Video-based Vibrato Detection and Analysis for Polyphonic String Music

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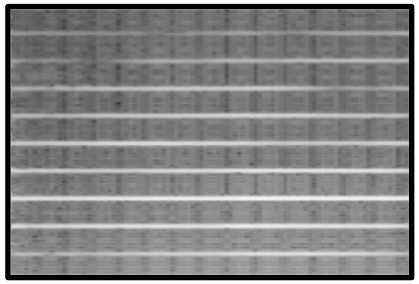
Introduction: Vibrato in Music

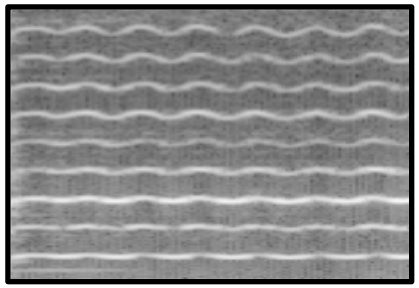
- Important artistic effect
- Pitch modulation of a note in a periodic fashion
- Characterized by Rate & Extent

Audio

Spectrogram



Non-vibrato



Vibrato

Applications of Vibrato Analysis

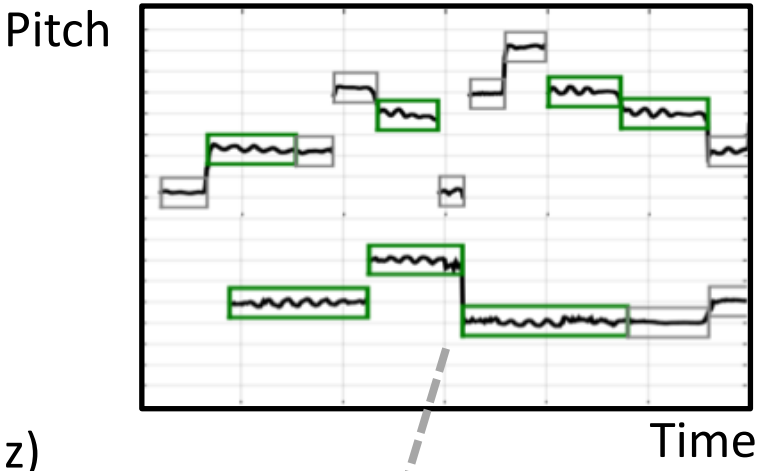
- Musicological studies
- Sound synthesis
- Voice extraction

Introduction: Problem Statement

Vibrato Detection & Analysis for polyphonic music played by string instruments

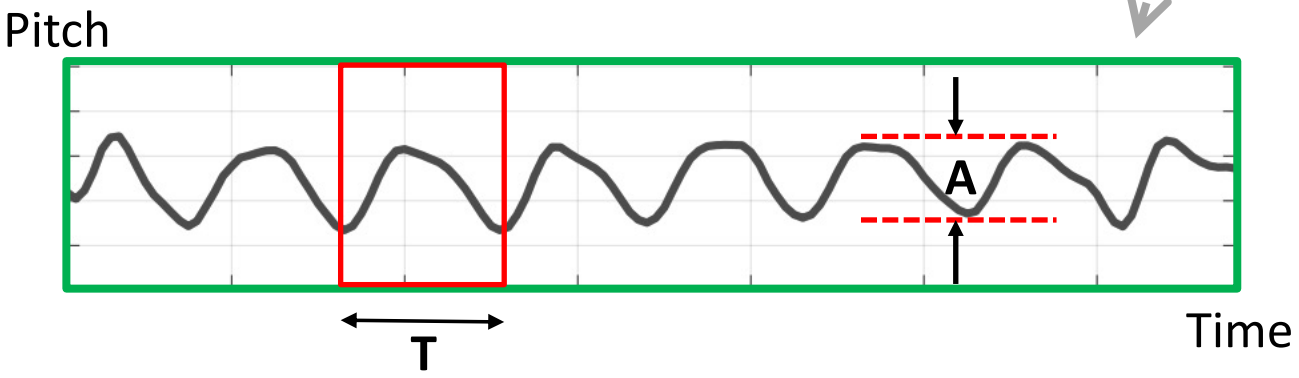
Vibrato Detection

- Note-level vibrato/non-vibrato classification



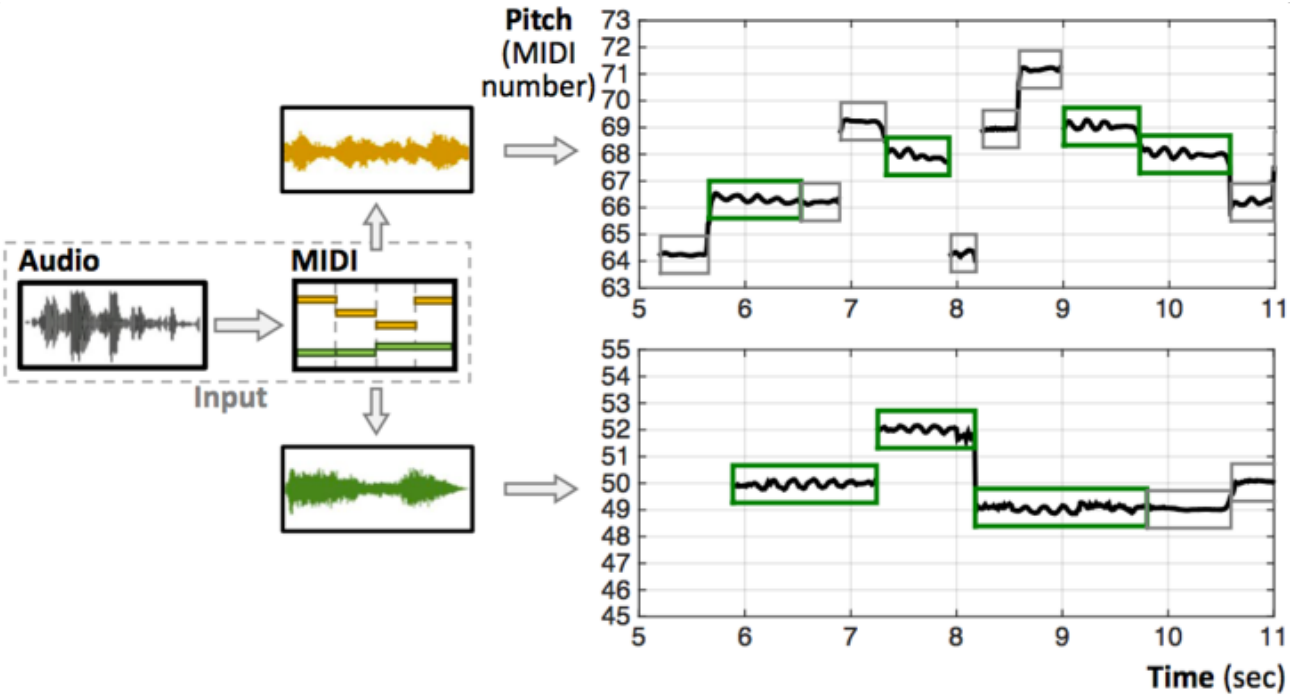
Vibrato Analysis

- Vibrato rate: speed of pitch variation (1/T Hz)
- Vibrato extent: amount of pitch variation (A cents)



Introduction: Prior Audio-based Methods

- Score-informed [Abeßer et al. 2015] (Baseline)



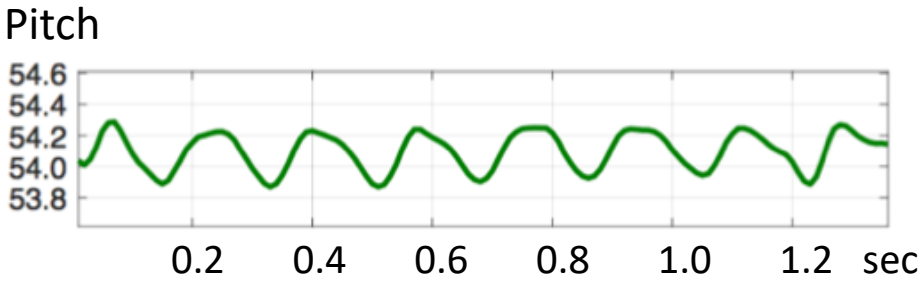
- Template-based [Driedger et al. 2016]
- Harmonic partial [Hsu et al. 2010]

Major drawbacks

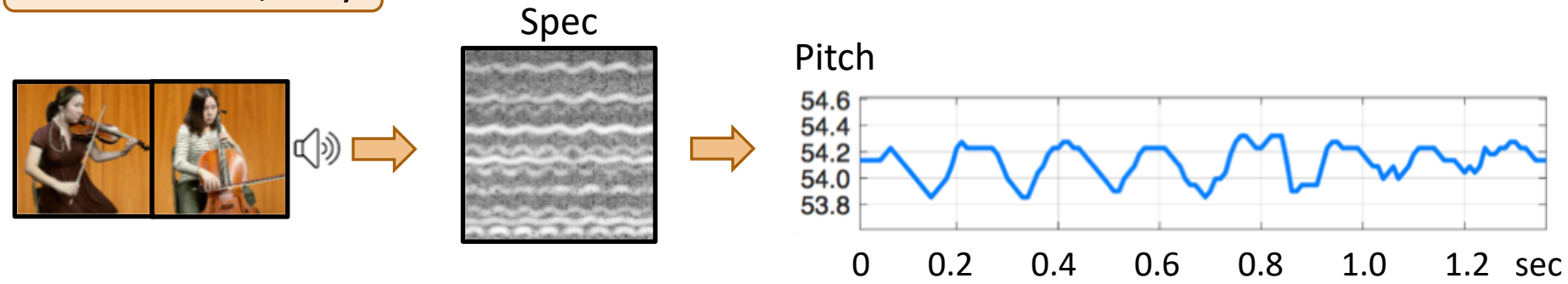
- One source from mixture
- Fails in high polyphony

Proposed Method Overview and Key Contribution

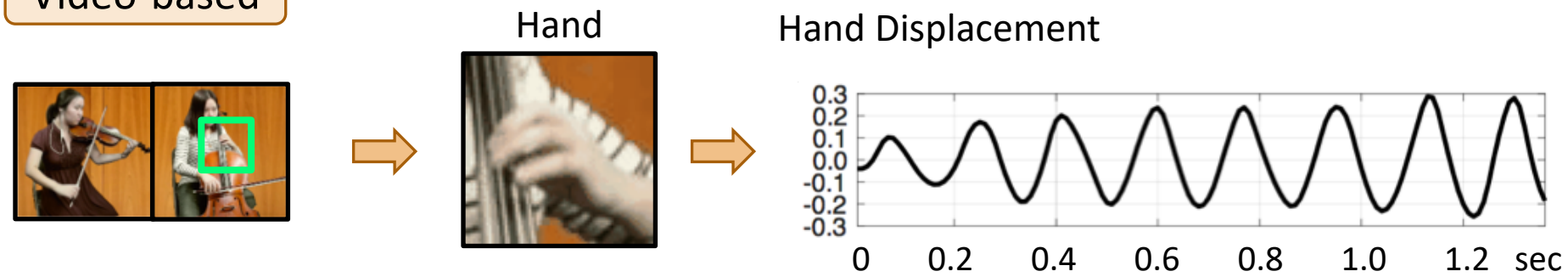
Ground-truth



Audio-based, Poly

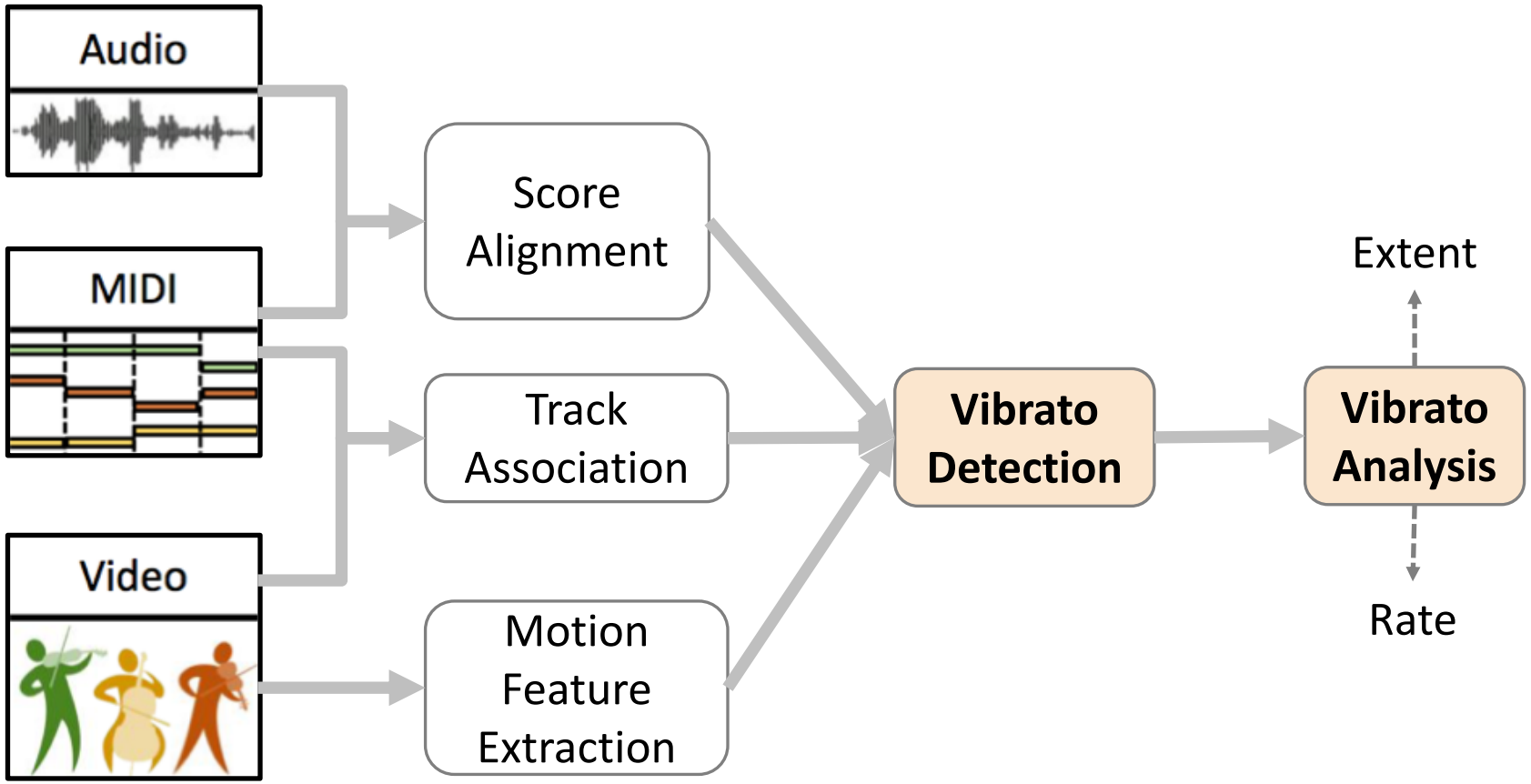


Video-based



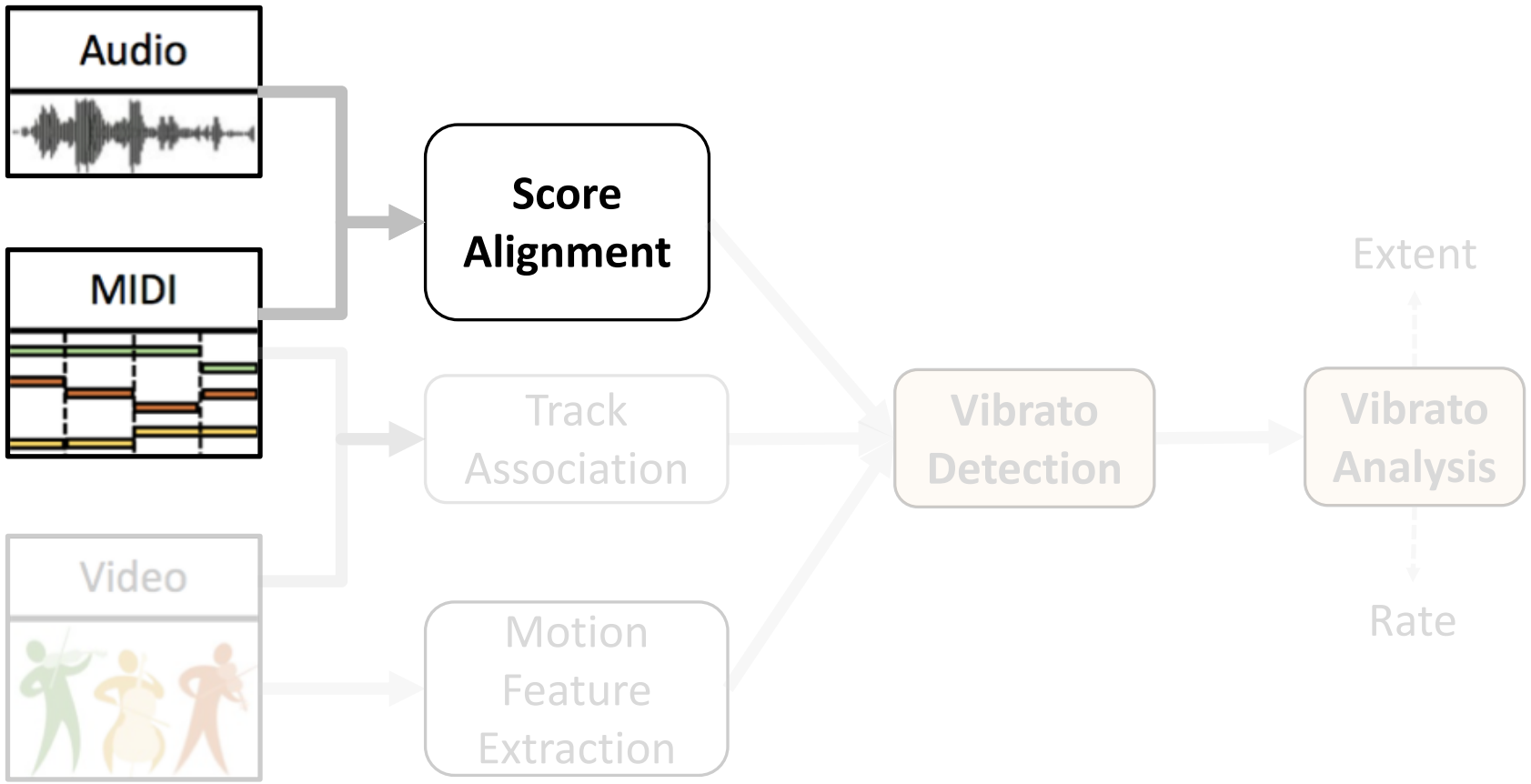
Proposed Method Overview

Video-based Method



Proposed Method

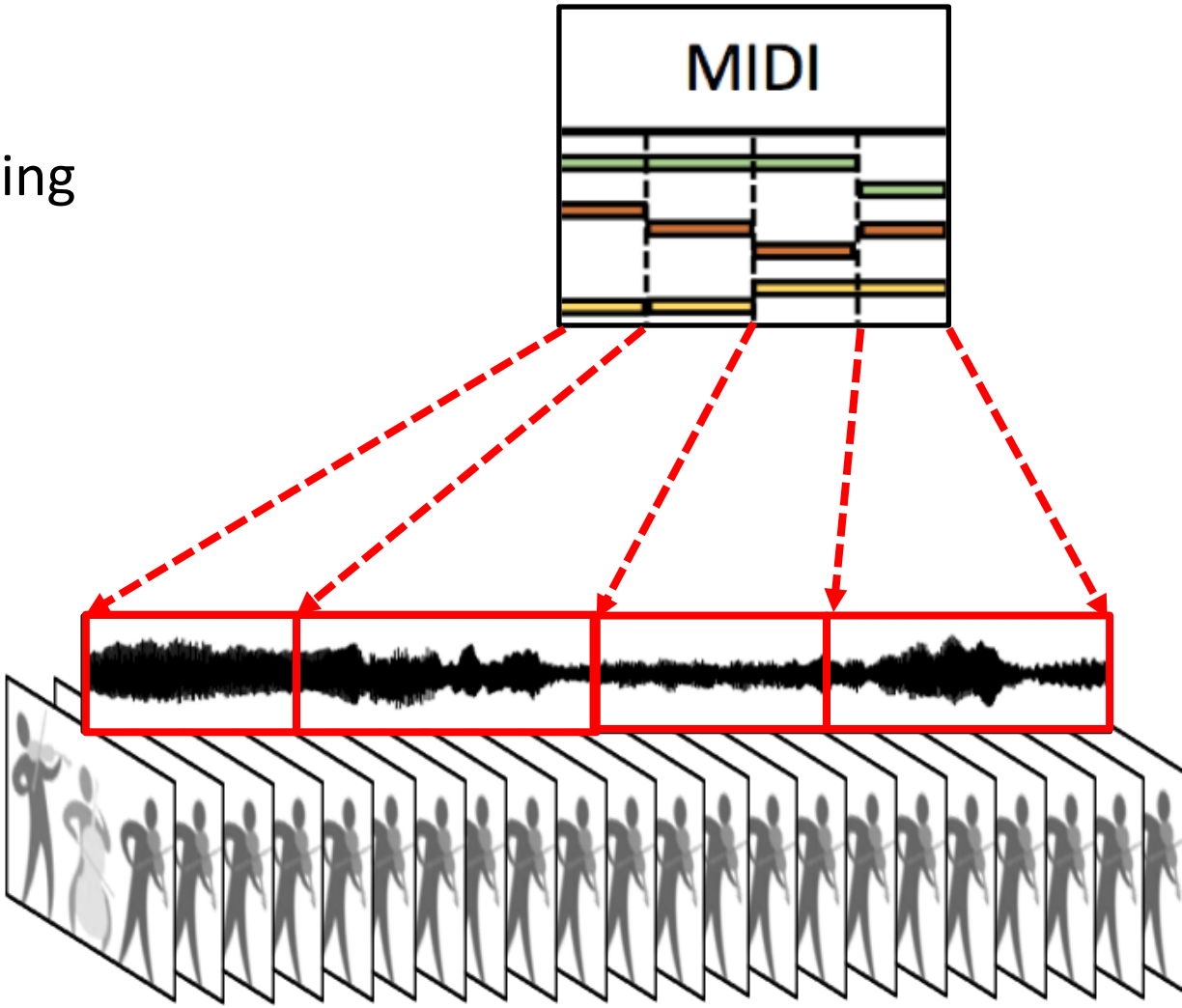
Score Alignment



Proposed Method

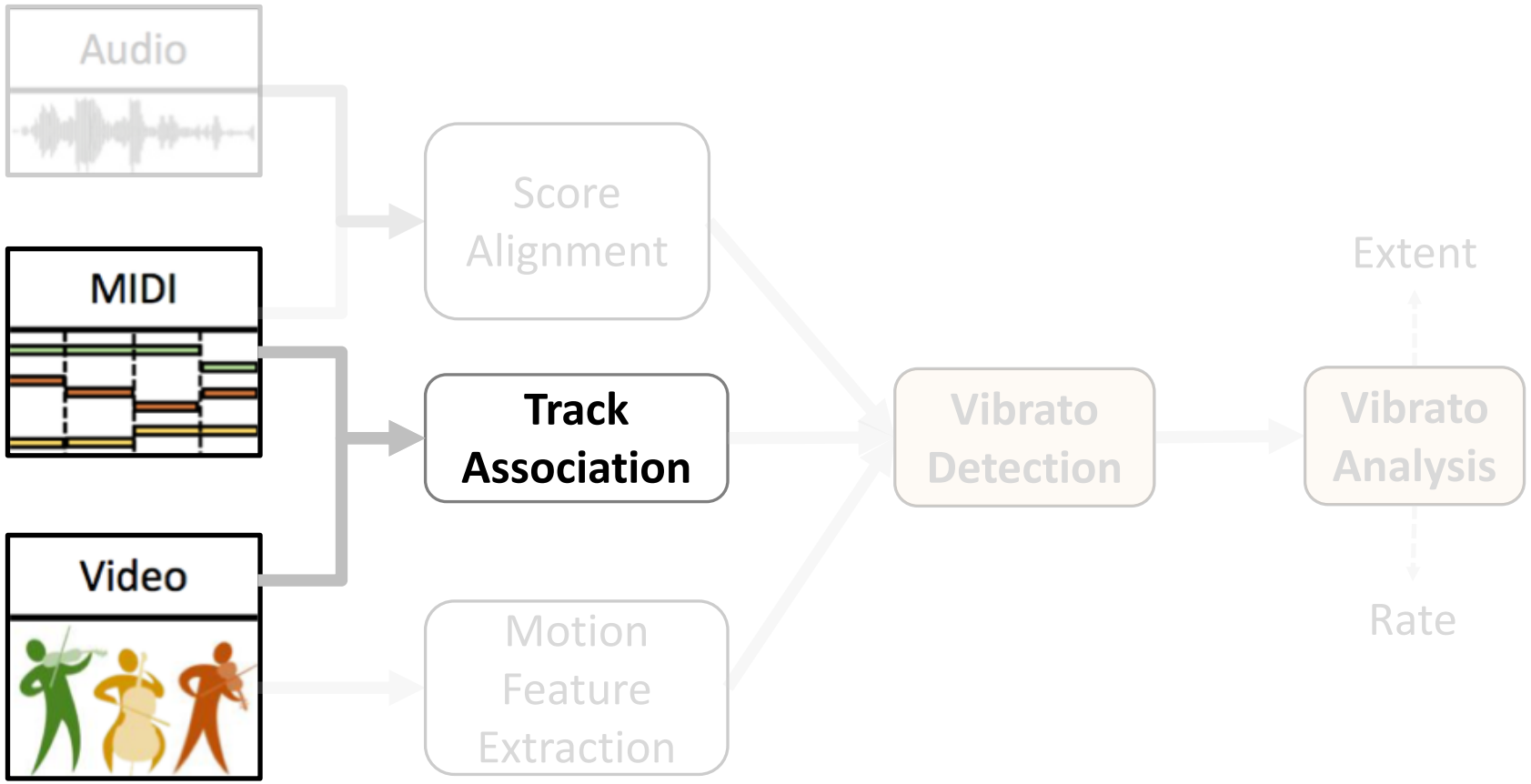
Score Alignment

- Chroma feature
- Dynamic Time Warping



Proposed Method

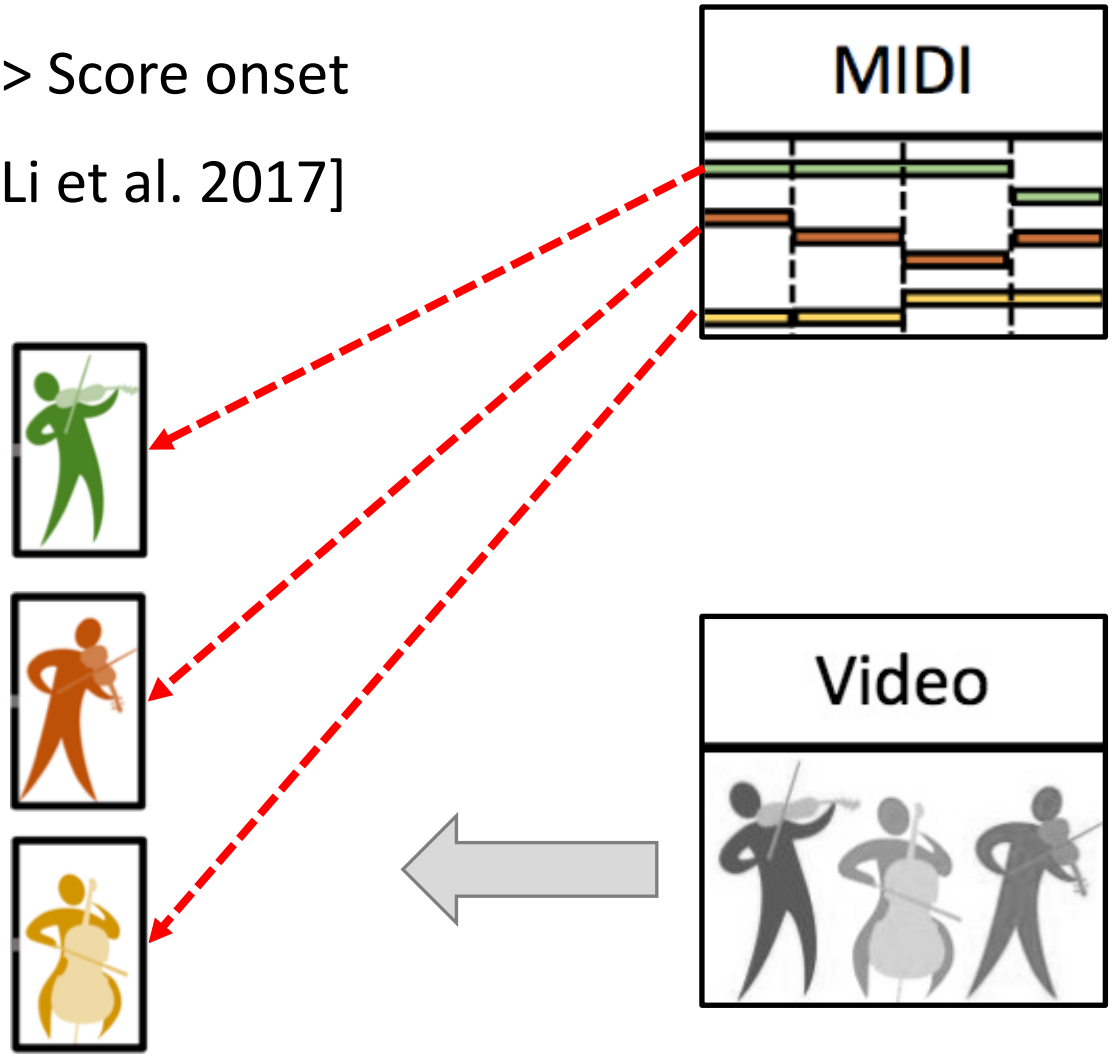
Track-player Association



Proposed Method

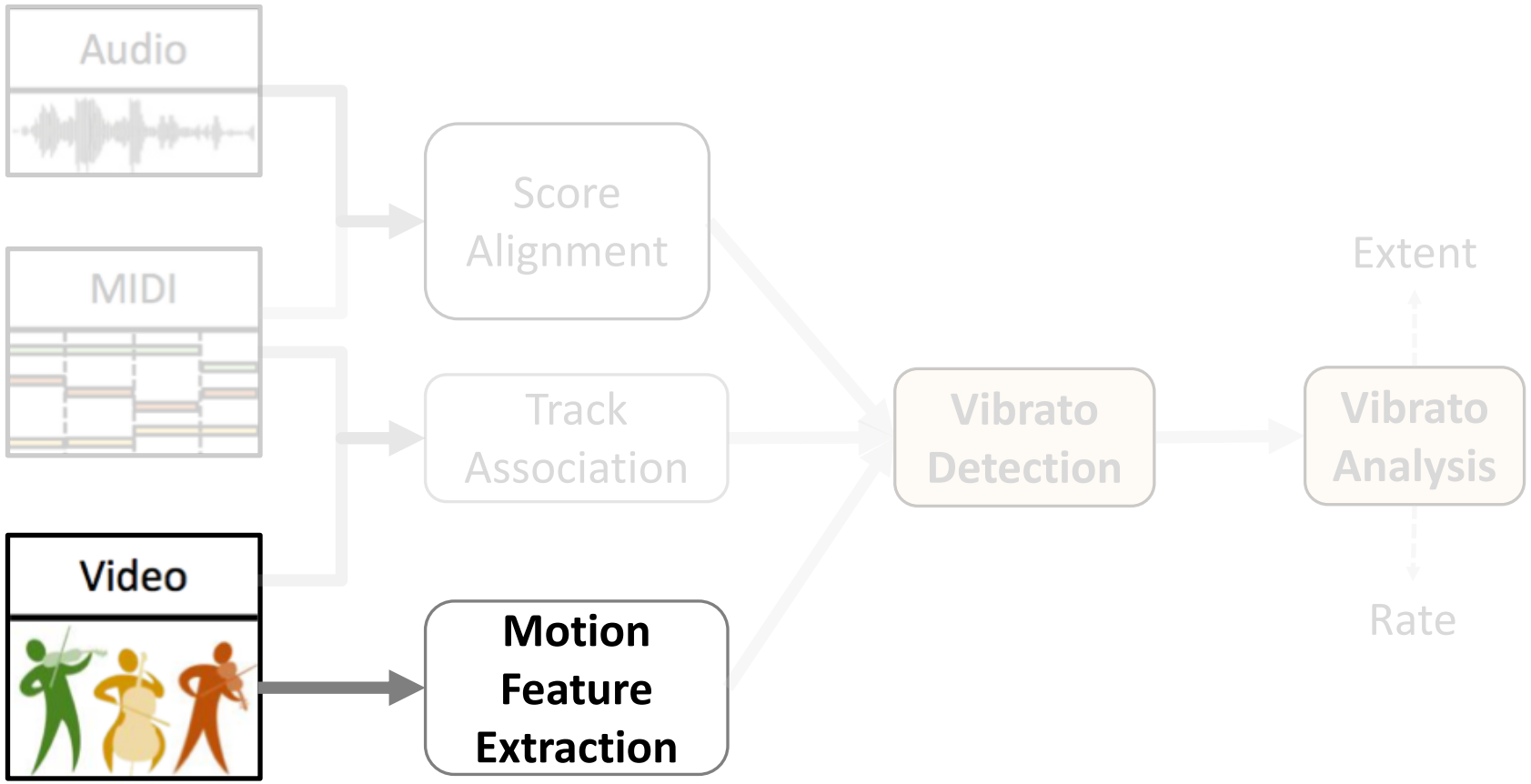
Track-player Association

- Bow motion <--> Score onset
- Previous work [Li et al. 2017]



Proposed Method

Track-player Association



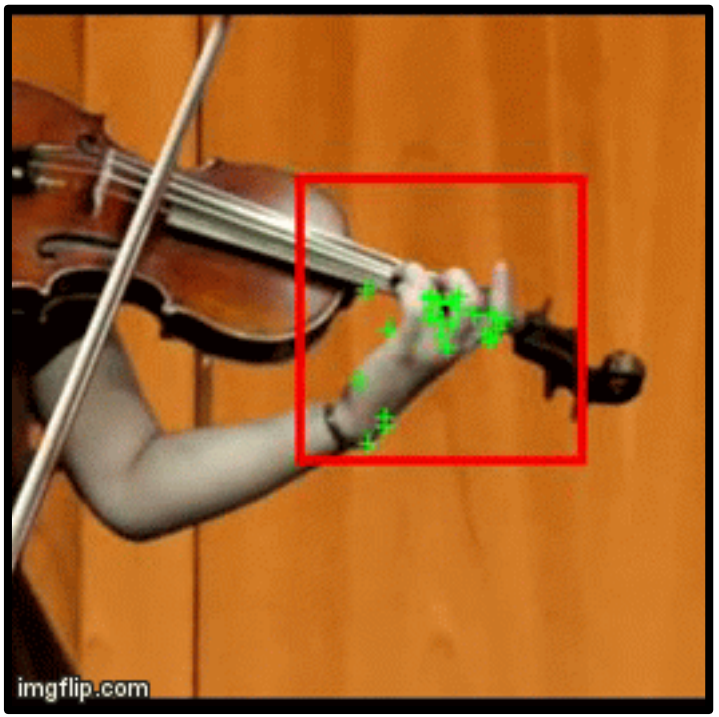
Proposed Method

Motion Feature Extraction

- Hand tracking

  - KLT tracker with 30 feature points

  - Bounding box: 70 x 70 pixels



Proposed Method

Motion Feature Extraction

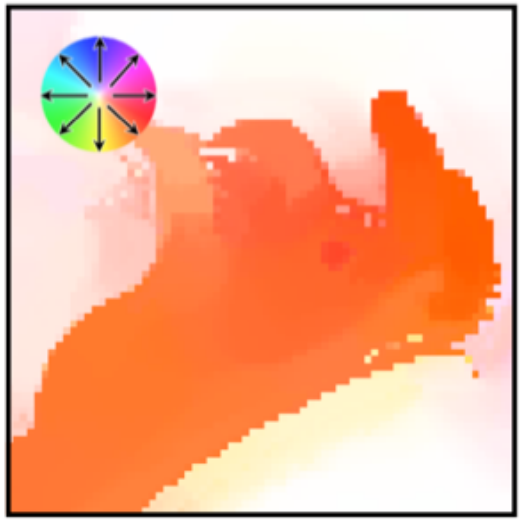
- Fine-grained motion capture

  - Optical flow estimation → pixel-level motion velocities

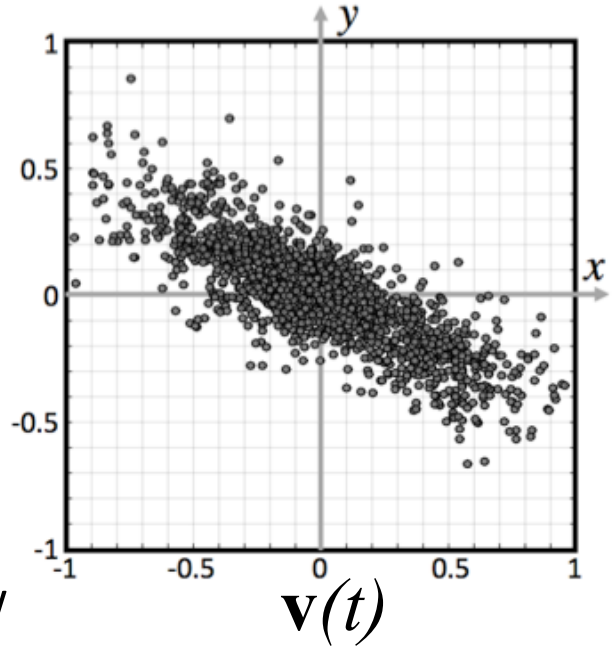
  - Frame-wise average: $\mathbf{u}(t) = [u_x(t), u_y(t)]$

  - Subtract moving mean: $\mathbf{v}(t) = \mathbf{u}(t) - \bar{\mathbf{u}}(t)$

Original Frame

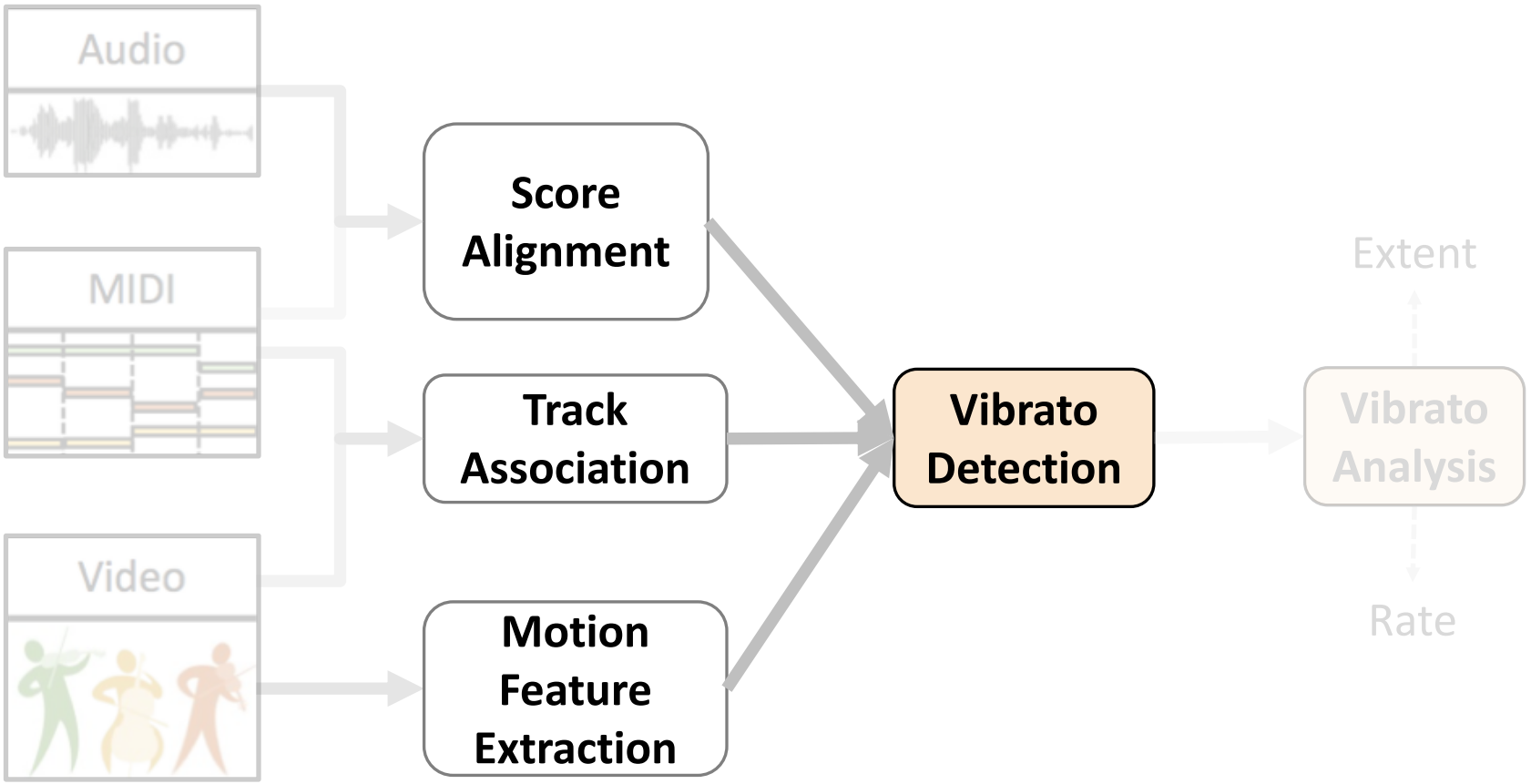


Color-encoded Optical Flow



Proposed Method

Track-player Association



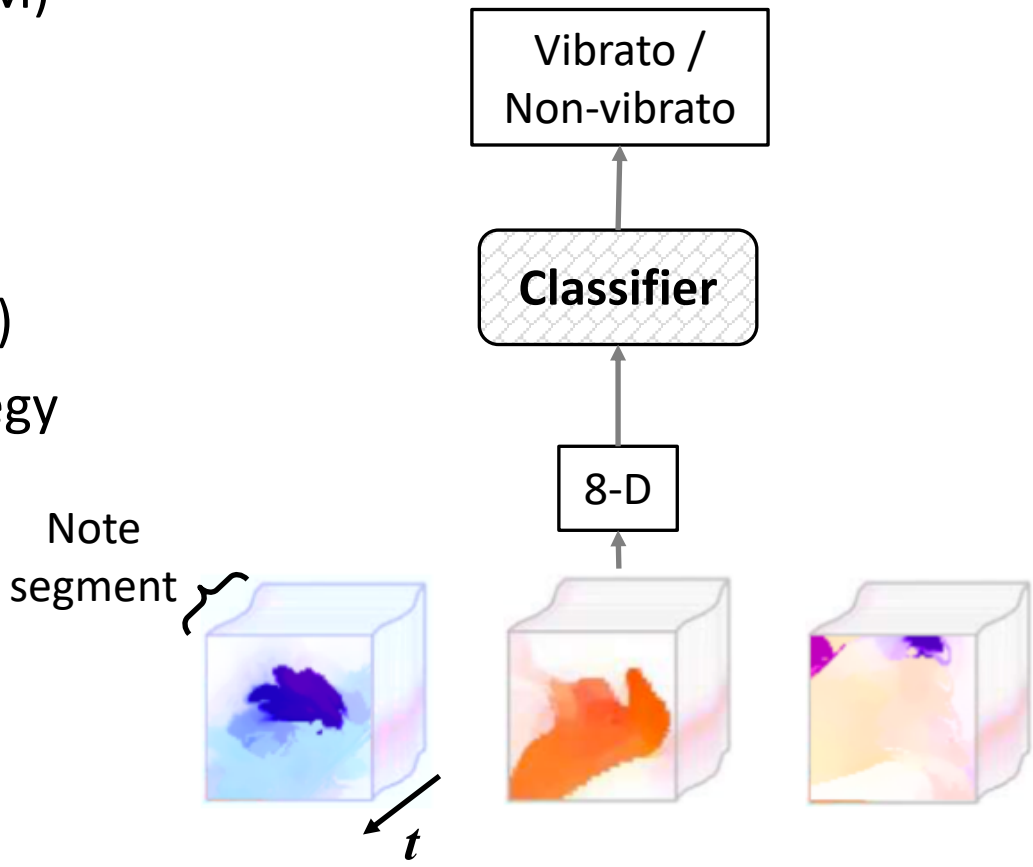
Proposed Method

Vibrato Detection

Method 1: Supervised framework

- Support Vector Machine (SVM)
- 8-D feature

  Zero-crossing rate (4-D)
  Frequency (2-D)
  Auto-correlation peaks (2-D)
- Leave-one-out training strategy



Proposed Method

Vibrato Detection

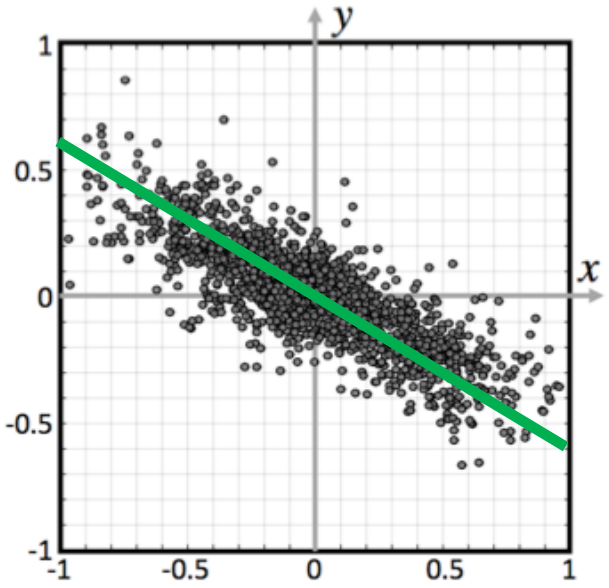
Method 2: Unsupervised framework

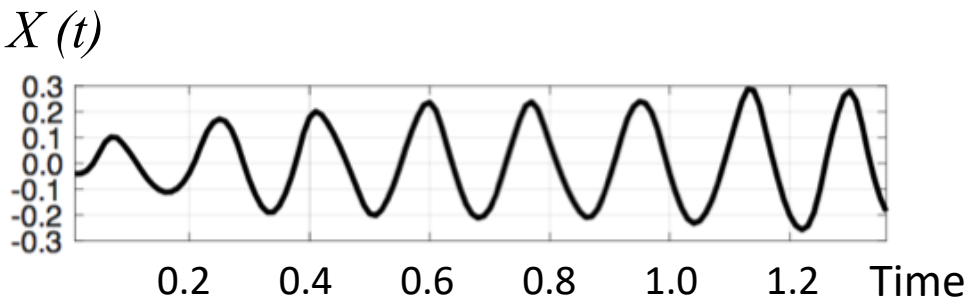
- Principal Component Analysis (PCA)
- 1-D Motion Velocity Curve:

$$V(t) = \frac{\mathbf{v}(t)^T \tilde{\mathbf{v}}}{\|\tilde{\mathbf{v}}\|}$$

- Integration → Motion Displacement Curve:

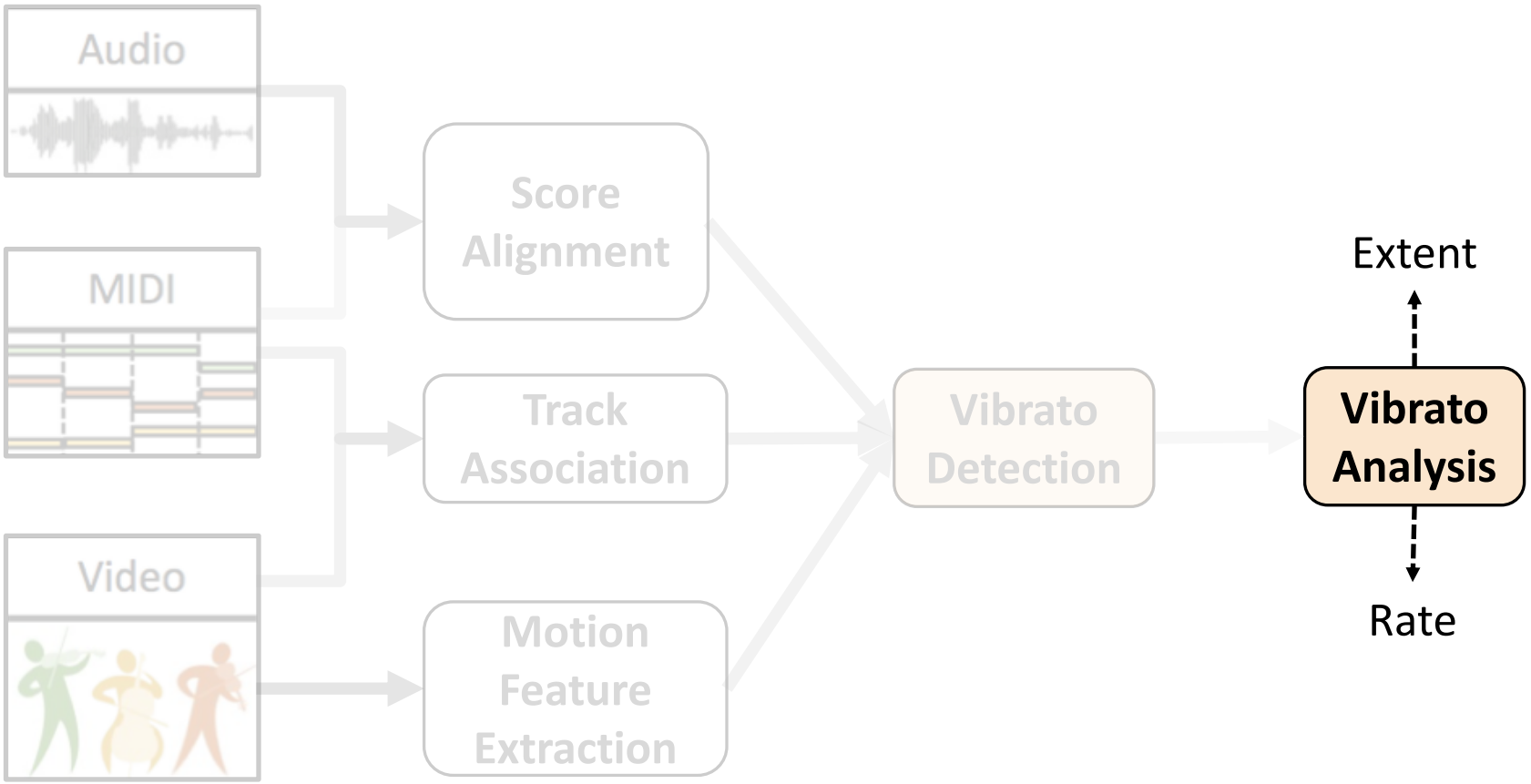
$$X(t) = \int_0^t V(\tau) d\tau$$





Proposed Method

Vibrato Analysis



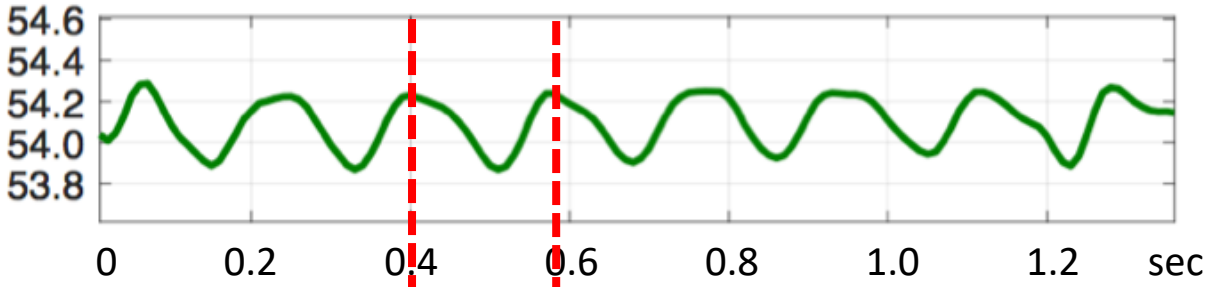
Proposed Method

Vibrato Analysis

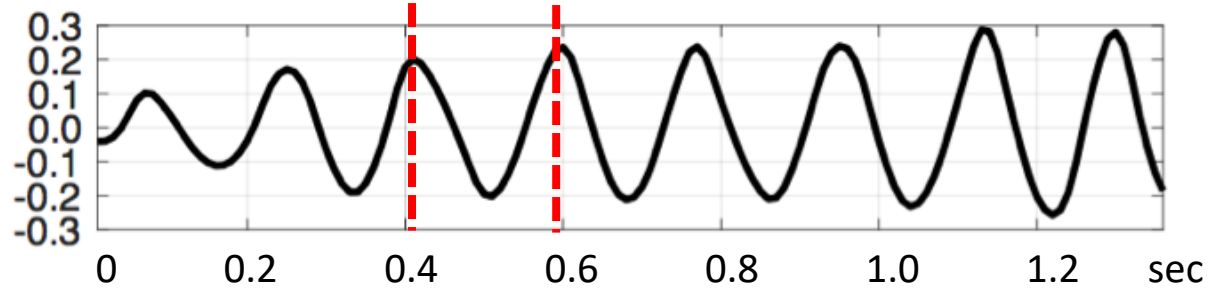
Rate

- Motion rate = Vibrato rate
- Quadratic interpolation
- Peak distance on auto-correlation of motion curve $X(t)$

Ground-truth pitch contour



Motion displacement Curve $X(t)$



Proposed Method

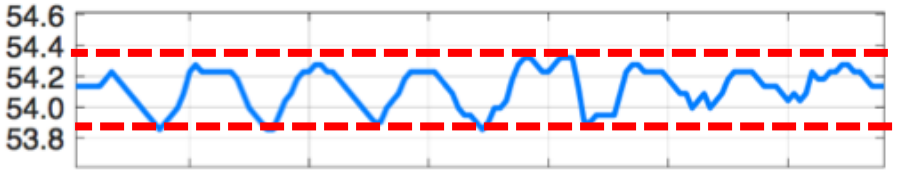
Vibrato Analysis

Extent

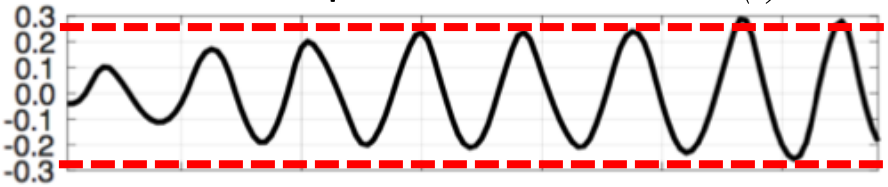
- Motion extent ≠ Vibrato extent
- Pixel → Musical cents
- Scale motion curve $X(t)$ to fit pitch contour

Ground-truth pitch contour

Estimated pitch contour



Motion displacement Curve $X(t)$



Estimated vib extent

$$\hat{v}_e = \arg\min_{v_e} \sum_{t=t^{on}}^{t^{off}} \left| 100 \cdot F(t) - v_e \frac{X(t)}{\hat{w}_e} \right|^2$$

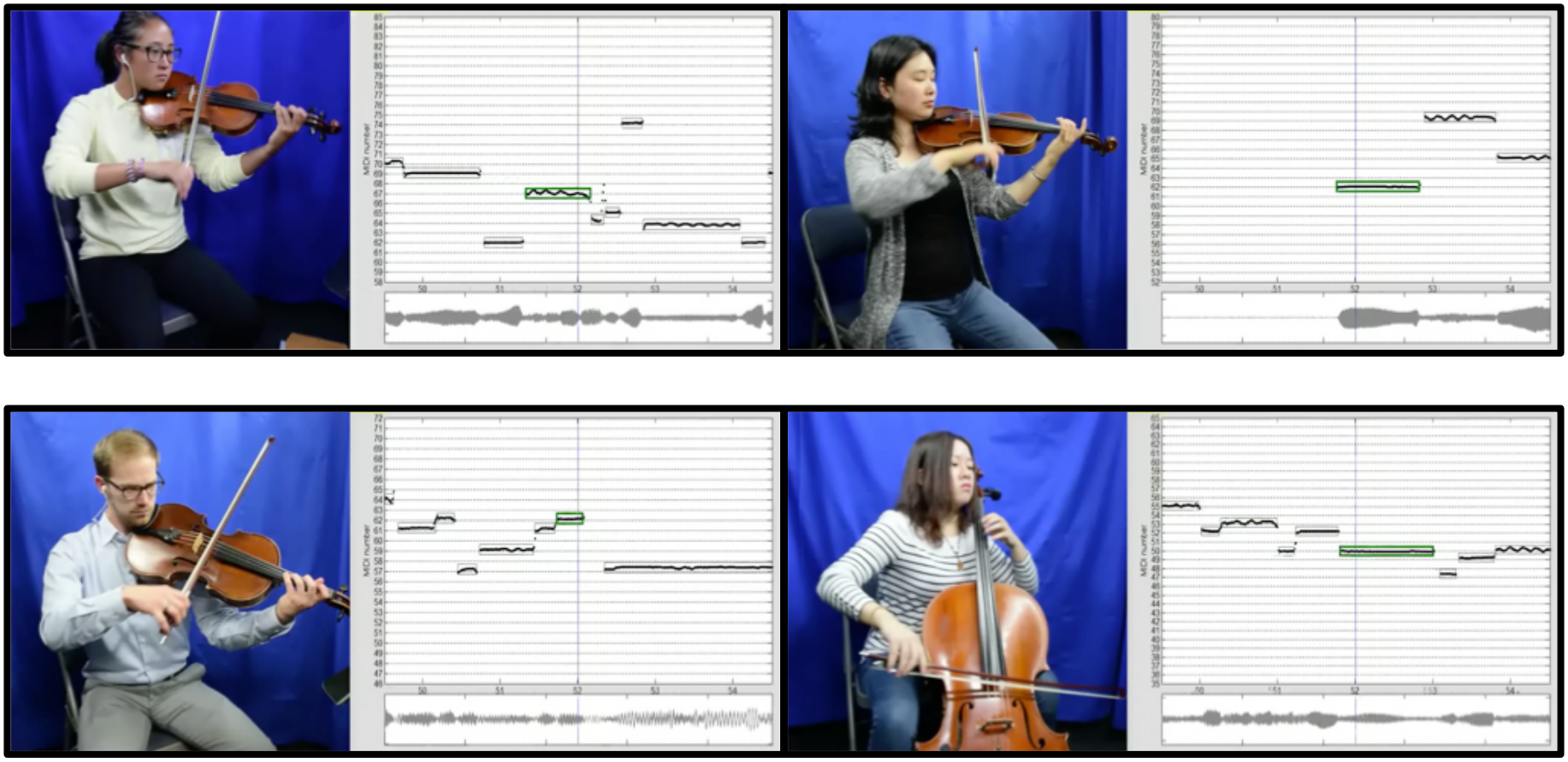
Pitch contour

Motion extent

Demo of Dataset

Dataset: URMP Dataset

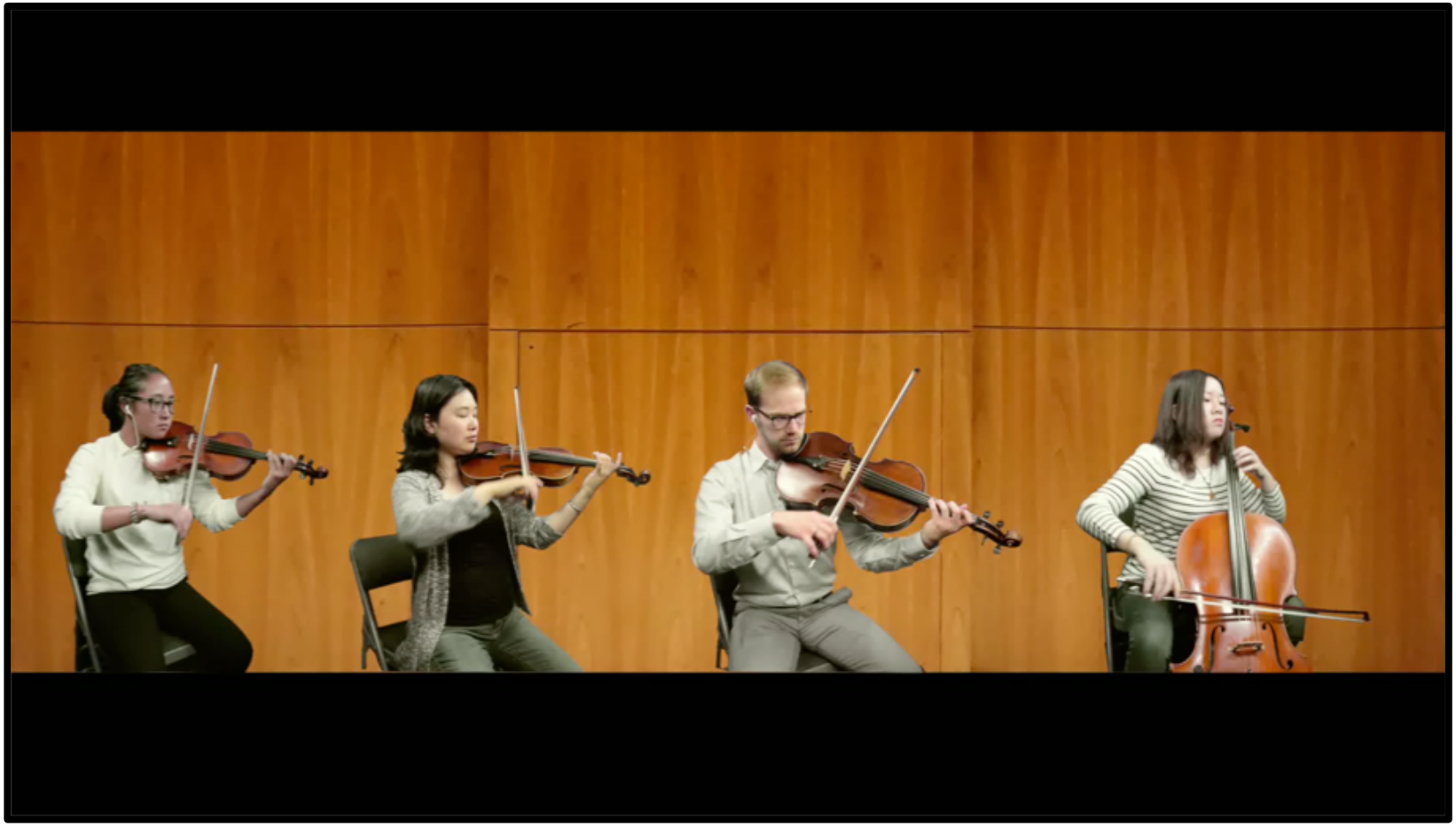
- Individually recorded in sound booth
- Annotated frame-level / note-level pitch



Demo of Dataset

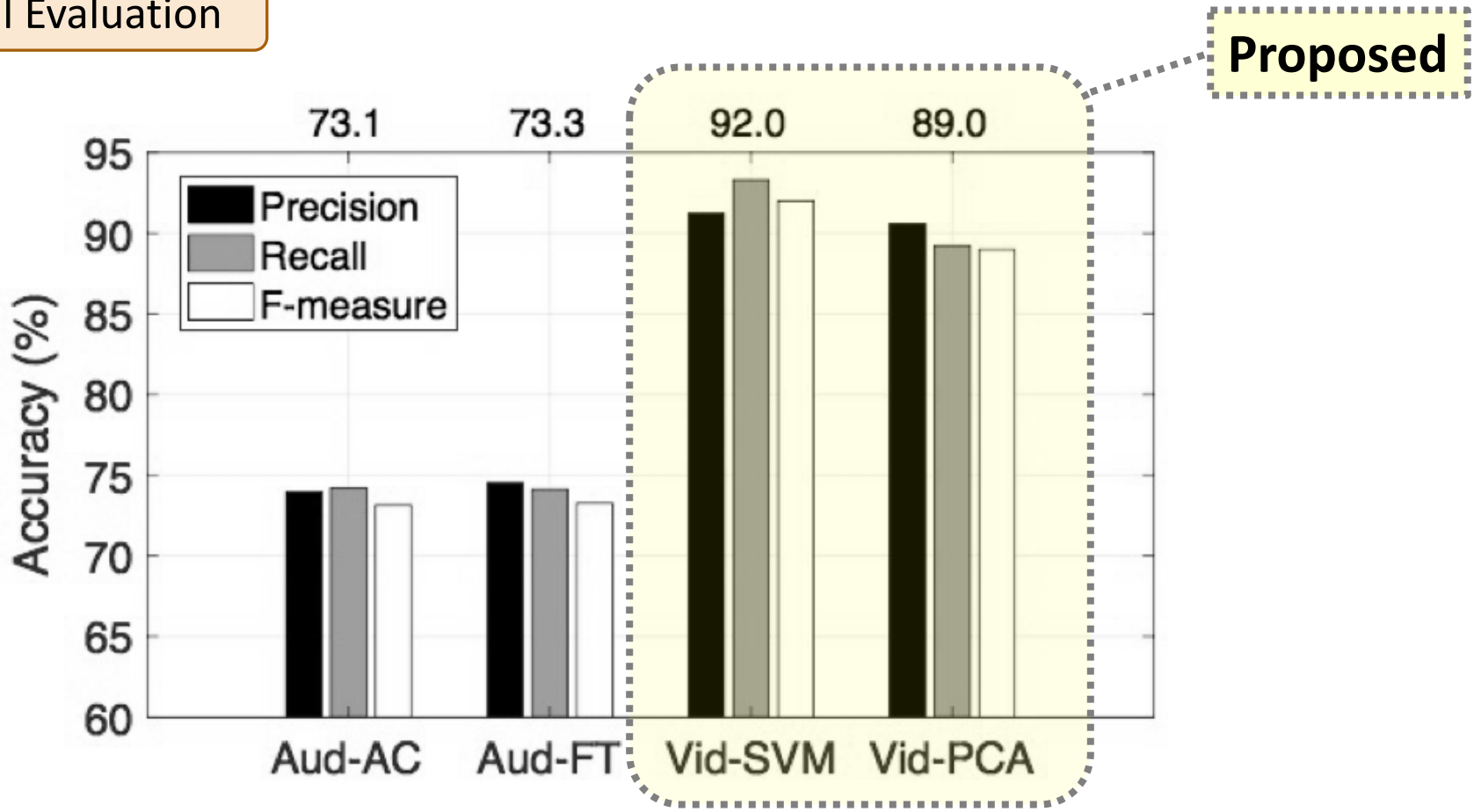
Dataset: URMP Dataset

- Assembled together with concert stage background



Experiments: Vibrato Detection Results

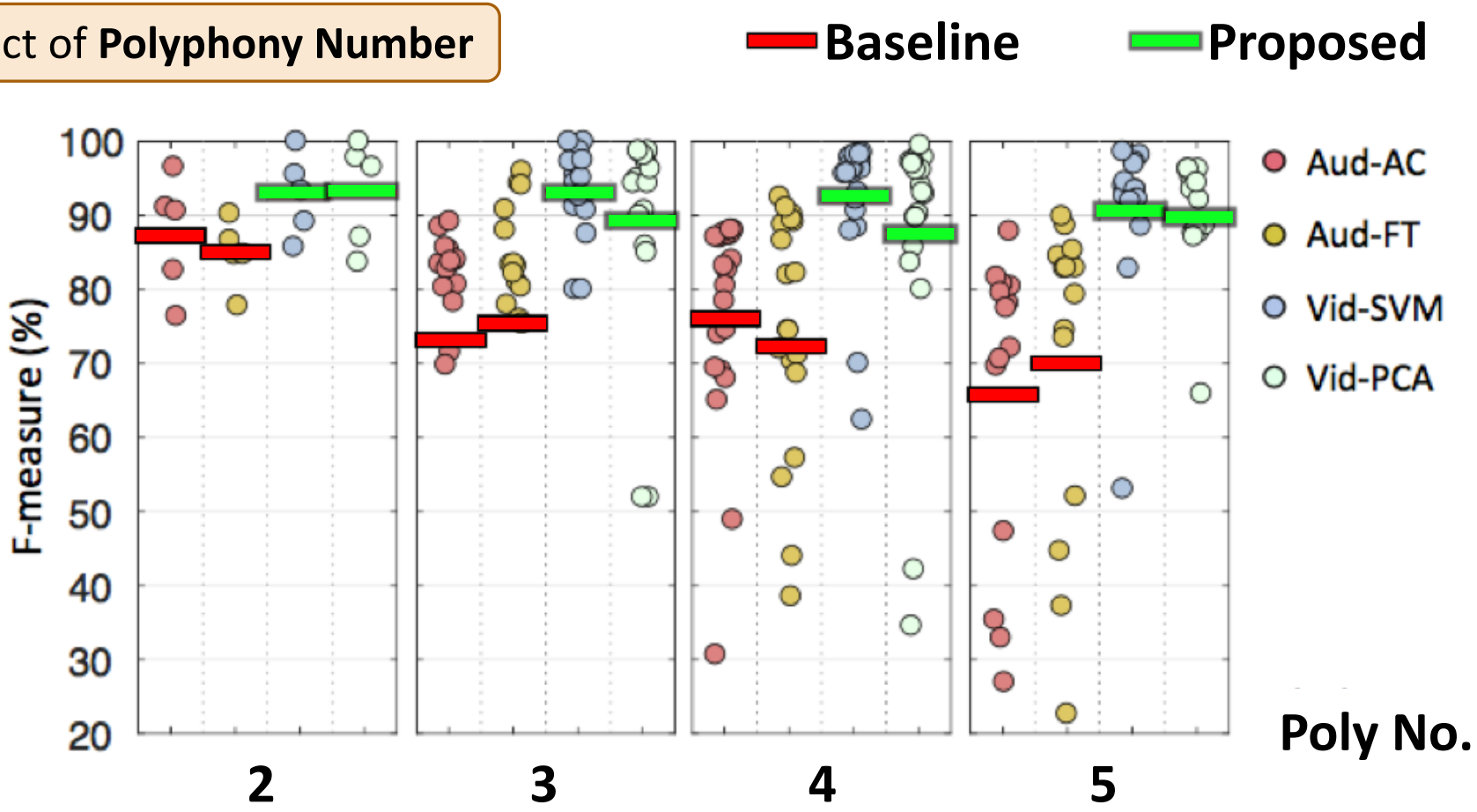
Overall Evaluation



- Video-based method → 92% F-measure
- Improvement over audio-based method
- SVM > PCA

Experiments: Vibrato Detection Results

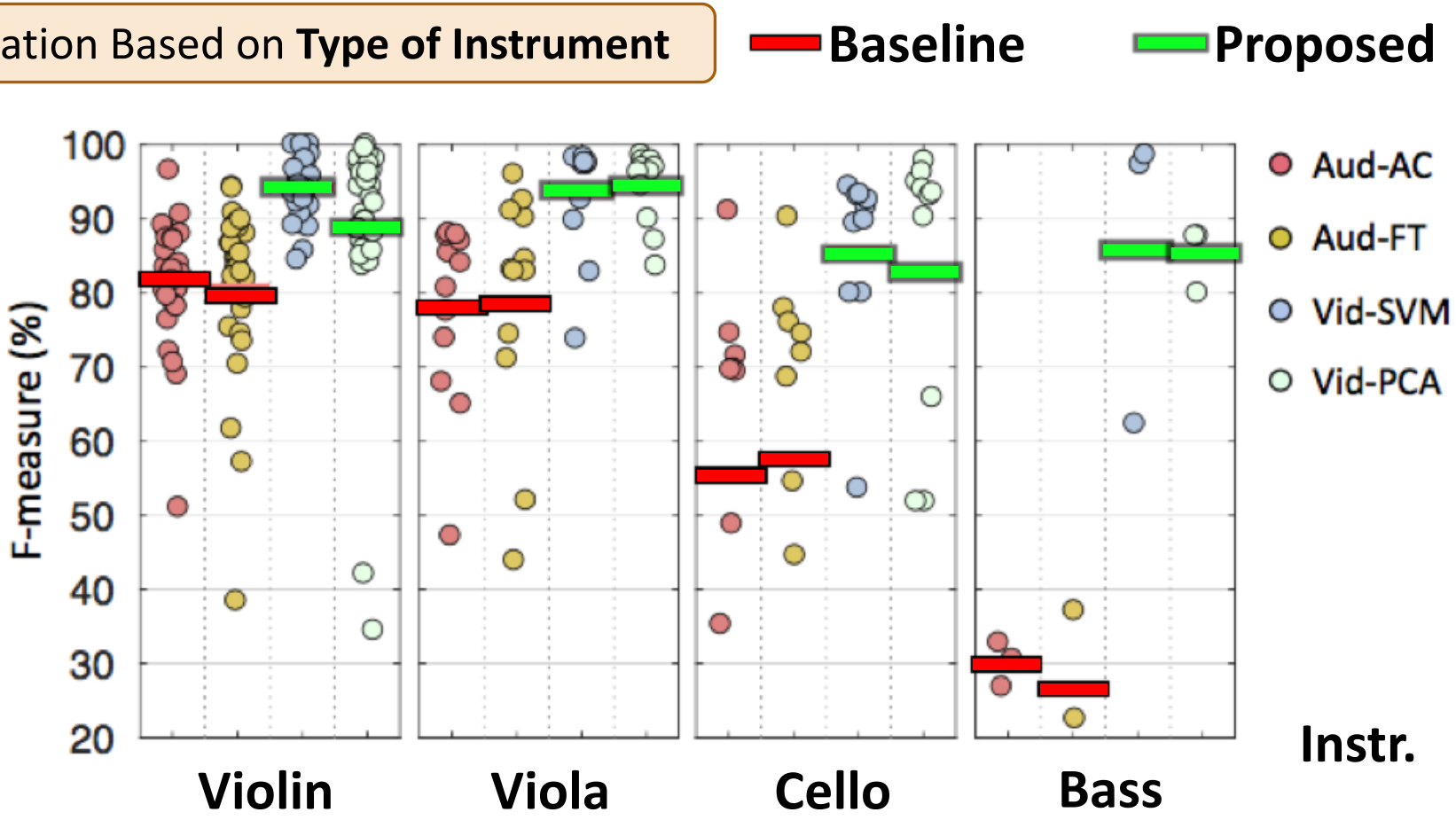
Impact of **Polyphony Number**



- Audio-based method: Poly ↗ Performance ↘
- Proposed video-based method: Robust

Experiments: Vibrato Detection Results

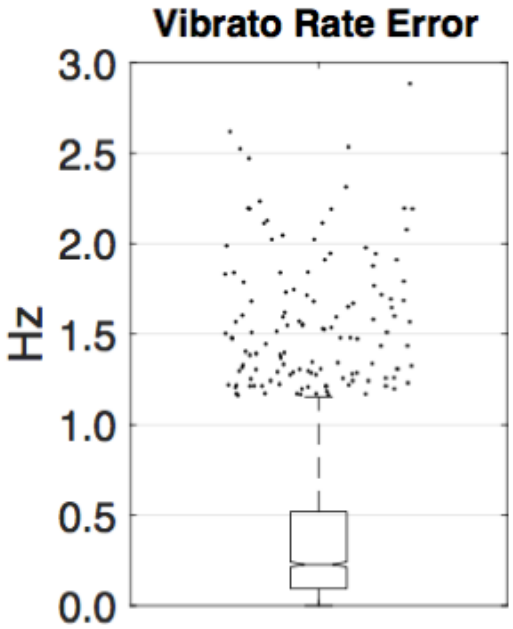
Variation Based on **Type of Instrument**

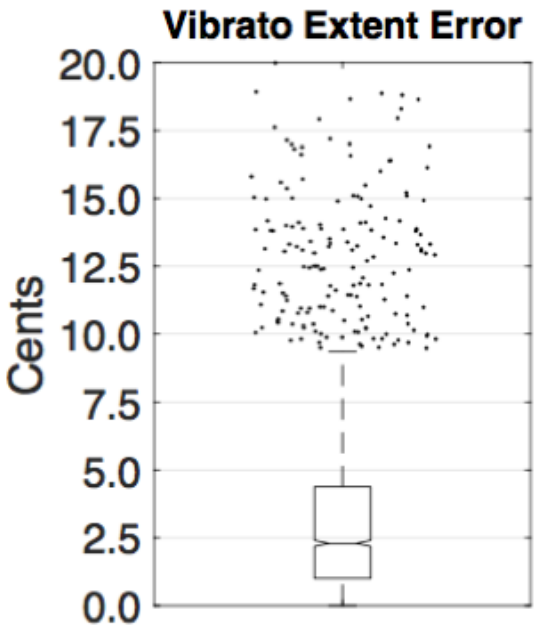


- Audio-based method: Pitch range ↘ Performance ↘
- Proposed Video-based method: Robust

Experiments: Vibrato Analysis Results

Vibrato Rate / Extent





- 2290 vibrato notes
- Rate error: 0.38 Hz
- Extent error: 3.47 cents

Conclusions

- Proposed **video-based** vibrato detection/analysis offers significant improvement over conventional audio-only analysis
- Compared to audio-based methods, proposed video-based method is
  - Robust for **polyphonic** sources
  - Robust for different types of **instruments**
- Proposed method provides good estimates for vibrato rate and extent
  - A powerful tool for analyzing string **ensembles**


air
AUDIO INFORMATION RESEARCH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ROCHESTER

Thank you!

Experiments: Dataset

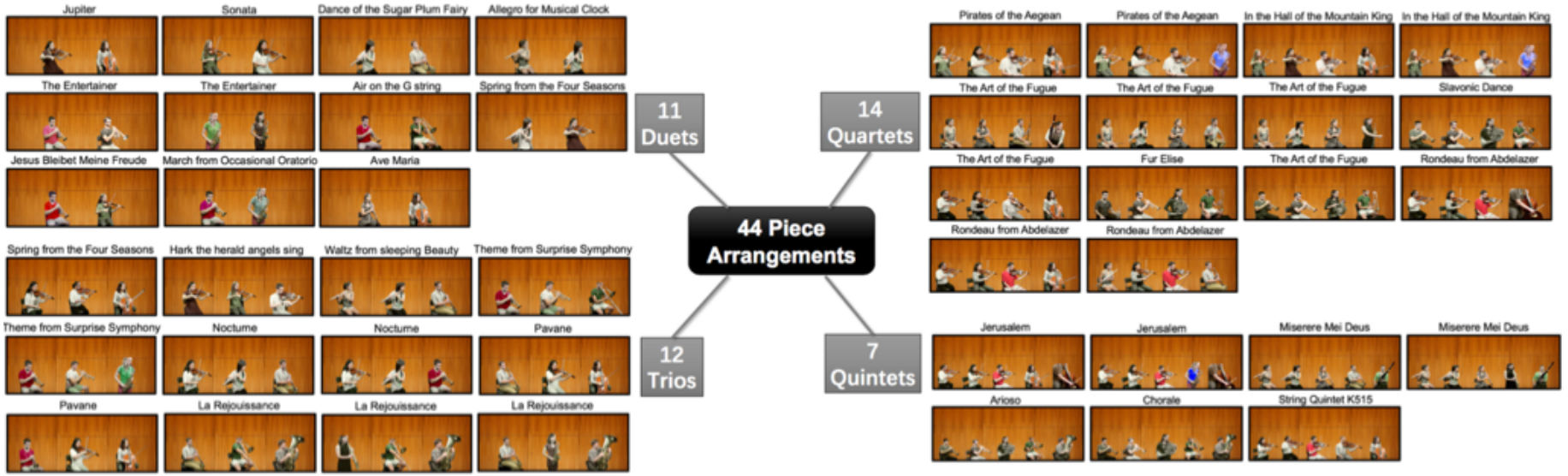
URMP Dataset

- 19 string ensembles (57 tracks)
- 5 duets, 4 trios, 7 quartets, 3 quintets
- Audio: 48k Hz
- Video: 1080P, 29.97 fps

Demo of Dataset

Dataset: URMP Dataset

- 14 instruments, 44 piece arrangements

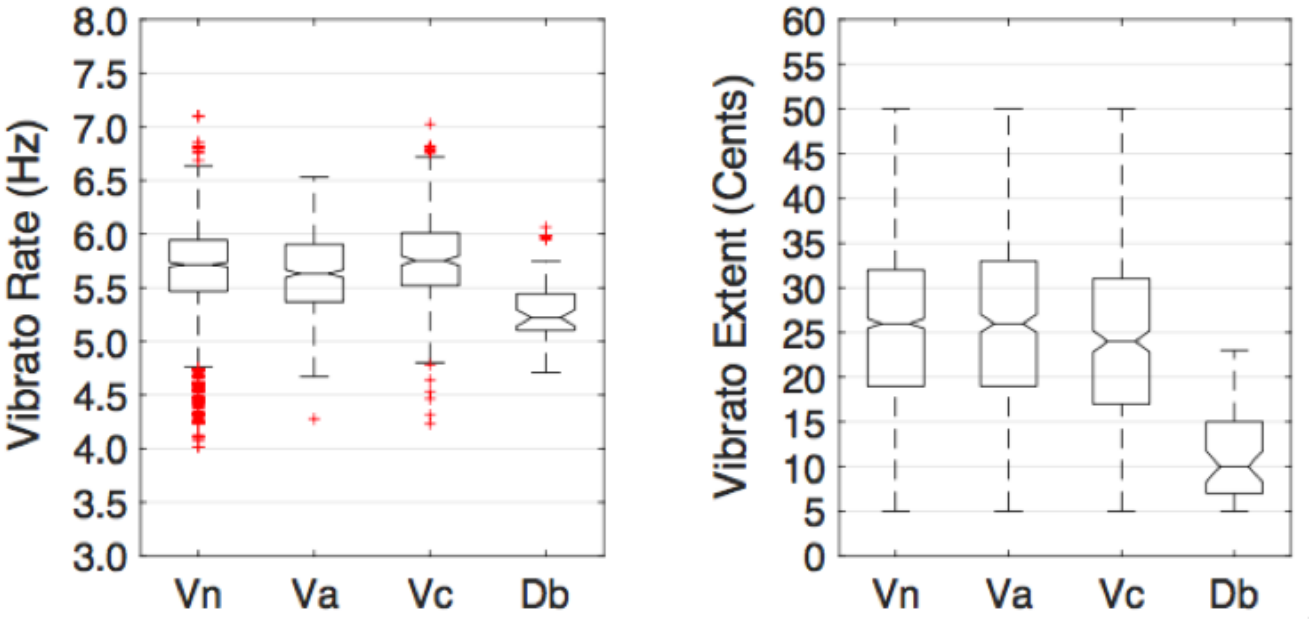


Experiments

Results

Potential Application on Musicologies

Vibrato characteristics for different **instruments**



- Test on TPs from Vid-PCA method: 2290 vibrato notes
- Average error: 0.38 Hz / 3.47 cents
- Double bass → lower rate / extent [1]

[1] James Paul Mick. *An analysis of double bass vibrato: Rates, widths, and pitches as influenced by pitch height, fingers used, and tempo*. PhD thesis, The Florida State University, 2012.