Knowledge-Based Systems 67 (2014) 169–179

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

A probability model for key analysis in music

Lorenzo J. Tardón *, Isabel Barbancho, Ana M. Barbancho, Carles Roig

Universidad de Málaga, Andalucía Tech, ATIC Research Group, E.T.S.I. Telecomunicación, Campus de Teatinos s/n, E29071 Málaga, Spain

ARTICLE INFO

Article history:
Received 6 December 2013
Received in revised form 28 February 2014
Accepted 10 May 2014
Available online 20 May 2014

Keywords:
Music information retrieval (MIR)
Key probability model
Key profile model
Key analysis
Tonal behaviour
Pitch Class Profiles

ABSTRACT

This paper presents a novel method to analyse the tonal behaviour of a music piece. The method is based on the development of a novel probability model of the predominant key using the well known Pitch Class Profile (PCP or chroma) descriptor. This feature represents the importance of each note of the chromatic scale within the spectral content of the audio signal.

Making use of PCP feature, a main novel contribution presented is the development of new profile models for the characterization of major and minor keys. Most of the key profile models found in the literature assign a single value to each pitch class for a particular key. This value represents the salience of this pitch class in a specific key. The new key profiles, that will be described in this paper, are based on the identification of specific probability density functions (PDFs), defined after the analysis of the presence of the pitch classes of the chromatic scale in the different keys.

1. Introduction

In the last years, key or tonality analysis has become a common subject of study in the music information retrieval community. A main reason for this fact is that tonality is an important concept in musical theory since the key justifies the presence of each note within a piece of music and its relation to nearby notes. Also, the psychological perception of music is strongly determined by its tonal behaviour [1].

Every key is associated with a hierarchy of the pitches of the musical scale [2,3]. This hierarchy establishes an ordering of the importance of the pitches. These relations are defined upon the concept denominated scale degree (Fig. 1). The tonic note is the centre of the key, around this note, the other degrees are organized with the dominant being the second most important degree. The dominant and the subdominant note define the tonal degrees set. On the other hand, the modal degrees set, that determines the mode of the key (mainly major or minor), is formed by the mediant, submediant, leading tone and also, although less important, the supertonic. In the minor mode, the seventh degree is called subtonic because the distance between this degree and the tonic degree is one tone, instead of a semitone as in the major mode [4].

These degrees are defined for the diatonic scale (seven elements). However, a large number of studies on key estimation use the chromatic scale (12 elements), so it is common to define 12 pitch classes ($C, C^{\#}, D, D^{\#}, E, F, F^{\#}, G, G^{\#}, A, A^{\#}$ and B) for each key mode [5]. Then, C major and c minor keys are taken as reference of major and minor keys, respectively. In this way, all the results and conclusions obtained for these pitch classes can be equally applied to each of the 24 keys (12 major and 12 minor keys) by transposition of these sets of pitch classes [4].

Most studies about tonality and key analysis are based on the model defined by Krumhansl and Kessler in [6]. The major and minor key profiles defined by Krumhansl and Kessler are based on experimental data and represent the importance of the 12 pitch classes in major or minor keys. The key estimation algorithm finds the largest correlation between an input vector that represents the estimated Pitch Class Profile (PCP) and the possible key profiles. Note that the utilization of the PCP was originally proposed by Fujishima [7] and it is commonly employed for the detection of chords [8] and key profiles.

Temperley [9] modified Krumhansl's model taking into account fundamental aspects of music theory, like the importance of the dominant seventh. He also replaced the correlation score by the scalar product. Later, in 2002, Temperley developed a new tonal model using Bayesian principles to determine the key of a MIDI piece of music [10,11].

In recent years, many researchers have used the key profiles defined by Krumhansl [6] and Temperley [9] as reference for key analysis. In [12], Izmirli compared the key estimation results obtained using three different chroma profiles: Krumhansl's, Temperley's and the flat diatonic profiles. Then, Izmirli defined a number of templates computed by a weighted combination of the spectra obtained from the recorded waveforms of monophonic

* Corresponding author. Tel.: +34 952131188; fax: +34 952132027.
E-mail addresses: lorenzo@ic.uma.es (L.J. Tardón), ibp@ic.uma.es (I. Barbancho), abp@ic.uma.es (A.M. Barbancho), carles@ic.uma.es (C. Roig).

http://dx.doi.org/10.1016/j.knosys.2014.05.015
0950-7051/

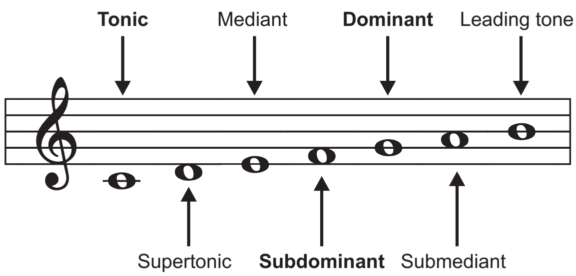

Fig. 1. Scale degrees of the *C* major key.

notes. Later, Izmirli [13] presented two different models for key detection: the first model was based on the idea of the correlation with templates and the second one used a tonal representation of reduced dimensionality based on Principal Component Analysis (PCA).

Gómez [14,15] developed another similar method for key identification based on a modified Pitch Class Profile (PCP) called Harmonic Pitch Class Profile (HPCP). The main differences with other methods are the increase of the frequency resolution to less than one semitone and the fact that the influence of the notes' harmonics is taken into account in the analysis. Also, in this paper, Gómez considered machine learning methods for key estimation using HPCP. Other researchers focused on audio tonality mode classification using chroma features [16].

In this paper, a novel concept of key profile model is presented that is able to lead to the design of new key analysis and detection systems. The new key profile models defined constitute a more detailed representation of the real contribution of each pitch class to a specific key based on probabilistic concepts. In the model developed, the conventional key profiles (major and minor) are replaced by two sets of twelve probability density functions (PDFs). One set of PDFs will characterize major keys and another one minor keys. Each PDF in these sets will account for the probability of each grade in each key. Using these probabilistic models, instead of the commonly used scalar values of the classic profile models, a procedure will be developed to estimate the most probable key of a musical piece. The experiments done and the good results obtained in the well known MIREX contest [17] show the good performance of the methods developed and validate the new profile models proposed.

The paper is organized as follows: in Section 2, the new profile models for key characterization of polyphonic music are presented. In Section 3, the key detection method based on the new probability based Pitch Class Profiles is proposed. Experimental results, comparisons and a global discussion on the performance of the method are presented in Section 4. Finally, some conclusions are drawn in Section 5.

2. Development of a probability based key model for polyphonic music

In this section, we will describe the procedure followed to define a new probability model for key analysis in music. This model is based on a probabilistic analysis of the presence of each of the pitches in the different keys. This approach will lead to the definition of two sets of 12 probability density functions that will replace the commonly used key profiles, i.e. we will completely define a PDF for each degree in each key.

Recall that the key of a piece of music determines the set of tones that are used in the melodic line of the piece. In the case of a monophonic piece, its monophonic nature greatly restricts the tones used in order to obtain a successful harmony induction. Since notes will have to placed sequentially, the composer will have to give enough clues of the desired harmony. This is accomplished by including enough chord tones and avoiding too many passing tones that can blur the harmonic sensation [18]. In addition, there are some dissonant intervals that should be avoided [19]. This fact makes the voicing of monophonic music predictable and restricts the number of available solutions regarding a fixed key and a harmonic progression. On the other hand, the voicing of tonal behaviour becomes considerably more flexible in polyphonic and multi-instrumental music. Since the composer has simultaneous tracks available, the harmony induction is easily achievable. However, the composition also becomes more complex since the voicing of simultaneous several instruments complicate the correct connection of the tones without infringing any harmonic rule [19]. In our analysis, we will not consider monophonic and polyphonic separately.

A flowchart of the procedure developed to define our key model is shown in Fig. 2. A dataset with musical pieces labelled with the

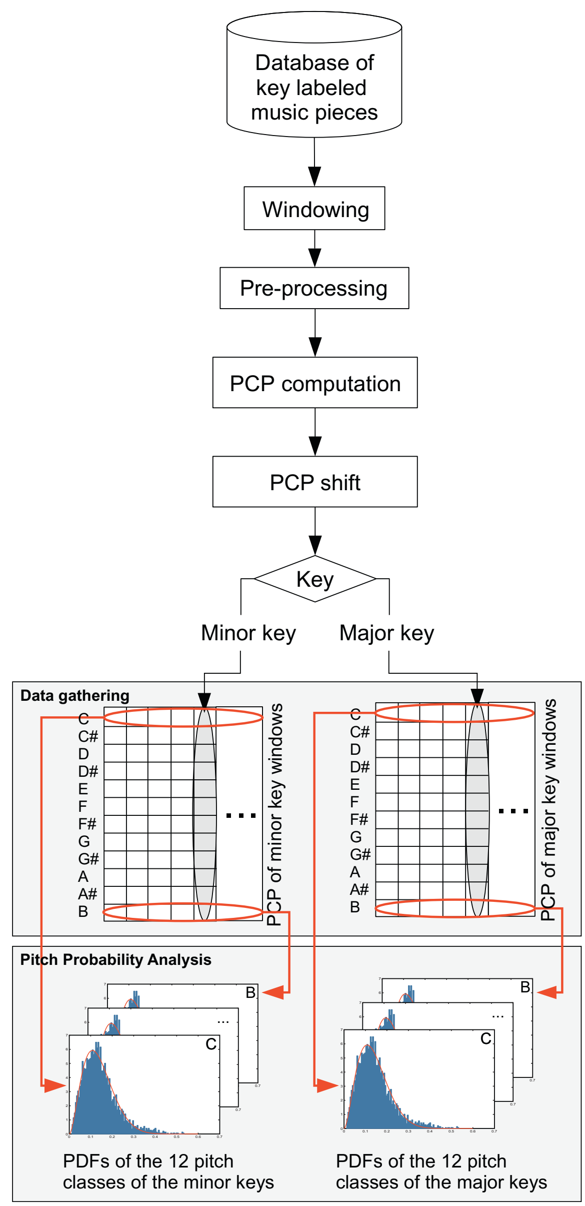

Fig. 2. Flowchart of the procedure developed for the determination of a probability based key model for polyphonic music.