A computational study on divergence between theory and practice of *tanbur* fretting

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Background in music theory: *Tanbur* (or *tambur*), long-necked, fretted, plucked lute performed in traditional Turkish art music (TTAM) can be said to have a place similar to piano in western classical music. Therefore, throughout the history of this musical culture, there has been a strong relationship between the *tanbur* fretting and the tuning system of TTAM. However there is a certain divergence of theory and practice in TTAM (Bozkurt et al. 2009; Gedik and Bozkurt 2009): While the theory dictates fixed pitch interval values and fixed number of pitches, both the number of pitches and pitch intervals have a certain flexibility in practice depending on the performers and tanbur makers. Very few studies in the literature (e.g. Yekta 1986; Açın 1994, 2002; Yavuzoğlu 2008) present *tanbur* fretting which are simply the direct applications of theoretical frequency ratios. In addition, a well-known problem, fret compensation, the change in the length and tension of the string when pressed by a finger, is simply neglected.

Background in computing: An automatic method for the tuning analysis of TTAM recordings was presented by Bozkurt (2008) and successfully applied in a number of studies (e.g. Bozkurt et al. 2009; Gedik and Bozkurt 2010). Tuning analysis consists of following algorithms: pitch frequency analysis, pitch histogram computation and automatic tonic detection. Although there is no computational study on the *tanbur* fretting, the study of Bozkurt (2012) presents a system for tuning the instruments of TTAM and presents tests on *kanun*, a plucked box zither.

Aims: Mainly we discuss and demonstrate empirically the fretting problems of *tanbur*. Secondarily, we develop an automatic analysis method that can estimate fret locations of a *tanbur* given a recording.

Main Contribution: In order to demonstrate the fretting problem we have compared fret measurements of the most influential figures, musicologist Rauf Yekta Bey, *tanbur* maker Cafer Açın and master performer Necdet Yaşar as presented in literature with those of a *tanbur* performed in our research for the first time in the literature. It has been shown in this paper that the fret measurements of the *tanbur* performed considerably diverges from the ones presented in the literature. Secondly, given a recording of *tanbur* our method automatically estimates the fret positions necessary for the performance of that recording for the first time in the literature. The string length and the 5 reference fret locations (1st major second, 1st and 2nd octave, 1st and 2nd perfect fifth) of the *tanbur* to be performed (which can be easily measured and tuned manually by the *tanbur* player) are also used as the input to the system. The mean error of the method is found as 0.2 cm, which is half of the thickness of frets, based on tests on 14 recordings.

Implications: We think that the discussion and the empirical results about *tanbur* fretting and the automatic estimation of fret locations of master *tanbur* players for the performance of specific pieces can clearly supply useful information for the production, performance and education of the instrument.

Keywords: *tanbur* fretting, fret compensation, traditional Turkish art music, *makam*, maqam, computational music analysis.

1 Introduction

Tanbur (or *tambur*) (pl. *tanburlar*) is the common name of long-necked, fretted, plucked lutes of the Middle East and Central Asia (Hassan 2009). Manuscripts of theorists such as Al-Fārābī (d 950) and Safī al-dīn (d 1294) are considered as common sources for the theory of traditional art musics of the Middle East and include the description of various *tanburlar* of their time. It is accepted that the oldest *tanbur* description that resembles most to the *tanbur* performed in traditional Turkish art music (TTAM) today is given by Dimitrie Cantemir (1673–1723) who was also respected as a master of the instrument of his time (Popescu-Judetz 2000). The first analytical study, which forms a basis for the theory and practice, TTAM is also presented by Cantemir in his treatise, *Edvar-i musiki* ('Textbook of music') (Popescu-Judetz 2000).

The interest of theorists on *tanbur* continues in the 20th century. The founder of the "modern" theory of TTAM, Rauf Yekta Bey (1875-1935) whose article on TTAM was published in the *Encyclopédie le da Musique et Dictionaire du Conservatoire* in 1922 was also a *tanbur* player. In his article he discusses the tuning theory of TTAM based on *tanbur* and underlines the importance of the instrument, as follows:

> *Tanbur* is the most beloved instrument of Turks. While old Arabian and Iranian writers consider *ud* as the most perfect instrument, Turkish writers consider *tanbur* holding such an honor. For a comparison, it can be said that the *tanbur* plays the similar role which piano plays for Western composers. Similarly, most of the Turkish composers are *tanbur* players, also. (Yekta 1986, 87)

Rauf Yekta Bey together with the most prominent *tanbur* player Mesut Cemil represented Turkey in The Congress of Arab Music held in Cairo in 1932 (Racy 1991). Cemil also performed in the congress, which was recorded by the recording committee of the congress. The congress was a historical turning point toward standardizing the theory and practice of traditional art musics of the Arabian geography. Yekta and Cemil, as members of the musical scale committee, rejected the proposal of some Egyptian members on the use of equal-tempered quarter-tone scales, for its inappropriateness in measuring the Near Eastern pitch (Racy 1991, 74). As reported by Racy (1991, 91), "tanbur was favored by some committee members for its rich and enchanting sound, and because its fretted long neck was useful for devising a standard theoretical scale."

Although *ud* and *kanun* started to dominate the genre by displacing *tanbur* to a degree in the 1900s (Feldman 2009), *tanbur* preserves its central role in education and performance of the genre at least in certain circles such as few private educational institutions, state conservatories, vocal and instrumental ensembles of state TV and radios, and amateur choruses where the tradition is said to have survived. Therefore, while it is more likely to hear and see *ud* and *kanun* performances then *tanbur* performances in more popularized discourses of the genre in private TV, radios and concerts, *tanbur* is still indispensably performed in all forms of the genre, either vocal or instrumental in those rather restricted circles in Turkey, today.

However, the most prominent and respected performers of TTAM are *tanbur* players such as Tanburi Cemil Bey, Mesut Cemil, Necdet Yaşar, Ercüment Batanay, İzzettin Ökte, and Fahrettin Çimenli in any circle of the genre. Furthermore *tanbur* still preserves its central role in theoretical writings today. Recently Yavuzoğlu (2008) proposed a new tuning system for the genre and applied his system on a *tanbur*, which was also performed in a recent conference on TTAM after the presentation of the proposed theory.[i]

Consequently, *tanbur* still occupies a distinctive place in education, performance and theory of TTAM. However this is the point where the *tanbur* also stands at the center of various problems about the genre in the 20th century. These problems mainly result from a certain divergence of theory and practice in TTAM[ii] (Gedik and Bozkurt 2009).

As stated by Bohlman (2008), historically, practice and theory have a loose relation where the former is based on oral tradition and the latter is rather a combination of speculation and a musicological scientific method. While the theory was rather based on verbal descriptive information formerly, especially the theory of Arel-Ezgi-Uzdilek (AEU)[iii] in the 20th century intended to formulate the theory based on more analytical approaches using a terminology similar to western music theory, such as scale degrees, tetrachords, pentachords, etc. (Öztürk 2006, 214-216). The political and ideological dimensions of AEU theory about the standardization and westernization of TTAM was discussed in detail by Gedik and Bozkurt (2009).

Therefore a new discourse started to dominate the genre especially after the institutionalization of the TTAM by the state conservatories and ensembles: "the theory should generate practice" (Thomas 2007, 4). The theory of AEU became the official theory of TTAM by the foundation of the state conservatory of TTAM in 1976. The outcome of the institutionalization of TTAM both in education and performance is the appreciation of theory more seriously by the performers than ever before.[iv] The problem of divergence becomes more apparent than before and leads to a generation of new discourses among musicians, resulting in the description of practice with respect to theory. On the one hand, performance of certain pitches which contradict with the theory are defined with respect to theory by using a terminology such as "a little higher", "a little lower" or "minus a comma" (Marcus 1993, 50)[v]. On the other hand, the theorists observing the divergence of the AEU theory and practice, proposed new theories which target converging the theory to practice. These theories, which proposed various numbers of pitches for an octave such as 24, 29, 41, 53, 79 etc., were considered and computationally evaluated by Bozkurt et al. (2009). However, except the AEU theory, these theories have no practical reflections in TTAM.

As a result, reflection of the problem of divergence of theory and practice in TTAM on *tanbur* can be summarized as follows: While the theory dictates standardization in practice, there is almost no standardization in any appearance of *tanbur* in practice. This fact more specifically demonstrates itself in production, performance and education as follows:

i. Production: The dimensions of the sound box and the neck, and the number of frets and their locations vary due to instrument makers. Zeren (2003, 128) points to the problem of standardization of *tanbur* by implying that there can not be found two *tanburlar* which are the same in shape, number of frets and their locations. As stated by Yavuzoğlu (2008, 12) each instrument maker can apply various tuning systems resulting in various numbers and locations of frets and thus there is no standard in production whose frets match with the theory.

ii. Performance: A performer can also reorganize the number of frets and their locations according to personal choices. Tanbûrî Cemîl Bey (1992, 22) states that frets of the *tanbur* are movable, not fixed on the keyboard like a guitar and the keyboard of the tanbur enables the addition of new frets. Similarly Signell (2006, 144-145) describes the frets of *tanbur* of master musician Necdet Yaşar as having frets more than necessary for each pitch interval.

iii. Education: Textbooks consist of theoretical information and, exercises and compositions written on western staff notation adapted according to the theory of TTAM. These are used in amateur choruses as well as in conservatories. However due to the divergence of theory and practice, certain pitches represented on the notations do not match exactly with the performed pitches. Two of the well-known *tanbur* methods written for education by Sadun Aksüt (1971) and Emin Akan (1989) demonstrate both qualities; use of western staff notation and pitch intervals defined in theory.

It should be noted that the standardization attempts of the AEU School include an important dimension of 'invention', also. As a case study, the invention of *makam çargah* by Arel and Ezgi is well reported by Wright (1990). Therefore, it is not surprising to observe pluralism both in theory and practice, including the fretting of *tanbur*.

However, there is almost no study considering *tanbur* fretting as a problem except suggestion of new theories for the solution of divergence problem, which do not have practical correspondence. Firstly, there is no source about the calculation of fret locations on *tanbur* except tables for fixed string lengths according to this or that musician or theorist (e.g. Yekta 1986; Açın 1994, 2002; Yavuzoğlu 2008). The rest of the relevant literature is mainly based on instruments of western music. These studies are distributed among 4 sources: General physics of musical instruments (e.g. Hopkin 1996; Martin 1998; Fletcher and Rossing 1998), guitar making (e.g. Middleton 1997; Cumpiano and Natelson 1993), and guitar luthiers web sites (e.g. Gilbert and Gilbert 2012; Stenzel 2012) and patents on guitar fretting (e.g. Merkel 2004; Salazar 2006; Muncy 2008). There are also computational studies aiming to retrieve fret positions of guitar either from audio (Traube and Smith III 2001) or video (Burns and Wanderley 2006) recordings.

The most comprehensive study on a fretted string instrument other than guitar focuses on the lute (Lundberg 2002), an instrument that is no more similar to *tanbur* than the guitar considering the fretting problem. Other studies on non-western fretted string

instruments such as sitar, vina (Subramanian 1985), Iraqian long necked lute (Hassan 1982) etc. do not consider the fret location problems such as fret compensation. More specific studies on the acoustics of non-western string instruments such as the edited volume by Rossing (2010) again does not discuss the fret compensation problem.

Mostly the fret location of *tanbur* is given as a table with measured distances between frets and nut or bridge in the literature on TTAM (Yekta 1986; Açın 1994, 2002; Yavuzoğlu 2008). However this information is unreliable since neither the height of the strings measured from the nut and bridge is given nor the problems of fret location in fretted string instruments is taken into account. Therefore the well-known fret compensation problem (Fletcher and Rossing 1998, 263) is simply ignored in the literature on *tanbur*. The most comprehensive study on *tanbur* lists fret locations directly computed by applying the theoretical intervals on the string length (Açın 1994, 2002). Other studies (Öksüz 1998; Coşkun 2005) on *tanbur* simply folllow the fret locations given by Açın (1994). The only computational study on *tanbur* is also far from dealing with fret location of *tanbur* but presents the acoustic analysis of the instrument (Erkut and Valimali 2000). The study of Signell (2006) covers an empirical research based on measurement of pitch intervals from *tanbur* recordings, rather than fretting problems of the instrument. Although the study of Bozkurt (2012) is not a study on *tanbur*, he presents a system for tuning the instruments of TTAM and presents tests on *kanun*, a plucked box zither. Given a recording of TTAM, the system supplies auditory and visual feedback in order to enable the performer to tune her/his instrument according to the tuning of the recording.

Besides the inconvenient fret locations presented in the literature, there are various other problems in practice due to the materials used in *tanbur* making which effects *tanbur* fretting. These problems can be shortly listed as follows:

  i. The shape of the fretboard and soundboard can change due to the climate, which changes the string length, in turn.

  ii. *Tanbur* makers can use different frets in terms of thickness and can tie frets either below or above or at the exact fret locations.

  iii. *Tanbur* makers can use different strings in terms of the materials used. Therefore the amount of string tension can change which is directly related with the fret locations of *tanbur*.

As the fretting problems of *tanbur* summarized above show, a complete solution toward the problem also requires exhaustive research on the materials used for making *tanbur*. Considering the problems and the state of art of the literature on *tanbur*, it is not possible to apply complex mathematical and physical models derived from experimental research made in laboratory such as the study of Varieschi and Gower (2010) targeting western fretted instruments such as the guitar and mandolin. Therefore here we also propose a method, which does not aim to solve the fretting problems of *tanbur* completely, but has important practical implications for performance, production and education of the instrument.

As a result our study both demonstrates the *tanbur* fretting problem empirically and suggests a method towards the solution for the first time in the literature. Therefore, our study can be summarized under two titles, which presents the contributions also:

i. An empirical demonstration of the fretting problem of *tanbur*: We have empirically demonstrated that the theoretical fret locations do not match with the fret locations of *tanbur* in practice due to the well-known fret compensation problem. We have also compared empirically fret locations of the most influential figures on *tanbur* fretting; musicologist Rauf Yekta Bey whose theory is still used for *tanbur* fretting, and *tanbur* maker Cafer Açın, the author of a book on tanbur making and master *tanbur* performer Necdet Yaşar presented in literature with the fret locations of a *tanbur* performed in our research. It has been shown that the fret locations of the *tanbur* performed and used in our study, considerably diverges from the ones presented in the literature.

ii. A computational solution to the fretting problem of *tanbur*: We present a method for the automatic estimation of fret locations of *tanbur* from audio recordings. Given a recording of *tanbur* our method automatically estimates the fret positions necessary for the performance of that recording. The string length and 5 reference fret locations (1st major second, 1st and 2nd octave, 1st and 2nd perfect fifth) of the *tanbur* to be performed (which can be easily measured and tuned manually by the *tanbur* player) are also used as the input to the system.

Consequently our method, automatic estimation of fret locations from audio recordings, is a potential solution towards the problems of *tanbur*. The calculation of frets locations of master *tanbur* players for the performance of specific pieces can clearly supply useful information for the production, performance and education of the instrument.

However it should be noted that our study does not intend to constitute any standardizations in any of these practices of *tanbur*.

2 *Tanbur* fretting in theory and practice

2.1 Morphology of *tanbur*

There are various *tanburlar* with different dimensions specified by the string length (distance between the bridge and the nut) such as 100, 102, 104, 106, 108, 110, and 112 cm *tanburlar* (Açın 2002, 27). All other dimensions of the *tanbur* are determined by certain ratios reference to the string length in production. For example the ratio of the string length to the length of the fretboard is 4/3. The most common *tanbur* dimension used today is the *tanbur* with 104 cm string length and 78 cm length fretboard (Öksüz 1998, 119). The frets along the fretboard cover a range of two octaves.

The frontal view of *tanbur* performed in TTAM today are presented in Fig. 1. The quasi-hemispheric soundbox is made of thin slices with 3 mm thickness, 3-4 cm width and 55-60 cm length. Slices are made of hard woods such as ebony, rosewood, pearwood, walnut and cherry. The soundboard usually consists of 2 thin pieces cut

from spruce with 1.80-2 mm thickness. Rosewood or juniper is used for the bridge and originally tortoise shell is used for the plectrum, which is replaced by synthetic materials today. Finally the fretboard is made of ebony or juniper and the frets are made of nylon. The frets wounded on the fretboard are 0.4 - 0.6 mm wide.
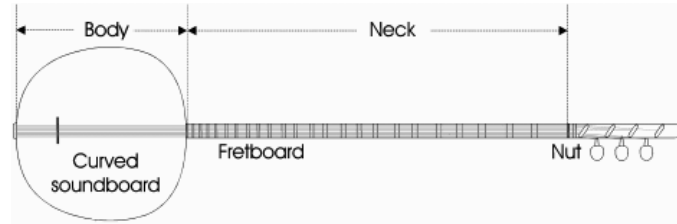

Figure 1. The frontal view a *tanbur* performed in Turkey, today (Erkut and Valimali 2000).

Either 7 or 8 strings are used on the instrument as pairs and tuned as shown in Fig. 2. However the tuning of the first pair can be changed when transposition is necessary. Traditionally only the string couple tuned as *yegah* is used to play the melody of a composition or improvisation and the other string pairs function as resonators or to supply the tonic during improvisations. If 7 strings are used at the *tanbur*, then the 4th pair is reduced to one string. Two kinds of strings are used on *tanbur* today: plain steel strings and yellowish strings made of brass, copper and bronze or mixture of them. The diameter and the kind of the strings in millimeter are as follows: plain steel 1st pair strings (D) - 0.3 mm, yellowish 2nd pair strings - 0.4 mm, plain steel 3rd pair strings – 0.3, mm yellowish 4th pair strings – 0.5 mm. The tension of the strings applied on the *tanbur* is around 75-80 kg. but this tension is subject to changes due to the transposition applied.
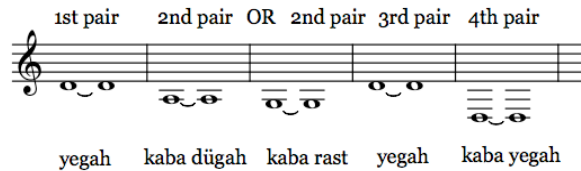

Figure 2. The tuning of the *tanbur* as couple of strings (Öksüz 1998, 92).

Finally Fig. 3 represents how the instrument is held and played in the photograph of famous *tanbur* player Necdet Yaşar.

Fig. 3 The photograph of famous *tanbur* player Necdet Yaşar playing the instrument.

2.2 Fretting problems of *tanbur*

As stated in the introduction, the main difficulty about *tanbur* fretting occurs due to the divergence of theory and practice in TTAM. Therefore the problem is not specific to an instrument. However, *tanbur* stands at the center of the discussions about this divergence problem due to its central role in both theory and practice. Firstly the number of pitches in TTAM is still subject to discussions, which leads to the question about the number of frets to be used in a *tanbur*. Yekta presents 49 frets (for two octaves) for a *tanbur*, which are explicitly related with the tuning system he proposed as 24 pitch intervals within an octave. Similarly, the *tanbur* with 98 frets presented by Yavuzoğlu (2008) is the application of his tuning system with 48 pitch intervals within an octave. However none of the theoretical proposals for *tanbur* are applied in practice. The theory of AEU, which is considered as the official theory of TTAM, is simply the predecessor of the theory presented by Rauf Yekta Bey whom suggested 49 frets for *tanbur*. However, the number of frets used by one of the most notable *tanbur* players, Necdet Yaşar is 65. Although the increase in the number of frets is explained by the need of transposition, there is no standard to meet this need. Therefore, it is also possible to find *tanburlar* with 56 frets. The student of master *tanbur* player Ercüment Batanay, the *tanbur* player Ahmet Nuri Benli states the well-known fact about the increase of frets by time:

> And now they [tanbur-s] come with too many frets, also—Ercüment would just cut them off until there were 24 rather than 31 or 55 or whatever. Tanburi Cemil Bey had 27 frets, and others then followed him, but he was a master; how are you going to make 55 frets sound better than he did 27? (Quoted from Ederer 2011, 136)

Besides the problem of the number of frets, fret location is another crucial point where the practice diverges from theory. In production, the commonly applied methodology is to use templates drawn on sheets, which mark the fret locations on *tanbur* (every producer has her/his own template). These templates are either derived

from theoretical information or specific to this or that instrument maker. Fig. 4 presents the templates used by *tanbur* makers Coşkun and Karatekeli.
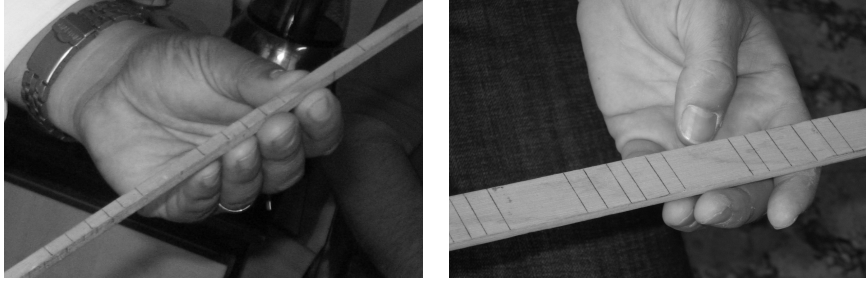
Fig. 4 Templates used by *tanbur* makers Coşkun (on the left) and Karatekeli (on the right).

However there is no reliable scientific source about the procedure of producing these templates. Interviews made with several *tanbur* makers reveal this fact clearly. *Tanbur* maker Çekiç (interview, 2008) from İstanbul states that he tries to standardize *tanbur* fretting by observing the frets of master *tanbur* performers such as Necdet Yaşar, Abdi Coşkun, Birol Yayla, Özer Özel. Similarly *tanbur* maker Karatekeli (personal interview, 2012) from İzmir states that he uses templates constructed by a continuous collaboration with locally well-known *tanbur* performers such as Cem Çırak and Bora Uymaz. On the other hand *tanbur* maker Coşkun (personal interview, 2012) working in the department of instrument making in the state conservatory of Turkish music states that he uses a template constructed 20 years ago.

Table 1 presents the pitch interval values as frequency ratios and the fret locations of a *tanbur* with 1064 mm string length given by Yekta (1986). Only the first 25 frets are given in the table to save space. The next 24 frets are simply the octave shift of the first 25 frets, which can be simply found by applying the frequency ratios. Consequently the frequency ratios reflects the tuning theory proposed by Yekta which supplies the pitch interval values used as official theoretical information as a result of AEU theory.

The interesting point in the table is that fret locations are simply reflections of frequency ratios applied to a *tanbur* with 106.4 cm length. In fact it is not practically possible to have an octave relation (2/1) between the frets *yegah* and *neva* given as 1064 mm and 532 mm with reference to the bridge, due to the change in the length and tension of the string when pressed by a finger. This mismatch is also valid for other fret locations.

Table 1. The pitch interval values and the fret locations of a *tanbur* with 1064 mm string length given by Yekta (1986).

No	Frequency Ratios	Fret Distance to Bridge (mm)	Pitch Names Turkish	Western	No	Frequency Ratios	Fret Distance to Bridge (mm)	Pitch Names Turkish	Western
1	1/1	1064	YEGÂH	D	25	2/1	532	NEVA	D
2	256/243	1009.97	Nim Pest Hisar		26	512/243	504.99	Nim Hisar	
3	2187/2048	996.38	Pest Hisar		27	2187/1024	498.19	Hisar	
4	65536/59049	958.69	Dik Pest Hisar		28	131072/59049	479.35	Dik Hisar	
5	9/8	945.78	HÜSEYNİAŞİRAN	E	29	9/4	472.89	HÜSEYNİ	E
6	32/27	897.75	Acemaşiran		30	64/27	448.88	Acem	
7	19683/16384	885.67	Dik Acemaşiran		31	19683/8192	442.84	Dik Acem	
8	8192/6561	852.17	ARAK		32	16384/6561	426.09	Eviç	
9	81/64	840.70	Geveşt		33	81/32	420.35	Mahur	
10	2097152/1594323	808.89	Dik Geveşt		34	8/3	404.45	Dik Mahur	
11	4/3	798	RAST	G	35	177147/65536	399	GERDANİYE	G
12	1024/729	757.48	Nim Zengûle		36	2048/729	378.74	Nim Şehnaz	
13	729/512	747.29	Zengûle		37	729/256	373.65	Şehnaz	
14	262144/177147	719.02	Dik Zengûle		38	524288/177147	359.51	Dik Şehnaz	
15	3/2	709.34	DÜGÂH	A	39	3/1	354.67	MUHAYYER	A
16	128/81	673.32	Kürdî		40	256/81	336.66	Sünbüle	
17	6561/4096	664.26	Dik Kürdî		41	6561/2048	332.13	Dik Sünbüle	
18	32768/19683	639.13	SEGÂH		42	65536/19683	319.57	TİZ SEGÂH	
19	27/16	630.52	Puselik		43	27/8	315.26	Tiz Puselik	
20	8388608/4782969	606.67	Dik Puselik		44	32/9	303.34	Dik Tiz Puselik	
21	16/9	598.5	ÇARGÂH	C	45	59049/16384	299.25	TİZ ÇARGÂH	C
22	4096/2187	568.11	Nim Hicaz		46	8192/2187	284.06	Nim Tiz Hicaz	
23	243/128	560.47	Hicaz		47	243/64	280.24	Tiz Hicaz	
24	1048576/531441	539.26	Dik Hicaz		48	2097152/531441	269.63	Dik Tiz Hicaz	
25	2/1	532	NEVA	D	49	4/1	266	TİZ NEVA	D

Table 2 presents three fretting systems given for a *tanbur* with 104 cm string length given by *tanbur* maker Cafer Açın (2002): fret locations of the *tanbur* of Necdet Yaşar (NY), a master of the instrument, the theory of AEU and the fretting system of master *tanbur* maker Cafer Açın (CA). Only the frets within the first octave are given to save space in the table. Therefore, Table 2 reflects available information in the literature on *tanbur* frettings for a respected performance, the official musicological and the production in charge. Since Yekta presented the fret locations in his article, which presents the TTAM to the international community for the first time, and he was not a *tanbur* maker, this mismatch seems to be reasonable. However we observe similar problems in comparatively very recent documents like the unique book on *tanbur* making written by a *tanbur* maker, Cafer Açın (2002).

The same mismatch of Yekta's values (the double octave fret being at exactly one quarter of the string length) also holds true for the other two fretting systems of Açın and Yaşar. The two systems exactly fit to the theoretical fretting of Yekta, except the additional frets as can be observed from the table. Furthermore it is also clear from the same table that the tuning system of AEU is exactly the same as the system of Yekta. Consequently, it can be said that the fret locations presented in the rather limited literature, referring to a master player and a master *tanbur* maker are simply the application of the AEU/Yekta tuning system to a *tanbur* with a given string length which is far from the actual practical fret locations. Therefore it is clear that the reliability of literature is questionable.

Table 2. Fret locations given for a *tanbur* with 104 cm string length for NY, AEU and CA. The number of frets for each fretting system is 65, 24 and 56 respectively. All grey shaded rows are the frets that do not exist in theory. Black shading: slight differences among the same frets. Dark grey: Additional frets of NY. Light grey: Additional frets of CA and NY.

No	Frequency Ratios (Yekta)	Fret Distance to Bridge (cm)			Pitch Names	
		NY	AEU	CA	Turkish	Western
1	1/1	104	104	104	YEGÂH	D
2	256/243	98.7	98.7	98.7	Nim Pest Hisar	
3	2187/2048	97.42	97.42	97.42	Pest Hisar	
		96.16				
		95.49		95.54		
4	65536/59049	93.67	93.67	93.67	Dik Pest Hisar	
5	9/8	92.46	92.45	92.46	HÜSEYNİAŞİRAN	E
6	32/27	87.74	87.74	87.74	Acemaşiran	
7	19683/16384	86.6	86.6	86.6	Dik Acemaşiran	
		85.48		85.48		
		84.93		84.93		
8	8192/6561	83.27	83.27	83.27	ARAK	
9	81/64	82.19	82.19	82.19	Geveşt	
10	2097152/1594323	79.02	79.02	79.03	Dik Geveşt	
11	4/3	78	78	78	RAST	G
12	1024/729	74.03	74.02	74.03	Nim Zengûle	
13	729/512	73.06	73.06	73.06	Zengûle	
		72.12				
		71.65				
14	262144/177147	70.25	70.25	70.25	Dik Zengûle	
15	3/2	69.34	69.34	69.34	DÜGÂH	A
16	128/81	65.81	65.8	65.81	Kürdî	
17	6561/4096	64.95	64.95	64.95	Dik Kürdî	
		64.11				
		63.69				
18	32768/19683	62.45	62.45	62.45	SEGÂH	
19	27/16	61.64	61.64	61.64	Puselik	
20	8388608/4782969	59.27	59.27	59.27	Dik Puselik	
21	16/9	58.5	58.5	58.5	ÇARGÂH	C
		57.74				
		56.99				
		56.62				
22	4096/2187	55.52	55.52	55.52	Nim Hicaz	
23	243/128	54.8	54.79	54.8	Hicaz	
24	1048576/531441	52.69	52.68	52.68	Dik Hicaz	
25	2/1	52	52	52	NEVA	D

In order to demonstrate the mismatch of the theoretical fret locations presented in the literature and fret locations used in practice, *tanbur* of a locally well-known player, the third author of the paper, is measured and compared empirically. Given the string length, it is also easy to find the fret locations of Yekta/AEU system by simply applying the frequency ratios of Yekta. Visual comparison of the fret locations of *tanbur* used in the experiment and the theoretical measures is presented in Fig. 5.
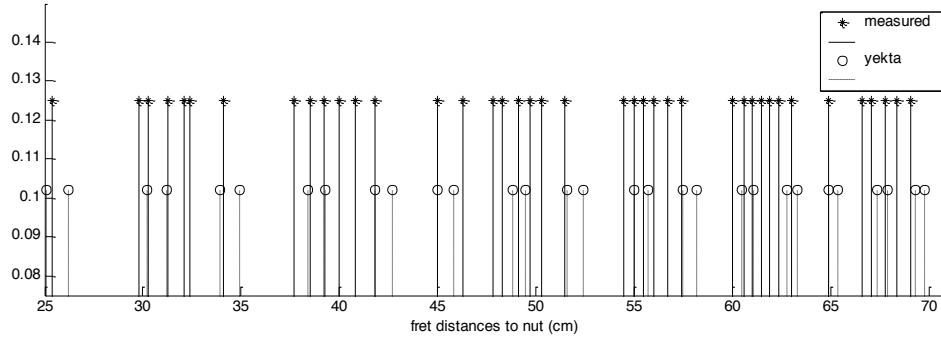

Figure 5. Fret locations of *tanbur* measured (M), and derived from the Yekta/AEU system.

The first observation is that although the *tanbur* used in the experiment has 56 frets as one of the *tanbur* type reported by Açın (2002), most of these frets do not match with the theoretical system of AEU. It can be seen from the figure that although there are many additional frets of the measured *tanbur*, most of them do not correspond to the theoretical frets.

Table 3 presents a more detailed numerical comparison of the two fret locations. It should be noted that fret placements of AEU for 104 cm string length are converted according to the string length of the *tanbur* used in the experiment, 104.7 cm. Therefore, fret measures given for AEU are different in Table 2 and 3, accordingly.

In order to save space, fret names are not given in Table 3 but names of the frets can be easily found from the corresponding number in Table 1 (eg. 1-yegah, 11-rast, 15-dügah etc.). Only the fret locations defined in theory are given and the additional frets of the measured *tanbur* are not presented in Table 3, to save space. While average error rate is found as 0.4 cm, the most important frets of the measured *tanbur*, *hüseyni aşiran* (5), *rast* (11), *dügah* (15), *çargah* (21), *neva* (25), *and their* corresponding *octaves hüseyni* (29), *gerdaniye* (35), *muhayyer* (39), *tiz çargah* (45) and *tiz neva* (49) considerably diverge from theory with an average of 1 cm which is not tolerable for the fret locations of *tanbur*. Therefore our theoretical argument about the inconvenience of the theoretical fret placements is empirically supported.

It should also be noted that inconvenient fret locations presented in the literature is only one dimension of the fretting problem of *tanbur*. The materials used in *tanbur* making also produce various problems related with the *tanbur* fretting. Most well-known problems are the change of shape of the fretboard and soundboard due to the change in the climate and thus environment (Yavuzoğlu 2008, 46). Both the fretboard and the soundboard either curved inside or outside in varying degrees according to the

humidity and temperature of the environment (Yavuzoğlu 2009; personal interview with Karatekeli 2012). Therefore the string length changes due to the movement of the bridge on the soundboard and/or nut on the fretboard. Such changes directly effect the fret locations, which have no ultimate solution until convenient materials are used for *tanbur* making which in turn will effect the timbre of the *tanbur*. A practical solution for this problem used by the performers is to have 2-3 bridges with different heights and use the convenient one whenever the instrument's shape changes, in order to compensate the change of string length depending on the change of the instrument's shape (interview with Coşkun 2012).

Table 3. The measured (M) fret locations of the *tanbur* used in the experiment and the calculated (AEU) fret locations from the Yekta system for the *tanbur* used with 104.7 cm string length. (f_M = measured frets, f_{AEU} = frets of AEU, ϵ=error). All values are given in centimeters.

No	f_M	f_{AEU}	ϵ	No	f_M	f_{AEU}	ϵ
1	104.7	104.7	0	25	53.2	52.35	0.85
2	99.8	99.4	0.4	26	50.2	49.7	0.5
3	98.6	98.1	0.5	27	49.2	49	0.2
4	94.6	94.4	0.2	28	47.3	47.2	0.1
5	93.8	93.1	0.7	29	44.7	46.5	1.8
6	88.9	88.3	0.6	30	44.1	44.2	0.1
7	87.8	87.2	0.6	31	43.7	43.6	0.1
8	83.6	83.9	0.3	32	41.7	41.9	0.2
9		82.7		33		41.4	
10		79.6		34	39.8	39.8	0
11	79.3	78.5	0.8	35	38.1	39.3	1.2
12	74.4	74.5	0.1	36	37.6	37.3	0.3
13	73.4	73.5	0.1	37	36.9	36.8	0.1
14		70.8		38	35.6	35.4	0.1
15	70.6	69.8	0.8	39	33.6	34.9	1.3
16	66.3	66.3	0	40	33.1	33.1	0
17	65.5	65.4	0.1	41	32.6	32.7	0.1
18	62.9	62.9	0	42	31.7	31.5	0.2
19		62		43	30.1	31.0	0.9
20	59.7	59.7	0	44	29	29.9	0.9
21	58.4	58.9	0.5	45	28.5	29.5	1.0
22	55.6	55.9	0.3	46	27.7	28	0.3
23	55	55.2	0.2	47		27.6	
24		53.1		48		26.5	
25	53.2	52.35	0.8	49	26.8	26.2	0.6

Depending on the changing shape of the *tanbur* by time after production, the practice of *tanbur* making and performance seems to have a mutual relationship. At least *tanbur* maker Karatekeli (2012) states that his long period of collaboration with *tanbur* performers Bora Uymaz and Cem Çıraklı results with various fret templates constructed in different years. The solution proposed by Karatekeli depends on the talent of *tanbur* performers: a *tanbur* performer should be able to solve the *tanbur* fretting problem by moving frets and/or bridge whenever faced with problems related with the change of the shape of the instrument.

Tying *tanbur* frets is another problematic topic, which effects the fretting locations directly. Tying a specific *tanbur* fret either below or above or at the exact mark of the template depends on the instrument maker (Karatekeli 2012). As stated by Karatekeli (2012), the thickness of the frets also changes throughout the fretboard, which ranges between 0.4-0.6 mm. Karatekeli (2012) states that he uses 0.4 mm frets until the *neva* fret and then 0.45 mm until the *dügah* fret. Therefore fret thickness changes also depending on the choice of *tanbur* maker.

A final problem effecting the fret locations is the materials used for strings, which is theoretically discussed by Zeren (2003, 120-124). The amount of string tension depending on the material used determines the vibration of string, which is directly related, with the fret locations of *tanbur*. There is again no standardization about the materials used for strings, which is naturally left to the choice of *tanbur* makers.

If *tanbur* had a standard stable construction then it would be possible to study the fret compensation problem as shown in the literature on guitar. However the use of appropriate materials for making standard stable *tanbur* would no doubt change the timbre of the instrument. Following comments of the *tanbur* player Ahmet Nuri Benli reveals the fact that even small changes in the shape of the *tanbur* within a century has effected the timbre:

> Tanbur construction was changed; thinner tops ruined the sound. Now the sound is thin, "wah-wah" instead of "tuuung"—it's become cold. So tanbur picking went from many notes for each stroke [i.e., the fretting fingers played several tones for each pluck] to one note per stroke. Also, in the old times a pick was a millimeter and a half thick. Ercüment [Batanay, his teacher] used 1 or 2. Nowadays they play with 5 millimeters thick. Today they play with too thick a pick, and their position is too high. (Quoted from Ederer 2011, 136)

3 Automatic estimation of fret locations from audio recordings

Recently Gedik and Bozkurt (2010) comprehensively discussed the challenges in computational studies on TTAM. These problems can be briefly listed as follows:

- Pitches demonstrate distributional characteristics instead of fixed frequency values.
- There is no reference frequency such as A4 = 440 Hz in western music.
- There is no reliable theory to consider as a reference as in western music.

- The number of pitch intervals and their values are still hot topics of discussion.

Bozkurt (2008) presented a solution to the first problem by developing pitch-frequency histogram representation of TTAM. Related with the second problem, we have shown in our previous publications (Gedik and Bozkurt 2009; Gedik and Bozkurt 2010) that automatic tonic detection can be very reliably achieved via template matching. In addition, by aligning pitch histograms with respect to tonics, automatic tuning analysis can be reliably performed for a given collection of recordings. Finally, instead of unreliable theoretical information, data-driven models were proposed and successfully used for the final two problems (Bozkurt 2008; Gedik and Bozkurt 2009; Gedik and Bozkurt 2010).

In this study, the algorithms are extended to achieve automatic detection of fret locations from audio recordings. The steps of the method applied to audio recordings for the estimation of fret locations are listed below:

- Representation of a given recording as pitch-frequency histogram.
- Automatic computation of tonic of the given recording by using the pitch-frequency histogram.
- Automatic detection of peaks of the histogram to find pitch interval values.
- Pitch-interval values are converted to frequency ratios.
- Frequency ratios are applied to a *tanbur* with given effective string lengths to find the fret locations.

Since the first two steps of the method listed above are comprehensively considered in our previous papers, we focus only on the rest of the steps. The main contribution of this study from the computational point of view is to assign the string length in an adaptive manner for fret compensation purposes, instead of considering it constant throughout the fretboard as applied in the theoretical approaches. Finally, Figure 6 presents the overall block diagram of our method.

As shown in Fig. 6, we firstly applied f0 estimation, representation of f0 as pitch-interval histogram and automatic tonic detection. In our method, we also applied automatic peak detection and alignment of the pitch-interval histogram with respect to the pitch *yegah*, which corresponds to the vibration of the open string. Therefore the pitch interval values corresponding to the performed pitches according to the frets of the *tanbur* are found. Finally, pitch interval values are converted to frequency ratios.

Secondly, five reference fret locations are used to compute corresponding five effective string lengths. Due to the complexity of the fret compensation problem, it is a common practice for instrument makers to detect the octave fret locations using harmonics and then computes effective string length to be used in computations (interview with Karatekeli, 2012). Hopkin (1996, 133) also gives the procedure in detail, as follows:

> Find the stopping location at which the string produces a true octave when pressed down to the fingerboard. (You can determine when the octave is true by comparing the fingered pitch to the harmonic tone generated by lightly touching the string at its midpoint and plucking.) The fingered true octave location will be a little short of the

actual string midpoint. Double the active string length at this true-octave stopping point to get a slightly long "corrected" total string length, and use the corrected string length in place of the actual string length for your calculations.

We follow a similar approach and use five reference fret locations as effective string lengths. Effective string length for each reference fret is found by simply multiplying the measure of reference fret (e.g. fret measure of 1st octave) by the corresponding frequency ratio (e.g. 2). Thus, five effective string lengths are found corresponding to the five fret regions. These reference frets are the ones, which can be easily tuned manually by the *tanbur* player using the harmonics: *hüseyni aşiran* (1st major second), *neva* (1st octave), *dügah* (1st perfect fifth), *muhayyer* (2nd perfect fifth) and *tiz neva* (2nd octave) with reference to *yegah*. The exact locations of these 5 reference frets are available in Table 3 at fret numbers 5, 15, 25, 39 and 49 in turn.
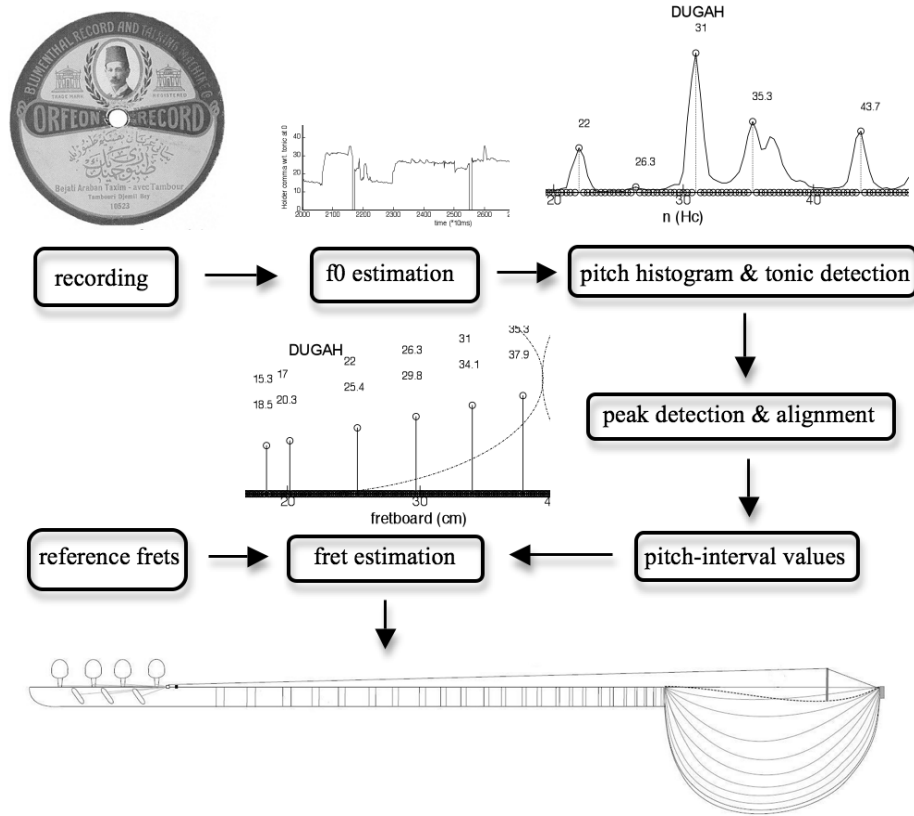

Figure 6. Block diagram of the method.

These reference frets are also the first steps of constructing templates for fret locations by *tanbur* makers (interview with Karatekeli 2012). Therefore the measured 5 reference frets of a given *tanbur* with reference to nut are used as input to the system. Finally, frequency ratios are converted to fret locations for each of the 5 effective string lengths according to the equation below:

$$\text{fret}_{En} = ESL_n - ESL_n / R_f \quad 1 \leq n \leq 5 \quad (1)$$

fret$_{En}$: estimated fret locations for the nth effective string length,

ESL$_n$: nth effective string length,

R$_f$: frequency ratios obtained from a given recording,

Therefore, the algorithm is applied as if there are five fret regions on *tanbur* as shown in Fig.7: 1st region *yegah*, 2nd region *dügah*, 3rd region *neva*, 4th region *muhayyer* and 5th region the *tiz neva*. As can be seen from the figure each fret region covers the relevant reference fret approximately in the middle of each region.
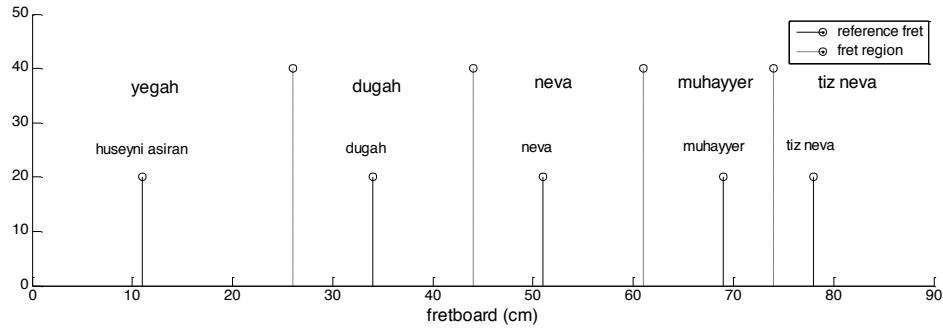

Fig.7. 1st region *yegah*, 2nd region *dügah*, 3rd region *neva*, 4th region *muhayyer* and 5th region the *tiz neva*.

As a result, fret locations (fret$_{En}$) are estimated 5 times for each of 5 effective string lengths from frequency ratios (R$_f$) obtained for a given recording by Eq. 1. (ESL$_n$). Each time, only the estimated fret locations which lay within the relevant fret region are selected. As an example, only values of fret$_{E1}$ which lay within 1st fret region *yegah* are selected and then only values of fret$_{E2}$ which lay within 2nd fret region *dügah* are selected, etc. Consequently, the estimated fret locations of a *tanbur* performed in a recording are found by concatenating the selection of estimated frets for each of the five fret regions. Finally, fret estimation algorithm is applied for each recording.

Although it is clear that each region should include the corresponding reference fret, it is not trivial to determine the range of each region where the corresponding effective string length will be applied. Therefore, in order to determine the range of each region we run an experiment on the 2 *hüseyni* recordings performed by the *tanbur* measured in our study. Range of 5 fret regions, which give the minimum error rate, is found by the experiment. The error rate is taken as the difference between the measured and estimated fret locations. Finally, Table 4 presents the details of the estimated fret locations for the range of 5 fret regions, which give the minimum error rate.

Table 4. Measured and estimated locations of frets for 2 *hüseyni* recordings, which give the minimum error rate. (SL: string length, f_M: measured frets, f_E: estimated frets, ϵ: error). All values are given in centimeters.

	hüseyni #1			*hüseyni #2*	
	Adaptive SL			**Adaptive SL**	
f_M	**f_E**	**ϵ**	**f_M**	**f_E**	**ϵ**
94.6	94.6	0	94.6	94.2	0.4
			85.4	85.5	0.1
79.3	79.4	0.2	79.3	79.1	0.2
70.6	70.6	0	70.6	70.6	0
67	67.9	0.9			
66.3	66.4	0.1			
65.5	65	0.5	65.5	65.3	0.2
			63.9	63.9	0
62.9	62.5	0.4			
59.7	60.1	0.4	59.7	60.1	0.4
53.2	53.2	0	53.2	53.2	0
47.3	47.3	0	47.3	47.3	0
44.7	44.5	0.2			
43.2	43.3	0.1	43.2	43.3	0.1
			41.7	41.7	0
42.3	42.4	0.1			
39.8	39.9	0.1	39.8	39.9	0.1
38.1	38.5	0.4			
36.9	37	0.1			
35.6	35.6	0	35.6	35.6	0
33.6	34.1	0.5			
32.1	32.3	0.2	32.1	32.5	0.4
30.1	30.3	0.2	30.1	30.5	0.4
26.8	26.8	0			
Mean error		**0.2**	**Mean error**		**0.15**

As a result, our algorithm applies adaptation in two steps: use of 5 effective string lengths, instead of the measured string length and determination of corresponding fret regions. Once 5 effective string lengths are calculated from the 5 reference frets and corresponding 5 fret regions are found for a given *tanbur*, the use of information extracted from recordings comes as the last step. Hence the first two steps do not need to be performed for each given recording.

As an example, Fig. 8 shows how the pitch-interval histogram obtained from an *uşşak* recording is mapped to the fretboard. In order to demonstrate the details, only first octave is shown. Fig. 8.a shows pitch-interval histogram in terms of Holdrian comma (Hc), which is obtained by the division of an octave into 53 logarithmically equal partitions. Pitch-interval histogram is aligned with respect to pitch *yegah*, which corresponds to the vibration of open string. In other words, the reference pitch *yegah* in the histogram corresponds to point 0. Figure 8 also shows the pitch-interval values over each peak. The highest two peaks correspond to the two pitches, *dügah* and *neva* which are also used as reference frets for the automatic estimation of fret locations. Fig. 8.b shows the estimated fret locations which are computed by converting pitch intervals to fret locations by Eq. 1 where effective string lengths are used for each region (e.g.yegah, dügah and neva regions as marked in the figure).
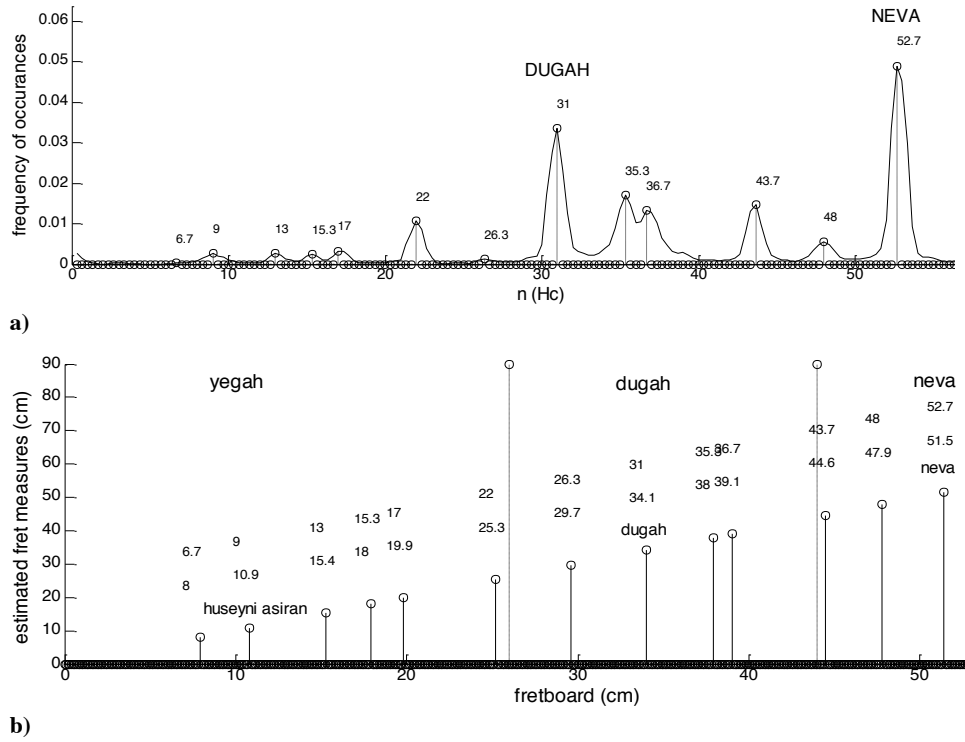

a)

b)

Fig. 8. Mapping the 1st octave of the pitch-interval histogram obtained from an *uşşak* recording to the 1st octave of the fretboard; **a)** Pitch-interval histogram with reference to fret *yegah* (nut) and the detected peaks used as pitch intervals, **b)** Estimated fret measures (each number couple over each peak shows the distance from nut and corresponding pitch-interval value, respectively).

3.1 Tests

14 *taksimler* (an improvisational form) from 7 *makamlar* are performed by the measured *tanbur* and recorded for the experiment. 2 *taksim* recordings from each of

the following *makamlar* are used in the tests: *hicaz, rast, neva, nihavend, saba, uşşak* and *suzinak*. The total duration of 14 recordings is 33 minutes and minimum and maximum durations are 1'18'' and 3'40'', respectively. As a result, we tried to estimate the fret locations of the *tanbur* from the 14 recordings and evaluate the success of the system based on the measured values of the fret locations. In order to evaluate the algorithm, the difference of the estimated fret distances and the measured fret distances are considered as error rate. The overall mean error rate of the proposed method for the 14 recordings is found as 0.2 cm where the mean error is also found to be 0.2 cm for each *makam*.

In order to demonstrate the success of the algorithm more clearly the error of our adaptive approach is compared with the error of the non-adaptive approach where the measured string length is used, as suggested both in theory and production. In other words, the frets are estimated again by our algorithm but by using the actual string length, 104.7 cm as constant. The overall mean error of the method for non-adaptive approach for the 14 recordings is found as 0.7 cm where the mean error ranges between 0.6 and 0.8 for the 8 *makamlar*. Thus the adaptive approach is found more successful than the non-adaptive approach. While the adaptive approach gives very close fret estimation values, the non-adaptive approach does not give reliable fret estimation values even for the most important frets, *dügah*, *neva* and *muhayyer*. Consequently, the theoretical non-adaptive approach is unreliable also for the estimation of the fret locations from audio recordings.

However it should be noted that the average error rate found as 0.4 cm from Table 3 is comparable with neither the error rate found as 0.2 cm for adaptive approach nor the error rate found as 0.7 cm for non-adaptive approach. While the average error rate 0.4 cm is found by comparison of theoretical and practical fret placements, average error rates 0.2 cm (adaptive approach) and 0.7 cm (non-adaptive approach) are calculated from the comparison of fret placements found from automatic estimations and practical *tanbur* measures.

Finally Table 5 enables us to compare the two approaches numerically by presenting the frets estimated from the two *uşşak* recordings, in comparison to the fret locations measured. As can be seen from the table while the deviation of the most important frets (light gray shaded) estimated by the theoretical non-adaptive approach has an average of 0.7 cm, the deviation of the most important frets estimated by the adaptive string length approach has an average of 0.08 cm.

Table 5 also presents the differences between the estimated frets. As can be seen from the table, only 4 frets are different among 18 common frets resulting an average error of 0.07 cm.

Table 5. Measured and estimated locations of frets for 2 *uşşak* recordings, demonstrating the success of adaptive and non-adaptive approaches. SL: string length. Grey shading: the most important frets of the *tanbur*. (f_M: measured frets, f_{AEU}: frets of AEU, ϵ: error, f_N: fret names, f_{EdA}: fret estimation difference for adaptive SL). All values are given in centimeters.

	Uşşak #1						*Uşşak #2*					
f_M	Adaptive		f_N	Non-Apadtive		f_M	Adaptive		f_N	Non-Apadtive		f_{EdA}
	f_E	ϵ		f_E	ϵ		f_E	ϵ		f_E	ϵ	
96.5	96.7	0.2		96	0.5							
93.8	93.5	0.3	E1	93.1	0.7	93.8	93.8	0	E1	93.1	0.7	0.3
88.9	89.3	0.4		88.3	0.6	88.9	89.3	0.4		88.3	0.6	0
86.4	86.7	0.3		85.7	0.7							
84.6	84.8	0.2		83.5	0.1	84.6	84.4	0.2		83.5	0.1	0.4
79.3	79.4	0.1	G1	78.5	0.8	79.3	79.4	0.1	G1	78.5	0.8	0
74.9	75	0.1		74.2	0.7							
70.6	70.6	0	A1	69.8	0.8	70.6	70.6	0	A1	69.8	0.8	0
67	66.7	0.3		66	1	67	66.7	0.3		66	1	0
65.5	65.6	0.1		64.8	0.7	65.5	65.3	0.2		64.5	1	0.3
59.7	60.1	0.4		59.1	0.6							
56.9	56.8	0.1		55.9	0.7	56.9	56.8	0.1		55.9	1	0
53.2	53.2	0	D1	52.6	0.6	53.2	53.2	0	D1	52.3	0.9	0
49.7	49.4	0.3		48.6	1.1							
47.3	47.5	0.2	E2	46.7	0.6	47.3	47.5	0.2	E2	46.7	0.6	0
44.7	44.9	0.2		44.2	0.5	44.7	44.9	0.2		44.2	0.5	0
43.2	43.1	0.1		42.3	0.5	43.2	43.1	0.1		42.3	0.9	0
39.8	40	0.2		39.3	0.5	39.8	40.2	0.4		42.3	0.5	0.2
38.1	38	0.1	G2	37.3	0.8	38.1	38	0.1	G2	39.4	0.4	0
37.6	37.4	0.2		36.6	1	37.6	37.4	0.2		37.3	0.8	0
35.6	35.6	0	A2	35.1	0.5	35.6	35.6	0	A2	36.6	1	0
33.6	33.9	0.3		33.3	0.3	33.6	33.9	0.3		35.1	0.5	0
32.1	32.2	0.1		31.6	0.5	32.1	32.2	0.1		31.6	0.5	0
Mean error	**0.2**				**0.7**	**Mean error**	**0.2**				**0.7**	**0.1**

35 frets are estimated totally from 14 recordings. While maximum and minimum frets estimated from one recording are 23 and 17 respectively, 20 frets are estimated in average for one recording. Therefore different frets are used across 14 recordings.

As an example Table 6 presents the first 10 measured frets and their corresponding estimated frets across 14 recordings. The table also shows standard deviation of estimated frets corresponding to each measured frets and the number of recordings a fret is used.

Table 6. The first 10 measured (M) fret locations of the *tanbur* used in the experiment and their corresponding estimated fret locations across 14 recordings. Abbreviations for the *makamlar* used in the table are as follows: Su: *suzinak*, Ne: *neva*, H: *hicaz*, Sa: *saba*, R: *rast*, Ni: *nihavent*, U: *uşşak*. Numbers 1 and 2 beside the abbreviation of *makam* names are used to denote different recordings from the same *makam*. (#: number of recordings a fret is used, std: standard deviation of estimated frets corresponding to a measured fret) All values are given in centimeters.

No	M	Su1	Su2	N1	N2	H1	H2	Sa1	Sa2	R1	R2	Ni1	Ni2	U1	U2	#	std
2	99.8	99.3	99.3													2	0
3	98.6																
	96.5			96.7	96.7		96.7	96.7				96.7	96.7	96.7		7	0
4	94.6					94.2										1	-
5	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.5	93.8	13	0.1
6	88.9	89	89	89	89		89	89.3	89	89	89	89	89	89.3	89.3		0.1
7	87.8																
	86.4													86.7		1	-
	85.4		85.2							85.2						2	0
	84.6	84.4		84.1			84.4				84.8	84.4	84.4	84.8	84.4	8	0.2
8	83.6																
9																	
10																	
11	79.3	79.4	79.4	79.4	79.4	79.8	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	14	0.1

We calculate standard deviation of each estimated fret across 14 recordings. The number of frets used commonly in more than 10 recordings is 13 and the average standard deviation is found as 0.1, which implies that the most commonly used frets, are estimated as close fret measures. The number of frets used commonly in between 5 and 10 recordings is 5 and the average standard deviation is found as 0.2 cm. The number of frets used commonly in between 2 and 5 recordings is 4 and the average standard deviation is found as 0.1 cm. The number of estimated frets used only in one recording is 8.

4 Discussion, conclusion and future work

In this study we discussed one of the most neglected and challenging issues in the literature from a music theory and computing perspective: the problem of *tanbur* fretting. We first discussed the importance of the instrument within various perspectives: the music theory, performance and production of *tanbur*. Secondly, we presented the main difficulties within the context of the divergence of theory and practice. We summarized the literature of *tanbur* fretting and showed that there is a lack of reliable information in the domain.

We introduced our method for estimation of fret locations from audio recordings and presented our test results, which show that the method is indeed reliable. As a result a computational study for the study of *tanbur* fretting is presented for the first time in the literature. Furthermore the current fretting systems proposed in theory and used in production were compared for the first time.

However our study lacks some details we hope to pursue in future studies. The main theoretical discussion within TTAM is about certain pitches, which are performed in

practice, but not represented in theory. These pitches are mainly the pitches, which exist between the main pitches such as *dügah* and *çargah*, *hüseyni aşiran* and *arak* etc. Therefore our method can be improved by increasing the number of reference frets by including these main pitches, besides *dügah*. As stated by Karatekeli (2012), it is again possible to tune manually these main frets. In order to see the amount of improvement by additional reference frets we made a small test only on the recording uşşak#1 and found that the error is decreased to 0.1 cm which is half of the error found in our method. On the other hand, an interesting result of the experiment of Bozkurt (2012) makes the use of additional reference frets for the main pitches discussable. Bozkurt reports that the well-known *kanun* player Reha Sağbaş surprised to observe that even the major second (*rast-dügah*) performed by Tanburi Cemil Bey and commented that no one performs the interval of that size today.
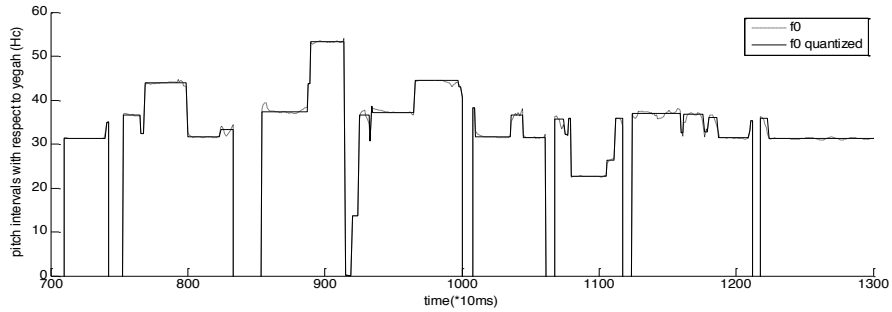

Fig. 9. An excerpt from the f0 curve of recording uşşak#1.

In this sense the study of Bozkurt (2012) presents a useful tool, which enables performers to decide the main pitches by audio and visual feedback for the tuning of their instruments. However, as Bozkurt (2012) states, many of the performers found such a procedure intriguing.

It is also possible to extend our study in order to estimate all fret locations necessary for the performance of certain *makam* from the collection of recordings of master musicians performed in the same *makam*. However, as can be seen from Table 4 and 5 presented in the previous chapter, the same *tanbur* player could perform the same *makam* using a different set of pitch intervals. The difference between the two *hüseyni* performances is not only about the number of pitches, but also about some of the pitches which correspond to the same fret and are performed slightly different as presented in Table 4: Measured fret location, 79.3 is estimated as 79.4 and 79.1, for recordings hüseyni#1 and #2, respectively. The same considerations are also valid for the differences between two *uşşak* performances.

Furthermore, it is common to perform some motifs and modulations, which correspond to performing pitches of a *makam* different than the one performed. Therefore estimating fret measures even from more than the 2 recordings of the performance of the same *makam* for the performance of that *makam* should be able to handle such ambiguous conditions, which are not trivial problems.

Anyway, an important exclusion in our existing method is the perceptual evaluations of the results about the improvement of adaptive approach and success of estimated frets. Firstly, the improvement of our system based on adaptive approach in comparison to non-adaptive approach needs an explanation about its perceptual implications. Since we did not apply a perceptual test about the error rates, we can only comment about the perceptual implications of error rates based on the given measured fret distances. The distribution of distances between successive measured frets has following calculated parameter values: mean is 1.2 cm, maximum distance is 4.9 cm, minimum distance is 0.3 cm and standard deviation is 1.1 cm. We can compare the parameters of the distribution with error rates of two approaches as follows: While the mean error rate of adaptive approach, 0.2 cm is less than the minimum fret distance, 0.3 cm and 6 times smaller than the mean fret distance, 1.2 cm, the mean error rate of non-adaptive approach, 0.7 cm is more close to the mean fret distance, 1.2 cm. Furthermore, there are also 13 fret distances which lay between 0.6cm and 0.8 cm among 61 measured frets. Therefore, it can be said that it is more likely for the non-adaptive approach to estimate frets with an error as big as the distances of 13 measured frets. Nevertheless, it is necessary to make further observations and calculations such as comparison of each estimated fret found both by adaptive and non-adaptive approach with the measured frets in order to make more strict comments. Secondly, tanbur players for perceptual evaluations could test frets estimated from the recordings of the tanbur masters. Therefore, we plan to complete these two points as future study.

The number of recordings used to design our system is also important. Only 2 *hüseyni* recordings are used to determine the range of 5 fret regions. Therefore, we think that the use of more recordings for the design of the system would improve the results.

The impact of historical recordings, which we hope to constitute fundamental sources for the usage of our system, were discussed by Gedik and Bozkurt (2009) as follows:

> 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.

Another issue is about the practical usage of our system. Since a graphical user interface (GUI) is not designed, our system in its current form is not accessible to *tanbur* makers, students and performers. We plan to design a GUI for our system as a future project.

Nevertheless, we hope that our study will pave the way for colleagues from various disciplines interested in the *tanbur* to contribute to the current state-of-art of research on the *tanbur*.

Acknowledgement

References

Açın, C. 1994. Enstruman Bilimi (Organaloji), İstanbul.

Açın, C. 2002. *Tanbur Yapım Sanatı ve Sanatçıları*, Bilgi Basımevi, İstanbul,.

Akan, E. Tanbur metodu. Çağlar Musiki Yayınları, Istanbul, 2007.

Aksüt, S. 1971. Yeni Öğrenenler için Tanbur Metodu, Cümbüş Yay., İstanbul.

Bohlman, P. V. (2008). 'Middle East, §I: Concepts of music', Grove Music Online ed. L. Macy (Accessed 09 February 2008), http://www.grovemusic.com

Bozkurt, B., Yarman, O., Karaosmanoglu, M.K. and 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,pp. 45-70.

Bozkurt, B. 2008. An automatic pitch analysis method for Turkish maqam music, *Journal of New Music Research*, 37(1), 1-13.

Bozkurt, B. 2012. A System for Tuning Instruments Using Recorded Music Instead of Theory-Based Frequency Presets, *Computer Music Journal*, 36:3, pp. 43–56, Fall

Burns, Anne-Marie and Marcelo M. Wanderley, 2006. Visual methods for the retrieval of guitarist fingering, Proceeding NIME '06 Proceedings of the conference on New interfaces for musical expression, pp. 196 – 199.

Coşkun, Cengiz . 2005. *Tambur yapımı*, MSc. Thesis, Ege Üniversitesi - Sosyal Bilimler Enstitüsü -

Coşkun, Cengiz. 2012. Personal Interview with Ali C. Gedik, İzmir , September 7, 2012

Çekiç, Özgür. 2008. Tanbur Standartları. Interview with R. Özgür Altun, Saz ve Söz, 10:4.

Cumpiano, W. R. and J. D. Natelson, 1993. *Guitarmaking: Tradition and Technology,* Chronicle Books, San Francisco, USA.

Ederer, E. 2011. The Theory and Praxis of Makam in Classical Turkish Music 1910-2010, PhD Thesis, Universtity of California, Santa Barbara,

Erkut, C. and Välimäki, V. "Model-Based Sound Synthesis of Tanbur, a Turkish Long-Necked Lute". Proc. Of the International Conference on Acoustics, Speech and Signal Processing, vol. 2, Istanbul, Turkey, pp. 769-772, June 5-9, 2000.

Feldman, W. Z., "Ottoman music". Grove Music Online. Oxford Music Online. http://www.oxfordmusiconline.com/subscriber/article/grove/music/52169, Access date: 10 Aug. 2009.

Fletcher, N.H. and Rossing, T.D. The Physics of Musical Instruments. New York: Springer-Verlag, Second Edition 1998.

Gedik, Ali C. and Barış Bozkurt. 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, A. C. and Bozkurt, B. (2010). Pitch Frequency Histogram Based Music Information Retrieval for Turkish Music, *Signal Processing*, 10:1049-1063.

Gilbert, J. and W. Gilbert, Intonation and Fret Placement, http://www.schrammguitars.com/intonation.html

Hassan, S. Q. et al. "Tanbūr." Grove Music Online. Oxford Music Online. 22 Mar. 2009 http://www.oxfordmusiconline.com/subscriber/article/grove/music/52071

Hassan, S. Q. "The Long Necked Lute in Iraq". Asian Music, Vol. 13, No. 2 (1982), pp. 1-18.

Hopkin, B. Musical Instrument Design: Practical Information for Instrument Design. See Sharp Press, 1996.

Karatekeli, Barış Yekta. 2012. Personal Interview with Ali C. Gedik, İzmir , September 11, 2012

Lundberg, R. 2002. *Historical Lute Construction*, Guild of American Luthiers.

Marcus, S. "The interface between theory and practice: Intonation in Arab music". Asian Music, Vol.24, No.2. pp.39-56, 1993.

Martin, D. "Innovation and the Development of the Modern Six-String Guitar". The Galpin Society Journal, Vol. 5, pp. 86-109, Jul., 1998.

Merkel, S.L. 2004, Intonation System for Fretted Instruments, US Patent.

Middleton, R. 1997. *The Guitar Maker's Workshop*, The Crowood Press, Ramsbury, UK.

Muncy, G.O. and Griffitts, J.N. 2008, Stringed Instrument and Associated Fret Mapping Method, US Patent.

Mus2. URL: http://www.musiki.org/, Access date: 15th Sept. 2009.

Öksüz, M. A. Türk musikisinde tanbur sazının gelişimi. Marmara Üniversitesi, PhD thesis, İstanbul, 1998.

Öztürk, O. M. 2006. *Zeybek Kültürü ve Müziği*, İstanbul: Pan Yay.

Popescu-Judetz, E. Prens Dimitrie Cantemir, Trans. S. Alemdar, Pan Yay., İstanbul, 2000.

Racy, A. J. "Historical Worldviews of Early Ethnomusicologists: An East-West Encounter in Cairo, 1932," In Ethnomusicology and Modern Music History, eds. Stephen Blum, Philip V. Bohlman, and Daniel M. Neuman, p. 68–91, Urbana: University of Illinois Press, 1991.

Rossing, T.D. 2010. The Science of String Instruments, (ed. Thomas D. Rossing), Springer.

Salazar, J.G. 2006. Mathematical Fret Placement System, US Patent.

Signell, K. (2006). *Makam: Türk Sanat Musikisinde Makam Uygulaması* [Makam: Modal Practice in Turkish Art Music](trans.:İlhamiGökçen), Yapı Kredi Yayınları, İstanbul.

Subramanian, K. S. "An Introduction To The Vina". Asian Music, Vol. 16, No. 2, pp. 7-82, Spring, 1985.

Stenzel, S., Classical Master Guitars, http://www.stenzel-guitars.de

Tanbur-i Cemil Bey. 1993. Rehber-i Musiki, (Çeviriyazım Hakan Cevher), Ege Ünv. Basımevi, İzmir.

Thomas, A. E. "Intervention and reform of Arab music in 1932 and beyond". Conference on Music in the world of Islam, Assilah, 2007.

Traube C. and J. O. Smith, 2001. Extracting the fingering and the plucking points on a guitar string from a recording, IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA'01),.

Varieschi, Gabriele U.; Gower, Christina M. 2010. Intonation and compensation of fretted string instruments, *American Journal of Physics*, Volume 78, Issue 1, pp. 47-55

Wright, O. (1990). Çargah in Turkish Classical Music: History versus Theory, *The Bulletin of the School of Oriental and African Studies*, 53:224-244.

Yarman, O. Kantemir Fontu, http://www.ozanyarman.com/kantemirfontu.html, Access date: 15th Sept. 2009.

Yavuzoğlu, N. 21. Yüzyılda Türk Müziği Teorisi. Istanbul: Pan Yayıncılık, 2008.

Yavuzoğlu, Nail. 2009. Nail Yavuzoğlu ile Türk Müziğinde Tampereman, Interview with R. Özgür Altun, Saz ve Söz, 4:7.

Yekta, R. Türk Musikisi. (Translated from French by O. Nasuhoğlu), Pan Yay., İstanbul, 1986.

Zeren, A. 2003. *Müzik Sorunlarımız Üzerine Araştırmalar*, Pan Yay. İstanbul.

[i] International Congress of Problems on the Divergence of Theory and Performance, 6-8 March 2008, İstanbul

[ii] Gedik and Bozkurt (2009, 114) states that although there are either few pitch intervals diverges or do not exist in theory, such deficiencies "mean a great change within the logic of Arel theory from the perspective of ethnomusicology."

[iii] Feldman (1990:100) 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 rejects traditional Turkish art music. Stokes (1996) also refers to these attempts as the "Arel project" in reference to its strong relations with nationalization and westernization.

[iv] As stated by Gedik and Bozkurt (2009, 106): "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." Karl Signell and M. Kemal Karaosmanoğlu (quoted from Can Akkoç) shared their measurement experiences with foremost performers.(personal communication with Signell and Karaosmanoğlu, 6-8 March 2008, İstanbul)

[v] As stated by Gedik and Bozkurt (2010) based on Karl Signell and M. Kemal Karaosmanoğlu (quoted from Can Akkoç) shared their measurement experiences with foremost performers.(personal communication with Signell and Karaosmanoğlu, 6-8 March 2008, İstanbul): "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."

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