Beat Detection by Dynamic Programming

ECE 272/472 Audio Signal Processing

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Abstract

A beat is a salient periodicity in a music signal. It provides a fundamental unit of time and foundation for the temporal structure of the music. The significance of beat tracking is that it underlies music information retrieval research and provides for beat synchronous analysis of music. It has applications in segmentation of audio, interactive music accompaniment, cover-song detection, music similarity, chord estimation and music transcription. It is a fundamental signal processing task of interest to any company providing information services related to music.

The goal of this project is to implement a beat tracker system and to demonstrate the performance with creative output such as, but not limited to, drumming, pop music or flickering lights.

Objectives

The designed system performs the following fundamental objectives for beat tracking:

- Estimates a global tempo
- Uses the tempo to construct a transition cost function.
- Uses dynamic programming to find the best-scoring set of beat times.

The beat tracking system is designed as follows:

- The front-end processing to convert the input audio into the onset strength envelope.
- The global tempo estimation which provides the target inter-beat interval.

Methods & Theory

The goal of the beat tracker is to generate beat times that correspond both to perceived onsets in the audio signal at the same time as constituting a regular, rhythmic pattern in themselves. We can achieve this using the function below:

$$C(\{t_i\}) = \sum_{i=1}^{N} O(t_i) + \alpha \sum_{i=2}^{N} F(t_i - t_{i-1}, \tau_p)$$

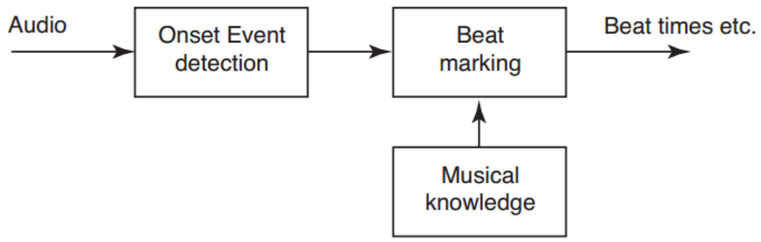
Methods & Theory (Cont..)

where:

- $\{ti\}$ = the sequence of N beat instants found by the tracker
- $O(t)$ = an 'onset strength envelope' derived from the audio.
- α = a weighting to balance the importance of the two terms.
- $F(\Delta t, \tau) = -\left(\log \frac{\Delta t}{\tau}\right)^2$ = a function that measures the

consistency between an inter-beat interval Δt and the ideal beat spacing τ defined by the target tempo.

A block diagram of the system is as follows:



- Onset detection (steps): Resample input to 8kHz → Calculate STFT → Convert to approximate auditory perception → Mel spectrogram in db→ half wave rectification→ reconstruction, filtering and windowing.
- Global tempo Estimate: Estimate time period strength using the following functions:

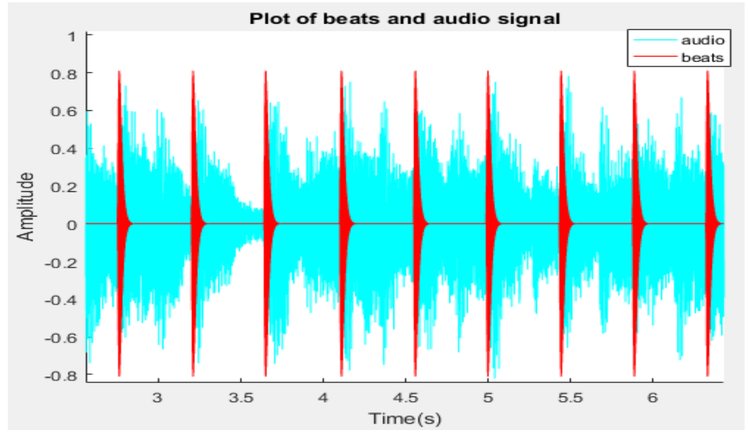
$$TPS(\tau) = W(\tau) \sum_{t} O(t) O(t - \tau)$$

Where W(τ) = Gaussian weighting function on a log time axis:

$$W(\tau) = \exp\left\{-\frac{1}{2}\left(\frac{log_2 \tau / \tau_0}{\sigma_\tau}\right)^2\right\}$$

and τ_0 is the center of the tempo period bias and σ_τ controls the width of the weighting curve.

Results



Plot of the beats detected against the audio signal specified. Note beats are detected at the beginning of the onsets in the signal.

Song	Human-Detected tempo	Machine detected tempo	Difference (absolute)
Song 1	110	109.89	0.11
Song 2	110	109.5	0.5
Song 3	185	186.19	1.19
Song 4	91	55.98	35.02
Song 5	78	59.72	18.28
Song 6	152	88.56	63.44
Song 7	119	80.06	38.94
Song 8	139	140.33	1.33
Song 9	118	118.13	0.13
Song 10	110	112.42	2.42
Average			16.136

Table 1: Showing the performance of the beat detection system in comparison to human beat detection data acquired via Sonic Visualizer system.

Future Work

- Future improvement includes improving the accuracy of the system for very fast beats and a mixture of bits, i.e., ability to isolate different instruments with various beats which are more realistic for current audio signals (i.e., music).
- Improvement on the realistic functioning of the system (real time beat detection).

References

[1] Ellis, Daniel P.W (2007). Beat Tracking by Dynamic Programming, Retrieved: 5/2/2017 'https://www.ee.columbia.edu/~dpwe/pubs/Ellis07-beattrack.pdf

[2] IEEE Signal processing Cup 2017, Real time Beat Tracking challenge, https://piazza-syllabus.s3.amazonaws.com

[3] https://www.slideshare.net/Leejw41/beat-tracking-by-dynamic-programming-3984194 (Author, unknown)