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Evaluation of the *Makam* Scale Theory of Arel for Music Information Retrieval on Traditional Turkish Art Music

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Abstract

Current music information retrieval (MIR) methods are specifically tailored to the needs of western music. Therefore, it is not straightforward to apply these methods to non-western musics such as traditional Turkish art music (TTAM). Western music theory plays a crucial role in MIR studies. The divergence, however, between theory and practice in traditional Turkish art music (TTAM) results in a lack of a reliable theory of TTAM on which MIR techniques can be based. This is particularly true for theories regarding pitch scales and interval structures in TTAM. In this paper, we evaluate the most influential (yet disputable) theory of TTAM, Arel theory, by means of a *makam* classification task, to understand whether it can provide a basis for MIR studies on TTAM in a similar way western music theory provides a basis for MIR studies on western music. It is shown that Arel theory is overall successful when applied for modality finding in TTAM and that it can be improved if small modifications are introduced following pitch values obtained from musical practice.

1. Introduction

Music Information Retrieval (MIR) is a recently established research field (Casey et al., 2008). MIR studies are primarily applied on western music. Although the current state of the art in MIR studies provides the necessary framework for research on non-western musics, the application of current MIR methods developed for western music to non-western musics is a challenging task due to several fundamental differences between western and non-western musics (Moelants et al., 2006). As a result, the number of MIR studies on non-western musics is very limited and methods are usually applied blindly to non-western musics by engineers or computer scientists with little or no musicological considerations (Tzanetakis et al., 2007).

On the other hand, the volume of research using computational methods on non-western musics is much larger and has a much longer history than MIR studies on non-western musics. Tzanetakis et al. (2007) review these studies and introduce a new term, *computational ethnomusicology* (CE), 'to refer to the design, development and usage of computer tools that have the potential to assist in ethnomusicological research'; this term covers current computational studies, including MIR studies on non-western musics. Although Tzanetakis et al. (2007) underline the benefits of integrating MIR methods into ethnomusicological research, they use the term CE rather to emphasize an interdisciplinary collaboration between MIR and ethnomusicology.

In this sense, our study on traditional Turkish art music (TTAM) can be regarded as an attempt to provide an interdisciplinary collaboration of MIR and ethnomusicology under computational ethnomusicology. Our main motivation is to investigate whether the theory of TTAM can provide a basis for MIR studies on TTAM in a similar way western music theory provides a basis for the current MIR studies on western music. Western music theory plays a crucial role in current MIR methods, especially for the representation of the pitch space as 12 equal tempered pitch-classes. Consequently, we investigate whether the theory of TTAM can provide such valid pitch-class definitions for MIR studies on TTAM. However, there are several different theories of TTAM, each hypothesizing a different number of

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discrete pitch classes, which range from 17 to 79 pitch classes per octave. These theories are highly debated in TTAM, due to the divergence between theory and practice (Yarman, 2008).

The divergence between theory and practice is common[1] in the traditional art musics of the Middle East, where practice is mainly based on oral tradition and theory is a combination of speculation and insight with musicological scientific method (Bohlman, 2008). This divergence appeared as a 'problem' due to the westernization and nationalization by the 20th century, which also brings standardization in music. The lack of standardization in the production, for instance, of instruments seems to lead to the discussions about the divergence of theory and practice.

In this study, we consider the most influential theory[2] in TTAM developed mainly by Hüseyin Sadeddin Arel (1880–1955). Arel theory is an official theory used in music education; musical transcriptions are also written with respect to Arel theory in Turkey. On the other hand, the discussions about the divergence between the theory and practice are mostly held with respect to Arel theory, especially in regards to the defined *makam* scales. Therefore, both for the research in MIR and ethnomusicology, Arel theory is worthy of investigation. In this paper, the theory of TTAM is represented by Arel theory, and the practice of TTAM is represented by 20th century recordings.

This study evaluates the *makam* scale theory of Arel. Although Arel theory gives place to other central concepts of the definition of TTAM such as *seyir*, i.e. melodic organization, and *usul*, i.e. rhythmic organization, the most disputable and discriminative dimension of the theory is the theory of *makam* scales. In other words, the discussion of Arel theory usually corresponds to the discussion of *makam* scales in theoretical studies on TTAM. Therefore, we prefer to use the term, 'Arel theory' throughout the study, instead of '*makam* scale theory of Arel'.

The most straightforward approach for the evaluation of the theory and its suitability to MIR-type methods is to compare the theoretically defined pitch-classes with the pitch values obtained from practice. A comprehensive computational research based on such a comparison is presented by Bozkurt et al. (2009) on five theoretical systems, including Arel theory. Although this study provides empirical results over a significantly large amount of data for the first time, the suitability of a theory for MIR applications should be evaluated within the context of MIR. As a result, our study evaluates Arel theory within the context of MIR studies.

Western music theory most explicitly contributes to the MIR studies on tonality finding where the key of a given piece is classified as belonging to one of 12 major and 12 minor keys. Pitch space representation of western music, based on 12 equal tempered pitch-classes, constitutes the most critical step in these studies. The given piece and the tonality templates are represented as pitch-class distributions. The pitch distribution of a given piece is then compared to the tonality templates, and the tonality whose template has the highest similarity determines the tonality of the piece. Whilst these studies present an appropriate framework for the investigation of tonality in TTAM by means of Arel theory, TTAM and western music are significantly different from each other which prohibits a direct application of the current MIR methods.

Gedik and Bozkurt (2009) present the obstacles against applying current MIR and tonality finding methods in TTAM by developing a data-driven model, without any contribution from theory. Whilst our current study shares the conceptual framework of this study, the computational methodology employed in this paper is based on a music theoretical model. Since TTAM is based on a modal system, our study rather corresponds to modality finding, analogous to tonality finding studies on western music. The modal system of TTAM is mainly determined by modal entities called *makam*,[3] and each *makam* is roughly defined in Arel theory as a subset of 24 pitch-classes. Therefore, TTAM is basically classified by *makam* names both in theory and practice. In this sense, finding the *makam* of a given piece refers to finding the modality of a given piece. In this paper, modality (*makam*) templates are constructed based on Arel theory and a given piece is compared with these modality templates. Consequently, the modality whose template has the highest similarity is identified as the modality of the piece.

Instead of the pitch-class distributions used for western music, both the modality templates and the recordings are represented as pitch-frequency histograms over a frequency range (Bozkurt, 2008). Each modality template is represented as a sum of Gaussian distributions: firstly, each fixed pitch interval value defined in theory for a *makam* is used as the mean value of a Gaussian distribution and secondly, each of these Gaussian distributions for a *makam* are summed up to obtain the pitch-frequency histogram. This operation transforms theory into a computationally comparable format with practice. Finally, the success rate of modality finding based on Arel theory is used to evaluate the

[1]Even as early as in the 13th century, the theory of Urmevi slightly diverged from the practice of his time (Marcus, 1993, p. 50).

[2]Although Arel–Ezgi–Uzdilek is conventionaly used to refer to the theory, we prefer to use the term 'Arel theory' since the theory is mainly represented by a book written by Arel, and there are slight differences among Arel, Ezgi and Uzdilek. Arel theory is also used here to imply a discourse which transcends beyond the mere theory itself.

[3]The Turkish term '*makam*' (pl. *makamlar*) is used instead of 'maqam' (pl. maqamat).

suitability of the Arel theory for MIR studies on TTAM. This evaluation determines whether the pitch-classes defined in the Arel theory are appropriate.

Our study involves nine modalities (*makamlar*) which represent approximately 50% of the current repertoire of TTAM among approximately 600 modalities (*makamlar*) (Öztuna, 2006). Since given samples are classified according to their distances to the templates, we prefer to consider the problem of modality finding as an automatic classification of TTAM recordings by Arel theory, where the template matching technique is applied as proposed by Temperley (2001) for tonality finding studies on western music.

The presentation of the paper is as follows: the next section presents a brief description of Arel theory and the practice of TTAM from an ethnomusicological point of view. Section 3 presents the theoretical classification of *makam* types in TTAM. Section 4 describes the automatic classification of TTAM recordings by the *makam* scales defined in Arel theory. In Section 5, Arel theory is evaluated computationally.

2. Arel theory: An ethnomusicological perspective

Two representative examples of the westernization and the nationalization of music are Egypt and Turkey. The Congress of Arab Music held in Cairo in 1932 is a historical attempt to standardize the theory and practice of traditional art music[4] (Racy, 1991, p. 68). Although nationalism was not very explicitly present in the congress, the term 'Arab music' was clearly implying a distinction from Turkish and Persian musics (Thomas, 2007, p. 2). The cultural policies of the government in Egypt intended both to define an 'Arab music' and raise it to the 'level' of western music (Racy, 1991, p. 70) in accordance with the general top-down direction of westernization and nationalization processes.

On the other hand, the same processes followed a different course in Turkey. A few years after the 1923 revolution, educational institutions of traditional art music such as official schools, religious lodges and cloisters were closed (Tekelioğlu, 2001, p. 95). This music was regarded as a symbol of Ottoman past, which implies a primitive, morbid, non-rational, non-western and non-Turkish heritage, blurred with Arab, Persian and ancient Greek effects (Signell, 1976, pp. 77–78). Thus, the new Turkish music was defined as the synthesis of 'pure' Turkish folk music and western classical music. This, however, led neither to the disappearance of traditional art music nor to the prevention of its westernization and nationalization. This can be considered as a characteristic of late modernization: the concurrent existence of modernity and traditionality and/or hybrid structures.

Music theorists did not follow the cultural policies of the state, and developed new discourses and theories based on the 'Turkishness' and 'westernness' of traditional art music. Despite the ideological and physical interventions of the state, even the radio broadcasting of traditional art music was banned between 1934 and 1936, these theories and discourses were started to prevail among the theorists and the musicians. However, the political climate of Turkey after the 1940s changed and seemed to become more tolerate towards traditional art music (Öztürk, 2006b, p. 153). The journal, *Musiki Mecmuas i* (founded by Arel in 1948) and semi-official and unofficial schools of traditional art music played a crucial role in the appreciation of these theories and discourses. Nevertheless, traditional art music was not officially recognized until 1976 by the foundation of the first Conservatory of Turkish Music. Only after this the current theories and discourses were also officially recognized and appreciated, and thus constituted the basis of national education of the traditional art music. Therefore, these theories and discourses have prevailed much more and been established after 1976.

This process clearly does not fit with the general top-down direction of westernization and nationalization, although it is not easy to describe this process simply as bottom-up. Considering the ideological and physical interventions, the process and the 'motivation' behind the Arel theory can be explained in terms of coercion and consent within the Gramscian conception of hegemony, as reconceptualized by Hall (1996).

It should be added that neither the Arab music congress nor the Turkish revolution was a sudden turning point for the westernization of traditional musics. Westernization dates back to the 19th cenutry, both in Egypt and Turkey: Khedive Isma'il (1830–1895), a reformist ruler of Egypt, and Selim III (1761–1808), a reformist Ottoman emperor, were both patrons of music, interested in western and traditional musics and took important steps toward westernization of musical life. So the new theories and discourses in Turkey can be considered as a continuation of the trends started in the 19th century. Furthermore, two of the most influential modernist theorists of the 20th century, Rauf Yekta Bey (1871–1935) and Arel were also the 'students' of the heads of dervish lodges (Akdoğu, 1993, p. xii).

The study of Yekta on the westernization of the theory provides a historical turning point. The term 'Ottoman music' is replaced by 'Turkish music', and the traditional number of intervals is increased from seventeen to twenty-four (Öztürk, 2006a, pp. 213–214). However, his colleague Arel went much further in trying to 'prove' both the Turkishness[5] of the traditional art

[4]The term 'traditional art music' is used to refer to the relevant musics of Egypt and Turkey.

[5]All past theorists are considered as ethnic Turks, although many of them were non-Ottoman or even non-Turkish.

music and its resemblance to western music. He invented new instruments (soprano, alto, tenor, bass and double-bass *kemençe*) and a new *makam* (*çargah*) compatible with his new theory.

Feldman (1990, p. 100) compares the positions of Yekta and Arel as follows: while Yekta appears to be more involved with musicological works, Arel plays the main role in the ideological struggle against the cultural policies of the state which explicitly refers to the struggle of hegemony. Nevertheless, it should be noted that Yekta had already written an explicit answer against the arguments of the cultural policies in his 1925 articles (Yekta, 1997a, pp. 5–7; 1997b, pp. 33–34) twenty years before Arel. However, Arel seems to exceed the logical limits of past trends both theoretically and discursively in the 20th century.

Arel theory was first published as a book in 1968 after its earlier publication as articles in 1948, though Zeki Yılmaz's book, published in 1977, which is a simplified and somewhat distorted version of the Arel theory, has prevailed as if it was an official textbook. Shiloah (2008) describes a similar tendency in Egypt after the second half of the 20th century as a shift of interest from theory to practical theory. Therefore, Arel theory is not much known in detail today, except among theorists and a few musicians. This fact can also be interpreted as the continuation of 'oral tradition', *meşk*, in the 20th century.

The main points of Arel theory can be listed as follows (Öztürk, 2006a, pp. 214–216):

- A non-existing scale, *makam çargah*, has been invented and attributed as a general scale, which is identical to the C major scale and tonality in western music. The hierarchical tonal functions are attributed to the specific scale 'degrees' and a new notation system similar to western staff notation is introduced for the first time.
- One of the most important aspects of TTAM, the melodic progression (*seyir*), is underestimated. Therefore, the *makam* concept is reduced to a tonal scale as in western music.

Stokes (1996) also refers to these attempts as the 'Arel project' in reference to its strong relations with nationalization and westernization. However, there is an increasing tendency toward criticizing Arel theory today, especially among the theorists because of its divergence from the practice.

As a result, the westernization and the nationalization of the theories and discourses have become more established by the official institutions founded in Turkey and in Egypt after the second half of the 20th century. Thus, the divergence between the theory and the practice became more apparent and problematic in countries due to the officially institutionalized common discourse: 'the theory should generate practice' (Thomas, 2007, p. 4). Especially the standardization of a tuning system as equal-tempered quarter-tone scales in Egypt and as a division of the octave into 24 unequal intervals in Turkey generates similar new discourses among musicians: pitch interval values are performed differently than the ones defined in theory, and musicians describe this flexibility with respect to the theory by using such terminology as 'a little higher', 'a little lower' or 'minus a comma' (Marcus, 1993). Unstandardized fret positions in the production of instruments such as *kanun* and *tanbur* explicitly provide evidence for these flexible pitch preferences of performers in Turkey (Yavuzoğlu, 2008, p. 12).

On the other hand, practice has also been affected by westernization and nationalization, even though it is not easy to claim that the new theory has generated a new practice. The westernization trends in the practice are observable from the performances of Tanburi Cemil Bey, Mesud Cemil, Niyazi Sayın, etc., but this does not result in convergence between theory and practice. For instance, although the performances diverge from the theory, the Arel theory is highly respected among performers, and they hesitate to contradict the theory when the pitch intervals of their performances are measured by musicologists.[6]

3. Theoretical classification of TTAM

Turkish traditional art music is basically classified into several *makamlar*, both in theory and in practice. Each *makam*, having a distinct name, generally implies a set of rules for composition and improvisation. These rules are roughly defined in theory in terms of the scale type and the melodic progression. Although there is a general consensus about the names of *makamlar*, at least in practice, the rules that define them remain problematic.

However, the definitions and the number of *makamlar* have greatly changed throughout history. While 27 *makamlar* are mentioned in the treatise of Dimitrie Cantemir (17th century), Arel (1993) defines 113 *makamlar*. The defining rules of *makamlar* are also considerably altered in Arel theory, such as the abandonment of the traditional concepts and classification categories *avaze*, *şube* and *terkib*. On the other hand, Öztuna (2006) reports that historically, there have been as many as 600 *makamlar*, but only one sample for each of the 333 *makamlar* are left today, and approximately 70% of the current repertoire consists of only 20 *makamlar*.

[6]Karl Signell and M. Kemal Karaosmanoğlu (quoted from Can Akkoç) shared their measurement experiences with foremost performers Necdet Yaşar and Niyazi Sayın, respectively (personal communication with Signell and Karaosmanoğlu, 6–8 March 2008, İstanbul).

Form provides an additional classification for TTAM in theory and in practice. Each composition has a distinct *makam* name such as *hicaz*, *saba*, *nihavend* and a distinct form such as *peşrev*, *sazsemai*. So each composition is referred to as *hicaz peşrev*, *saba sazsemai* etc., where the *makam* name is followed by a form name. The *Usul*, the rhythmic structure of a composition such as *aksak* (9/8), *semai* (3/4) etc., is also mentioned in the naming of compositions. Improvisation is considered as a free-rhythmic form and classified as instrumental (*taksim*) and vocal (*gazel*).

Since only the *taksim* recordings are used in this study, information about the form and the *usul* is out of our scope. Therefore, we focus only on *makam* classification. While the description of *seyir* (melodic progression) is underestimated by Arel, which is one of the fundamental features of TTAM, the scale structure of each *makam* as a subset of 24 pitch-classes constitutes the most important dimension in the description of each *makam*. Our study is based on distributional information of the pitch space of TTAM and *seyir* is out of our scope due to the temporal information it requires. Finally, only the scale structure of each *makam* as a subset of 24 pitch-classes is considered under the term 'Arel theory' where each pitch-class has a distinct name as in western music (Arel, 1993).

For further information about *makam* scale theory of Arel, the reader is referred to the studies of Yarman (2007, 2008) which compare the scale theory of Arel with the preceding *makam* scale theories in detail. A brief review on *makam* scale theories dating from the 13th century to today is provided by Bozkurt et al. (2009), and a very short review of the Arel theory in terms of notation, basic intervals and terminology is provided in the Appendix by Bozkurt (2008).

Our study is also limited to nine *makamlar* which represent approximately 50% of the current repertoire (Öztuna, 2006). Therefore, only scale structures of these nine *makamlar* are considered. It is common practice to use Holdrian comma (Hc) obtained by the division of an octave into 53 logarithmically equal partitions as the unit for pitch intervals in the theories of Turkish traditional art music. We also preferred the Hc in order to make comparisons with other studies possible. For each *makam*, a scale usually within an octave[7] and its pitch intervals are defined in Arel theory. The 2nd pitch interval types and their values in Hc defined in the Arel theory are as follows: *bakiyye*-4, *küçük müneccep*-5, *büyük müneccep*-8, *tanini*-9, *artık ikili*-12 or 13. Based on these 2nd pitch interval values and the definition of *makamlar* in Arel theory, we have derived a list of other pitch intervals[8] with respect to the tonic (*karar*) for the nine *makamlar* as shown in Table 1.

Figure 1[9] enables one to compare the pitch interval types of TTAM and western music by showing all the pitch intervals defined in Arel theory within an octave at a chromatic clavier. Since all the pitch intervals are represented in the figure, 31 pitch-classes are seen. However only 24 pitch-classes are defined in Arel theory as a subset of those 31 pitch-classes (Arel, 1993, p. 36). The octave in the figure consists of 53 Hc.

4. Automatic classification[10] of TTAM according to the *makam* scales

In tonality finding studies, pitch distribution of a given piece is compared to two tonality templates, and the tonality whose template is more similar is regarded as the tonality of the piece. Although there are various models for the construction of templates such as music theoretical, cognitive, and data-driven models in current MIR studies, both the given piece and the tonality templates are represented by pitch-class distributions based on 12 pitch-classes as defined in western music theory (Gedik & Bozkurt, 2009).

However, TTAM and western music are different in terms of the pitch space, which limits the direct application of the current MIR methods to the analysis of TTAM (Gedik & Bozkurt, 2009). Pitches performed in TTAM do not correspond to fixed frequencies as in western music, depending on several factors:

- the concept *ahenk* (the tuning system);
- the performance of each pitch within a frequency band rather than a fixed frequency;
- freedom of musicians in performance of a specific *makam* by varying the pitches for certain pitches of the scale;
- the small variations of pitches performed depending on the direction of melodic progression, either descending or ascending.

All these factors necessitate standardization of pitch-frequency histograms via alignment to compare measurements from different recordings. Therefore, the pitch

[7]Only the *makam saba* among the *makamlar* used is defined in Arel theory as exceeding the range of an octave. Since we consider all *makamlar* within an octave, intervals higher than 53 Hc (for example 61 Hc) of *saba* scale are omitted.

[8]7th interval for *hicaz*, *segah* and *saba makam* scales are defined by Arel with respect to the *seyir* features of these *makamlar*. According to Arel, these *makam* scales either use 6th interval or 7th interval depending on the melodic direction (ascending or descending).

[9]http://www.xs4all.nl/huygensf/scala/, Version 2.24j, Command language version 1.86i, Copyright Manuel Op de Coul, 2007.

[10]All codes for automatic classification are written in MatLab 6.1.

Table 1. *Makam* scale intervals of nine *makamlar* in Arel theory. Intervals for each *makam* are given in Hc with respect to tonic.

	1	2	3	4	5	6	7	8
hicaz	5	17	22	31	35	39	44	53
rast	9	17	22	31	40	48	–	53
segah	5	14	22	31	36	45	49	53
kurdili hicazkar	4	13	22	31	35	44	–	53
huzzam	5	14	19	31	36	49	–	53
nihavend	9	13	22	31	35	44	–	53
hüseyni	8	13	22	31	39	44	–	53
uşşak	8	13	22	31	35	44	–	53
saba	8	13	18	31	35	44	49	–

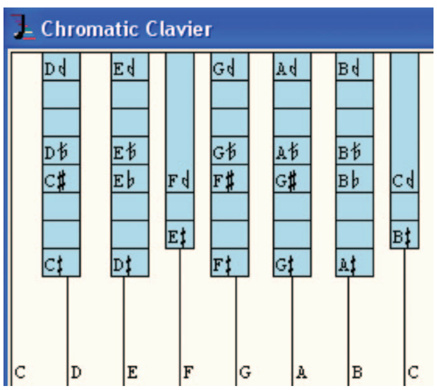

Fig. 1. The 24 pitch-classes defined in Arel Theory are represented at a chromatic clavier obtained by Scala software (T24 Turkish notation system of Arel-Ezgi).[9]

interval value with respect to the tonic of the *makam* is used as a unit instead of frequency in Hertz. Consequently, pitch frequencies and pitch frequency histograms are represented as intervals in Hc. 1/3 Holdrian comma resolution, a value obtained empirically that optimizes smoothness and precision of pitch histograms is used (Bozkurt, 2008).

As mentioned in the introduction, we consider modality finding as the aim of our study, where each *makam* corresponds to a modality, analogous to tonality finding studies on western music. However, due to the difference of pitch spaces between western music and TTAM, both the modality templates and recordings are represented as pitch-frequency histograms instead of pitch-class distributions used for western music. In a similar fashion to current MIR studies, modality templates are constructed first, based on Arel theory: the pitch-frequency histograms derived from theoretical *makam* scales are used as templates. Then a given piece, represented again as a pitch-frequency histogram, is compared to the modality templates.

The name of the *makamlar* and the number of recordings used for each *makam* are as follows: *hicaz*-20, *rast*-19, *segah*-20, *kürdili hicazkar*-16, *hüzzam*-14, *nihavend*-18, *hüseyni*-20, *uşşak*-24, *saba*-21. The uneven distribution of samples for each *makam* is due to the current database of recordings we have collected so far. One-hundred-and-seventy-two recordings of historically prominent musicians were selected for classification. Recordings were not partitioned; they were analysed as a whole. These were monophonic (non-heterephonic) recordings of the following instruments: *ney*, *tanbur*, *kemençe*, violin, clarinet and cello. Some of the performers in the recordings were: Tanburi Cemil Bey (1873–1916), Mesut Cemil (1902–1963), Niyazi Sayın (b. 1927), Necdet Yaşar (b. 1930), Sadrettin Özçimi (b. 1955).[11]

4.1 Representation of practice

A new method proposed by Bozkurt (2008) for the analysis of pitch frequencies in TTAM was used to pre-process and then to represent the recordings as pitch-frequency histograms. In this method, each recording in audio format (wav file) is analysed by YIN (de Cheveigne & Kawahara, 2002) and the estimated fundamental frequency values are post-processed with filters. These filters are especially designed for TTAM, based on its acoustic characteristics (Bozkurt, 2008). Then the automatic tonic detection algorithm presented by Bozkurt (2008) is applied, and the results are checked and corrected manually. Pitch frequencies are converted into pitch interval values with respect to the tonic in Hc and the distributions are computed. These distributions also represent the scale structure of a *makam* performed in a recording. As a result, each recording is represented as a pitch-frequency histogram (Figure 2).

4.2 Representation of theory

Although Arel defines fixed pitch intervals for each *makam* scale, none of the 172 recordings demonstrates such absolute characteristics. All the pitch histograms we have computed in this study from recordings showed rather flexible pitch frequencies. Consequently, we have transformed the theoretical *makam* scales following a convergence to the characteristics of practice, and represented each fixed pitch interval value of a *makam* scale defined in theory by Gaussian distributions. The mean of each Gaussian distribution was set at the fixed pitch interval values defined in the theory for each *makam*, and their standard deviations were selected as 2 Hc, heuristically. Finally, each theoretical *makam* scale was represented as the sum of these Gaussian

[11]Detailed information about the recordings and relevant MATLAB codes can be found at project web page: http://likya.iyte.edu.tr/eee/labs/audio/Main.html.

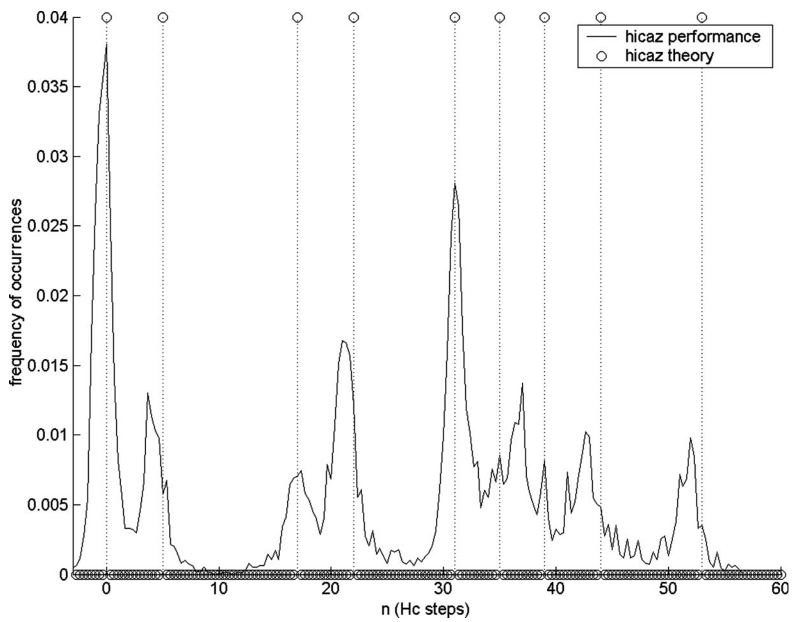

Fig. 2. Pitch interval histogram of a *hicaz taksim* by Tanburi Cemil Bey and *hicaz* scale defined in Arel theory.

distributions (Figure 3). Each of the Gaussian distributions is calculated by the equation shown below:

$$g(x,\mu) = \frac{1}{\sigma(2\pi)^{1/2}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]. \quad (1)$$

Here g is the Gaussion distribution, μ (mean) is assigned as a constant which corresponds to fixed pitch values (Hc) defined in theory for each pitch of a *makam* scale, and σ (standard deviation) is a constant value used here as 2.

The *makam* scales are then represented in terms of these Gaussian distributions as shown below:

$$s_m = \sum_{k=1}^{n} g(x, \mu_k). \quad (2)$$

Here s_m is a template of *makam* m , m is the *makam* index, $1 < m < 9$, n is the number of intervals, and μ_k (mean) is the mean of each Gaussian distribution, which is defined as fixed pitch values of each *makam* scale in theory.

As a result, each *makam* scale defined in Arel theory is represented as a template, and both the scales defined in theory and the recordings are transformed into computationally comparable formats.

4.3 Automatic classifier

Our classifier is designed as a supervised and a non-parametric classifier where each data object is labelled to its own class and no probability density is used. This means that the *makam* of each recording is known. Then the classifier is evaluated according to its ability to classify positive (P) and negative (N) samples by their true (T) and false (F) classification rates. Conventionally the design of an automatic classifier consists of four phases: data pre-processing, feature extraction, training and evaluation of the classifier. The first two phases are described above. However, since the templates used in the classifier are derived from the pitch interval values defined in theory, construction of the templates did not require a training phase in the implementation of the classifier. Thus, we did not split the data as test and training sets. As a result, our classifier is specifically designed to evaluate the success of Arel theory for MIR studies on TTAM.

In summary, the pitch-frequency histogram of each recording (see Figure 2) is compared with the template of each theoretical *makam* scale (see Figure 3) according to a similarity measure. This method is called template matching in pattern recognition (Theodoradis & Koutroumbas, 1999, p. 283). Finally, all recordings are classified based on Arel theory. Below we present the similarity metrics for modality finding:

$$d(x, v) = \sum |x - v|. \quad (3)$$

Here d is the distance, x is the data (pitch interval histogram of samples), and v is the template (theoretical pitch interval histogram of each *makam*).

The evaluation results of the classifier is shown in Table 2 for the quality measures (Fawcett, 2006, p. 862;

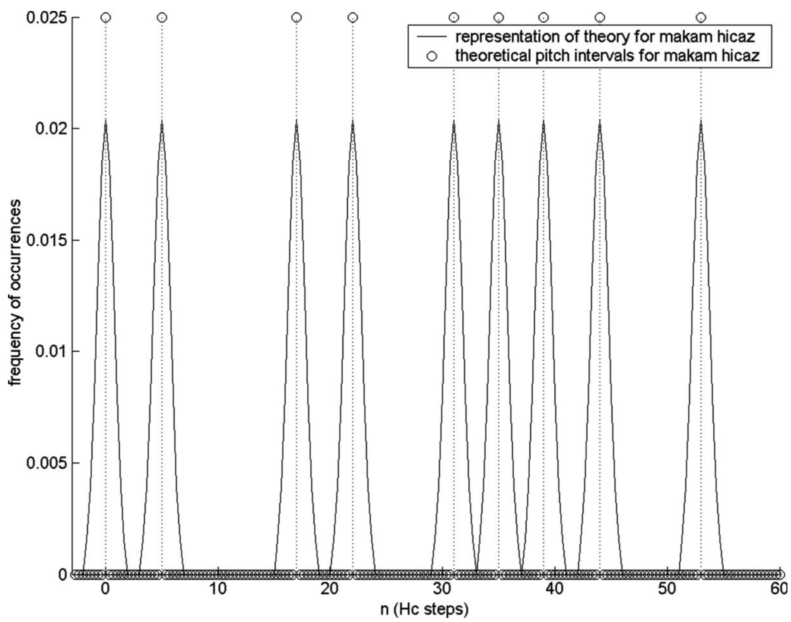

Fig. 3. Representation of *hicaz makam* scale defined in Arel theory as Gaussian distributions.

Arbel & Rokasch, 2006, p. 1620) based on the parameters given below:

$$recall = \frac{n_{\mathrm{TP}}}{n_{\mathrm{TP}} + n_{\mathrm{FN}}},$$
$$precision = \frac{n_{\mathrm{TP}}}{n_{\mathrm{TP}} + n_{\mathrm{FP}}}, \quad (4)$$
$$F\text{–}measure = \frac{2 \cdot recall \cdot precision}{(recall + precision)}.$$

Here n_{TP} is the number of true positives, n_{TN} is the number of true negatives, n_{FP} is the number of false positives, and n_{FN} is the number of false negatives.

Table 2. Evaluation results of the classifier in terms of recall (R), precision (P), and F-measure.

	n_{TP}	n_{TN}	n_{FP}	n_{FN}	R	P	F-measure
hicaz	20	146	0	6	77	100	87
rast	17	151	2	2	89	89	89
segah	13	140	7	12	52	65	58
kürdili hicazkar	7	143	9	13	35	44	39
huzzam	5	154	9	4	56	36	43
nihavend	16	147	2	7	70	89	78
hüseyni	6	147	14	5	55	30	39
uşşak	13	139	11	9	59	54	57
saba	17	151	4	0	100	81	89
mean	**13**	**146**	**6**	**6**	**66**	**65**	**64**

5. Arel theory: A computational perspective

According to the success rate of automatic classification presented in Table 2, *makamlar* can be grouped in terms of the F-measure: while the classification results for the *makamlar segah*, *hüzzam*, *kürdili hicazkar*, *hüseyni* and *uşşak* demonstrated low success rates, the remaining *makamlar hicaz*, *rast*, *nihavend* and *saba* demonstrated high success rates. However, it is not straightforward to infer that Arel theory is unsuccessful for the first *makam* group from these classification results.

The confusion matrix of the automatic classification presented in Table 3 reveals the reason for the low classification success rates of the first *makam* group. It can be seen from the table that the most confused makamlar occur within two groups: *makamlar kürdili hicazkar*, *hüseyni* and *uşşak* are highly confused in the first confusion group (light gray) and *makamlar segah* and *hüzzam* are highly confused in the second confusion group (dark gray).

This suggests that the practice of the *makamlar* from each confusion group have similar pitch-frequency histograms. Figure 4 gives visual evidence of such similarities within each confusion group by presenting a mean pitch-frequency histogram of each *makam* practice in each confusion group. Mean pitch-frequency histograms of the *makamlar* from the first confusion group (*kürdili hicazkar*, *hüseyni* and *uşşak*) and the second confusion group (*segah* and *hüzzam*) are presented in Figures 4 (a) and (b), respectively. As can be observed from the figures, the *makamlar* in each confusion group exhibit strong similarities. The practice of *makamlar kürdili hicazkar*, *hüseyni* and *uşşak* in the first confusion group are quite similar to each other as shown in

Table 3. The confusion matrix. Two confusion groups are marked with gray levels: *segah* and *hüzzam* (dark gray), and *kürdili hicazkar*, *hüseyni* and *uşşak* (light gray).

	hicaz	rast	segah	kürdili h.	huzzam	nihavend	hüseyni	uşşak	saba
hicaz	–	–	–	–	–	–	–	–	–
rast	–	–	–	–	–	1	1	–	–
segah	–	–	–	3	**4**	–	–	–	–
kürdili h.	3	–	1	–	–	–	2	**3**	–
huzzam	–	–	**9**	–	–	–	–	–	–
nihavend	–	1	1	–	–	–	–	–	–
hüseyni	3	–	–	**4**	–	3	–	**4**	–
uşşak	–	–	1	**6**	–	3	1	–	–
saba	–	1	–	–	–	–	1	2	–

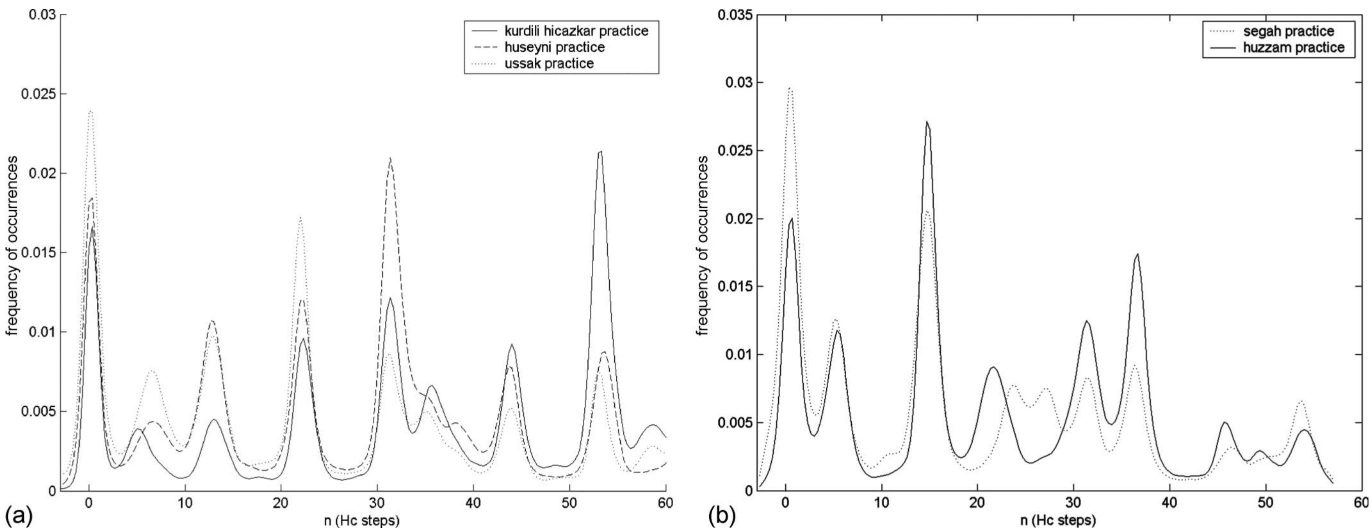

Fig. 4. Comparison of the most confused *makam* groups in practice: (a) *kürdili hicazkar- hüseyni-uşşak* and (b) *hüzzam-segah*. Practice of each *makam* is represented as a mean pitch histogram.

Figure 4 (a). The practice of *makamlar segah* and *hüzzam* in the second confusion group are quite similar to each other, which is shown in Figure 4 (b).

Since the confused *makamlar* showed strong similarities in practice, it is not possible to conclude directly that Arel theory is unsuccessful for the *makamlar* with low classification success rates. Nevertheless, it can be said that the failure of the theory in reflecting the pitch intervals of practice, contributed to the low success rate. Table 4 presents the comparison of pitch interval values obtained from the practice and as defined in the theory for each *makam* in the confusion groups. The pitch interval values of the practice are obtained by a peak detection algorithm applied to the mean pitch-frequency histogram of each *makam*. A more detailed and comprehensive comparison of the theory and the practice based on pitch interval values is presented by Bozkurt et al. (2009).

Table 4 demonstrates that Arel theory converges considerably in practice in terms of the pitch interval values. The pitch interval values of practice and theory which diverge by at least 1 Hc are marked as bold italic in the table. Especially the 1st pitch interval values in *makam hüseyni* and *uşşak*, which diverge from the theory, are the intervals subject to the discussions in TTAM. Another noticeable divergence can be observed from the 3rd pitch interval of *makam segah* as shown in Table 4. In practice, the 3rd pitch interval consists of two pitch interval values: the first one 23.3 Hc diverges from the theory and the second one 27 Hc is lacking in the theory. As a result, since the pitch interval values of the confused *makamlar* are also similar, Arel theory can be considered successful except for the few pitch interval values which diverge from the practice.

A similar investigation can also be made for the *makamlar* with high classification success rates, *hicaz*, *rast*, *nihavend* and *saba*. Although Arel theory seems to be successful for the automatic classification of practice for these *makamlar*, it is also possible that the theory could diverge from the practice in terms of pitch interval values which contribute to the decrease in success rates. Table 5 presents the comparison of pitch interval values obtained from practice (gray) and defined in theory for the *makamlar* with high classification success rates. As can be seen from Table 5, Arel theory considerably converges to practice in terms of pitch interval values except for the pitch interval values marked as bold italic.

Finally, despite the divergence of a few pitch interval values, Arel theory seems to provide a valid framework for MIR studies on TTAM. However, in order to obtain more robust evaluation of the Arel theory, it is necessary to measure the effect of pitch interval values which diverge from practice in automatic classification.

5.1 Automatic classification of TTAM based on pitch intervals obtained from practice

In order to measure the effect of divergence of pitch intervals in automatic classification, firstly the pitch interval values obtained from practice are replaced with the theoretical pitch intervals. Therefore, Gaussian representations of *makam* templates are reconstructed by using the pitch interval values obtained from practice. Then the automatic classification of recordings is applied by using the new templates. Finally, the results of automatic classification by using the pitch interval values obtained from the practice can be compared with the automatic classification by using the pitch intervals defined in theory. This comparison would give a more robust evaluation of Arel theory within the same classification context.

The pitch interval values are obtained by applying a peak detection algorithm to the mean pitch-frequency histogram of each *makam*. Then, the templates for each *makam* are computed by using these pitch interval values as new means of the Gaussian distributions as presented in Equations 1 and 2. Finally, automatic classification is applied by new templates using the same distance measure as presented in Equation 3. Table 6 presents the success rates of the automatic classification for each *makam* computed based on the same parameters as presented in Equation 4.

Consequently, the classification results obtained by using the pitch interval values based on theory and practice can be compared by looking at Tables 5 and 6, respectively. The two automatic classifications can be described as classification based on theory and classification based on practice. First of all, it can be said that the effect of pitch intervals which diverge from practice in automatic classification results in a 6% decrease in terms of the mean F-measure: while the success rate of classification based on the theory is found to be 64%, and the success rate of classification based on practice is found to be 70% as can be seen from Tables 4 and 5, respectively.

Although the amount of decrease in success rate seems to be not very significant, there is a considerable amount

Table 4. Comparison of pitch interval values obtained from practice (gray) and defined in theory for each *makam* in confusion groups.

	1	2	3	4	5	6	7	8
1st confusion group								
kurdili hicazkar	4.7	12.7	22	31	35.3	43.7	–	53
	4	13	22	31	35	44	–	53
hüseyni	***6.3***	12.3	22	31	***38***	43.3	–	53.3
	8	13	22	31	***39***	44	–	53
uşşak	***6.7***	13	22	31.3	35	44	–	53
	8	13	22	31	35	44	–	53
2nd confusion group								
segah	5	14.3	***23.3 & 27***	31	36	***46***	49	53.3
	5	14	***22***	31	36	***45***	49	53
huzzam	4.7	14	***21***	30.7	36	48.7	–	53.3
	5	14	**19**	31	36	49	–	53

Table 5. Comparison of pitch interval values obtained from practice (gray) and defined in theory for the *makamlar* with high classification success rates.

	1	2	3	4	5	6	7	8
hicaz	4.3	17	21.7	31	35	***37.7***	43.3	53
	5	17	22	31	35	***39***	44	53
rast	9	16.7	21.7	31	40.3	47.7	–	53
	9	17	22	31	40	48	–	53
nihavend	9.7	13.3	22.3	31.3	35.7	44.3	–	53
	9	13	22	31	35	44	–	53
saba	7.3	13	18.7	31.7	34.7	44.3	48	***53***
	8	13	18	31	35	44	49	–

Table 6. Evaluation results of the classifier based on pitch interval values obtained from practice in terms of recall (R), precision (P), and F-measure.

	n_{TP}	n_{TN}	n_{FP}	n_{FN}	R	P	F-measure
hicaz	18	149	2	3	86	90	88
rast	18	149	1	4	82	95	88
segah	19	146	1	7	76	95	84
kürdili hicazkar	7	151	9	5	58	44	50
huzzam	11	158	3	0	100	79	88
nihavend	10	150	8	4	71	56	63
hüseyni	5	145	15	7	42	25	31
uşşak	16	129	8	19	46	67	54
saba	17	148	4	3	85	81	83
mean	**13**	**147**	**6**	**6**	**72**	**70**	**70**

of increase in the success rates of *makamlar segah* and *hüzzam* as 26% and 45% in terms of the F-measure for the classification based on practice (Table 5) in comparison to the classification based on theory (Table 4). Therefore, it can be said that the most important effect of automatic classification about the divergence between the theory and the practice occurs due to the pitch interval 27 Hc in *makam segah* which is not present in Arel theory. A simple operation of adding this pitch interval value to the theoretical definition of *makam segah* results in a 67.5% success rate in terms of mean F-measure in automatic classification based on theory. From this it is clear that the amount of decrease, 3.5% in success rate of the classification based on the theory in comparison to the classification based on the practice, occurs due to the lack of the 27 Hc pitch interval in the theory. A similar effect of divergence in automatic classification about the pitch interval 53 Hc for *makam saba*, which is not part of the theory, is computed in a similar way and found to be 1%. Therefore, the lack of two pitch intervals in theory results in a 4.5% decrease in automatic classification and the remaining amount of decrease, 1.5% in the success rate of classification based on the theory, occurs due to the other pitch intervals defined in the theory which diverge from the pitch intervals performed in practice.

On the other hand, there is a considerable amount of decrease, 15% in the success rate of *makam nihavend* in automatic classification, based on practice in comparison to classification based on theory. Since the pitch interval values obtained from the practice provide the most reliable values, it can be argued that the high success rate of classification based on theory for *makam nihavend* does not reflect a valid success rate.

5.2 Arel Theory and the pitch-classes for TTAM

If our aim was to develop a modality finding framework for TTAM, or automatic classification of recordings from TTAM, it would be more reliable to apply a data-driven model as presented by Gedik and Bozkurt (2009). In this study, the modality templates are constructed based on mean pitch-frequency histograms instead of Gaussian representations. The success rate of automatic classification in the context of our study for such a data-driven model is found as 77.5% in terms of the F-measure.

However, our aim was to evaluate Arel theory to understand whether it can supply a basis for MIR studies on TTAM. So the main point is to evaluate whether Arel theory is valid for its definition of pitch-classes for each *makam*. Without the existence of reliable pitch-class definitions in TTAM, it would not be possible to apply MIR methods for TTAM especially for the applications based on temporal information such as automatic transcription of TTAM. The results presented so far show that Arel theory considerably converges to practice except for the few pitch-intervals (pitch-classes) marked as bold italics in Tables 4 and 5. Especially the lack of two pitch intervals 27 Hc for *makam segah* and 53 Hc for *makam saba* in theory results in a significant decrease in automatic classification.

Nevertheless, we think that the pitch intervals which are not part of the theory and diverge considerably from the practice can be modified within the context of Arel theory for its application for MIR studies on TTAM. As an example, the Arel theory is improved by modifying the pitch-classes according to the pitch interval values

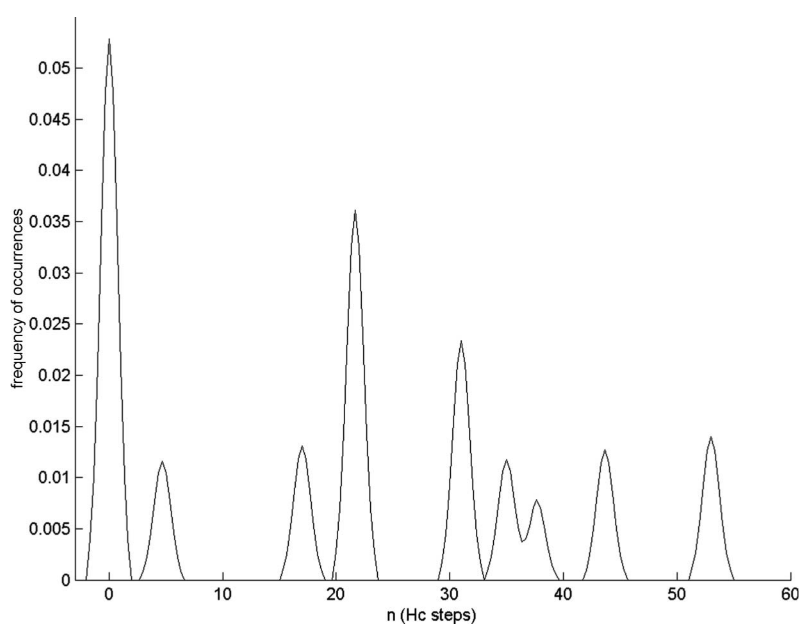

Fig. 5. Representation of *hicaz makam* template obtained by the improved Arel theory as Gaussian distributions.

obtained from the practice. In addition, the weight of each pitch from the mean pitch-frequency histogram of each *makam* is applied to the Gaussian distributions. Therefore, templates are reconstructed as the sum of Gaussian distributions as defined in Equations 1 and 2, only multiplying the amplitude of the distributions by the weights obtained from the practice (Figure 5). Consequently, the success rate of the automatic classification based on the improved Arel theory is found as 75% in terms of the F-measure, which is almost as high as the success rate obtained by the data-driven model.

6. Discussion and conclusion

Since Arel theory is both the most influential theory and subject of discussions about its divergence from practice, we have attempted to evaluate it in order to understand whether it can provide a basis for MIR studies on TTAM in a similar way western music theory provides for western music. Although the context of our study is MIR applications, we have also presented the evaluation of Arel theory from the perspective of ethnomusicology which provides important insights into our computational approach. More specifically, the main problem was to understand whether a theory of TTAM can provide valid pitch-class definitions for MIR studies on TTAM, as 12-pitch-classes defined in western music theory do.

Since our investigation is intended for MIR applications on TTAM, we have evaluated the theory within the context of MIR studies. Therefore, current MIR studies on tonality finding are selected as a framework for our evaluation. Due to the significant differences between TTAM and western music, we have adapted the current methods for TTAM. In short, modality (*makam*) templates are constructed based on Arel theory and a given piece is compared with these modality templates.

It has been shown that despite the few pitch intervals defined in theory but which are not part of practice, Arel theory is successful when applied in an MIR context for TTAM for modality finding. The effect of pitch intervals defined in theory which diverges from practice results only in a 6% decrease in terms of the F-measure. However, it has been shown that these few problematic pitch intervals can be improved within Arel theory based on the pitch interval values obtained from practice. Regarding the modality finding problem, it has also been shown that when weights of the templates obtained from practice are used, the success of Arel theory is found to be 75%, which is very close to the success of the data-driven model 77.5% in terms of the F-measure. On the other hand, it is clear that without improving the pitch interval values within the theory it will not be possible to apply MIR methods based on temporal information. As a result, we conclude that Arel theory with a few improvements provides valid pitch-class definitions for MIR studies on TTAM, similar to the 12-pitch-classes defined in western music theory.

Although Arel theory can be improved by slight changes in the pitch-class definitions for computational applications, such changes mean a great change within the logic of Arel theory from the perspective of ethnomusicology. The 24 pitch-classes are the distinctive feature of Arel theory which supports the Arel discourse in terms of 'westerness' and 'Turkishness' of TTAM. However, it has been shown that two pitch intervals seem to be lacking in theory, and there are six pitch-classes defined in theory considerably diverging from practice, more than or equal to 1 Hc (Tables 4 and 5), which points to serious problems for Arel theory from the ethnomusicological point of view.

On the other hand, possible problems about our study should be mentioned related with the data used. First of all, recordings consist of performances in the form of *taksim*. Arel does not give place to forms in his book, but it is known that the distinguishing feature of the form *taksim* is the modulations (i.e. short-term *makam* changes) used during a performance. Therefore, a *taksim* performance of a specific *makam* naturally shows the characteristics of other *makamlar* where it is modulated. However, the weight of these modulations changes from performance to performance which can be estimated intuitively as between 10%–30% with respect to the whole performance. Without the existence of an automatic segmentation algorithm, it is not possible to detect the modulations in the performance. Automatic segmentation is among our future goals. Therefore, this study lacks an analysis of the effect of modulations to the classifier's performance.

The other two main problems related to the data, which probably affected the classification results, is their representation value of the practice. First, most of them were recorded in sound studios, far from the natural contexts of musical performance. Although we do not have enough information about the general conditions of all recordings, at least Ünlü (2004, p. 199) reports the terrible psychological mood of Tanburi Cemil Bey during the recording sessions. Of course, the time limitations due to the recording technologies should have also affected the performances. Second, the time period of recordings spread roughly between the years 1900 and 2000. So it is hard to say that the practice is left unchanged during a century which prevents to make strict generalizations over them. It should be added that the modernization process which makes the 'traditional art music' one of the most popular genre between 1950 and 1960 (Aksoy, 2006, p. 17) has affected the practice too.

However, as mentioned before one of the most challenging issues for the pitch-class analysis of practice in TTAM is the freedom of musicians in the performance

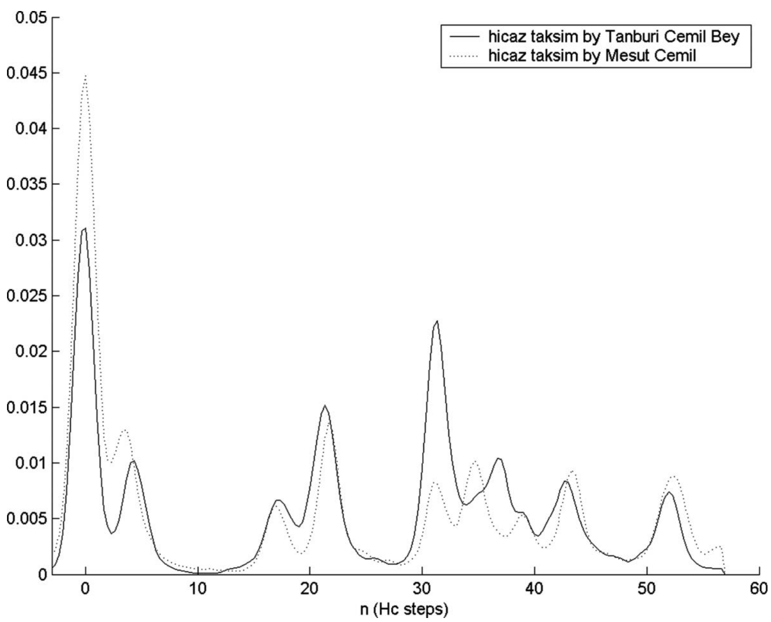

Fig. 6. *Hicaz taksim* performances by Tanburi Cemil Bey and Mesut Cemil. (Histograms are smoothed by low pass filters to enable a more explicit comparison between performances).

of pitches. The performances of the same *makam* by the two most prominent performers of TTAM, Tanburi Cemil Bey and his son Mesut Cemil, demonstrate this freedom as shown in Figure 6. Even the most characteristic pitch intervals of *makam hicaz*, 1st, 2nd and 3rd intervals, are performed at different values. Furthermore, while all other theories including the Arel theory give almost the same interval value at least for the 3rd interval as 22 Hc (Bozkurt et al., 2009), Tanburi Cemil Bey and Mesut Cemil perform this interval as 21.3 and 21.7, respectively. Consequently, such performance characteristic of pitch-classes can be considered as one of the most important divergences between theory and practice which seriously affects the success of automatic classifications presented in this study.

Finally, what makes the divergence between theory and practice more apparent in the 20th century seems to be that in the circle of traditional art music the perception of theory has been more important than before. Although the practice seems to develop its own course, it is clear that the practice defines itself with reference to theory as stated by Marcus (1993, p. 50): he quotes from Wright (2008) that 'the smaller intervals of theory were then sometimes 'enlarged' in practice', and adds, based on his study in Egypt, that 'today, when theory dictates a large interval, musicians speak of 'shrinking' these intervals'. In this sense, Table 4 seems to demonstrate both tendencies of the performers since the theory covers both types of intervals: while the third and the sixth interval defined for *segah* seem to be 'enlarged', the first interval defined for *uşşak* and *hüseyni* seem to be 'shrunk'.

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