SYNTHESIS OF TURKISH MAKAM MUSIC SCORES USING AN ADAPTIVE TUNING APPROACH

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ABSTRACT

Music synthesis is one of the most essential features of music notation software and applications aimed at navigating digital music score libraries. Currently, the majority of music synthesis tools are designed for Eurogenetic musics, and they are not able to address the culture-specific aspects (such as tuning, intonation and timbre) of many music cultures. In this paper, we focus on the tuning dimension in musical score playback for Turkish Makam Music (TMM). Based on existing computational tuning analysis methodologies, we propose an automatic synthesis methodology, which allows the user to listen to a music score synthesized according to the tuning extracted from an audio recording. As a proof-of-concept, we also present a desktop application, which allows the users to listen to playback of TMM music scores according to the theoretical temperament or a user specified reference recording. The playback of the synthesis using the tuning extracted from the recordings may provide a better user experience, and it may be used to assist music education, enhance music score editors and complement research in computational musicology.

1. INTRODUCTION

A music score is a symbolic representation of a piece of music that, apart from the note symbols, it contains other information that helps put those symbols into proper context. If the score is machine-readable, i.e. the elements can be interpreted by a music notation software, the different musical elements can be edited and sonified. This sonification can be done using a synthesis engine and with it, the users get an approximate real-time aural feedback on how the notated music would sound like if played by a performer.

Currently, most of the music score synthesis tools render the audio devoid of the performance added expression. It can be argued that this process provides an exemplary rendering reflecting theoretical information. However, the music scores of many music cultures do not explicitly include important information related to performance aspects such as the timing, dynamics, tuning and temperament. These characteristics are typically added by the performer, by using his or her knowledge of the music, in the context of the performance. Some aspects of the performance, such as the tuning and temperament, may differ due to the musical style, melodic context and aesthetic concerns. In performance-driven music styles and cultures, the "theoretical" rendering of a music score might be considered as insufficient or flawed.

In parallel, the mainstream notation editors are currently designed for Eurogenetic musics. While these editors provide a means to compose and edit music scores in Western notation (and sometimes in other common notation formats such as tablatures), the synthesis solutions they provide are typically designed for 12 tone-equal-tempered (TET) tuning system, and they have limited support to render intermediate tones and mictotonal intervals. The wide use of these technologies may negatively impact the music creation process by introducing a standardized interpretation and it might even lead to loss of some variations in the expression and understanding of the music culture in the long term (McPhail, 1981; Bozkurt, 2012).

For such cases, culture-specific information inferred from music performances may significantly improve music score synthesis by incorporating the flexibility inherent in interpretation. In this study, we focus on the tuning and temperament dimensions in music score synthesis, specifically for the case of Turkish makam music (TMM). Turkish makam music is a suitable example since performances use diverse tunings and microtonal intervals, which vary with respect to the makam (melodic structure), geographical region and artists. Based on an existing computational tuning analysis methodology, we propose an adaptive synthesis method, which allows the user to synthesize the melody in a music score either according to a given tuning system or according to the tuning extracted from audio recordings. In addition, we have developed a proof-of-concept desktop application for the navigation and playback of the music scores of TMM, which uses the adaptive synthesis method we propose. To the best of our knowledge, this paper presents the first work on performance-driven synthesis and playback of TMM.

For reproducibility purposes, all relevant materials such as musical examples, data and software are open and publicly available via the companion page of the paper hosted in the Compmusic Website. [1]

The rest of the paper is structured as follows: Section 2 gives a brief information of TMM. Section 3 presents an overview of the relevant commercial music synthesis software and the academic studies. Section 4 explains the

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[1] `http://compmusic.upf.edu/node/339`

methodology that adapts the frequencies of the notes in a machine readable music score to be synthesized and the preparation of the tuning presets. Section 5 explains the music score collection, the implementation of the methodology and the desktop software developed for discovering the score collection. Section 6 wraps up the paper with a brief discussion and conclusion.

2. TURKISH MAKAM MUSIC

Most of the melodic aspects of TMM can be explained by the term *makam*. Each makam has a particular scale, which gives the "lifeless" skeleton of the makam (Signell, 1986). Makams are modal structures (Powers, et al., 2013), which gains its character through its melodic progression (*seyir* in Turkish) (Tanrıkorur, 2011). Within the progression, the melodies typically revolve around an initial tone (*başlangıç* or *güçlü* in Turkish) and a final tone (*karar* in Turkish) (Ederer, 2011; Bozkurt et al., 2014).

Karar is typically used synonymous to *tonic*, and the performance of a makam ends almost always on this note. There is no definite reference frequency (e.g. $A4 = 440$Hz) to tune the performance tonic. Musicians might choose to perform the music in a number of different transpositions (*ahenk* in Turkish), any of which might be favored over others due to instrument/vocal range or aesthetic concerns (Ederer, 2011).

There are several theories attempting to explain the makam practice (Arel, 1968; Karadeniz, 1984; Özkan, 2006; Yarman, 2008). Among these, Arel-Ezgi-Uzdilek (AEU) theory (Arel, 1968) is the mainstream theory. AEU theory is based on Pythagorean tuning (Tura, 1988). It also presents an approximation for intervals by the use of Holderian comma (Hc)[2] (Ederer, 2011), which simplifies the theory via use of discrete intervals instead of frequency ratios. "Comma" (*koma* in Turkish) is part of daily lexicon of musicians and often used in education to specify intervals in makam scales. Some basic intervals used in AEU theory are listed in Table 1 (with sizes specified in commas on the last column)

Since early 20$^{\text{th}}$ century, a score representation extending the traditional Western music notation has been used as a complement to the oral practice (Popescu-Judetz, 1996). The extended Western notation typically follows the rules of AEU theory. Table 2 lists the accidental symbols specific to TMM used in this notation.

The music scores tend to notate simple melodic lines and the musicians follow the scores of the compositions as a reference. Nevertheless, they extend the notated "musical idea" considerably during the performance by adding non-notated embellishments, inserting/repeating/omitting notes, altering timing, and changing the tuning and temperament. The temperament of some intervals in a performance might differ from the theoretical (AEU) intervals as much as a semi-tone (Signell, 1986).

Name	Flat	Sharp	Hc
Koma	𝄳	𝄲	1
Bakiye	𝄭	♯	4
Küçük mücennep	♭	𝄰	5
Büyük mücennep	𝄬	𝄱	8

Table 1: The accidental symbols defined in extended Western notation used in TMM, their theoretical intervals in Hc according to the AEU theory.

3. BACKGROUND

Many commercial music notation software tools such as Sibelius[3], Finale[4] and MuseScore[5] support engraving and editing the accidentals used in Turkish makam music. However, they provide no straightforward or out-of-the-box solution for microtonal synthesis. For example, MuseScore only supports synthesis of 24 tone-equal-temperament system, which is not sufficient to represent the the intervals in either TMM practice or theory.

Mus2[6] is a music notation software specifically designed for the compositions including microtonal content. It includes a synthesis tool that allows users to playback music scores in different microtonal tuning systems such as just intonation. In addition, Mus2 allows the users to modify the intervals manually. Nevertheless, manually specifying the intervals could be tedious. In addition, the process may not be straightforward for many users, which do not have a sufficient musical, theoretical or mathematical background.

There exists several studies in literature for automatic tuning analysis of TMM (Bozkurt, 2008; Gedik & Bozkurt, 2010) and Indian art musics (Serrà et al., 2011; Koduri et al., 2014). These studies are mainly based on pitch histogram analysis. Bozkurt et al. (2009) analyzed the recordings of masters in 9 commonly performed makams by computing a pitch histogram from each recording and then detecting the peaks of histograms. Considering each peak as one of the performed scale degrees, they compared the identified scale degrees with the theoretical ones defined in several theoretical frameworks. The comparison showed that the current music theories are not able to explain the intervallic relations observed in the performance practice well.

Later, Bozkurt (2012) proposed an automatic tuner for TMM. In the tuner, the user can specify the makam and input an audio recording in the same makam. Then, the tuning is extracted from the audio recording using the pitch histogram analysis method described above. The tuning information is then provided the user interactively, while she/he is tuning an instrument. Similarly, Şentürk et al. (2012) has incorporated the same pitch histogram based tuning analysis methodology into an audio-score alignment methodology proposed for TMM. In this method, the tuning of the audio recording is extracted as a preprocessing

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[2] i.e. 1 Hc $= \frac{1200}{53} \approx 22.64$ cents

[3] `http://www.avid.com/sibelius`

[4] `http://www.finalemusic.com/`

[5] `https://musescore.org/`

[6] `https://www.mus2.com.tr/en/`

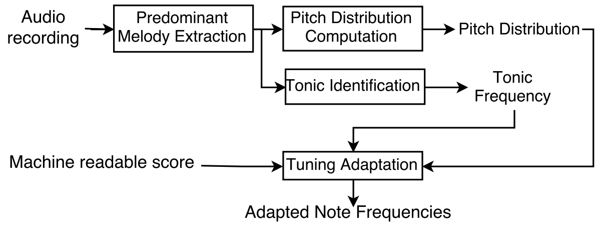

Figure 1: The flow diagram of the adaptive tuning methodology

step prior to the alignment step. Next, it is used (instead of the theoretical temperament) to generate a synthetic pitch track from the relevant music score. This step minimizes the temperament differences between the audio predominant melody and the synthetic pitch track, and therefore a smaller cost is emitted by the alignment process.

4. METHODOLOGY

The proposed system differs from existing synthesizers by allowing the user to supply a reference recording (for temperament) from which the intervals may be learned automatically. When a reference recording is not available, our method maps the note symbols according to the intervals described in the music theory with respect to the user provided tonic frequency. If the user provides a reference audio recording, our method first extracts the predominant melody from the audio recording. Next, it computes a pitch distribution from the predominant melody and identifies the frequency of tonic note in the performance. By applying peak detection to the pitch distribution, our method obtains the stable frequencies performed in the audio recording. Then, the stable pitches are mapped to the note symbols in the music score by taking the identified tonic frequency as the reference. Finally, synthesis is performed by using the Karplus-Strong string synthesis method. The flow diagram of the adaptive tuning method is shown in Figure 1.[7]

4.1 Predominant Melody Extraction

To identify the tuning, the method first extracts the predominant melody of the given audio recording. We use the methodology proposed in (Atlı et al., 2014).[8] It is a variant of the methodology proposed in (Salamon & Gómez, 2012), which is optimized for TMM. Then, we apply a post-filter[9] proposed in (Bozkurt, 2008) on the estimated predominant melody. The filter corrects the octave errors. It also removes the noisy regions, short pitch chunks and extreme valued pitch estimations of the extracted predominant melody.

4.2 Pitch Distribution Computation

Next, we compute a pitch distribution (PD) (Chordia & Şentürk, 2013) from the extracted predominant melodies (Figure 2). The PD shows the relative occurrence of the frequencies in the extracted predominant melody.[10] We use the parameters described for pitch distribution extraction in (Şentürk, 2016, Section 5.5) as follows: The bin size of the distribution is set as 7.5 cents $\approx 1/3$ Hc resulting in a resolution of 160 bins per octave (Bozkurt, 2008). We use kernel density estimation and select the kernel as normal distribution with a standard deviation of 7.5. The width of the kernel is selected as 5 standard deviations peak-to-tail (where the normal distribution is greatly diminished) to reduce computational complexity.

4.3 Tonic Identification

In parallel, we identify the tonic frequency of the performance using the methodology proposed by Atlı et al. (2015). The method identifies the frequency of the last performed note, which is almost always the tonic of the performance (Section 2). The method is reported to give highly accurate results, i.e. $\sim 89\%$ in (Atlı et al., 2015).

4.4 Tuning Analysis and Adaptation

We detect the peaks in the PD using the peak detection method explained in (Smith III & Serra, 1987).[11] The peaks could be considered as the set of stable pitches performed in the audio recording (Bozkurt et al., 2009). The stable pitches are converted to scale degrees in cent scale by taking the identified tonic frequency as the reference using the formula:

$$c_i = 1200 \log_2(f_i/t) \tag{1}$$

where f_i is the frequency of a stable pitch in Hz, t is the identified tonic frequency and c_i is the scale degree of the stable pitch in cents.

In parallel, the note symbols in the scale of the makam[12] is inferred from the key signature of the makam[13] and extended to ± two octaves. The note symbols are initially mapped to the theoretical temperaments (scale degrees in cents) according to the AEU theory (e.g. if the tonic symbol is G4, the scale degree of A4 is 9 Hc ≈ 203.8 cents).

Next, the performed scale degrees are matched with the theoretical scale degrees using a threshold of 50 cents (close to 2.5 Hc, which is reported as an optimal by (Bozkurt et al., 2009)). If a performed scale degree is close to more than one theoretical scale degree (or vice versa), we only match the closest pair. If there are no matches for a theoretical scale degree, we keep the theoretical value. As a trivial addition to (Bozkurt et al., 2009), we re-map the

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[7] The implementation of our methodology is openly available at `https://github.com/hsercanatli/symbtrsynthesis`.

[8] The implementation is available at `https://github.com/sertansenturk/predominantmelodymakam`.

[9] The implementation is available at `https://github.com/hsercanatli/pitchfilter`.

[10] We use the implementation presented in (Karakurt et al., 2016): `https://github.com/altugkarakurt/morty`.

[11] The implementation is available in Essentia (Bogdanov et al., 2013): `http://essentia.upf.edu/`.

[12] The makam is known from the music score (Section 4.5).

[13] Available at `https://github.com/miracatici/notemodel/blob/v1.2.1/notemodel/data/makam_extended.json`.

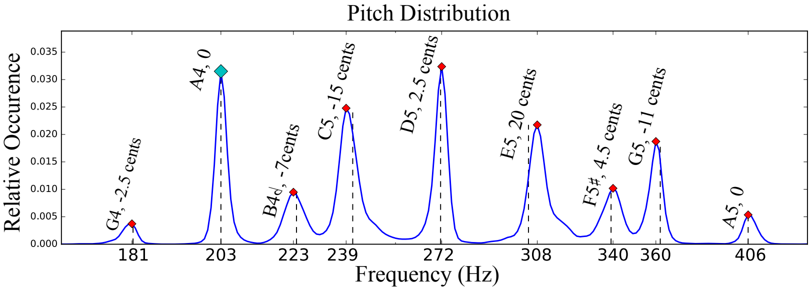

Figure 2: The tuning extracted from a recording in Hüseyni makam, performed by Tanburi Cemil Bey.

theoretical scale degrees to the note symbols and obtain the $<$ *note symbol - stable pitch* $>$ pairs. [14]

Figure 2 [15] shows an example tuning analysis applied on a historical recording in Hüseyni makam performed by Tanburi Cemil Bey. [16] The frequency of each stable note is shown on the x-axis. The vertical dashed lines indicate the frequencies of the notes according to the theoretical intervals. The matched note symbol and the deviation from the theoretical scale degree of each stable pitch is displayed right next to the corresponding peak on the PD. It can be observed that the some of the notes - esp. çargah (C5) and hüseyni (E5) notes - substantially deviate from the AEU theory.

4.5 Score Synthesis

From the machine-readable music score, we read the note sequence, nominal tempo, makam and tonic symbol (last note in the sequence). The note symbols are converted to a stable pitches, by referring to the $<$ *note symbol - stable pitch* $>$ pairs obtained from tuning analysis. In parallel, the symbolic note durations are converted to seconds by referring to the nominal tempo. Next, we generate a pitch-track from the note sequence in the score by sampling the mapped stable pitches relative to the their duration in seconds at a frame rate of 44100 Hz and then concatenating all samples (Şentürk et al., 2012). The score pitch-track is synthesized using the Karplus-Strong string synthesis (Jaffe & Smith, 1983). [17]

In addition, we mark the sample index of each note onset in the score pitch-track to later use to synchronize the music score visualization during playback in our desktop application (Section 5.4).

5. APPLICATION

As a proof-of-concept, we have developed a desktop application [18] , for the navigation and playback of the music scores of TMM. In this section, we showcase the application (Section 5.4) and discuss how it fits into the Dunya ecosystem, which comprises all the music corpora and related software tools that have been developed as part of the CompMusic project. In specific, we describe the music score collection (Section 5.1), the tuning presents extracted from audio recordings (Section 5.2), and the data processing and storage platform hosted on web (Section 5.3).

5.1 Music Scores

In this study, we use the music scores in the SymbTr score collection (Karaosmanoğlu, 2012). [19] SymbTr is currently the most representative open-source machine-readable music score collection of TMM (Uyar et al., 2014). Specifically, we use the scores in MusicXML format. This format is preferred, because it is commonly used in many music notation and engraving software. The scores in MusicXML format does not only contain the notes, but also other relevant information such as the sections, tempo, composer, *makam* and *form* of the related musical piece. We use some of this information to search the scores in the desktop application (Section 5.4).

To render the music scores during playback (Section 5.4), we first convert the scores in MusicXML format to LilyPond and then to SVGs. [20] Each note element in the SVG score contains the note indices in the MusicXML score.

5.2 Tuning Presets

Using the methodology described in Section 4, we extracted the tuning from 10 "good-quality" recordings as presets for each of the Hicaz, Nihavent, Uşşak, Rast and Hüzzam makams (i.e. 50 recordings in total). [21] These are the most commonly represented makams in the SymbTr collection, and they constitute more than 25% of the music scores in the SymbTr collection (Şentürk, 2016, Table 3.2). The recordings are selected from the CompMusic Turkish makam music audio collection (Uyar et al., 2014), which is

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[14] The implementation is available at `https://github.com/miracatici/notemodel`.

[15] The Figure and the explanation is reproduced from (Şentürk, 2016, Section 5.9).

[16] `https://musicbrainz.org/recording/8b8d697b-cad9-446e-ad19-5e85a36aa253`

[17] We modified the implementation of the Karplus-Strong model in the PySynth library: `https://github.com/mdoege/PySynth`.

[18] `https://github.com/MTG/dunya-desktop/tree/adaptive-synthesis`

[19] The SymbTr collection is openly available online: `https://github.com/MTG/SymbTr`.

[20] The score conversion code is openly available at `https://github.com/sertansenturk/tomato/blob/v0.9.1/tomato/symbolic/scoreconverter.py`.

[21] The recording metadata and the relevant features are stored in GitHub for reproducibility purposes: `https://github.com/MTG/otmm_tuning_intonation_dataset/tree/atli2017synthesis`.

currently the most representative audio collection of TMM, available for computational research.

We have synthesized 1222 scores according to the presets (in total 12220 audio synthesis) and all the 2200 scores with the theoretical tuning.

5.3 Dunya and Dunya-web

Dunya is developed with Django framework to store the data and execute the analysis algorithms developed within the CompMusic Project.[22] The audio recordings, music scores and relevant metadata are stored in a PostgreSQL database.[23] Its possible to manage information about the stored data and submit analysis tasks on the data from the administration panel. The output of each analysis is also stored in the database. The data can be accessed from the Dunya REST API. We have also developed a Python wrapper, called pycompmusic,[24] around the API.

To showcase our technologies developed within the CompMusic project, we have created a web application for music discovery called Dunya-web (Porter et al., 2013). The application displays the resulting automatic analysis. Dunya-web has a separate organization for each music culture studied within the CompMusic project.[25]

5.4 Dunya-desktop

In addition to Dunya-web, we have been working on a desktop application for accessing and visualizing the corpora created in the scope of CompMusic project. The aim is developing a modular and customizable music discovery interface to increase the reusability of the CompMusic research results to researchers.

Dunya-desktop[26] is directly connected to the Dunya Framework. The user could query the corpora and download the relevant data to the local working environment such as music scores, audio recordings, extracted features (predominant melody, tonic, pitch distribution and etc.). The interface provides an ability to create sub-collections to the user. It also comes with some visualization and annotation tools for extracted features and music score that the user could create a customized tool for his/her research task.

Our software is developed in Python 2.7/3 using PyQt5[27] library. This library allows us to use the Qt5 binaries in Python programming language. The developed software is compatible with Mac OSX and GNU/Linux distributions.

The software that we developed as a proof-of-concept is an extension and customization of Dunya-desktop. The flow diagram of the user interaction in the desktop application is shown in Figure 3. The application allows the user to search a specific score by filtering metadata. If the selected composition is in one of the *makam*s with a preset, the user can choose to playback the score synthesized according to the AEU theory or to the available tuning presets. Otherwise, only the synthesis according to the AEU theory is available.

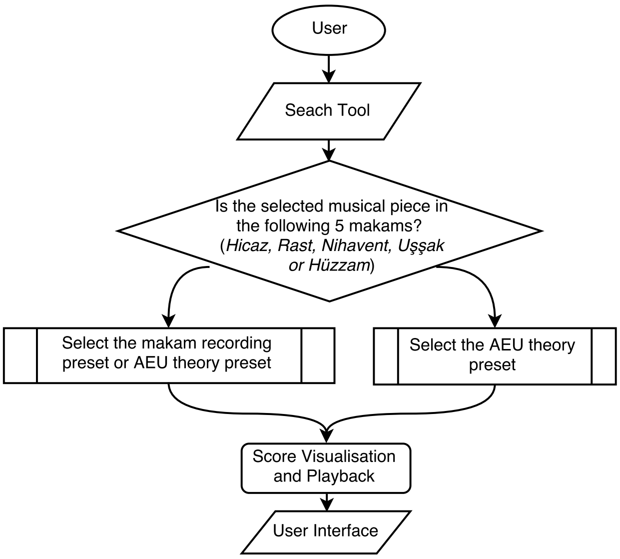

Figure 3: The flow diagram of the desktop software

A screenshot of the score playback window is shown in Figure 4. Remember that, we have the mapping between the synthesized audio and the note indices in the MusicXML score (Section 4.5) and also the mapping between the note indices in the MusicXML score and the SVG score (Section 5.1). Therefore, we can synchronize the SVG score and the synthesized audio. The current note in playback is highlighted in red on the rendered SVG score.

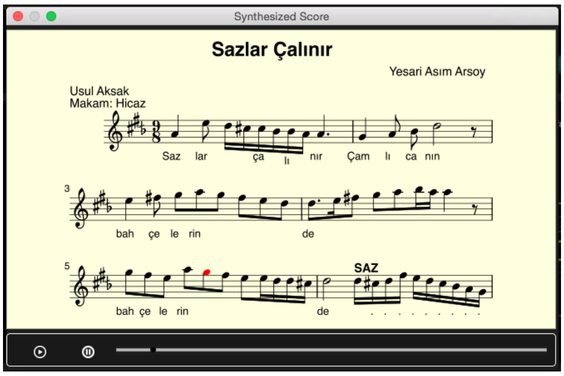

Figure 4: A screenshot of the playback window of the software

6. DISCUSSIONS AND CONCLUSIONS

In this paper, an automatic synthesis and playback methodology that allows users to listen a music score according to a given tuning system or according to the tuning extracted from a set of audio recordings is presented. We have also developed a desktop software that allows users to discover a TMM score collection. As a proof-of-concept,

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[22] `https://www.djangoproject.com/`

[23] `https://www.postgresql.org/`

[24] `https://github.com/MTG/pycompmusic`

[25] for TMM: `http://dunya.compmusic.upf.edu/makam/`.

[26] `https://github.com/MTG/dunya-desktop`

[27] `https://wiki.python.org/moin/PyQt`

we apply the software on the SymbTr score collection. According to the feedback we have received from musicians and musicologists, the playback using the extracted tuning from a performance provides a better experience. In the future, we would like to verify this feedback quantitatively by conducting user studies. We would also like to improve the synthesis methodology by incorporating the score-informed tuning and intonation analysis (Şentürk, 2016, Section 6.11) obtained from audio-score alignment (Şentürk et al., 2014).

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