**Abstract**: A stochastic representation of singing styles is proposed. The dynamic property of melodic contour, i.e., fundamental frequency ($F_0$) sequence, is assumed to be the main cue for singing styles because it can characterize such typical ornaments as *vibrato*. $F_0$ signal trajectories in the phase plane are used as the basic representation. By fitting Gaussian mixture models to the observed $F_0$ trajectories in the phase plane, a parametric representation is obtained. The effectiveness of our proposed method is confirmed through experimental evaluation where 94.1% accuracy for singer-class discrimination was obtained.

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**Example of Stochastic Phase Plane**

Classical: Large vertical deviation
Amateur: Large horizontal deviation

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**Signal features**

- Singing formant
- Vibrato
- Overshoot
- Preparation
- Fine fluctuation

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**Stochastic Representation of the Dynamical Property of Melodic Contour**

$F_0$ signal

- Dynamic property of $F_0$ affects the perception of the individuality.
- **Singing style**: Dynamics of a sung melody

**Previous study**: Graphical representation of the $F_0$ contour in phase plane in our study: Modeling for Singing Style

Use the local dynamics of the $F_0$ sequence on the phase plane

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**Experimental Evaluation**

Effectiveness of using SPP ⇒ Discriminate different singing style

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**Discrimination Experiment**

- Discrimination of 3 singer classes based on MAP

$$\hat{\Theta} = \arg \max_{\Theta} \left\{ p(s|F_0, \Delta F_0, \Delta \Delta F_0) \right\}$$

$$\hat{\Theta} = \arg \max_{\Theta} \left\{ \frac{1}{N} \sum_{n=1}^{N} \log p(s|F_0(n), \Delta F_0(n), \Delta \Delta F_0(n)) + \log p(s) \right\}$$

- **Training**: "Twinkle-Twinkle, Little Star" and 5 etudes
- **Testing**: "Ode to Joy"

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**Result**

- The accuracy increases with the length of the test signal
- The best performance of 94% (13 [s], 8-mixture GMM)

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**Summary and future works**

- Singing style represented as a phase plane trajectory
- Model the $F_0$ trajectory on the phase plane with a GMM
- More than 90% accuracy can be achieved in discriminating the 3 classes
- Increasing the number of singers and singer classes is a critical future work