A DYNAMIC PROGRAMMING APPROACH WITH POSITIONAL WEIGHTING WINDOW TO BEAT TRACKING FOR AUDIO MUSIC

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ABSTRACT

Automatic beat tracking is challenging task, especially for audio music with time-varying meters. This study proposes a dynamic programming approach with positional weighting window to handle beat tracking with time-varying meters. In particular, the tempo curve is the reference to obtain correct beat positions. The weighting window is used to adapt bandwidth of tempo which reciprocal represents likelihood of beat position candidates. Combining with the strength of novelty curve, the beat tracking result of dynamic programming surpass those scores of other algorithms for MAZ dataset. The beat tracking algorithm outperforms eight out of ten performance indexes in MIREX2012 contest.

***Index Terms* –** Tempo Curve, Novelty Curve, Time-varying meter, Dynamic programming, Weighting Window

1. INTRODUCTION

Rhythmic information is the essential element in music. The prominent features of rhythm are beat position and tempo which comprise the basic characteristic of music. Although the sense of beat sometimes is obvious for human being, the exact estimation is still challenging task when especially the music has time-varying tempo.

Conventional beat tracking schemes [1] handle certain music contents with stable tempo well. Under the related stable-tempo assumptions, most approaches of beat tracking are accomplished by two phases. In the first phase, the onset detection of music along time, called *novelty curve*, is obtained to indicate the possible positions of note onsets. In the following phase, the quasi-periodic patterns in novelty curve are analyzed to discover the possible tempo value and the corresponding beat positions. Usually in the deduction process, tempo is assumed to be stable throughout the whole piece of music. However, the above-mentioned assumptions do not hold true universally, especially for music of classical and jazz. Music of these genres often has significant tempo variations, making it unreasonable to make the assumption of stable tempo. In our work, we break the assumption of stable tempo. Therefore, we generate the tempogram from the novelty curve, which the tempo information is embedded. Then we apply dynamic programming (DP) to the tempogram to derive the so-called *tempo curve*, which represents the most likely tempo at each time frame which is time-varying.

There are several important previous studies that attempted to deal with time-varying meters. Klapuri et al. [2] used the bandwise time-frequency method to obtain accentuation information, then used comb filter resonators and probabilistic models to estimate pulse width and phase of different music meters, including tatum, tactus, and measurement. Davies and Plumbley [3] proposed the use of complex spectral difference onset function to obtain middle level representation. Their algorithm employs two-state switching model, including general state and context-dependent state, to obtain final beat positions. Groshe and Muller [4] used the novelty curve to generate predominant local pulse (PLP) for estimating time-varying tempos.

There are probabilistic framework studies. G. Peeters [5, 6] and H. Papadopoulos [6] propose a probabilistic framework for estimation of beat and down-beat simultaneously given information of tempo and meter. The probabilistic model is based on HMM (Hidden Markov Model) which has beat-times and their associated beat-position-inside-a-bar (BPIB) as the hidden states. The model is based on non-casual signal observations of the local bar which the beat is located in. This provides the work with an inherent local optimization of the probabilities (an adaptation to the local properties of the signal).

In this study, we follow the three-phase framework [7] of beat tracking and attempt to remove the stable-tempo restriction by developing a two-fold DP approach for robust beat tracking with time-varying tempos. To this end, the first DP estimates the time-varying tempo curve from the tempogram (which is obtained from the novelty curve). Then the second DP uses the time-varying tempo curve to identify the optimum beat positions on the novelty curve. In the second DP, the tempogram strength values adaptive to the weighting window with the relative position to previous beats are obtained by learning process. The current beat position relative to previous beats which are searched in backward or forward direction is determined by a cost function. The following section describes the whole picture of the system and illustrates the detail of positional window weighting.

2. SYSTEM DESCRIPTION

The proposed beat tracking system is shown in Figure 1.

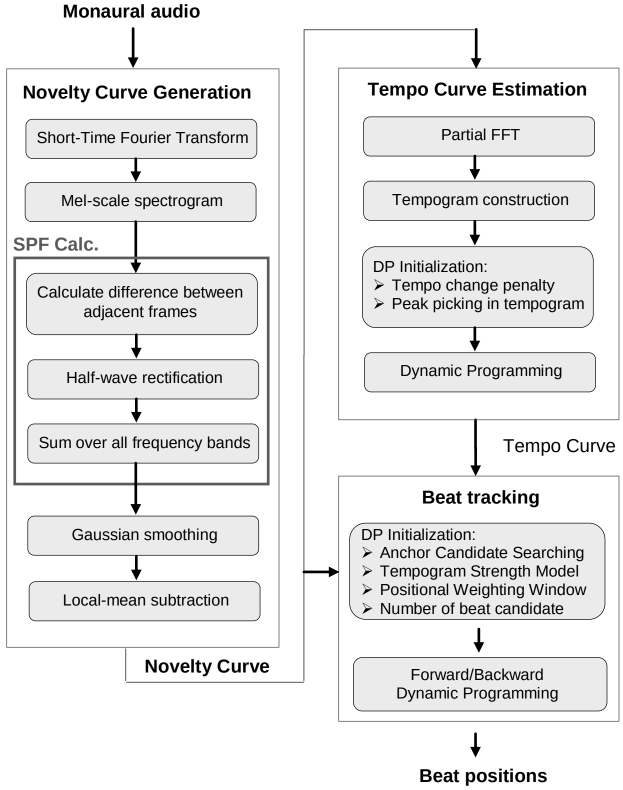

Figure 1. Flowchart of the proposed beat tracking system

The first block computes the novelty curve, while the second block generates the tempogram and estimates the tempo curve from the novelty curve [8]. The third block of beat tracking setups a DP cost model to count the strength of tempogram and relative position window weighting to previous beat position which illustrated in the subsection.

2.1 Positional Weighting Window of the Beat Tracker

This beat tracking block utilizes both the tempo curve and the novelty curve to find a sequence of beat positions that fits the tempo curve and the windowed weighted novelty strengths as much as possible. To achieve this task, we apply another DP-based method in a cost functional framework (just like Viterbi search in speech recognition) to perform forward and backward beat searching, starting from the anchor beat position (the position of the most prominent peak) of the novelty curve. We proposed the tempogram strength model and positional weighting window model to form the state and transition probabilities.

Here we use Figure 2 to explain the probability-based DP method for beat position identification. First of all, we find the maximum of the novelty curve as the first beat position, which is referred to as the anchor candidate. Starting from the anchor candidate, we search on both sides, one side at a time, to calculate all the cost of candidate beat positions.

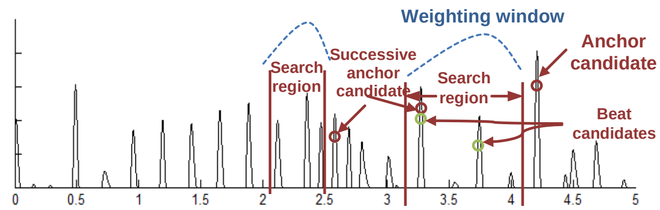

Figure 2. Backward beat search with N =2

The transition probabilities are defined under the positional weighting window showed as the Figure 2, the maximum of the window is on the position with the distance of the current tempo reciprocal, which is between the previous beat position and the possible next beat position. Then we apply DP for the optimum path of beat position.

3. REFERENCES

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