Automatic Detection of Melodic Patterns in Flamenco Singing by Analyzing Polyphonic Music Recordings

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Abstract

In this work an analysis of characteristic melodic pattern in flamenco fandango style is carried out. Contrary to other analysis, where corpora are searched for characteristic melodic patterns, in this work characteristic melodic patterns are defined by flamenco experts and then searched in the corpora. In our case, the corpora were composed of pieces taken from two fandango styles, Valverde fandangos and Huelva capital fandangos. The chosen styles are representative of fandango styles and are also different as for their musical characteristics. The patterns provided by the flamenco experts were specified in MIDI format, but the corpora under study were provided in audio format. Two algorithms had to be designed to accomplish the goal of our research: first, an algorithm extracting audio features from the corpus and outputting a MIDI-like format; second, an algorithm to actually perform the search based on the output provided by the first algorithm. Flamenco experts assessed the results of the searches and drew conclusions.

1. Introduction

1.1 Motivation and context

By its very nature, musical styles have always been controversial, complex and often easy to be misconstrued as far as its definition is concerned. The definition of musical style may be approached from many angles, namely: from pure musical analysis, from a sociological perspective, from a geographical perspective, or the more classical historical and comparative standpoints. Crocker [Cro86] defines musical style as a distinctive manner of presentation, construction and execution in music. His definition, although concise, circumvents the delicate question of what common elements can be identified in musical style. The processes pointed out by Crocker are distilled into a categorization that we termed musical style, this being the result of complex interactions of geographical, social and culture aspects with physiological and psycho-acoustical aspects. However vehemence that interaction might be, some elements should remain constant in order to safely speak of categories. Carterette and Kendall [CK99] contend that, at the level of "deep" structure, certain organizational principles remains identical. Levitin [Lev99] identified up to eight attributes in melody: pitch, rhythm, tempo contour, timbre, loudness, spatial, location, and environmental reverberation. Among these attributes, pitch contour -which implies both pitch and rhythm configuration- seems to be the most sensitive to change and, therefore, the most distinguishing feature (see [RB03] and the references therein).

Apropos of melodic patterns, Conklin [Con09] notices that patterns can evince musicological interest in isolation, but they can also be viewed as global features defining music style. This remark poses the problem of the level of abstraction in melodic representation. Indeed, a good level of abstraction is needed, as both very specific and very abstract patterns will reveal little about the style.

Thus, the study of characteristic melodic patterns is relevant to musical style, more so in the case of oral traditions, where many reveal a strong melodic nature. Flamenco music is an oral tradition where voice is an essential element. Hence, melody is a predominant feature and many styles in flamenco music can be characterized in melodic terms. However, in flamenco music the problem of characterizing styles through melodic patterns have received scant attention. In this paper characteristic melodic pattern, that is, melodic patterns that make a given style recognizable are studied. Two main approaches to the study of characteristic melodic patterns can be adopted. In the first, music is analysed to discover characteristic melodic patterns [Con10a] (distinctive patterns in his terminology); see, for example, [Con10b] for a practical application of this approach to finding characteristic patterns in Brahms' string quartet in C minor. Normally, the found patterns are assessed by musicologists to determine how meaningful they are; it is, essentially, an inductive method. The second approach is in certain sense complementary to the first. In this second approach, melodic patterns known or hypothesized to be characteristic are searched in the music. The results will allow musicologists to study important aspects of the given musical style, including confirming musical hypothesis previously formulated. Techniques to carry out those searches greatly vary according to the given situations, such as music representation (symbolic or audio representation), the style itself, or available corpora. This approach could be qualified as deductive.

In this paper, we adopted the second approach. Certain characteristic melodic patterns, carefully selected by a group of flamenco experts, were searched in a corpus of flamenco songs belonging to the style of fandango. At first sight, it seems that searching for a pattern in a piece of music should be easy. However, that is not so in the case of flamenco because of many reasons. First, most of the music is in audio format only. Also, flamenco music uses intervals smaller than a half-tone and is not strict about tuning. Furthermore, a given abstract melodic pattern can be sung in many different ways, sometimes undergoing dramatic transformations, and still be considered the same pattern within the flamenco style. Therefore, there is a technical problem to deal with, as we will see later on.

Preliminary work on detecting ornamentation in flamenco music was done [GPM11]. In that work, the authors studied ornamentation in flamenco music from the same deductive standpoint. They defined a set of ornaments, mainly taken or adapted from classical music, and looked up those ornaments in an audio-recorded flamenco corpus of *tonás* styles. In [MGG10] a melodic study of flamenco a cappella singing styles was performed.

1.2 Goals

The goal of this work is to study how certain characteristic patterns of a particular fandango style, that of Valverde fandango, are found in another fandango style, Huelva fandango. The flamenco fandango style evolved from folk fandango styles to its current flamenco form. This study tries to elucidate how that evolution took place by means of the examination of the possible common characteristic patterns.

As stated above, patterns were specified by flamenco experts in an abstract way. Then, from a technical point of view, the main problem was two-folded. First was the problem of how to transcribe the music, since flamenco is an oral musical tradition and transcriptions are meagre. Moreover, audio files contained both guitar and voice, and source separation had to be carried out. The final output was a MIDI-like sequence of pitch and duration representing the vocal line. Second was the problem of locating the characteristic patterns in the transcribed music. Our final algorithm combined several ideas taken from different local alignment algorithms.

As a final step, flamenco experts reviewed and assessed the results obtained from searching the specified characteristic patterns in the Huelva fandangos corpus. Several similarity threshold were set to examine the level of similarity between the distinctive patterns and results returned by the algorithm. In general, results were consistent with the flamenco experts' expectancies.

2. The Fandango Style

Fandango is one of the most fundamental styles in flamenco music. Fandangos are known at present as flamenco *cantes* (this word means song in the flamenco jargon), but at the beginning of the XIX century in most of Spain, this word meant a kind of festive gathering where dance was the fundamental part [Ber00]). The origin of the word comes from a Spanish dance style already known at the end of the XVII century. There are two main regions where the fandango has its distinct own musical characteristics in Andalusia: Malaga (verdiales fandangos) and Huelva (Huelva fandangos).

Verdiales fandangos are traditional folk *cantes* related to dance and a particular sort of gathering. There are local variants of these fandangos in some areas of the provinces the Cordoba, Jaen, Granada, Almeria, and also Murcia. The musical accompaniment is provided by one or more guitars, a violin and sometimes lutes and *bandurrias* (a type of Spanish mandolin). They used to have some percussion accompaniment with castanets, tambourine and little cymbals. The singing style is melismatic and flowing at the same time. This style gave rise to the eastern flamenco fandango styles such as malagueñas, granainas, rondeñas, tarantos, tarantas, mineras and cartagenas.

The oldest references about Huelva fandangos date back to the second half of the XIX century. Huelva fandangos are usually sung accompanied just with a guitar, but it still remain some places, like Almonaster or Cerro de Andevalo, where the old instrumentation with flute and tabor is preserved. At present Huelva fandangos are the most popular ones, displaying a great profusion of variants. They can be classified according to the following criteria: (1) Geographical origin: from the mountains (Encinasola), from Andévalo (Alosno), from the capital (Huelva capital fandango); (2) Tempo: fast (Calañas), medium (Santa Barbara), or slow (valientes from Alosno); (3) Tradition: village (Valverde), mainly traditional, or personal, those fandangos created out the tradition by important singers (Rebollo). More information on the different styles of fandango can be found in [Góm05].

Musically speaking, all fandangos have a common formal and harmonic structure composed of an instrumental refrain in flamenco mode (major Phrygian) and a sung verse or *copla* in major mode. The tonic of this major mode is the VI degree of the flamenco mode of the instrumental refrain. Fandangos can be closer to the folkloric style, or be interpreted in flamenco style, with predominance of melismas and greater freedom in terms of rhythm. The former kind of fandangos has a singular characteristic and that is the contradiction between the ternary rhythmic accents and the binary harmonic accents. In the *copla* each verse or *tercio* has a duration of 12 beats (four measures in 3/4 time signature). The latter kind of fandangos comprises many other styles such as *valiente* fandangos. The reader is referred to [Fer04] and [Fer11] for further information on the musical description.

The study of the fandangos of Huelva is interesting in its own. A few reasons supporting this claim are the following: (1) Identification of the musical changing processes in the evolution of folk styles to flamenco styles; (2) Definition of styles according to their melodic similarity; (3) Identification of musical variables defining each style; this includes melodic and harmony pattern discovery; (4) Establishment of links to other flamenco styles such as *soleá* or *bulería*; (5) Study of the relationships between the fandango and other musical styles, such as the Mexican fandangos (see [GdL92]).

3. The Characteristic Patterns of Fandango Styles

Patterns heard in the exposition (the initial presentation of the thematic material) are fundamental to recognizing fandango styles. The main patterns identified in the Valverde fandango style are shown in Figure 1. Those patterns are named as follows: *exp-1*, *exp-2*, *exp-4*, and *exp-6*. The number in the name of the pattern refers to the phrase it occurs in.

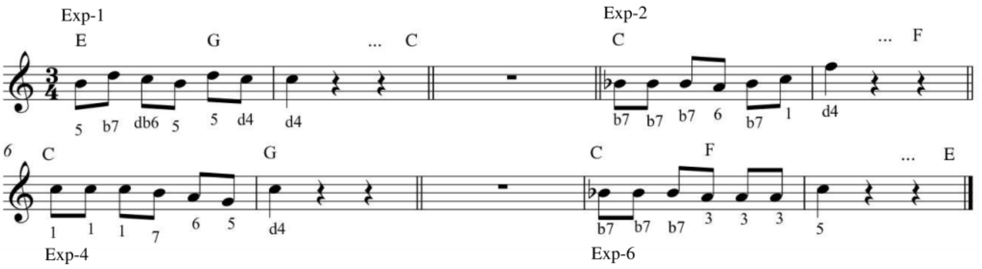

Figure 1: Characteristic patterns in Valverde fandango.

Pattern *exp-1* is composed of a turn-like figure around the tonic. Pattern *exp-2* basically goes up by a perfect fifth. First, the melody insists on the B flat, makes a minor-second mordent-like movement, and then rises with a leap of a perfect fourth. Pattern *exp-4* is a fall from the tonic to the fourth degree by conjunct degrees followed by an ascending leap of a fourth. Pattern *exp-6* is a movement from B flat to the tonic. Again, the B flat is repeated, then it goes down by a half-tone and raises to the tonic with an ascending minor third. The rhythmic grouping of the melodic cell is ternary (three eighth notes for B flat and three eighth notes for A).

Again, notice that this is a symbolic description of the actual patterns heard in the audio files. Any of these patterns undergo substantial in terms of duration, sometimes even in pitch, not to mention timbre and other expressive features.

3.1 The Corpus of Fandango

The corpus employed in our study was provided by *Centro andaluz de flamenco de la Junta de Andalucía*, an official institution whose mission is the preservation of flamenco music as cultural heritage. This institution possesses around 1200 fandangos, from which only 241 were selected. Four criteria for this selection were adopted, namely: (1) Audio files should contain guitar and voice; (2) Audio files should have enough recording quality so that they could be automatically processed; (3) Fandangos should be interpreted by singers from Huelva or acknowledged singing masters; (4) Time span of the recordings should be broad, in this case it ranges from 1950 to 2009.

This corpus was gathered for a larger project to investigate fandango in depth. The sample taken is broadly representative of styles and tendencies over time. The present paper represents the first work and, consequently, only 60 fandangos were taken, 30 Valverde fandangos and 30 Huelva capital fandangos. The styles that were not used in the experiment are Valientes of Huelva fandangos, Valientes de Alosno fandangos, Calañas fandangos, and Almonaster fandangos. All pieces were extracted in wav format, monophonic audio with 16 bit-depth and 44 Khz sampling rate.

4. Computational Method

4.1 Audio Feature Extraction

As already mentioned, written scores in flamenco music are scattered and scant. This can be explained to some extent because flamenco is music of oral transmission. The issue of what the best method to transcribe would be is quite controversial in the flamenco community. Some authors are in favour of Western notation, such as Hurtado and Hurtado [HTHT02], whereas others propose different methods, as Donnier [Don97], who advocates the use of plainchant neumes. In view of this controversy, for our work we used a more technological approach, consisting of automatic transcription through audio feature extraction.

Let us describe how this audio feature extraction algorithm works. Our goal was to extract the vocal line in an adequate format that at the same time was musically meaningful and could serve as input to the pattern detection algorithm. The audio feature extraction was mainly based on predominant *F*0 estimation from polyphonic signals. For this, we drew upon the work of

Salamon and Gómez [SG11, SG12]. Their algorithm is composed of four blocks. First, they extract spectral peaks from the signal by taking the local maxima of the short-time Fourier transform. Next, those peaks are used to compute a salience function representing pitch salience over time. Then, peaks of the salience function are grouped over time to form pitch contours. Finally, the characteristics of the pitch contours are used to filter out non-melodic contours, and the melody *F*0 sequence is selected from the remaining contours by taking the frequency of the most salient contour in each frame. Further details can be found in the two aforementioned references.

4.2 Pattern Recognition Method

The pattern detection method that is used in this paper is an extension of the so-called "Context-Dependent Dynamic Time Warping" algorithm (CDDTW), which was originally proposed by the authors in [PTK03]. Although standard dynamic time warping schemes assume that each feature in the feature sequence is uncorrelated with its neighboring ones (i.e. its context), CDDTW permits flexible grouping of neighboring features (i.e. forming feature segments) in order to exploit possible underlying mutual dependence. This is particularly useful in the case of noisy pitch sequences, because it permits canceling out several types of pitch tracking errors, including pitch halving/doubling errors and intervals that are broken to a sequence of subintervals. Furthermore, in the case of melismatic music, the CDDTW algorithm is capable of smoothing variations due to the improvisational style of singers or instrument players. For a more detailed study of the CDDTW, the reader is referred to [PTK03].

A drawback of CDDTW is that does not take into account the duration of music notes and focuses exclusively on pitch intervals. Furthermore, CDDTW was originally proposed for isolated musical patterns (pre-segmented data). The term isolated refers to the fact that the pattern that is matched against a prototype has been previously extracted from its context by means of an appropriate segmentation procedure, which can be a limitation in some real-world scenarios, like the one we are studying in this paper. Therefore, we are here proposing a the following extension to CDDTW algorithm:

• First, removes the need to segment the data prior to the application of the matching algorithm. This means that the prototype (in our case the time-pitch representation of a MIDI pattern) is detected directly on the pitch sequence of the uninterrupted audio stream, i.e. the pitch sequence that was extracted from the polyphonic fandango.

• Second, takes into account the note durations in the formulation of the local similarity measure. In addition, the new algorithm permits to search for a pattern iteratively, which means that multiple instances of the pattern can be detected, one per iteration.

A detailed description of the extension of the algorithm is beyond the scope of this paper. Instead we summarize the basic steps:

1.The MIDI pattern to be detected is first converted to a time-pitch representation

$$P = \{[f_1, t_1]^T, [f_2, t_2]^T, \ldots, [f_J, t_J]^T\},$$

where f_i is the frequency of the *i*-th MIDI note, measured in cents (assuming that the reference frequency is 55 Hz) and t_i the respective note duration (in seconds), for a MIDI pattern of *J* notes.

2.Similarly, the pitch sequence of the audio recording is converted to the above time-pitch representation,

$$R = \{[r_1, tr_1]^T, [r_2, tr_2]^T, \ldots, [r_I, tr_I]^T\},$$

where r_i is a pitch value (in cents) and tr_i is always equal to the short-term step of the feature extraction stage (10*ms* in our case), for an audio recording of *I* notes. In other words, even if two successive pitch values are equal, they are still treated as two successive short notes, whose length is equal to the short-term step of the feature extraction stage. This approach was adopted to increase the flexibility of the dynamic time warping technique to the expense of increased computational complexity. For the sake of uniformity of representation, each time interval that corresponds to a pause or to a non-vocal part is inserted as a zero-frequency note and is assigned a respective time duration.

3.Sequences R and P are placed on the vertical and horizontal axis of a similarity grid, respectively. The CDDTW algorithm is then applied on this grid, but, this time, the cost to reach node (i, j) from an allowable predecessor, say $(i-k, j-1)$, depends both on the pitch intervals and the respective note durations. More specifically, the interpretation of the transition

$$(i-k, j-1) \rightarrow (i, j)$$

is that the respective pitch intervals in the MIDI pattern and audio recording are equal to $f_j - f_{j-1}$ and $r_i - r_{k-1}$, respectively. Note that on the y-axis, the pitch interval only depends on the end nodes of the transition and not on any intermediate pitch values, hence the ability to cancel out any intermediate pitch tracking phenomena. In the same spirit, the time duration that has elapsed on the x–axis and y–axis is equal to t_j and $\sum_{i-k+1}^{i} tr_k$, respectively. It is worth noticing that we do not permit omitting notes from the MIDI pattern, and therefore any allowable predecessor of (i, j) must reside in column $j-1$. After the pitch intervals and respective durations have been computed, they are fed to a tree-structured similarity function, that yields a score for the transition and this procedure is repeated for every allowable predecessor of (i,j). In the end, one of them is chosen as the winner by summing the similarity of the transition with the accumulated similarity at the predecessors.

4.After the accumulated cost has been computed for all nodes in the grid, the maximum accumulated cost is selected and, if it exceeds a predefined threshold, a standard backtracking procedure reveals which part of the audio recording has been matched with the prototype; otherwise, the algorithm terminates.

5.All nodes in the best path are marked as stop-nodes, i.e. forbidden nodes and Steps 1-4 are repeated in order to detect a second occurrence of the prototype and so on, depending on how many patterns (at most) the user has requested to be detected.

5. Evaluation of Results

Four different exposition patterns were defined by the experts, which are distinctive of the Valverde style. The Valverde fandango has 6 exposition phrases in each *copla* (sung verse), where 1, 3 and 5 are usually the same pattern, and 2, 4 and 6 have different patterns each. Therefore, 4 exposition patterns (1, 2, 4, and 6) were chosen to be put to the test. Again, we insist that these patterns are abstract representations of the actual patterns heard in the audio files. Our algorithm then was run to find those four patterns in the corpus of Valverde fandangos and Huelva capital fandangos. Results are summarized in Tables 1 and 2. The algorithm have a similarity threshold in order to carry out the experiments in a more flexible and efficacious way. Once a particular value of the threshold is set, the algorithm only returns those patterns whose similarity value is higher than the similarity threshold. In our experiments we used three similarity thresholds, namely, 60%,70%, and 80%.

Valverde fandangos								
Pattern	Similarity threshold	Total expected	Total found	True positives	False positives	Precision	Recall	F-measure
Exp-1	60%	90	25	24	1	96%	40%	0.41
	70%	90	15	15	0	100%	25%	0.28
	80%	90	6	6	0	100%	10%	0.12
Exp-2	60%	30	13	13	0	100%	65%	0.6
	70%	30	7	7	0	100%	35%	0.37
	80%	30	1	1	0	100%	5%	0.06
Exp-4	60%	30	16	9	7	56%	45%	0.39
	70%	30	11	6	5	54.54%	30%	0.29
	80%	30	3	3	0	100%	15%	0.18
Exp-6	60%	30	15	10	5	66.66%	50%	0.44
	70%	30	8	8	0	100%	40%	0.42
	80%	30	3	3	0	100%	15%	0.18

Table 1: Results of the experiments for Valverde fandangos.

Since both fandango styles are quite different, it is not expected to find any of the exposition patterns as such. Hence, it would be otiose to reproduce computations like those in Table 1 as the total expected number of occurrences would be zero. Table 2 just shows the occurrences of the four exposition patterns in the Huelva capital fandangos.

Huelva capital fandangos			
	60%	70%	80%
Exp-1	1	0	0
Exp-2	0	0	0
Exp-4	14	7	3
Exp-6	11	6	4

Table 2: Results of the experiments for Huelva capital fandangos.

From a quantitative point of view the algorithm has proved a reasonably good performance in finding the patterns in the melody, despite of the problems posed by the polyphonic source, the highly melismatic content, and the note-duration variation. Regarding performance measures, on the one hand, precision is quite high, but, on the other hand, recall is low. Most of the values of F-measure are around $0.3-0.45$, with a few isolated exceptions. The algorithm is able to find the patterns at the right places in the pieces, but still misses many occurrences.

From a qualitative point of view, the evaluation of the experiment shows interesting results.

- *Exp-1*: This pattern is the exposition of the first phrase of the fandango. The most typical lyrics for this fragment are *Valverde de mi Valverde*. When the aficionado listens to the MIDI pattern, he or she immediately recognizes the Valverde style or the variant. Interestingly enough, not only the algorithm does find the pattern correctly in the first phrase of the Valverde fandango, but also in other phrases. Indeed, it identifies the pattern as a leit-motiv throughout the piece. The presence of this leit-motiv suggests that this fandango style is related to certain folk music styles, where *cantes* are more repetitive and sung in choirs. This pattern was detected only once by the algorithm in the Huelva capital fandangos, but it was found in an isolated transition.
- *Exp-2*: Here we have the pattern of the second exposition phrase in Valverde fandangos. This is the musical passage with the amplest tessitura of this variant. The algorithm detects it correctly in the Valverde corpus from 70% up, and there are no matches in the Huelva capital fandangos.
- *Exp-4*: In the Huelva capital fandango corpus this pattern is detected by the algorithm in the transition between phrases. This points to some influence of Valverde fandango upon Huelva capital fandango, which would be worth investigating. The influence is not that obvious to

perceive as the patterns appears in different modal contexts. When the similarity threshold is set to 70 % and 60 %, the algorithm still finds the pattern correctly in the Huelva capital corpus. We can state that pattern is there, more or less blurry or sketched, but still present.

In the Valverde corpus, at 80 % the algorithm finds this pattern only in the *cantes* sung by girls trained at flamenco clubs in Huelva. Those clubs are called *peñas flamencas*. Normally, *peñas* organize singing lessons. Girls from *peñas* are trained to sing very standard models and, therefore, they do not contribute in terms of innovation as other singers of fandango do (for instance, singers such as Toronjo or Rengel).

At 70 % and below this threshold, we find the well-established, acclaimed voices of fandango singing. The similarity distance increases on Toronjo, perhaps due to its particular vocal technique. Raya, another great figure, is also detected by the algorithm. Here we can pose the question of whether the system is sensitive to the hoarse voice of singers like Toronjo as opposed to the clean voices of the girls of flamenco clubs. Furthermore, the algorithm seems to be sensitive to dynamic. Toronjo has peaks and valleys in dynamics, where the children school has a rather flat singing, much less expressive. The algorithm detects the canon but not the personal "trait".

• *Exp-6*: This is a pattern used as preparation for the final cadence of the last phrase. In the Huelva capital corpus and at 60% and 70% of the similarity value, the algorithm finds it at a macro-structure level, that is, it finds it in the beginning, in the middle, and in the final section. When the similarity threshold is raised to 80%, then it is only found in the final cadence. For the Valverde corpus, at all levels of similarity, the algorithm returns correct results, although as pointed out above, it still misses many results. Again, at high similarity values, the pattern is only found in the final cadence.

6. Conclusions

In this work we have carried out a study of fandango styles through the analysis of archetypal melodic patterns. The problem that we tackled comprised different aspects. As already insisted, in flamenco no written scores are in general available; hence, symbolic analysis have left for future research. We designed an algorithm to extract a MIDI-like representation from the fandango corpus that at the same time were meaningful and tractable. After this step, a algorithm was designed to find the patterns in the given corpora. Our algorithm has proved to be robust inasmuch it was able to find the abstract patterns in the corpora in spite of the fact that music was polyphonic, there was a great deal of melismas as well as a high degree of tempo deviation. Still, some computational aspects of the algorithm could be still improved, such as time complexity. On the musicological side, we investigated the problem of finding certain archetypal patterns specified by flamenco experts in actual corpora of fandango styles. The presence and the position of the melodic patterns in the fandango provides important information. For instance, it could help to understand the evolution of fandango styles. Also, a complementary approach to analysing fandango style is Schenkerian analysis (see [Esc12]). This kind of analysis would provide a better understanding of the deep structure of these styles.

As for future work, this study could be extended to other Huelva fandango styles. A more ambitious goal would be to carry out the analysis for the whole corpus of fandango. Also, other musical features could be taken into account and thus perform a more general analysis, not only based on melody. In particular, form or stylistic ornamentations are suitable candidates for that potential analysis. Regarding the pattern detection algorithm, the main improvement lies in the number of returned results over the number of total expected results (see Table 1), which is still too low. The audio feature extraction algorithm can also be refined, specially in the source separation step.

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