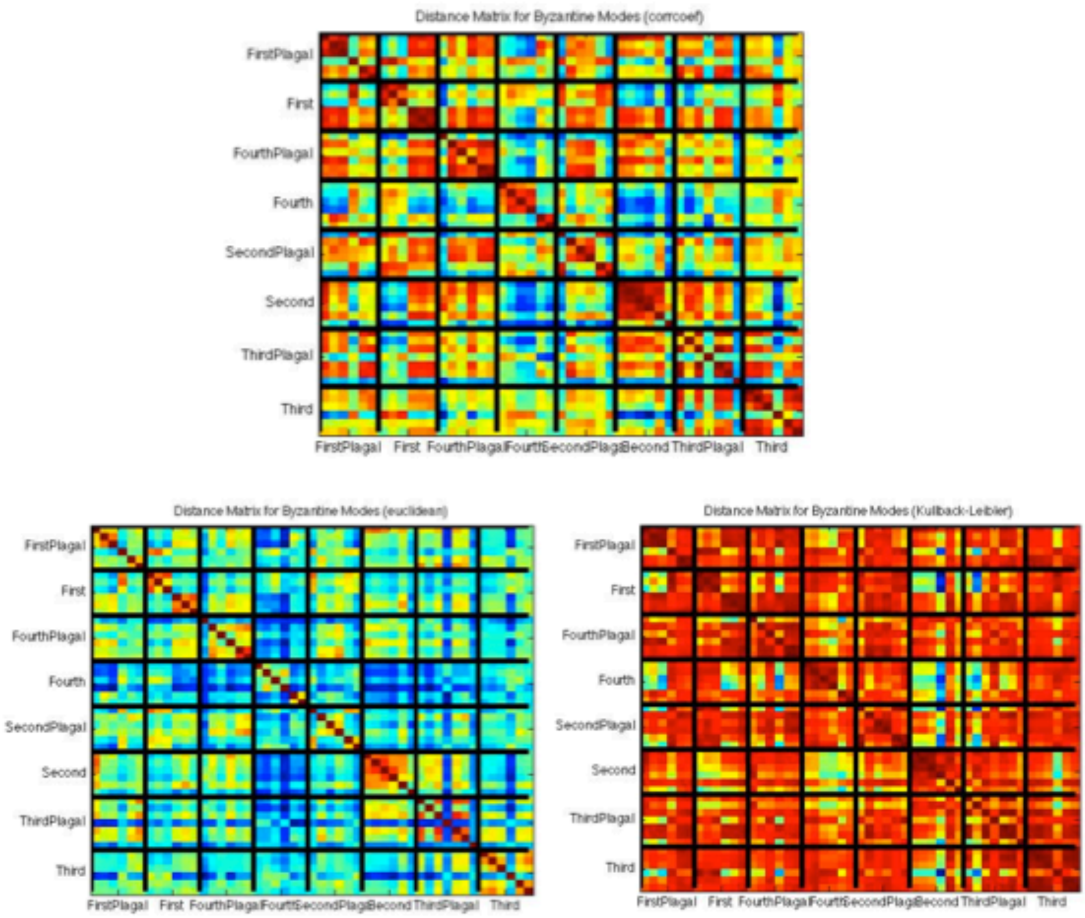

Figure 5.8: The performance of different distance measures applied on histogram similarity of the Byzantine echoi; Cross-correlation (Top), Euclidean (Bottom-Left) and Kullback-Leibler (Bottom right).

From a visualisation on the results we observe that the correlation coefficients method gives relatively better results than the Euclidean distance and the Kullback-Leibler divergence. The last two were rejected because, on one hand, Euclidean distance revealed that histograms were on average uncorrelated (majority of blue colour on Distance Matrix) whereas Kullback-Leibler on the other hand revealed that histograms were very correlated (majority of red colour on Distance Matrix).

The similarity measure therefore chosen was the correlation coefficients method. However, the choice should not be absolutely trusted, as neither of the three similarity measures was thoroughly analysed and tested.

5.8.1 Customised Distance Measure

For the tasks of measuring similarity of the scale notes a different approach was developed. First let us remind that scale notes were extracted from the pitch histogram based on the peak extraction algorithm described in Section 5.6. The main challenge was then to combine efficiently the information regarding location and amplitude of the various peaks of the two histograms in a single measure. Ideally, the location difference of two peaks should play a more important role in the total distance than the amplitude difference. This is because big location differences of two scale tones can imply two completely different scales, whereas the amplitude difference affects mainly the tonal hierarchy of the scale.

Moreover, before comparing scale tones, the peaks from two different pitch histograms have to be attributed a scale degree. This is accomplished via another function that compares the peaks and matches the ones that lie within a semitone distance. In this function, peaks from one histogram are taken as the theoretical scale notes and peaks from the other are matched to them (i.e. peaks from a makam histogram will be the theoretical scale notes and peaks from the Cypriot will be matched to them). The number of unmatched peak pairs should also be considered in the distance measure, as the more non-matches the more the dissimilarity.

The distance measure was therefore customised in the following way:

Customised Distance

For each pair of pitch histograms:
- Normalise histograms by mean and variance
- Extract peaks
- Attribute scale degrees to peaks by matching the two sets of peaks

---

- For scale degree i:
  - Compute location difference of peaks:
  - $dloc = |loc1 - loc2|$
  - Compute amplitude difference of peaks:
  - $damp = |amp1 - amp2|$
  - Multiply location difference by the square root of the amplitude difference:
  - $di = dloc \times \sqrt{damp}$
- End

- Average distance of all scale degrees:
- $d = mean(d1, d2, \ldots dn)$
- Weight by number of unmatched scale degrees:
- $d = mean(d1, d2, \ldots dn) \times w$

End

---

6 Results

6.1 Overview of Experiments

As explained in the methodology chapter, a series of experiments is performed for addressing the comparison between Cypriot and Byzantine/Turkish music. The experiments aim first at an analysis of the underlying music traditions and then at an investigation of the relations between them. In the first part the characteristics of Cypriot music are studied as well as the use of the Byzantine and Turkish scales in theory and practice. In the second part, relations are established between first, Byzantine and Turkish pitch patterns and then the results are integrated in a comparison with Cypriot pitch patterns. Investigation of the influence is applied on three aspects of the pitch pattern; the use of intervals, the prominence of scale tones and the employed scale.

The experiments are summarised in Table 6.1 along with the targeted task and brief description. Further details of each experiment are provided in the corresponding section.

Goal	Experiment	Brief Description
Study the characteristics of Cypriot pitch patterns	Semi-automatic analysis of Cypriot melodies	Analyse Yin melody and pitch histogram of a subset of Cypriot melodies.
Study the Byzantine/Turkish scales	Theory Vs. Practice in Byzantine/Turkish scales	Compare theorised scale tones with the empirical scale tones extracted from pitch histograms
Detect similarities of Makam-Echos in theory and practice	Echos-Makam similarity in Theory and Practice	Compare average histograms of all echoi and makams and find most similar pairs. Compare to theoretical similarity.
Investigate influence in the use of the intervals	Influence in the intervals	Compare the use of consecutive intervals in each music tradition; Which intervals are used? How many and how often? Theory agrees with practice?
Investigate influence in the use of scale tones	Influence in prominence of peaks	Compare the average amplitude of histogram peaks of each music tradition; Which peaks have the higher amplitudes? How many and how often?
Investigate influence in the scales	Measure similarity based on histogram distribution	Find most similar echos/makam histogram to given Cypriot recording and determine its scale upon greatest similarity
	Measure similarity based on scalenotes location and amplitude	Find most similar echos/makam scale notes to given Cypriot recording and determine its scale upon greatest similarity

Table 6.1: overview of experiments

6.2 Semi-automatic analysis of Cypriot melodies

In order to study the particularities of Cypriot music, a subset of 8 melodies, each representing a different Foni, was chosen for further analysis. According to theory, Fones are of the most typical melodies of Cypriot folk tunes (cf. Section 2.1.2). Therefore, such a collection can be considered representative for studying some of the characteristics of this music. The analysis was then concentrated on two aspects; melodic behaviour, based on observations of the estimated Yin melody, and tuning, based on intervals extracted from the histogram distribution. The histogram bin resolution used for this experiment was 1200, the size of the octave in cents.

An example of the Yin melody and histogram is presented in Figure 6.1. The characteristics for this subset of Cypriot melodies are summarised below.

Summary of observed characteristics

1. **The pitch range** of the melody is usually limited to a perfect fifth or sometimes a major sixth interval.
2. **Successive melodic steps** usually do not exceed a major 3rd, with semitones being used often.
3. **The main part** of the melodic phrase is characterised by the insistence on the fourth or fifth scale degrees and those contiguous notes.
4. **At the beginning and the end of the phrase** the melody ascends or descends in usually four or five consecutive steps, (a “tetra/penta-chordal” movement).
5. **The initial note** is usually the third (especially when interjection words occur) or the fourth. With interjections, we often observe a short ascending glissando just before introducing the starting note of the melody.
6. **Last note** of the melodic phrase is (usually) the tonic**.**
7. **Intervals other than equal-tempered** are used and are particularly emphasised in the embellishments of specific notes such as the highest note or the last note of the phrase.

The observed characteristics indicate some non-Western behaviour for this music (i.e. feature 7), something which was proposed in the literature and further justifies the reasons for comparing with Byzantine/Turkish music that, by theory, have non-Western structure. Moreover, the sixth feature, if it is applied in general in all Cypriot music can provide a direct similarity with Byzantine and Turkish music theory, which indicate that the tonic is usually at the last note of the musical phrase.

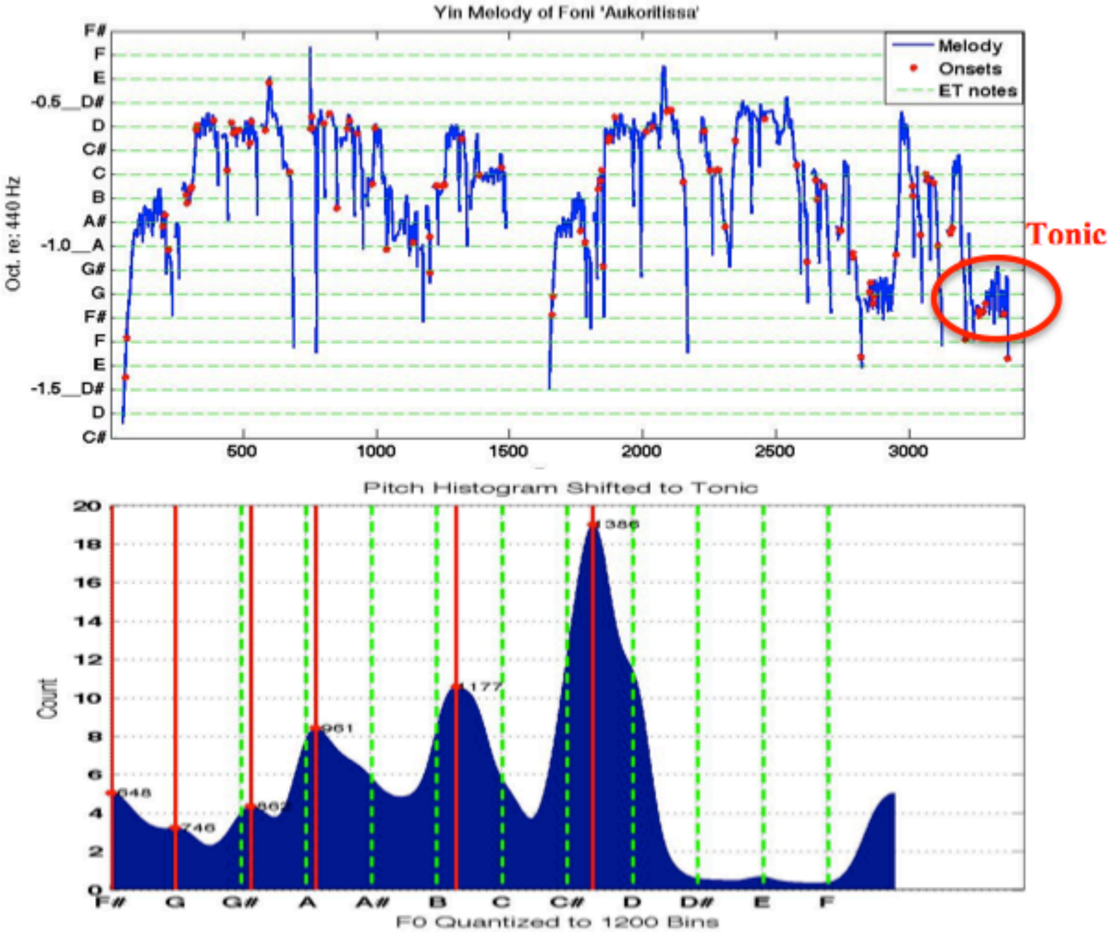

Figure 6.1: Yin melody (top) and pitch histogram (bottom) shifted to the tonic for the Foni 'Aukoritissa'.

6.3 Theory and Practice in Byzantine/Turkish scales

The Byzantine/Turkish pitch patterns were analysed through a comparison of the underlying scales as defined in theory and as used in practice. For each scale, histograms of the corresponding recordings were averaged and peaks were extracted from the mean histogram, which form now on will be called the *average histogram* (see an echos example in Figure 6.2).

The bin values of the peaks, that represent the empirical scale tones, were compared to the theoretical ones. Matching pairs were accepted only whenever the peak values lied within a smaller than a semitone distance apart from the corresponding theoretical values. Otherwise, the peak was not considered to be part of the notes of the scale. Four additional measures were taken into account to illustrate the deviation from theory to practice.

1. D: Scale notes deviation measure from theory to practice. For a given scale, the absolute difference of each scale note between the theoretical and empirical value is measured (in cents). For all scale-notes, the mean absolute error of that scale is then computed.
2. T: Similar to measure D, only that now the deviation of a given scale note is averaged across all scales.
3. E: Percentage of the number of histogram peaks that are smaller than a semitone apart from the theoretical values of the scale.
4. C: Percentage of the number of the theoretical scale values that were matched (again within a smaller than semitone distance) with the histogram peaks.

6.3.1 Theory and Practice in Byzantine Echoi

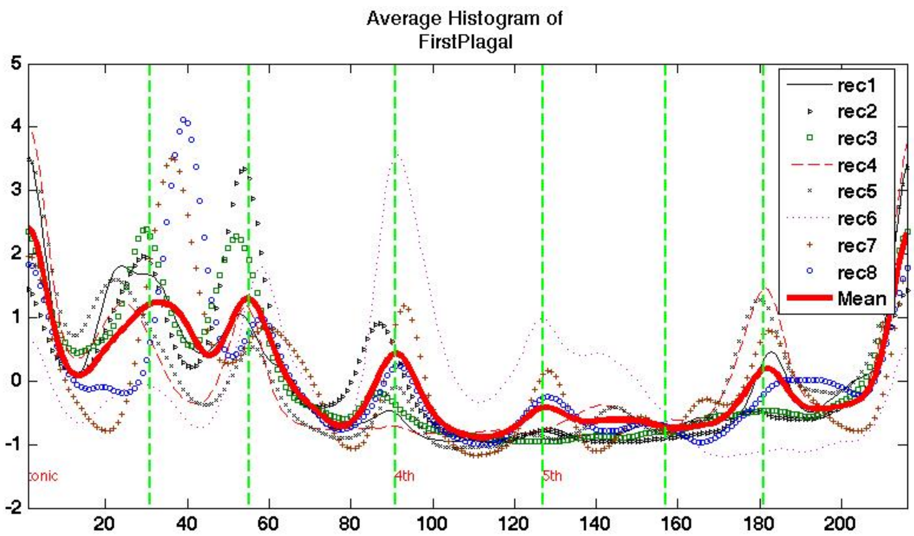

Figure 6.2: Average histogram of recordings of the First Plagal echos. The vertical dashed lines indicate the theoreised scale tones of this echos.

Echos	Scale Notes							D	E	C
First										
Theory	0	166.7	300	500	700	866.7	1000	14.3	100	100
Practice	0	133.3	311.1	500	700	922.2	1000			
First Plagal										
Theory	0	166.7	300	500	700	866.7	1000	12.7	100	100
Practice	0	177.8	300	500	705.6	800	1005.6			
Second										
Theory	0	133.3	366.7	500	700	833.3	1066.7	**21.4**	100	100
Practice	0	144.4	338.9	488.9	683.3	872.29	1022.2			
Second Plagal										
Theory	0	100	433.3	500	700	800	1133.3	14.8	100	85.7
Practice	0	116.7	388.9	505.6	711.11	811.1	NaN			
Third										
Theory	0	200	400	500	700	900	1100	6.5	100	85.7
Practice	0	200	377.8	488.9	700	894.4	NaN			
Grave										
Theory	0	200	400	500	700	900	1100	12.7	100	100
Practice	0	200	366.7	494.4	666.6	911.1	1094.4			
Grave(P)										
Theory	0	133.3	333.3	500	700	833.3	1100	16.7	100	85.7
Practice	0	127.8	355.5	533.3	722.2	850	NaN			
Fourth(E)										
Theory	0	133.3	333.3	533.3	700	833.3	1033.3	11.9	100	100
Practice	0	133.3	333.3	522.2	672.22	850	1061.1			
Fourth Plagal										
Theory	0	200	366.7	500	700	900	1066.7	16.7	100	100
Practice	0	222.2	377.8	516.7	722.2	916.7	1094.4			
T	0	11.1	19.1	10.5	15.4	26.5	18.5			

Table 6.2: Byzantine scale comparison of theory to practice. Scale notes and deviations between them are given in cents.

Observations:

1. Over all echos, the scale note that matches most accurately between practical and theoretical values is the second and the fourth degree.
2. The sixth and seventh scale degrees show the most deviation from the corresponding theoretical values. This can be justified by the following explanations:
    a. From Byzantine music theory and also from observation of the average histogram of each echos we note that melodies usually expand in a tetra/penta-chord range. In the histogram this is reflected with, either, low and wide peaks over the sixth and seventh scale degree or even no peak at all as often happens for the seventh scale degree.
    b. The theory of the First and First Plagal echos indicates alterations of particularly the sixth scale degree that is flattened when the melody direction is descending. This often produces additional peaks on the histogram of an individual recording, and when all recordings are averaged it results in a very inaccurate peak. Hence a big deviation is assigned for the sixth scale degree of those two echos that consequently increases the total deviation (T value of sixth scale degree).
3. Most accurate scale, according to the D measure, is the Third echos (cf. Figure 6.3) although the seventh scale degree was not matched in practice. The second most accurate scale is the Fourth echos for Eirmologika chants (Fourth (E)) which in contrast to the third echos had all its theoretical and practical scale-notes matched. On the other hand, the most inaccurate scale is the Second echos with most theory-to-practice deviation occurring on the sixth and seventh scale degree.

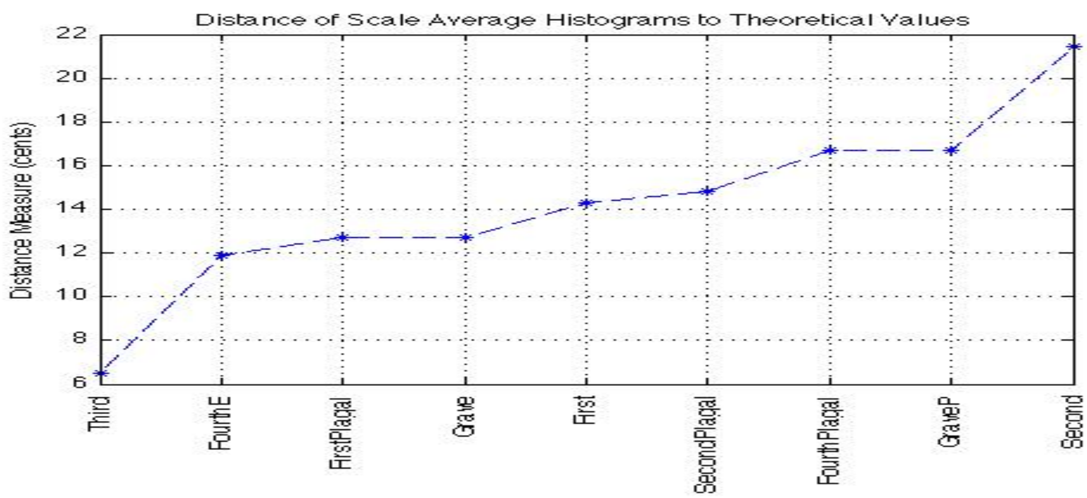

Figure 6.3: Deviation in theory and practice of all echoi.

We further investigate similarities of the histograms of the various echoi by computing the similarity of all histograms and visualising the results in a similarity matrix as shown below.

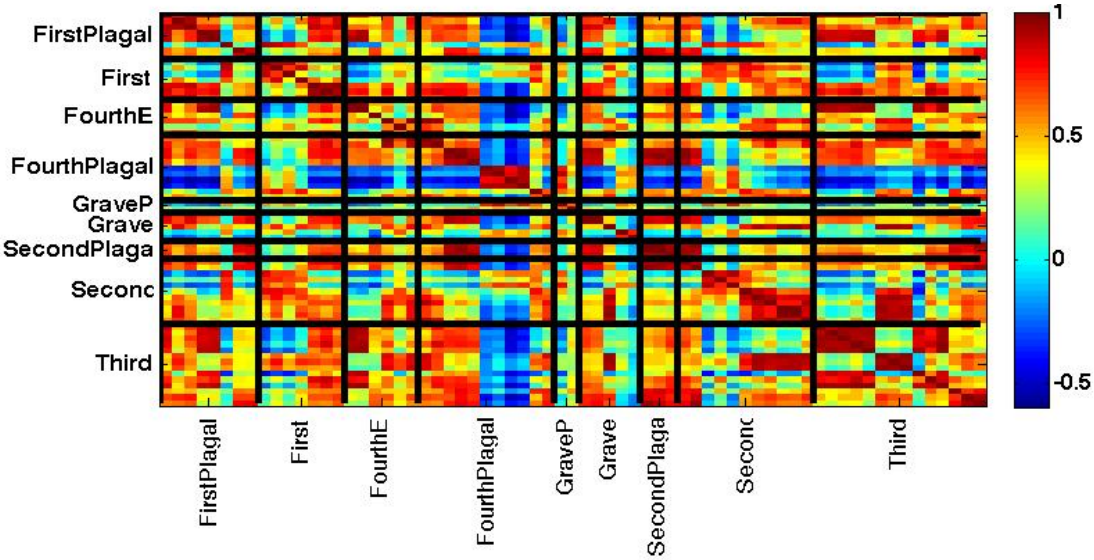

Figure 6.4:Similarity matrix of histograms of the Byzantine recordings (greatest similarity =1).

Observations:

1. In the similarity matrix above we observe a certain degree of dissimilarity among different recordings of the same echos. This is particularly emphasized in the Fourth Plagal echos where the amount of dissimilarity between the histograms of the middle recordings and the other recordings of that echos is at its maximum (dark blue colour). As a result, more subcategories seem to exist within an echos, i.e., First, Second and Fourth Plagal echos could be described by two such subcategories.
   This sub-categorisation of the echos is however related to Byzantine theory and the categorisation of chants (if not an artefact of wrong histogram computations or wrong tonic alignment). As explained in Section 2.2.2, Eirmologika, Stoichirarika and Papadika chants of a particular echos may use the scale of the echos differently, where different does not necessarily imply different scale intervals as in the Grave and Grave (P) echoi, but rather different tonal hierarchy. In a histogram representation, this affects mainly the amplitude rather than the frequency value of a peak. Big differences in the amplitude of the overall histogram distribution change significantly the similarity measure and thus the dissimilarities in the matrix above.
2. We can also observe that the most consistent class is the Second Plagal class whereas the Fourth Plagal, Grave and Second classes are not.

6.3.2 Theory and Practice in Turkish makams

We proceed with the Turkish analysis in the same way with Byzantine, as was presented in the previous section. Again, for each makam, histograms of the corresponding recordings were averaged and peaks were extracted from the mean histogram (see a makam example in Figure 6.5).

The bin values of the peaks were then matched with the theoretical scale-tones. The results are shown in Table 6.3 where the measures D, T, E, C are as previously defined.

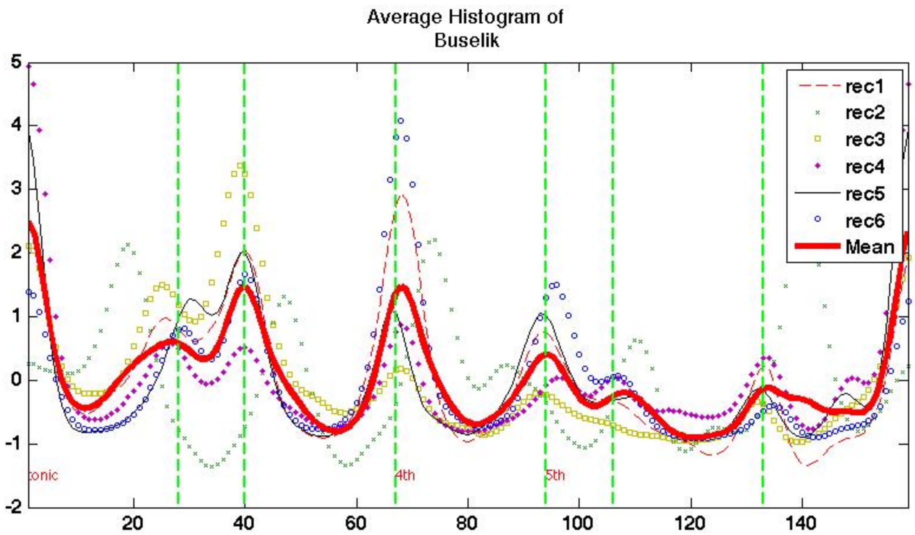

Figure 6.5: Example of the average histogram of recordings of the Buselik makam. The vertical lines indicate the theoretical values of the Buselik scale-tones.

Makam	Scale Notes							D	E	C
Buselik										
Theory	0	203.8	294.3	498.1	701.9	792.5	996.2	5.4	87.5	100
Practice	0	196.2	294.3	505.7	701.9	807.6	1003.8			
Hicaz										
Theory	0	113.2	384.9	498.1	701.9	792.5	996.2	8.6	100	100
Practice	0	120.8	377.4	498.1	717.0	815.1	988.7			
Hicazkar										
Theory	0	113.2	384.9	498.1	701.9	815.1	1086.8	16.2	100	100
Practice	0	105.7	392.5	498.1	709.4	807.6	1003.8			
Huseyni										
Theory	0	181.1	294.3	498.1	701.9	883.0	996.2	21.4	100	85.7
Practice	0	211.3	362.3	490.6	709.4	NaN	981.1			
Huzzam										
Theory	0	113.2	317.0	430.2	701.9	815.1	1109.4	24.8	87.5	100
Practice	0	105.7	324.5	498.1	701.9	815.1	1018.9			
Kurd./kar										
Theory	0	90.6	294.3	498.1	701.9	792.5	996.2	3.2	87.5	100
Practice	0	90.6	294.3	505.7	701.9	807.6	996.2			
Mahur										
Theory	0	203.8	407.6	498.1	701.9	905.7	1109.4	16.2	87.5	100
Practice	0	211.3	347.2	483.0	709.4	913.2	1094.3			
Nihavend										
Theory	0	203.8	294.3	498.1	701.9	792.5	996.2	5.4	100	100
Practice	0	211.3	301.9	498.1	701.9	807.6	1003.8			
Rast										
Theory	0	203.8	384.9	498.1	701.9	905.7	1086.8	5.4	100	100
Practice	0	211.3	384.9	483.0	701.9	913.2	1094.3			
Saba[30]										
Theory	0	181.1	294.3	407.6	701.9	792.5	996.2	16.2	100	87.5
Practice	0	135.9	286.8	437.7	717.0	784.9	988.7			
Sedaraban										
Theory	0	113.2	384.9	498.1	701.9	815.1	1086.8	20.1	85.7	85.7
Practice	0	NaN	400.0	498.1	709.4	807.6	996.2			
Segah										
Theory	0	113.2	317.0	498.1	701.9	815.1	1018.9	12.9	87.5	100
Practice	0	98.1	339.6	513.2	709.4	822.6	1041.5			
Suzidil										
Theory	0	113.2	407.6	498.1	701.9	815.1	1086.8	21.4	100	85.7
Practice	0	NaN	392.5	490.6	701.9	800.0	996.2			
Suzinak										
Theory	0	203.8	384.9	498.1	701.9	815.1	1086.8	3.2	87.5	100
Practice	0	203.8	377.4	490.6	701.9	815.1	1079.2			
Ussak										
Theory	0	181.1	294.3	498.1	701.9	792.5	996.2	15.1	100	85.7
Practice	0	203.8	294.3	505.7	694.3	NaN	1049.1			
T	0	12.8	15.1	12.6	5.0	9.9	33.7			

Table 6.3: Turkish makams between theory and practice. Scale notes and deviations between them are given in cents.

[30] Saba makam is actually defined by eight scale notes but we omit the eighth in this case.

Observations:

1. Over all makams, the scale note that matched most accurately between practical and theoretical values was the fifth scale degree as the T-measure revealed.
2. The third and seventh scale degrees showed the most deviation from the corresponding theoretical values. The second scale degree twice did not appear in practice and once deviated a lot from theory.
3. Most accurate scales considering practice against theory were the Kurdilihicazkar and Suzinak makams (cf. Figure 6.6). For these two makams, all scale degrees were almost absolutely matched between theory and practice and only the sixth scale degree showed rather big deviation from the expected theoretical value. On the other hand, the most inaccurate scales were the Huzzam and Huseyni makam with most theory-to-practice deviation occurring on the seventh scale degree.

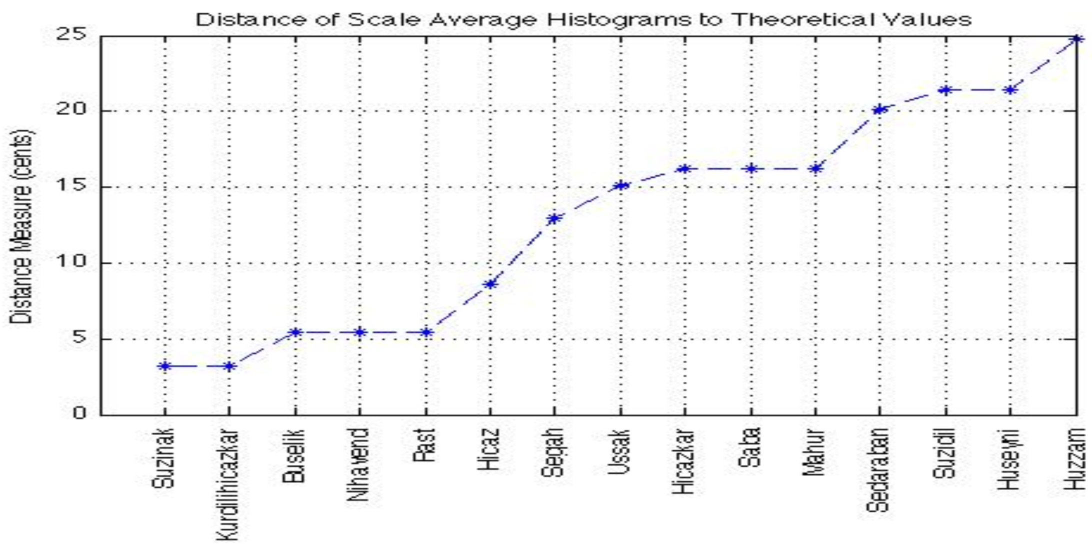

Figure 6.6: Deviation in theory and practice of all makams.

We further investigate similarities of the makam histograms by computing their correlation and visualising the results in a Similarity matrix as shown below.

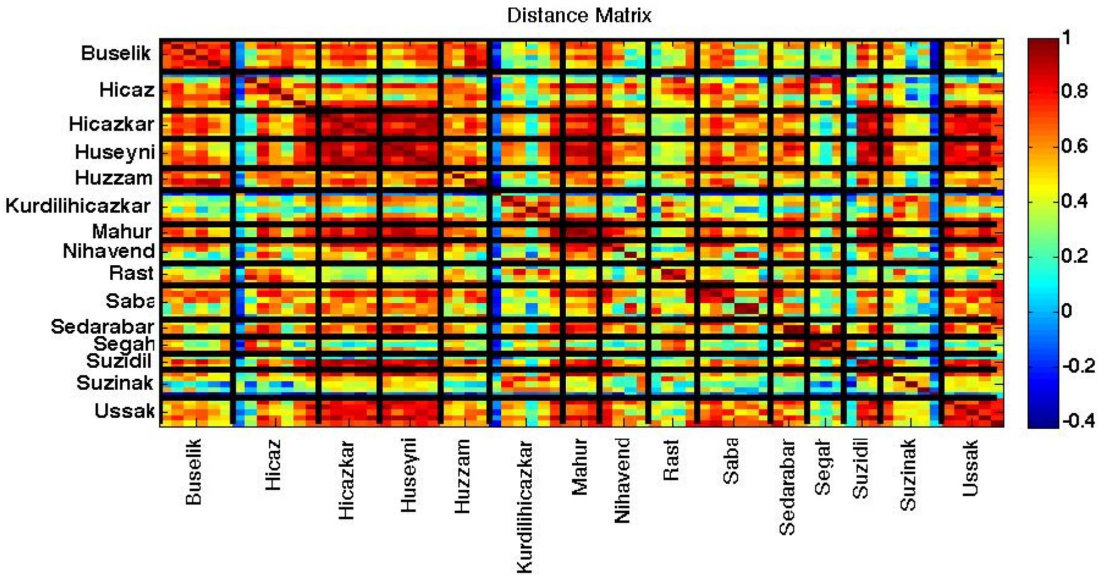

Figure 6.7: Similarity matrix of histograms of the Turkish recordings (greatest similarity =1).

Observations:

1. In Hicaz, Kurdilihicazkar and Suzinak makams we observe a few instances very dissimilar to the rest of the matrix. This might be either because those particular recordings don't accurately follow the theory or because the tonic detection algorithm failed to detect correctly the tonic hence histogram was also wrongly aligned.
2. Buselik, Hicazkar, Huseyni, Mahur and Ussak seem to form rather consistent classes where the corresponding histograms are very similar to each other. On the other hand, Kurdilihicazkar, Nihavend, Rast, Saba ans Suzinak seem to be less consistent.

6.3.3 Theory and Practice in Byzantine and Turkish scales: Combined Observations

From the analysis of Byzantine and Turkish music regarding theory and practice we try to make some overall observations combining both results. To facilitate this, we plot the measures D and T of all echoi and makams (cf. Table 6.2 and Table 6.3) which represent respectively the average deviation of the whole scale (Figure 6.8) from theory to practice and the average deviation of each scale degree (Figure 6.9).

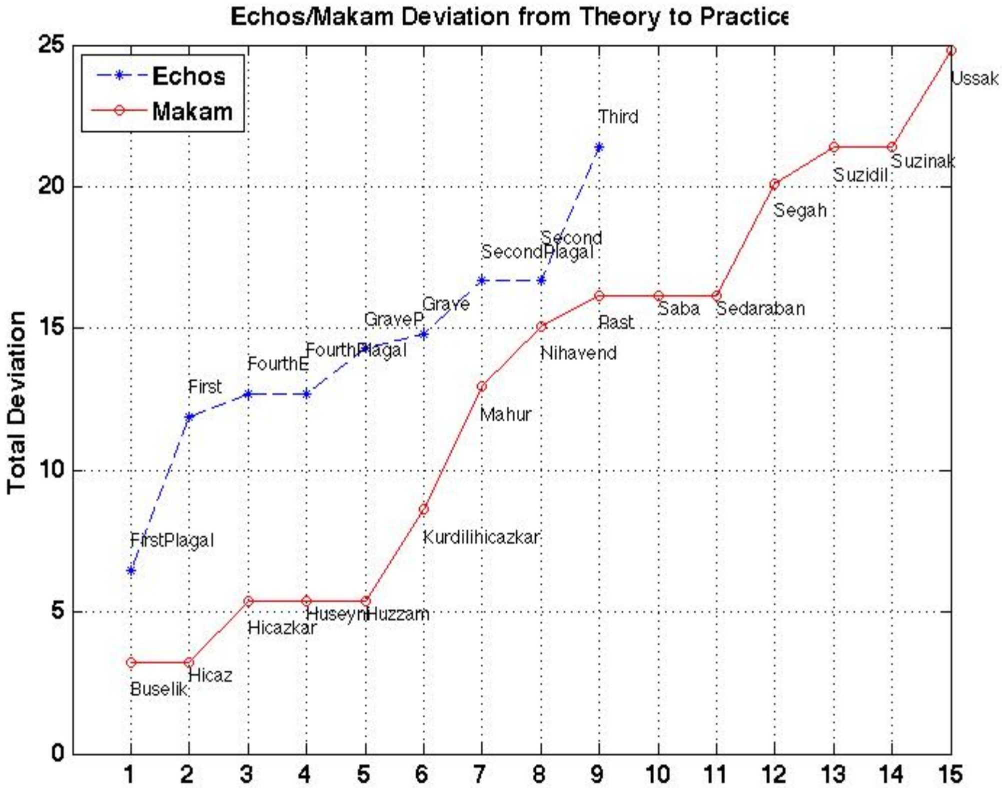

Figure 6.8: Average deviation (in cents) between empirical and theoretical scale tones for each echos/makam. The deviation represents the D measure in Table 6.2 and Table 6.3.

From the figure above we observe that empirical use of Turkish makams is, in the majority of instances, more consistent with the theory than Byzantine echoi. Considering the total deviation of each scale (y-axis), we see that the first five makams are significantly lower than the lowest echos. We additionally observe that, makams are spread out more than the echoi with some of which are below the range of the echoi (i.e. Buselik, Hicaz etc.) and some above (i.e. Ussak).

As there are more makam classes than echoi, the average deviation of theory and practice for all echoi and all makams is also considered. This measure gave 14.2 average deviation for Byzantine echoi and 13.0 for Turkish makams. Considering these values, we can conclude that Turkish makams are on average more consistent with theory than echoi, although with not a big difference.

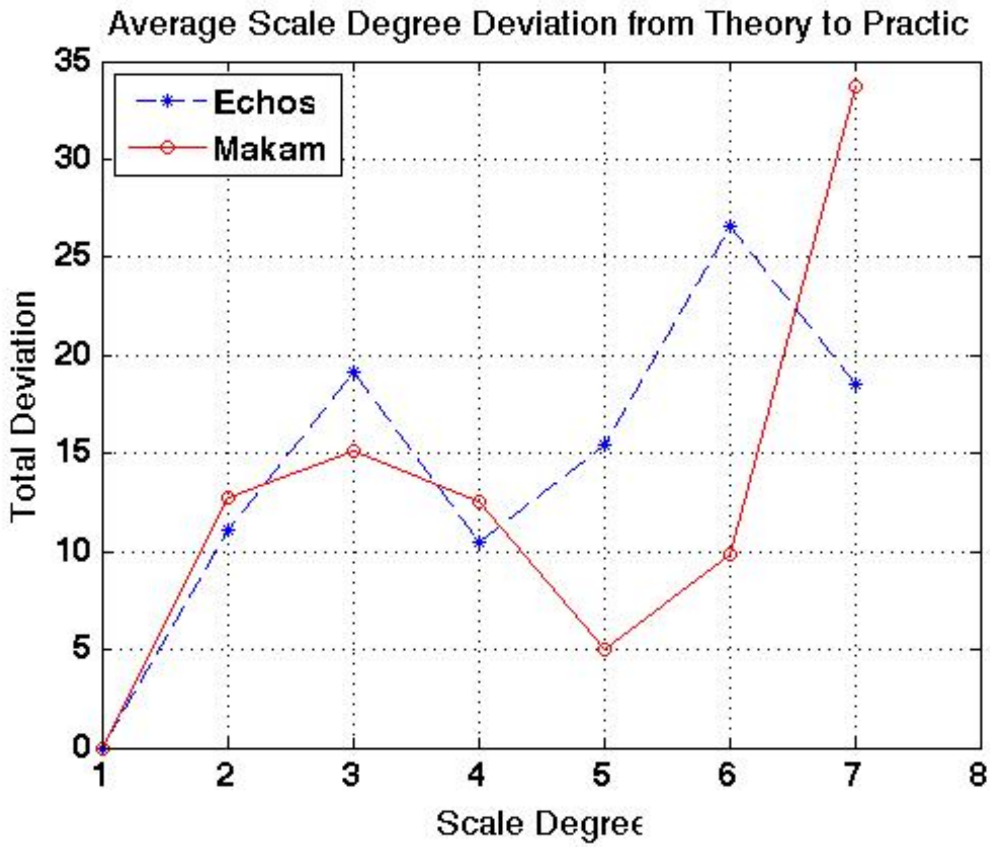

Figure 6.9: Average deviation (in cents) of each scale degree from theory to practice for all echoi/makams (First Scale Degree is the tonic to which each histogram was aligned hence there's no deviation). The deviation represents the T measure in Table 6.2 and Table 6.3.

In Figure 6.9 we observe that the least deviated scale degree of Turkish makams (the fifth) is significantly lower than the least of Byzantine echoi (the fourth). The deviation of the second and fourth scale degrees is relatively low for both music traditions. Overall we observe that the second, fourth and fifth scale degrees for both traditions are the degrees in which practice deviates the least from theory. On the other hand, the sixth scale degree, which is rather consistent between theory and practice of Turkish music turns to be quite inconsistent for Byzantine. The seventh scale degree is also inaccurately used, more deviation in Turkish music and less in Byzantine.

6.4 Echos-Makam similarity in Theory and Practice

Moving on from theory to practice, we tried to establish similarity between echos and makam by comparing the way these scales are used in the songs of our database. That is, for songs in a given echos/makam we computed the average histogram[31] and then for each echos, we measured the similarity[32] between its average histogram and the average histograms of all makams. The most similar average histogram was the one to define the corresponding makam. In this way, similarities between Byzantine and Turkish scales was established by considering the practice and not only the theory.

In Table 6.4, the values of the scale-notes of each echos and makam pair are represented in cents. The most similar makam regarding theory is also included in the table for further evaluation (cf. Section 2.2.4). A good match then is considered to be the one that the most similar makam to the corresponding echos was actually the makam expected from theory.

Echos							Makam (Theory)							Makam (Practice)						
First							Huseyni							Buselik						
1	126	301	492	687	913	987	1	199	346	480	695	---	971	1	179	278	493	688	793	988
First Plagal							Huseyni							Buselik						
1	167	288	490	694	792	995	1	199	346	480	695	---	971	1	179	278	493	688	793	988
Second							Hicazkar[33]							Mahur						
1	132	329	480	675	858	1010	1	69	391	485	694	790	985	1	200	333	470	694	783	1085
Second Plagal							Suzidil							Suzidil						
1	106	379	497	702	799	993	1	---	382	476	687	783	982	1	---	382	476	687	783	982
Third							Mahur							Mahur						
1	192	370	480	690	885	---	1	200	333	470	694	783	1085	1	200	333	470	694	783	1085
Grave							Mahur							Mahur						
1	191	358	485	659	896	1084	1	200	333	470	694	783	1085	1	200	333	470	694	783	1085
Grave(P)							Segah							Segah						
1	121	347	526	712	837		1	84	324	502	695	805	1027	1	84	324	502	695	805	1027
Fourth(E)							Kurdilihicazkar							Mahur						
1	125	324	511	663	837	1051	1	75	282	491	689	792	981	1	200	333	470	694	783	1085
Fourth Plagal							Rast							Rast						
1	213	365	504	709	908	1015	1	201	371	472	688	902	970	1	201	371	472	688	902	970

Table 6.4: Echos and makam similarity as a result of a comparison of their average histograms (empirical intervals) and theoretical intervals (cf. Section 2.2.4).

[31] In order to compare an echos with a makam, the bin resolution of their average histogram should be the same. The resolution of a size of 3816 is then used for the reasons discussed in Section 5.5.
[32] Similarity measured by the cross-correlation function (cf. Section 5.8)
[33] According to theory, most similar makams to the Second echos are the Hicazkar and Sedaraban (cf. Section 2.2.4). From the two, we choose to represent here the scale-notes of the Hicazkar's average histogram since it was more accurate regarding its theoretical values (cf. Section 6.3.2).

Observations:

1. The good matches regarding practice were the pairs Second Plagal with Suzidil, Third and Grave with Mahur, Grave (P) with Segah and Fourth Plagal with Rast as their corresponding interval sequences match also in theory (cf. Section 2.2.4).
2. First and First Plagal echoi were both matched to Buselik makam rather than the Huseyni as expected from theory (cf. Figure 6.10). The Byzantine intervals of size 10 and 12 were merged to a single Turkish interval of size 9, and the relatively small byzantine interval of 8 was matched to the smallest Turkish interval of 4. The big difference though between First/First Plagal and Buselik scales occured in the 5th and 6th intervals. However this should not necessarily be considered a bad match as according to Byzantine theory, the 5th and 6th intervals of First/First Plagal echoi change when melodic direction is descending in the following way that clearly matches better the Buselik intervals:

First/ First plagal Ascending	10	8	12	12	**10**	**8**	12
First/ First plagal Descending	10	8	12	12	**6**	**12**	12
Buselik	9	4	9	9	**4**	**9**	9

3. The matches of Second echos with Mahur makam and Fourth Plagal with Mahur are bad matches regarding the theoretical definitions. By looking at their average histograms we observe that the height of the first peak of these scales seemed to have been crucial for the distance measure as its strength have possibly overwriten the dissimilarities of the rest of the peaks (cf. Figure 6.10).

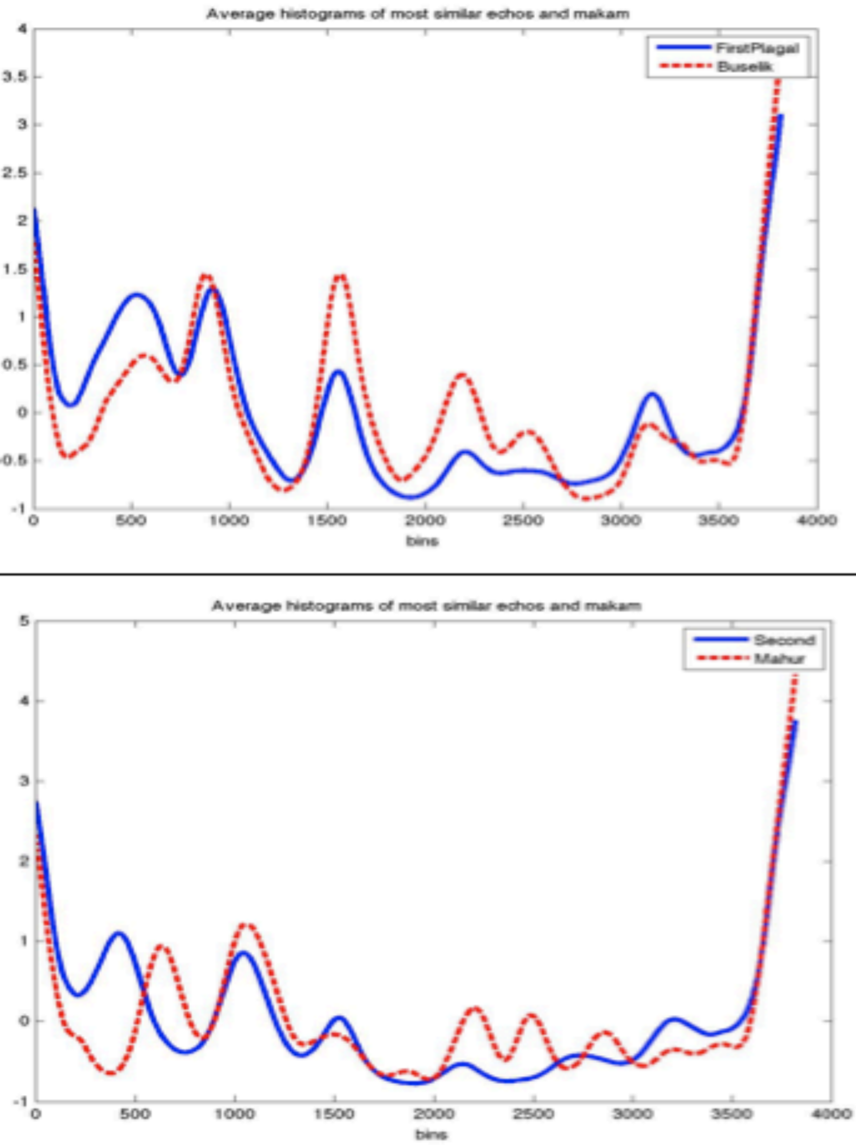

Figure 6.10: Average histograms of the most similar echos and makam regarding practice. The top plot (First Plagal-Buselik) is considered a good match whereas the bottom plot (Second-Mahur) is considered a bad one (refer to observations 2 & 3 respectively).

6.5 Influence in the Intervals

Another important aspect of a pitch pattern is the size and occurence of the underlying intervals. In order to analyse the intervals used in Cypriot, Byzantine and Turkish pitch patterns, we extract the distance of consecutive peak locations of the histograms of all recordings. These distances represent the consecutive intervals of a sequence of scale-notes. We then compute a histogram for the consecutive intervals used in each music tradition. The histogram is smoothed with a smoothing factor that was decided upon empirical tests.

Intervals larger than a third of the octave (bigger than a major third) were excluded, as by assumption, it is unlikely to have two consecutive scale-notes placed more than a major third apart. This is based on the theory of the Byzantine and Turkish scales we have analysed, where the biggest theoretical intervals that can be used are 20 of 72 octave partitions (333 cents) and 13 of 53 octave partitions (294 cents) respectively (cf. Section 2.2.2 & 2.2.3), which are both less than a third of the octave.

Moreover, since interval computation depends crucially on the peaks extracted from the histograms, we are aware of the existence of false intervals due to possible failures of the peak extraction algorithm. If a peak is missed, the corresponding scale interval becomes larger as it merges with the next or previous interval. The scale interval extracted is therefore a combination of two smaller (empirical) intervals that are ideally represented by respective theoretical intervals. In the same way, the false scale interval should ideally be represented by a combination of two theoretical intervals.

In the histogram of consecutive intervals (Figure 6.11) we integrate this fact by plotting vertical lines that correspond to all theoretical intervals but also pair-wise combinations of these, up to a major third. For example in Byzantine music, although theory indicates the largest intervals in the analysed echoi are of 16 and 20 commas, we also plot lines for intervals of 18 and 22 commas (300 and 367 cents resp.) as combinations of the smaller intervals 10+8 and 12+10. Likewise for Turkish music, largest interval in theory is of 13 Holdrian commas but in the histogram below we also plot lines for the intervals of 14 and 17 commas (317 and 385 cents resp.) as a combination of the smaller intervals 9+5 and 9+8 respectively.

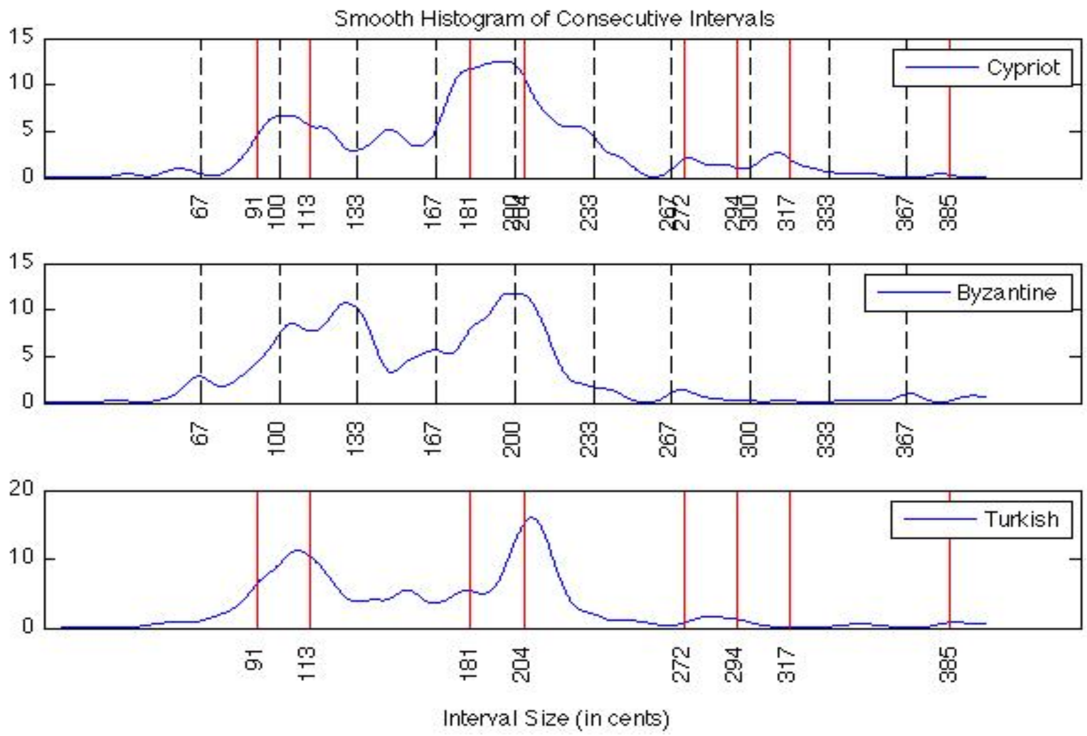

Figure 6.11: Interval distribution in Cypriot (top), Byzantine (middle) and Turkish (bottom) music. The vertical lines represent the size of theoretical intervals in Byzantine (dashed line) and Turkish (continuous line) music.

From the figure above the following can be observed:

Byzantine music (middle plot)

1. Most used intervals in Byzantine music seem to be the whole tone, the minimal tone and the semitone, 200, 133 and 100 cents respectively.
2. The first and fifth empirical intervals (histogram peaks) seem to be consistent with theory as the corresponding peaks occur close to the expected theoretical locations. The fourth empirical interval also seems to peak at the expected theoretical value although it is barely pronounced.
3. The second and third intervals on the other hand seem to deviate from theory to practice since the histogram has its local maxima slightly next to the expected theoretical positions.
4. For the intervals bigger than a whole tone, although not often used, we can observe histogram peaks near the intervals of size 267 and 367 cents respectively.

Turkish music (bottom plot)

1. Most used intervals in Turkish music are the whole tone and the slightly augmented semitone (of 113 cents). However, both these intervals in practice deviate slightly from theory. The rest of the theoretical intervals are still used but with less frequency.
2. There seems to be frequent used of an interval of approximately 160 cents that does not correspond to any of the Turkish theoretical intervals.

3. The histogram also seems to peak at intervals bigger than the whole tone, around the intervals of 294 and 385 cents and an interval between those values not indicated by theory.

Cypriot music (top plot)

1. The most used intervals in Cypriot music seem to be the whole tone and the semitone. However both peaks are quite wide, something which suggests that either those or the neighbouring intervals are often not accurately used.
2. As in Turkish music, there also seems to be a Cypriot interval of approximately 160 cents that is not represented neither in Byzantine nor in Turkish theoretical intervals.
3. There also seems to be some significant use of the smallest theoretical Byzantine interval, 67 cents, and of some Turkish/Byzantine theoretical intervals bigger than the whole tone, around 272 and 317 cents.

We investigated whether the distribution of intervals of the Cypriot music matches best with the Byzantine or Turkish music first in theory and then in practice by the following procedure:

1. To get similarities with theory we extracted the peaks of the histogram of the Cypriot intervals and compared with the theoretical interval sizes of Byzantine and Turkish music
2. To get similarities with practice we extracted the peaks of all three histograms and compared then the Cypriot peaks with the Byzantine and Turkish ones.

The peaks were compared in the same way as done in previous experiments. That is, peaks representing the theoretical or empirical intervals of Byzantine and Turkish music were first aligned with the Cypriot peaks and then their deviation from the Cypriot peak values was computed. The mean differences of these deviations were analysed with the help of the analysis of variance (ANOVA).

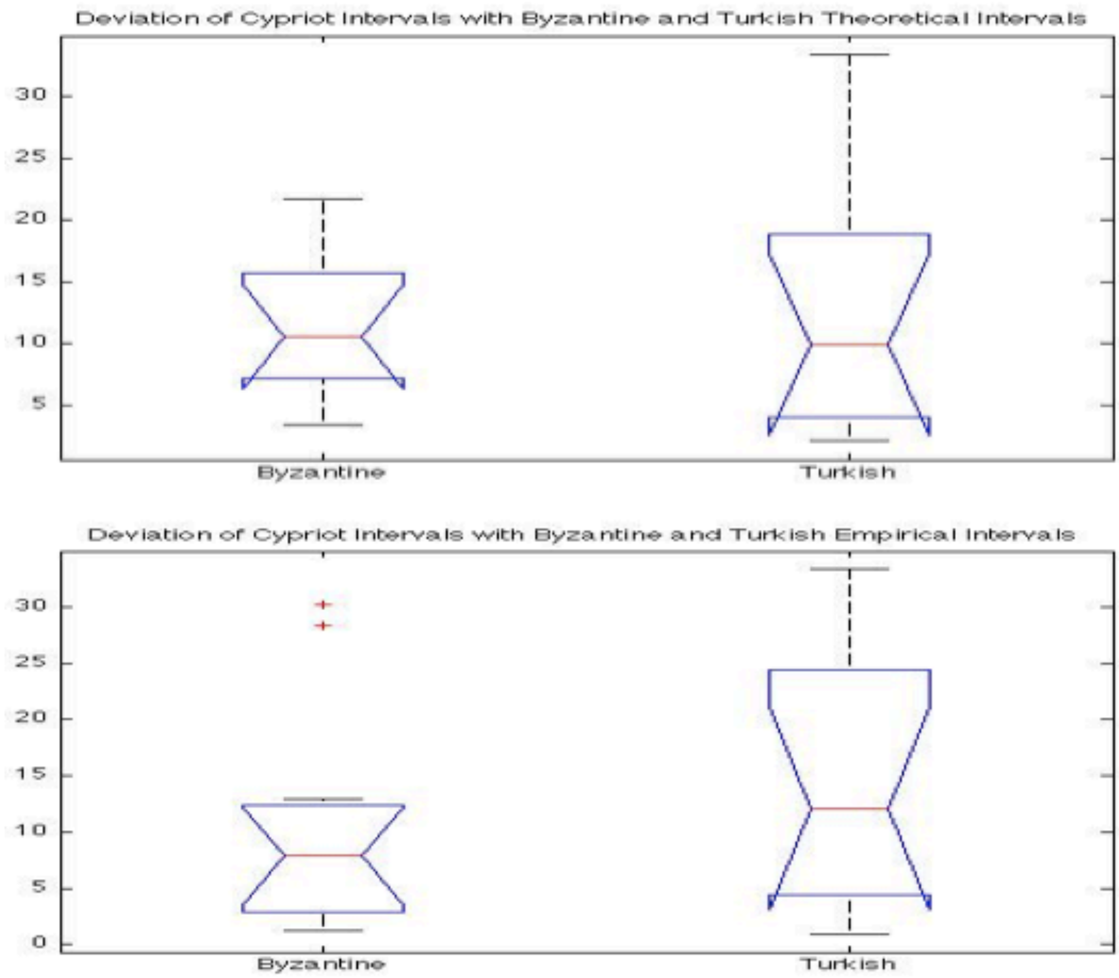

Figure 6.12: Mean deviation of Cypriot to Byzantine/Turkish theoretical (top) and empirical (bottom) intervals. The line in the middle of each box is the sample median and the notches display the variability of the median between samples.

		Deviation from Byzantine Intervals in cents	Deviation from Turkish Intervals in cents	P-value
Theoretical Intervals	Mean	11.4465	12.6572	0.7704
	Std	2.7188	3.0397	
Empirical Intervals	Mean	10.2344	14.3868	0.3784
	Std	3.3329	3.1910	

Table 6.5: Statistics results of Anova

A general observation from the above results is that the means of deviations of either theoretical or empirical intervals are not significantly different. Therefore, no conclusions can be made on which of the two traditions has more theoretical or empirical influence on the Cypriot intervals. However we can observe that deviation means of empirical intervals are more different than those of theoretical (smaller p-value). We notice then that the mean of deviation with Byzantine empirical intervals is smaller than Turkish ones. Therefore, for this dataset, Byzantine empirical intervals seem to be closer to Cypriot intervals than Turkish empirical intervals although up to a certainty limited by the significance p-value.

6.6 Influence in Prominence of Peaks

As a next step we investigated the prominence of the scale notes in each of the three traditions. The way we preceded for Byzantine and Turkish music was by considering the peaks of the average histograms of each echos. The peaks were matched with the theorised scale tones so that only the relevant peaks were considered for further processing. The chosen peaks were then assigned to a scale degree and their amplitudes were averaged over all scales of the corresponding music tradition. Even though this approach neglected the different tonal hierarchies of the individual scales it provided an idea of the average importance of the scale degrees. Results are shown in Figure 6.13.

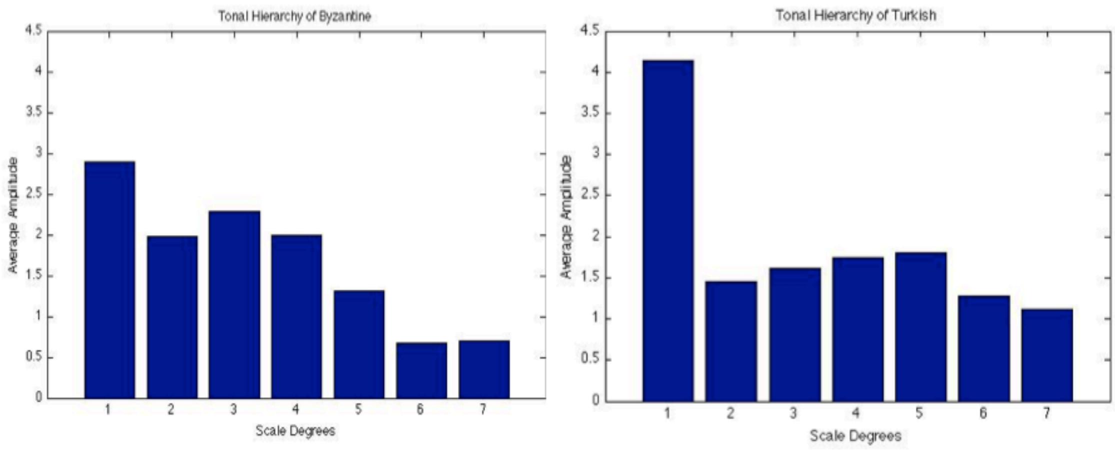

Figure 6.13: Peak prominence of scale degrees in Byzantine (left) and Turkish music (right).

In Figure 6.13 we observe that, on average, the most prominent peaks in the Byzantine scales are the first, third, fourth and second in descending order with the first (the tonic) having the highest amplitude. The sixth and seventh scale degrees are significantly deemphasized. The fifth scale degree, which is often one of the most prominent scale tones in major and minor scales [Temperley 1999], in Byzantine scales is not very emphasized. However, the prominence of scale notes observed in the figure above, can be partly justified by theory that specifies that predominant scale degrees of each echos are often the first and third or first and fourth (cf. Section 2.2.2).

In Turkish music on the other hand, we observe that the first peak of the makam histograms has on average significantly big amplitude whereas the second most prominent peak occurs at half its amplitude. This suggests that the tonic is often emphasised in the use of the makam scale. The prominences of the other peaks descend in the following order: fifth, fourth, third, and then the remaining 3 scale degrees, something which was also expected from theory (cf. Section 2.2.3). In contrast to Byzantine music, the sixth and seventh scale degrees are not very deemphasized compared to the rest of the peaks (apart from the tonic).

To study the tonal hierarchy in Cypriot music, a different procedure had to be followed. Firstly, the peaks of the Cypriot histograms had to be assigned to a scale degree. Since we have no ground truth for the scales of the Cypriot songs, the peaks were compared to theorised scale tones of echoi and makams. Two comparisons were then performed; one for matching Cypriot histogram peaks with scale tones of the several echoi and the other with scale tones of the makams. Note that scale tones of echoi and makams in this context, were represented by the peaks of the corresponding average histograms that were previously matched with the theoretical scale degrees.

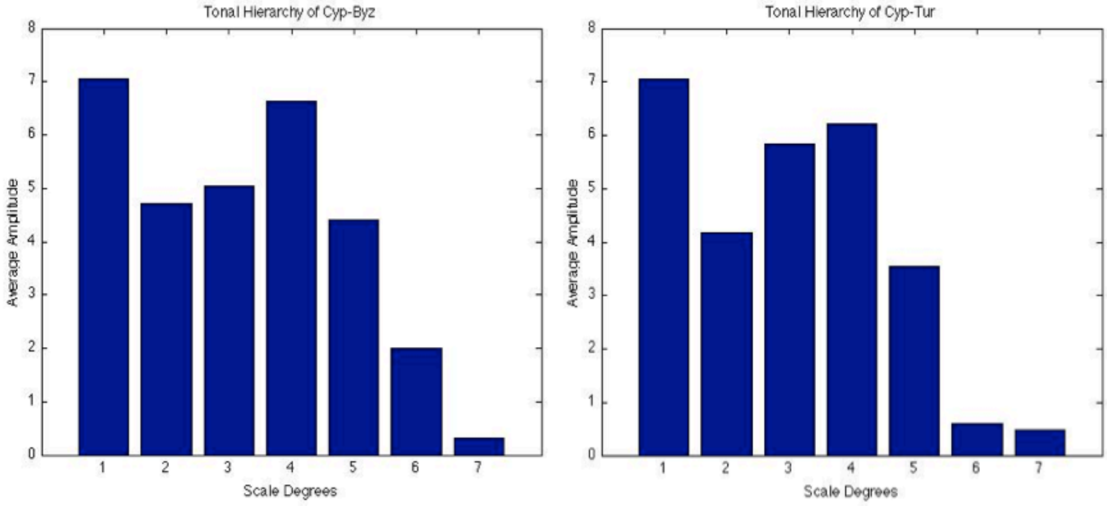

Figure 6.14: Peak prominence of scale degrees obtained from Cypriot-Byzantine scale tone comparison (left) and Cypriot-Turkish (right).

From the figure above we observe that the peak prominence distributions are quite distinct as for a given Cypriot song, the histogram peaks matched with the most similar echoi scale notes were not always the same as the ones matched with the most similar makam. However there are still some common characteristics that enable us to make some general observations regarding the prominence of peaks in the Cypriot histograms:

1. Most prominent peak of the Cypriot histogram is the first (the tonic) as it is also the case for the corresponding echoi and makams average histograms.
2. Second most prominent peak is the fourth scale degree with relatively high average amplitude.
3. The Cypriot to Turkish scale tone comparison revealed also significant amplitude of the third scale degree whereas in the Cypriot to Byzantine, the third scale degree was still one of the most prominent peaks but with relatively lower amplitude.
4. The second and fifth scale degrees are also relatively emphasised compared to the sixth and seventh which both have significantly low average amplitude.
5. Overall, comparing with the peak prominence results of Byzantine and Turkish (cf. Figure 6.13), we observe that the use of the sixth and seventh scale degrees, with relatively low average amplitude from all other peaks, seems to be more similar to the Byzantine distribution rather than the Turkish. Similarly, the use of the fifth scale degree in Cypriot music is not as emphasised as was in the Turkish music (second most prominent peak) but rather as used in Byzantine music (one of the three least prominent peaks).

The above observations in terms of the prominence of the histogram peaks in Cypriot music seem to suggest more influence from the Byzantine music. However, at this point, we cannot make any absolute conclusions as the Cypriot peaks considered in the distributions above were chosen upon greatest similarity with echoi and makams scale tones. The lack of ground truth makes it impossible to automatically evaluate the estimated Cypriot scale (and hence the choice of matching peaks). Therefore, from the above results we can conclude tendencies, the significant of which cannot be quantified.

6.7 Influence in the Scales

To investigate the influence of Byzantine and Turkish music on Cypriot scales we perform two main experiments that focus on different aspects of the pitch pattern. One experiment investigates the influence on the overall distribution of the pitch histogram whereas the other experiment considers only the isolated scale notes, their location and amplitude. Comparisons are then performed to find the echos and/or makam that best matches with the characteristics of a given Cypriot pitch pattern. For each experiment, two separate comparisons are performed; one considers Byzantine scales as appropriate candidates for the Cypriot scales and the other considers Turkish scales. In the end, the two are combined and the Cypriot scales are determined based on greatest similarity to the Byzantine or the Turkish scales.

The methodology of pitch pattern comparison is structured in the way described in Chapter 5. As a remark, bin resolution, pitch histogram alignment and similarity measures are defined as follows:

- The number of bins per octave is set to 216 for Byzantine scale comparison and to 159 for Turkish scale comparison (cf. Section 5.5).
- Pitch histograms of Byzantine and Turkish recordings are aligned to the pitch of the last phrase note as extracted from the tonic detection algorithm. On the other hand, pitch histograms of Cypriot recordings are aligned to the bin of highest correlation with Byzantine/Turkish histogram as computed by the correlation coefficients (cf. Section 5.7).
- The similarity measures employed for each experiment are the correlation coefficients for histogram distribution similarity, and the customised distance measure for scale tone similarity (cf. Section 5.8).

Last remark is that comparisons were performed directly between pitch histograms of the recordings of each tradition. We avoided using average histograms of echoi/makams or even theoretical templates as both these approaches average out the fine details of individual recordings that might be of great interest in the similarity measure.

6.7.1 Cypriot scales based on histogram distribution similarity

Assuming that Byzantine influence exists in Cypriot music, we determine the scales of the Cypriot songs in our collection in terms of Byzantine echoi based on greatest similarity amongst the histogram distributions. Likewise, assuming that Turkish influence exist in Cypriot music we determine the Cypriot scales in terms of Turkish makams. The figure below illustrates results from the Byzantine (top) and the Turkish (bottom) comparison.

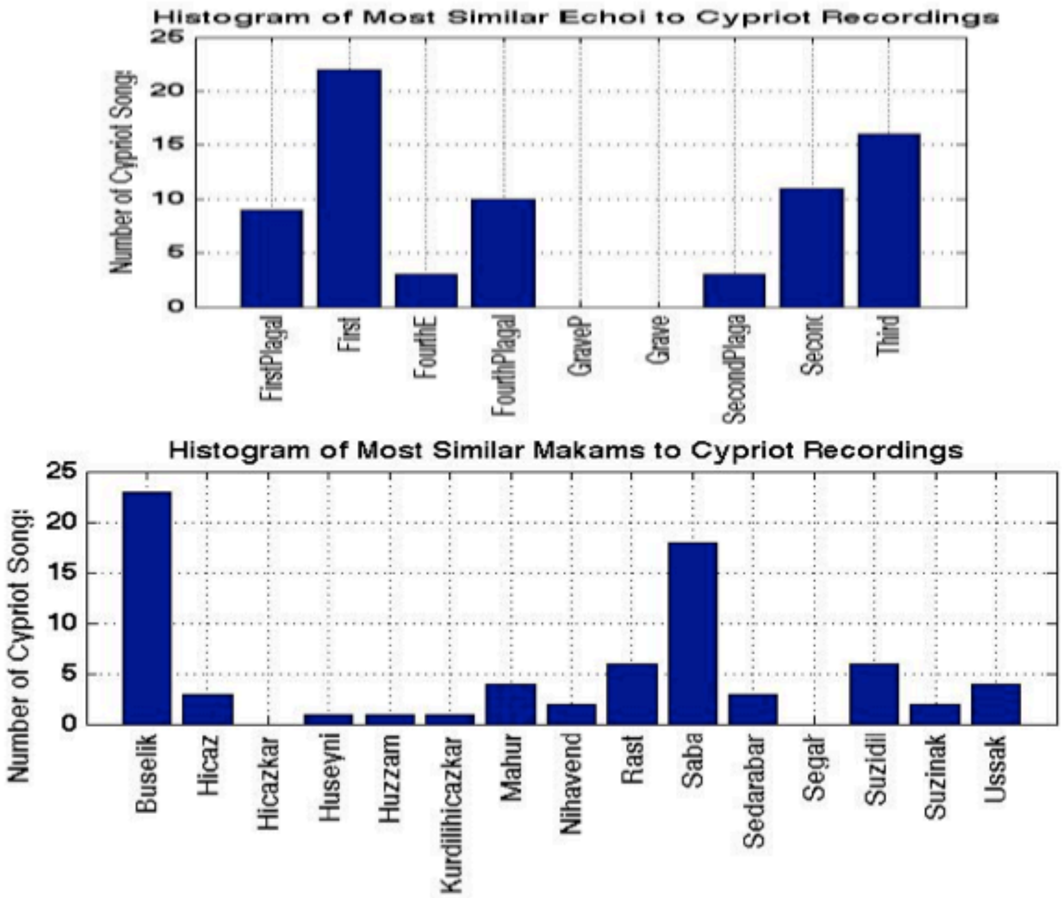

Figure 6.15: Histogram of echoi (top) and makams (bottom) most similar to Cypriot scales extracted from recordings.

From the figure above we observe that the five most used echoi and respectively, makams, in the Cypriot recordings are the following (in descending order):

Echos	Makam
First	Buselik
Third	Saba
Second	Suzidil
Fourth Plagal	Rast
First Plagal	Mahur

From previous analysis on the similarity of echoi and makams we have seen that the pairs First-Buselik, Third-Mahur and Fourth Plagal-Rast match in theory and/or practice (cf. Section 6.4). The Suzidil makam is most similar to the Second Plagal according to either theory or practice. However, if we consider the relative size of the intervals and their order in Suzidil makam and Second echos, we can still observe some similarity in the underlying tetrachord; defined by a small interval, then large (larger than a whole tone) and then again small. Therefore, Suzidil makam could be indirectly linked to the Second echos.

Furthermore, what is interesting in the above table is the use of the Saba makam, which is the second most used makam in the Cypriot music collection but is not directly similar to any of the Byzantine echoi we have studied in this case. This suggests that Saba makam is probably a Turkish scale employed in Cypriot music. However, Mavroeidis in (1999) refers to a variation of the First Plagal echos, namely the *First Plagal Difwnos Fthorikos*, as possibly the equivalent Byzantine scale to Saba makam. As chants from this particular echos were not included in our database we cannot make any conclusions if this is actually the case or not.

Based on the histogram similarity measure computed from each comparison we investigate whether Byzantine or Turkish histograms are most similar to the Cypriot histograms. That is, for each Cypriot recording we compare the distance measure from the most similar Byzantine against the most similar Turkish histogram and we determine the scale after the greatest similarity. The scales most often occurring in this case were the First, Third, Buselik, Second, Fourth Plagal and First Plagal (cf. Figure 6.16 - top plot).

Then we counted the instances where Byzantine histograms were more similar to the Cypriot than Turkish ones and vice versa. From these results, we observe that the similarity to the Byzantine histograms is usually stronger than to the Turkish histograms (cf. Figure 6.16 - bottom plot). Out of all Cypriot recordings, 70% have histograms most similar to Byzantine histograms whereas only 30% are most similar to the Turkish histograms.

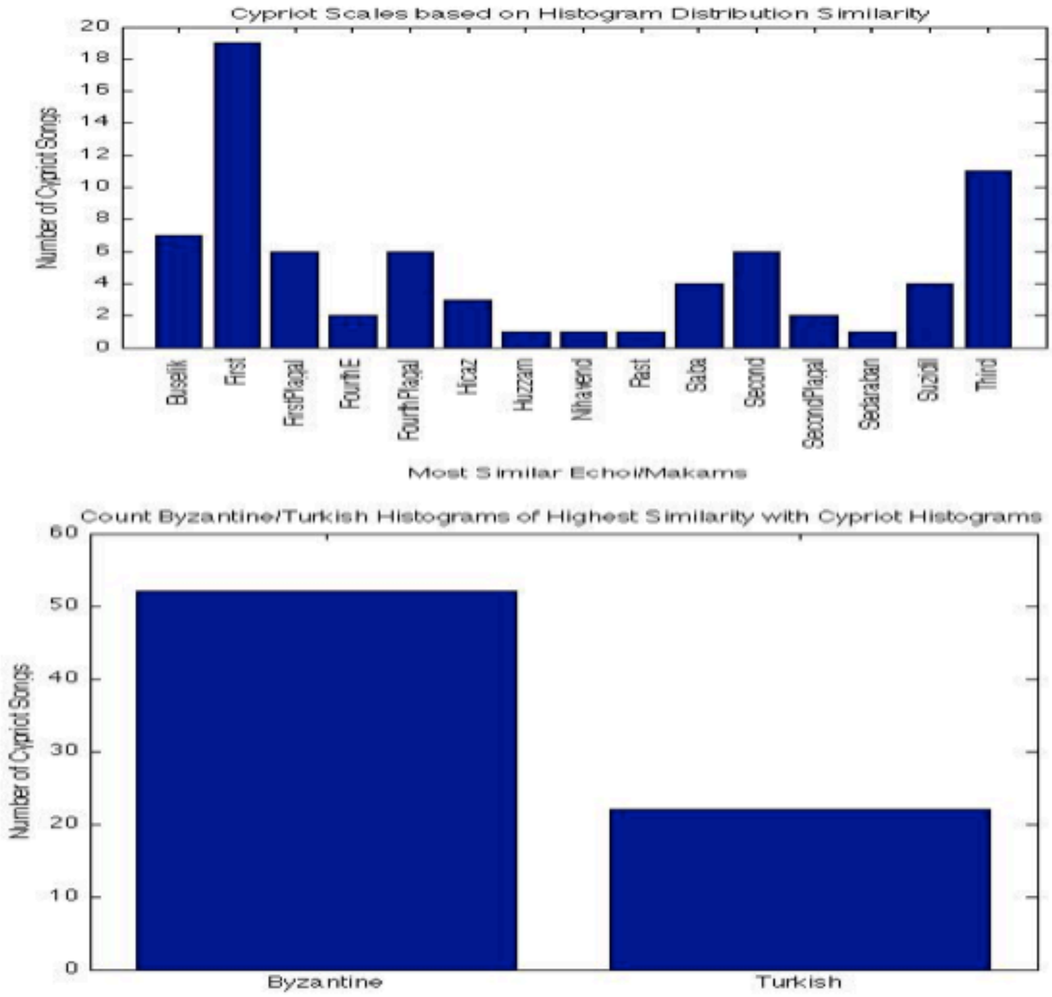

Figure 6.16: Cypriot scales determined by the greatest similarity between the estimated echoi/makams based on the histogram distribution comparison (top) and number of instances where Byzantine or Turkish similarity was the greatest (bottom).

6.7.2 Cypriot scales based on scale note similarity

As before, assuming that Byzantine influence exists in Cypriot music, we determine the scales of the Cypriot songs in our collection in terms of Byzantine echoi based on greatest similarity amongst the scale notes. We assume the same for Turkish influence and proceed likewise to determine the Cypriot scales in terms of Turkish makams. The figure below illustrates results from the Byzantine (top) and the Turkish (bottom) comparison.

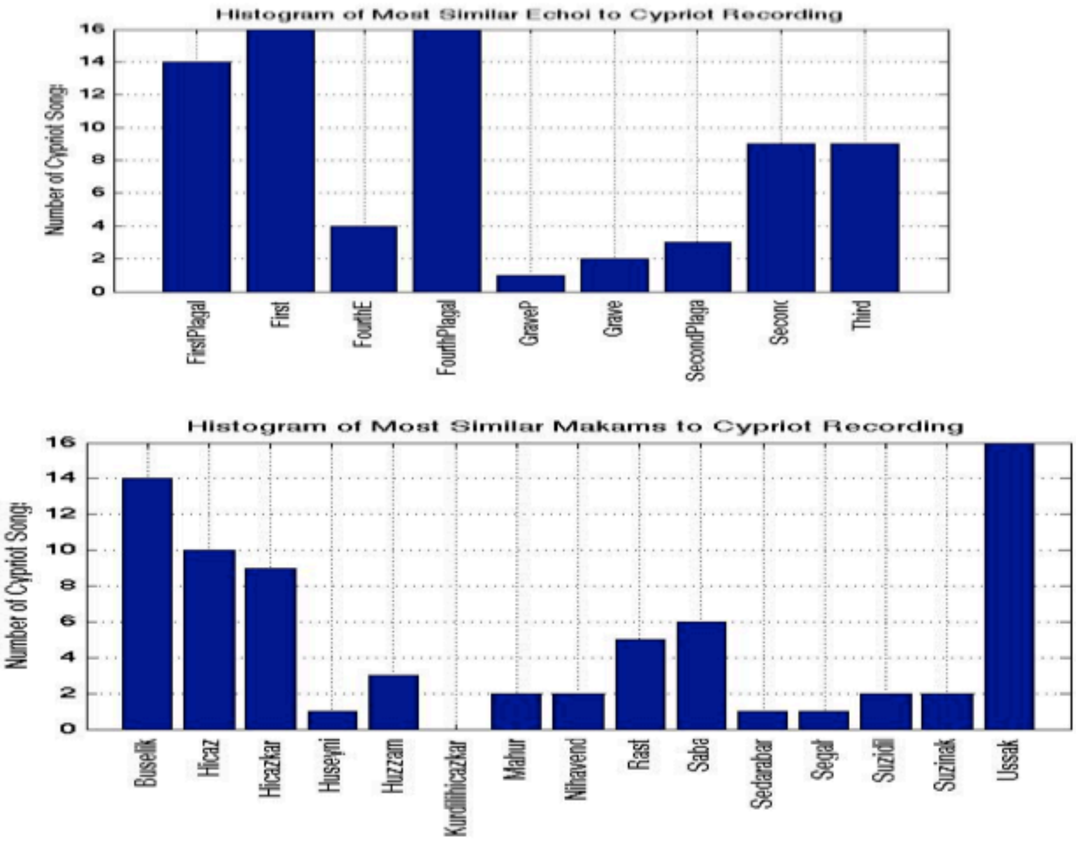

Figure 6.17: Distribution of most similar echoi (top) and makams (bottom) to Cypriot recordings based on similarity of the Scale tones.

From the figure above we observe that the five most used echoi and respectively, makams, in the Cypriot recordings are the following (in descending order):

Echos	Makam
First	Ussak
Fourth Plagal	Buselik
First Plagal	Hicaz
Second	Hicazkar
Third	Saba

With the above analysis we observe that the five most used echoi in the scale note comparison are the same as the ones in the histogram distribution comparison but with different order. What changes now most is the makam distribution that gave rise to new scales such as the use of Ussak, Hicaz and Hicazkar makams. These three makams came to replace the Suzidil, Rast and Mahur makams, which were 3 of the five most occurring makams in the histogram distribution similarity. The result differences of the first and second comparison are further discussed in the next section.

Before moving on to that, let us complete this section by noting which of the two, Byzantine or Turkish scale notes, were on average most similar to Cypriot scale notes. So, as before, the Cypriot scales are determined based upon greatest similarity of either makams or echoi. The scales most often occurring in this case were the First Plagal, Fourth Plagal, First, Second, Ussak and Buselik (cf. Figure 6.18 – top plot).

We then counted the Cypriot songs that showed greatest similarity with Byzantine scales and likewise with Turkish scales. Results showed that 60% of the Cypriot recordings have their underlying scale notes most similar to Byzantine scale notes whereas the 40% with Turkish (cf. Figure 6.18 - bottom plot).

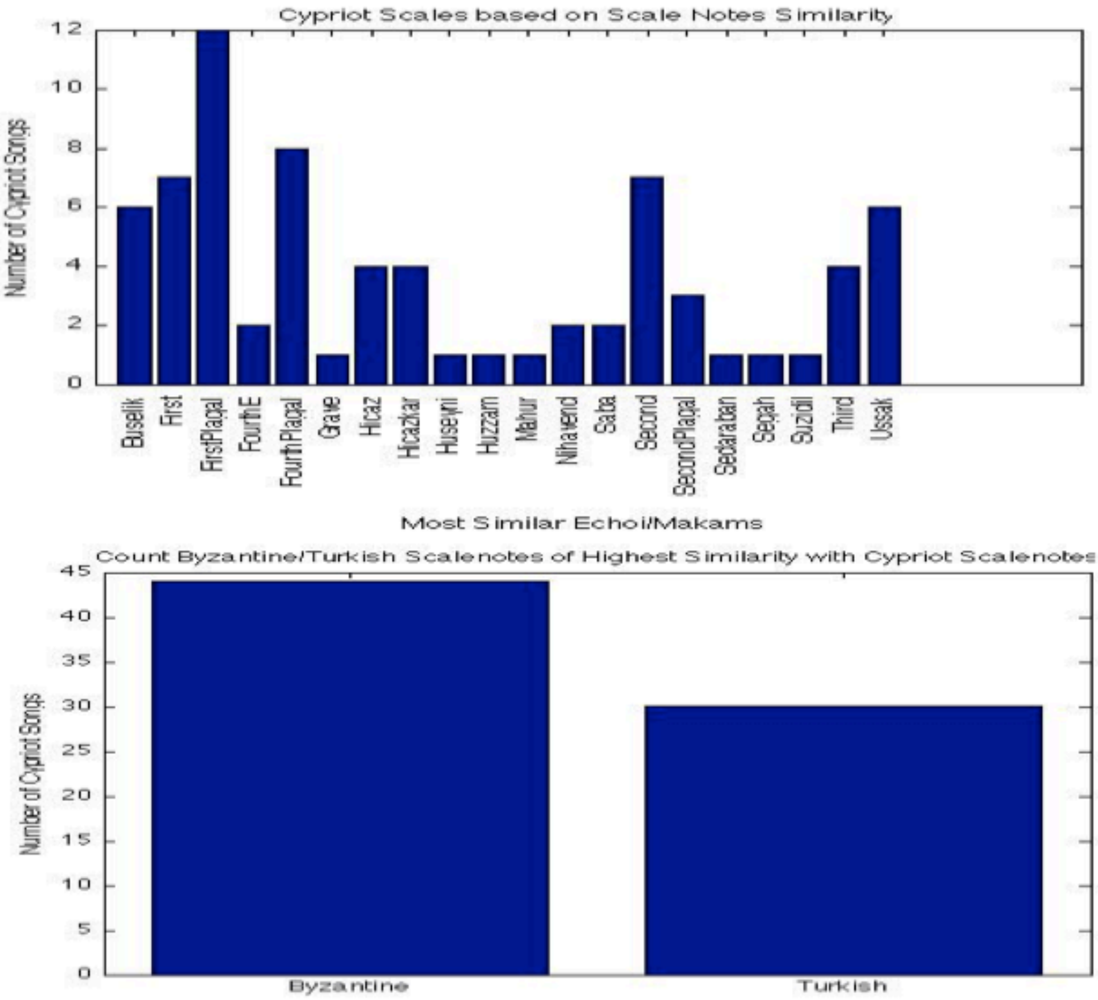

Figure 6.18: Cypriot scales determined by the greatest similarity between the estimated echoi/makams based on the scale note comparison (top) and number of instances where Byzantine or Turkish similarity was the greatest (bottom).

6.7.3 Cypriot scales based on histogram distribution and scale note similarity

General observation from the experiments on both histogram distribution (cf. Section 6.7.1) and scale note comparisons (cf. Section 6.7.2) revealed greatest similarity between Cypriot and Byzantine music. However, the disagreement in the estimated scales of each experiment indicates that results should not be trusted. We would have expected the scale to emerge in the overall histogram distribution as well as in the isolated scale note peaks. Since this does not apply we suspect that either in the first or in the second experiment the similarity occurred only in one of the two aspects. Two arguments can be made:

1. Either in the first experiment some scales (such as Suzidil, Rast and Mahur makams) occurred due to strong histogram distribution similarity whereas individual scale notes were significantly distinct in position and/or strength,
2. Or, in the second experiment, different scales occurred (Ussak, Hicaz, Hicazkar) due to strong scale note similarity either in location or amplitude but not on the whole. This argument implies also the weaknesses of the customised distance to integrate efficiently the difference in location, amplitude and number of matching peak pairs.

To investigate whether one and/or the other assumption applies we perform another experiment. This aims at revealing whether the similarity in the first comparison occurred in both distribution and scale notes.

We proceed in the following way:

1. For each estimated echos/makam according to the histogram distribution comparison (6.7.1), perform a scale note comparison between the Byzantine/Turkish histograms that were most similar to Cypriot histograms.
2. Average the deviation between Cypriot scale notes and Byzantine/Turkish scale notes of the two sets of histograms.
3. Sort from least to most deviation.

The above implies that for each estimated scale from 6.7.1, being either an echos or a makam, there will be a value describing the average deviation between Cypriot scale notes and Byzantine/Turkish scale notes of the corresponding histograms. The smaller this value, the less the deviation and hence the more similar the scale notes. This should give an idea whether scale similarity in 6.7.1 occurs both in histogram distribution and scale notes or not. Results are shown in Figure 6.19.

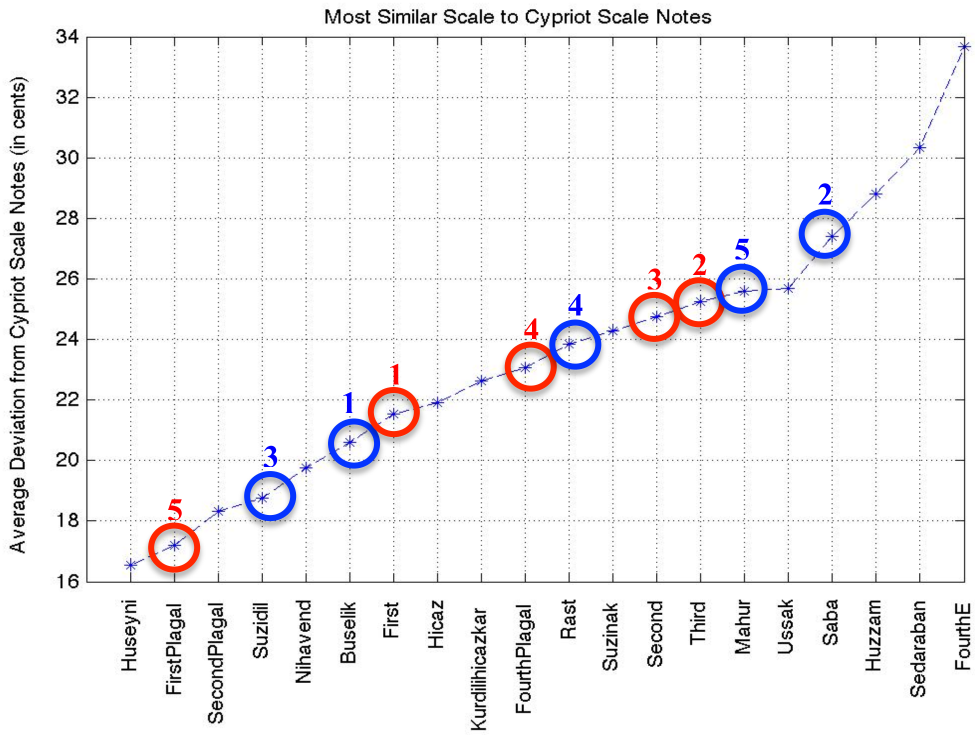

Figure 6.19: Scale note comparison of Cypriot and most similar Byzantine/Turkish histograms as extracted from the histogram distribution comparison. Circles and numbers indicate the five most frequently used echoi (red) and makams (blue) and their order as shown in Section 6.7.1.

We can observe that First Plagal, First echos and Suzidil, Buselik makam showed the least scale note deviation from Cypriot scale notes out of the five most used echoi/makams. This suggests that these scales do not only share a similar histogram distribution with the Cypriot histograms but also have relatively strong similarity in the scale notes. Therefore, we would expect these scales to also appear often in the scale note comparison (6.7.2). This was indeed the case for First, First Plagal and Buselik scales, which were in the top places of the most used scales in the latter comparison but did not apply for Suzidil.

On the other hand, scales that were similar in the histogram distribution comparison (6.7.1) but showed relatively big deviation in the scale notes (i.e. the circled scales of greater deviation than 22), would unlikely be expected to occur often in the scale note comparison (6.7.2). This was indeed the case for the scales Rast, Mahur, Second and Third that in the latter comparison their distribution amongst the Cypriot songs was significantly reduced. However this did not apply for Fourth Plagal echos and Saba makam.

The above observations are just an indication of which scales, on average, can best describe the Cypriot melodies according to both histogram distribution and scale note similarity. The only scales that were relatively similar in both aspects, as this experiment showed, were the First and First Plagal echoi and Buselik makam.

It should be noted though that, Cypriot songs named after one scale in (6.7.1) were not usually named after the same scale in (6.7.2). Therefore, when we compare the scale notes of the scales in (6.7.1) we don't evaluate exactly the same instances that were considered in (6.7.2). However, if two instances have similar histogram distributions we would expect to observe also at least some basic similarity in the underlying location and amplitude of the scale notes (and vice versa). Therefore, assuming that instances of the same set are on average similar on both aspects, direct comparisons between the two sets can still be made. Yet, further evaluation should be applied in order to have more trustable results.

7 Discussion

In the Results Chapter observations were drawn from a set of experiments. In this section, the observations of each experiment are first summarised and then a discussion follows.

In the first experiment, a semi automatic analysis of Cypriot melodies was performed based on the estimated Yin melody and the corresponding pitch histograms. Results from this analysis were used to justify and/or enhance the list of essential characteristics of Cypriot music as presented in Section 2.1.2.1. Among all, important were the observations regarding the use of not equally tempered intervals, the short pitch range of the melodies and the last phrase note being usually the tonic.

Second experiment was an analytical study on Byzantine and Turkish pitch patterns and the difference between theory and practice. From the employed measures for deviation analysis between practice and theory, we have seen that Turkish makams are on average more consistent than Byzantine echoi. Moreover, the more consistent scale degrees are the second and fourth for Byzantine music and the fifth for Turkish.

Next experiment investigated the empirical similarity of the underlying echoi and makams compared to the theoretical similarity of the interval sequences as stated in Section 2.2.4. The echos-makam pairs that were similar in theory matched also, in the majority, in practice. Bad matches were the pairs of Second echos with Mahur makam and Fourth Plagal echos also with Mahur makam. The proposed justification for this confusion was the prominence of some peaks (particularly of the first peak-the tonic) that affected significantly the similarity measure of the whole histogram distributions.

Moving on, an investigation of the intervals used in each tradition was performed. This revealed that Byzantine music makes frequent use of the whole, minimal (around 133 cents) and halftones, whereas Turkish music makes frequent use of the whole tone and the slightly big halftone (113 cents) intervals. Interesting was the observation of a rather frequently used Turkish interval of 160 cents that was not indicated in theory and seemed to be also used in Cypriot music. Apart from that interval, Cypriot music makes also frequent use of whole and halftones but rather in an inconsistent way that makes it difficult to judge whether intervals shorter or larger than whole and halftones match or not with respective Turkish and Byzantine (empirical or theoretical) intervals. Moreover, the existence of false intervals that have probably distorted the interval histograms of all three traditions makes it even more difficult to generalise any conclusions from this experiment.

Moreover, the prominence of the histogram peaks was studied for each tradition. In Byzantine music, the first four scale degrees have significantly bigger amplitude than the last three with the most prominent peaks being the first and the third scale degree. In Turkish music on the other hand, the tonic is significantly higher from the rest of the peaks and the second most prominent peak is the fifth, without though big amplitude difference from the rest of the peaks. As for Cypriot music, most prominent peaks of the histograms were the first and the fourth with relatively high amplitudes from the rest, followed by the third scale degree.

In this experiment, we observed overall that the second most prominent peak in Cypriot music (apart from the tonic that had always the most prominence) was the fourth scale degree and this differed from both the Byzantine and Turkish results. Although we noted some similarity between Byzantine and Cypriot music in the use of the least prominent scale degrees (the sixth and seventh) this cannot be generalised. Besides, results considered in the experiment were drawn from the average amplitude of the peaks so it could be that some recordings added significant weight to specific scale degrees that was not representative for all recordings.

Next challenge was to investigate influence in the scales of Cypriot songs by measuring similarity between the various echoi and makams. The experiment included Cypriot scale estimation from Byzantine and Turkish scale candidates. The scale was decided upon similarity on, first, the whole histogram distributions, and second, the position and prominence of the scale tones. Main observations were the following:

- The five most used echoi in the Cypriot songs, as both comparisons revealed, were the First, Third, Second, Fourth Plagal and First Plagal. On the other hand, the five most used Turkish scales in histogram distribution comparison were the Buselik, Saba, Suzidil, Rast and Mahur whereas in the scale note comparison the latter three makams were replaced by Ussak, Hicaz and Hicazkar.
- For both aspects, the scales in Cypriot music showed greatest similarity with the Byzantine scales; in the histogram distribution comparison Byzantine histograms matched with 70% of the Cypriot songs and in the scale note comparison with 60%.

This experiment, in general, revealed more influence with Byzantine music. To be more precise, similarity occurred within the empirical rather than theoretical use of the Byzantine scales, as this was what the underlying methodology was aiming for. However, in this experiment we have seen some contradictions in the use of (mainly) Turkish makams (cf. Section 6.7.3). These contradictions, if not originating in particularities of recordings, indicate some kind of inefficiency of the employed algorithms. Therefore the obtained results might be subject to erroneous methodology.

Despite this possibility, there is a relevant reason that can explain the observation of more Byzantine influence in the Cypriot scales. The reader is reminded that music material of Cyprus was gathered mainly from the music sung by the Greek speaking population of Cyprus. In religion, Greek-Cypriots are in the majority Orthodox, therefore, they have most likely been exposed to at least some basic use of Byzantine music. What is more, some of the Cypriot musicians recorded in the corresponding material, have a background in religious studies that implies some basic (if not extensive) knowledge of Byzantine music. This reflects mostly in the religious music material whose recordings included performances by religious, musically or not, trained people. Therefore, it is rather rational to expect Byzantine influence, and more precisely influence in the empirical use of Byzantine music, occurring more in the Cypriot recordings we analyse.

Having said that, we do not want to generalise any conclusions for all Cypriot music but rather point at the constraints implied by the music material itself. What is more, the strong similarity between Byzantine and Turkish scales adds more complexity on the decision of the influence origins. Therefore these, along with the efficiency of particular methods proposed should be reconsidered and further evaluated for an improved and reliable comparative analysis system.

8 Conclusion

An overview of the thesis is provided as a conclusion of this research. The concepts integrated throughout this report are summarised in the paragraphs below.

This thesis investigated the Byzantine and Ottoman influence in Cypriot music in terms of the characteristics of their pitch patterns. The musical parameters mainly considered in this investigation were the intervals between scale degrees, the tuning of the scales and the prominence of scale degrees.

Theory of the three music traditions was further studied and inter-relations of Byzantine and Ottoman music characteristics were established. A system was specifically designed to deal with the computational analysis of this kind of music. This was then applied to sung melodies of Cypriot music and mainly religious Byzantine and Ottoman music.

The developed system was based on pitch class profiles extracted from a combination of new and/or improved methods. We summarize below the algorithmic contributions employed in the methodology of this thesis:

1. A combination of source separation software (FASST) and pitch extraction algorithm (Yin) was introduced to reduce the possibility of erroneous frequency estimates caused by the polyphonic signals assigned to a leading melody.
2. A number of post-processing algorithms were applied to further filter erroneous frequency estimates. Two of these focused on erroneous frequencies estimated due to specific signal characteristics (i.e. noise or silent gaps of the audio excerpt) whereas the third focused on common characteristics of this music (i.e. short melodic range and smooth/slow transitions between the notes) and corrected frequencies estimated in the wrong octave and/or fifth.
3. Another integrated challenge was the computation and smoothing of a pitch histogram. The proposed methods implied histogram bin resolution derived from the tuning peculiarities of each music tradition and smoothing factors appropriately adjusted for either histogram distribution similarity measure or scale note detection.
4. The method proposed for tonic detection and histogram alignment incorporated the melodic information extracted from the pitch of the last phrase note. Further considerations were applied to improve robustness in noisy audio recordings.
5. A peak detection method was developed to select peaks theoretically relevant to the underlying scale degrees. This was tuned to the scale characteristics as defined in Byzantine and Turkish music theory.
6. Lastly, various similarity measures were considered for specific tasks of this thesis. Upon empirical tests, the correlation coefficients method was chosen for histogram similarity purposes. Additionally, a customised similarity measure was introduced for measuring particularly similarity of isolated scale notes.

Furthermore, Byzantine and Ottoman influence was investigated in a combination of approaches. Experiments focused on the one hand, on an empirical study of the characteristics of each music tradition and on the other hand, on their inter-relations. The first part dealt with the particularities of Cypriot melodies and the consistency of Byzantine and Turkish scales in theory and practice. The second part investigated firstly, the similarities between the tuning of Byzantine and Turkish scales and then the influence of those two traditions on Cypriot music by considering intervals, tuning and prominence of scale degrees.

Overall, the main contribution of this thesis was the innovative application of computational methods in a comparative analysis of Cypriot melodies. Computational analysis of the tuning of Byzantine scales in theory and practice was also a newly introduced concept. Furthermore, tuning similarities of Byzantine and Ottoman music traditions, although theoretically established in the past [Mavroeidis 1999, Zannos 1990], were for the first time empirically studied.

Conclusions on a possibly higher Byzantine or Turkish influence have to be differentiated. Some aspects of Cypriot pitch patterns showed more similarity with Turkish music and others displayed similarities with Byzantine music. In this thesis, the mutual influence between the Byzantine and the Ottoman music tradition was not considered. It is left to future work to consider these Byzantine-Ottoman inter-dependencies in their relation to Cypriot music.

9 Future Work

The current study is just a preliminary step to the broad challenge of tracking influence in music of Cyprus. It can be extended and/or improved in many ways, some of which mentioned in the paragraphs below.

Regarding the music material, Cypriot instruments like the pithkiavli and the violin can be included in the database. These two instruments are particularly interesting, the former because of its special tuning, artful use of ornamentations and uniqueness of the sound, and the latter because of the peculiar intonation inclined in the performance of various Cypriot melodies. Moreover, as similar instruments exist in Turkish (i.e. ney, kemençe) and Greek/Byzantine (i.e. souravli, lyra) music a comparison of their use could be of particular interest.

In this study we focused only on tonal features. However this can be extended to other musical aspects one of the most important being the rhythm. When considering rhythm, it is more reasonable to consider non-religious music, e.g. dance songs. Religious Byzantine and Ottoman music would then be rather replaced by Greek and Turkish folk music.

We have pointed out in literature that Fones songs are especially useful in a comparison with similar Byzantine and Turkish practice. This can be extended in an influence investigation that employs also melodic similarity rather than just pitch histogram comparison.

Regarding the methods used in this study, a source separation tool and the Yin algorithm were combined for pitch estimation of monophonic audio. However, other algorithms could be integrated that efficiently estimate pitch directly from polyphonic audio. Other stages in the processing chain such as post processing of the frequency estimates and histogram smoothing could be further developed.

As for the tonic detection algorithm, a more robust method can be designed that combines both melodic information (cadences) and theoretical histogram templates. The decision to the correct tonic can then be based on both results.

The choice of the similarity measures for pitch histogram comparison is a crucial element in this thesis. The correlation coefficients method was chosen after an informal comparison. However, more advanced methods could be applied that incorporate automatic classification algorithms such as Support Vector Machines.

Last but not least, the proposed system can be further evaluated with user input. Feedback from musicologists and/or musicians can be of particular interest in for example estimating the scale of the Cypriot melodies, deciding whether Byzantine or Turkish influence is stronger in some cases or suggesting characteristics that can be integrated into the formulation of a similarity measure.

In this thesis, for the first time, a quantitative and computational comparative analysis of recorded Cypriot music is performed, thereby laying out a basis for further research on Cypriot music at the intersection point of several prominent Mediterranean music traditions.

10 References

Akkoç, C. (2002). Non-deterministic scales used in traditional Turkish music. *Journal of New Music Research*, *31*(4), 285-293(9).

Angelopoulos, L. (1986). The Importance of Simon Karas' Research and Teaching Regarding the Taxonomy and Transcription of the Effect of the Signs of Cheironomy: Oral Interpretation of the Written Interpretation. *Psaltiki: The Online Journal*. Retrieved March 30, 2011, from http://www.psaltiki.net/journal/2.1/angelopoulos/angelopoulos_karas.html

Averof, G. A. (1989). *Τα Δημοτικά Τραγούδια και οι Λαϊκοί Χοροί της Κύπρου [Popular Songs and Dances of Cyprus]*. Nicosia: Bank of Cyprus Cultural Foundation.

Bozkurt, B. (2008). An Automatic Pitch Analysis Method for Turkish Maqam Music. *Journal of New Music Research*, *37*(1), 1-13.

Bozkurt, B., Yarman, O., Karaosmanoğlu, M. K., & Akkoc, C. (2009). Weighing Diverse Theoretical Models on Turkish Maqam Music Against Pitch Measurements: A Comparison of Peaks Automatically Derived from Frequency Histograms with Proposed Scale Tones. *Journal of New Music Research*, *38*(1), 45-70.

Encyclopaedia Britannica (2011). Cyprus. *Encyclopædia Britannica Online*. Retrieved August 24, 2011, from http://www.britannica.com/EBchecked/topic/148573/Cyprus

BBC News - Cyprus country profile. (2011). *BBC*. Retrieved May 22, 2011, from http://news.bbc.co.uk/2/hi/europe/country_profiles/1016541.stm#facts

Cabrera, J. J., Díaz-báñez, J. M., Escobar-Borrego, F. J., Gómez, Emilia, Gómez, F., & Mora, J. (2008). Comparative Melodic Analysis of A Cappella Flamenco Cantes. *Fourth Conference on Interdisciplinary Musicology (CIM08)*.

de Cheveigné, A., & Kawahara, H. (2002). YIN, a fundamental frequency estimator for speech and music. *The Journal of the Acoustical Society of America*, *111*(4), 1917.

Chordia, P. (2004). Automatic rag classification using spectrally derived tone profiles. *ICMC*.

Chordia, P., & Rae, A. (2007). Raag recognition using pitch-class and pitch-class dyad distributions. In S. Dixon, D. Bainbridge, & R. Typke (Eds.), *Proceedings of International Conference on Music Information Retrieval* (pp. 431-436).

Clarisse, L. P., Martens, J P, Lesaffre, M., De Baets, B., De Meyer, H., & Leman, M. (2002). An Auditory Model Based Transcriber of Singing Sequences. In M. Fingerhut (Ed.), *3rd International Conference on Music Information Retrieval ISMIR 2002* (pp. 116–123).

Cyprus Research Centre. (2004). *Δημοτικά Τραγούδια της Κύπρου: Θρησκευτικά - της Παναγίας [Popular songs of Cyprus, Religious songs - The Virgin Mary]*. Nicosia: Publications of the Cyprus Research Centre XLVI.

Demetriou, N. (2006). The Fones of Cypriot folk music: urbanisation and modernisation. *Bulletin of the Council for British Research in the Levant*, *1*(1), 62-64.

Dontsios, S. D. (n.d.). *Εγκόλπιον Εκκλησιαστικής Βυζαντινής Μουσικής και Σύντομη Θεωρία των Οκτώ Ήχων [Foundations of Byzantine Church Music and Overview of the Eight Echoi]*.

Erdener, Y. (1995). *The song contests of Turkish minstrels: Improvised poetry sung to traditional music*. New York: Garland.

Feldman, W. Z. (2011). Ottoman music. *Grove Music Online. Oxford Music Online.* Retrieved August 24, 2011, from http://www.oxfordmusiconline.com/subscriber/article/grove/music/52169

Fortoma, P. (1999). *Είσοδος στη Βυζαντινή Μουσική [Introduction to Byzantine Music]*. Athens.

Gedik, A. C., & Bozkurt, Barış. (2010). Pitch-frequency histogram-based music information retrieval for Turkish music. *Signal Processing*, *90*(4), 1049-1063.

Gedik, A., & Bozkurt, Barıs. (2009). Evaluation of the Makam Scale Theory of Arel for Music Information Retrieval on Traditional Turkish Art Music. *Journal of New Music Research*, *38*(2), 103-116.

Gedik, Ali C, & Bozkurt, Baris. (2008). Automatic Classification of Turkish Traditional Art Music Recordings by Arel Theory. *Proceedings of the fourth Conference on Interdisciplinary Musicology (CIM08)* (Vol. 56). Thessaloniki, Greece.

Giorgoudes, P. (2011a). Music of Cyprus. *Ethnomusicology Research Program*. Retrieved August 25, 2011, from http://www2.ucy.ac.cy/research/ethno/article2.htm

Giorgoudes, P. (2011b). Cyprus. *Grove Music Online. Oxford Music Online.* Retrieved April 2, 2011, from <http://www.oxfordmusiconline.com/subscriber/article/grove/music/40747>.

Gomez, E. (2005). Key Estimation from Polyphonic Audio. *Abstract of the Music Information Retrieval Evaluation Exchange*.

Gómez, E. (2006). *Tonal Description of Music Audio Signals*. *The Astronomical Journal*. Universitat Pompeu Fabra.

Gómez, Emilia, & Herrera, P. (2008). Comparative Analysis of Music Recordings from Western and Non-Western traditions by Automatic Tonal Feature Extraction. *Empirical Musicology Review*, *3*(3), 140-156.

Ioannou, M. D. (n.d.). *Θεωρητικόν Βυζαντινής Εκκλησιαστικής Μουσικής [Theory of Byzantine Church Music]*. Athens.

Izmirli, O. (2005). Algorithm for Key Finding from Audio. *Abstract of the Music Information Retrieval Evaluation Exchange*.

Kakoulidi, G. I. (2005). *Πρακτική Μέθοδος Εκμάθησης της Ψαλτικής Τέχνης [Teaching Methods of the Art of Chanting]*.

Karagiorgis, E. (2010). Δίστιχα-Οι Μουσικές τους Μορφές [Couplets-Their Musical Form]. Limassol: "Folklore Day", 5-6/11/2010. Limassol Folklore Foundation.

Krishnaswamy, A. (2003a). Pitch measurements versus perception of South Indian classical music. *Stockholm Music Acoustics Conference* (Vol. 2003, pp. 3-6).

Krishnaswamy, A. (2003b). *Application of Pitch Tracking to South Indian Classical Music*. *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics* (p. 49).

Krishnaswamy, A. (2004). Inflexions and Microtonality in South Indian Classical Music. *Frontiers of Research on Speech and Music*.

De La Cuadra, P., Master, A., & Sapp, C. (2001). Efficient Pitch Detection Techniques for Interactive Music. *Spectrum* (pp. 403–406).

Leman, M, De Baets, B., De Meyer, H., Lesaffre, M., Martens, G., Martens, J. P., & Van Steelant, D. (2002). Tendencies , Perspectives , and Opportunities of Musical Audio-Mining. *Musical Acoustics - Perception and Recognition of Music*, *SS-MUS-01*.

Leonidas, I. (2010). *Estimating the Makam of Polyphonic Music Signals : Template-Matching Vs . Class-Modeling*. *Computing*. Universitat Pompeu Fabra.

Levy, K., & Troelsgård, C. (2011). Byzantine chant. *Grove Music Online. Oxford Music Online.* Oxford Music Online. Retrieved August 24, 2011, from http://www.oxfordmusiconline.com/subscriber/article/grove/music/04494

Mavroeidis, M. (1999). *Οι Μουσικοί Τρόποι στην Ανατολική Μεσόγειο [The musical modes in East Mediterranean]*. Athens: Fagotto.

Moelants, D., Cornelis, O., & Leman, Marc. (2009). Exploring African Tone Scales. *10th International Society for Music Information Retrieval Conference (ISMIR)*, 489-494.

Mora, J., Gómez, F., Gómez, Emilia, Escobar-Borrego, F., & Díaz-Báñez, J. M. (2010). Characterization and Melodic Similarity of A Cappella Flamenco Cantes. *ISMIR 2010*, (Ismir), 351-356.

PFF LP VIII-XIV. (1989). *Κύπρος Δημοτική Μουσική [Folk Music of Cyprus]*. Athens: Peloponnesian Folklore Foundation.

Pratyush. (2010). *Analysis and Classification of Ornaments in North Indian (Hindustani) Classical Music*. Universitat Pompeu Fabra.

Purwins, H., Blankertz, B., & Obermayer, K. (2000). A new method for tracking modulations in tonal music in audio data format. *Proceedings of the*

IEEEINNSENNS International Joint Conference on Neural Networks IJCNN 2000 Neural Computing New Challenges and Perspectives for the New Millennium, *6*, 270-275. Ieee.

Rabiner, L. (1977). On the use of autocorrelation analysis for pitch detection. *ASSP*, *25*(1), 24-33.

Reinhard, K. et al. (2011). Turkey. *Grove Music Online. Oxford Music Online.* Retrieved April 28, 2011, from http://www.oxfordmusiconline.com/subscriber/article/grove/music/44912

Serra, X. (2011). A Multicultural Approach to Music Information Research. *International Conference on Music Information Retrieval*.

Sheather, S. J., & Jones, C. (1991). A reliable data-based bandwidth selection method for kernel density estimation. *Journal of the Royal Statistical Society Series B Methodological*, *53*(3), 683-690. Blackwell Publishing for the Royal Statistical Society.

Six, J., & Cornelis, O. (2011). TARSOS - A Platfrom to Explore Pitch Scales in non-Western and Western Music. *Proceedings of the 12th International Society for Music Information Retrieval Conference, ISMIR 2011*. International Society for Music Information Retrieval.

Temperley, D. (1999). What's key for key? The Krumhansl-Schmuckler key-finding algorithm reconsidered. *Music Perception*, *17*(1), 65-100. University of California Press.

The Arabic Maqam. (2011). *Maqam World*. Retrieved August 28, 2011, from http://www.maqamworld.com/maqamat.html

Thoukididi, A. (2003). *Κρηπίδα Βυζαντινής Μουσικής [Foundations of Byzantine Music]*. Cypruts: Kykkos Church.

Tombolis, S. (2002). *Κυπριακή Παραδοσιακή Μουσική: Συλλογή, Καταγραφή, Ανάλυση (Τόμος I) [Traditional Music of Cyprus: Collection, Annotation, Analysis (Part I)]* (pp. 422-423). Nicosia: Bank of Cyprus Cultural Foundation.

Tzanetakis, G., Ermolinskyi, A., & Cook, P. (2002). Pitch Histograms in Audio and Symbolic Music Information Retrieval. (M. Fingerhut, Ed.)*Journal of New Music Research*, *32*(2), 143-152. Routledge.

Tzanetakis, G., Kapur, A., Schloss Andrew, W., & Wright, M. (2007). Computational Ethnomusicology. *Journal of Interdisciplinary Music Studies*, *1*(2), 1-24.

Winnington-Ingram, R. P. (1936). *Mode in Ancient Greek Music*. Cambridge [Eng.]: The University press.

Yarman, O. (2007). A Comparative Evaluation of Pitch Notations in Turkish Makam Music : Abjad Scale & 24-Tone Pythagorean Tuning – 53 Equal Division of the Octave as a Common Grid. *Journal of Interdisciplinary Music Studies*, *1*(2), 43-61.

Yarman, O. (2008). *79-tone tuning & theory for Turkish maqam music*. Istanbul Technical University, Turkey.

Zannos, I. (1990). Intonation in Theory and Practice of Greek and Turkish Music. *Yearbook For Traditional Music*, *22*(1990), 42.

Zarmas, P. (1993). *Πηγές της Κυπριακής Δημοτικής Μουσικής [Sources of Folk Music of Cyprus]*. Λευκωσία: Κέντρο Μελετών Ιεράς Μονής Κύκκου.

Appendices

A collection of videos and audio examples was uploaded on the web for further illustration of the concepts discussed throughout this thesis.

Informative videos regarding specific aspects of Cypriot music tradition can be found in the web links listed below.

1. **Video**: How to Make a Pithkiavli
   Description:
   An illustration of pithkiavli making by Andreas Christakkos. Filmed on 27/04/11 by Xenis and Maria Panteli.
   Link: http://www.youtube.com/watch?v=h52Gyx4nmDM

2. **Video**: The Double-Pithkiavli Techniqe
   Description:
   Performance of the double-pithkiavli technique by Giannis Ttikkis. Filmed on 27/04/11 by Xenis and Maria Panteli.
   Link: http://www.youtube.com/watch?v=KV0IFjePE0M

3. **Video**: Fones Contest
   Description:
   A contest on lyrics improvisation based on the tradition of Fones melodies. Excerpt from the TV show "Συν-Πλην" (Syn Plin) previewed by Cyprus Broadcasting Corporation (CyBC) on the 5th, January, 2011 under the theme "Music Tradition of Cyprus".
   Link: http://www.youtube.com/watch?v=e7BvLqvkVwk

A small subset of audio examples used in the computational analysis of this thesis can be found at:
http://soundcloud.com/panteli_maria
The audio excerpts represent Cypriot melodies as well as Byzantine/Turkish pieces performed in particular scales.