Automatic Tuning of High Piano Tones

Sneha Shah

BITS Pilani - Goa, India

Supervised by Professor Vesa Välimäki

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Introduction

- What are we doing?
  - tuning a piano to make it sound better
  - done by slightly changing the frequency of each tone
  - achieved by changing tension in strings using tuning pin
- Challenges posed
  - piano strings are inharmonic
  - frequency of each tone is not fixed
  - frequency of tone is lowered with time
  - need to be tuned regularly

Ways to tune a piano

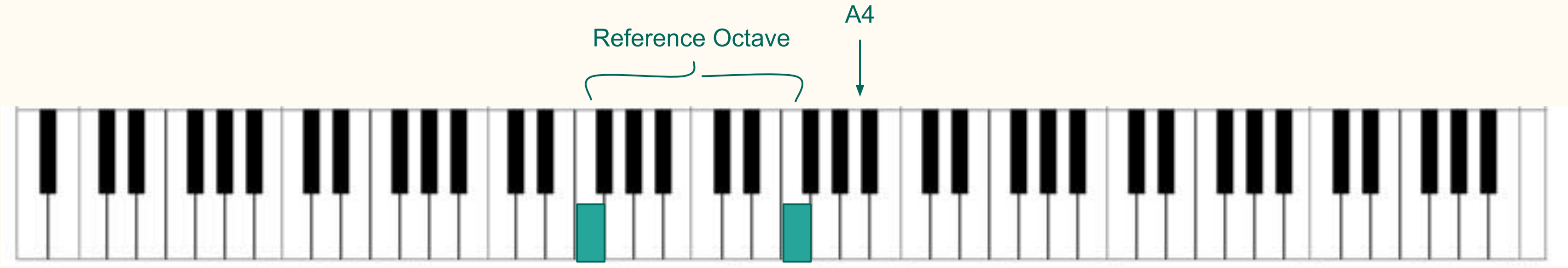
- Humans (Aural tuning)
  - used for centuries
  - been perfected over the years
- Computers (Automatic tuning)
  - new technology
  - no satisfactory devices as yet

Aural Tuning

- How it's done
  - based on the equal temperament scale
  - tuning by listening to intervals
  - done by counting and minimizing beats
- Challenges
  - Time consuming and expensive
  - Requires a professional or years of training

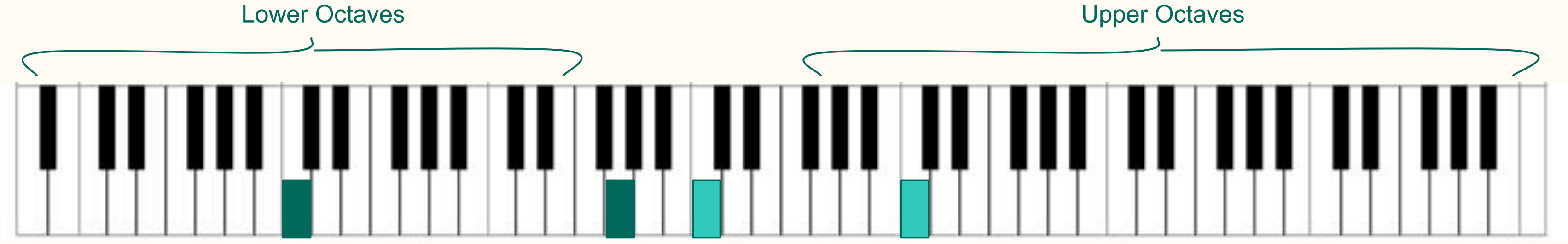
The process

- Reference note is tuned to some frequency
  - usually A4 tuned to 440 Hz
  - concert pitches are often 442 or 443 Hz
- Reference octave is tuned using this note
  - uses many intervals starting from reference note
  - octave is near the middle of piano
  - used to tune rest of the piano



The process

- Upper half of the piano tuned using reference octave
    - octaves used to tune
    - also sometimes use other tests
- Lower half of the piano tuned using reference octave
    - Uses octaves and some larger intervals



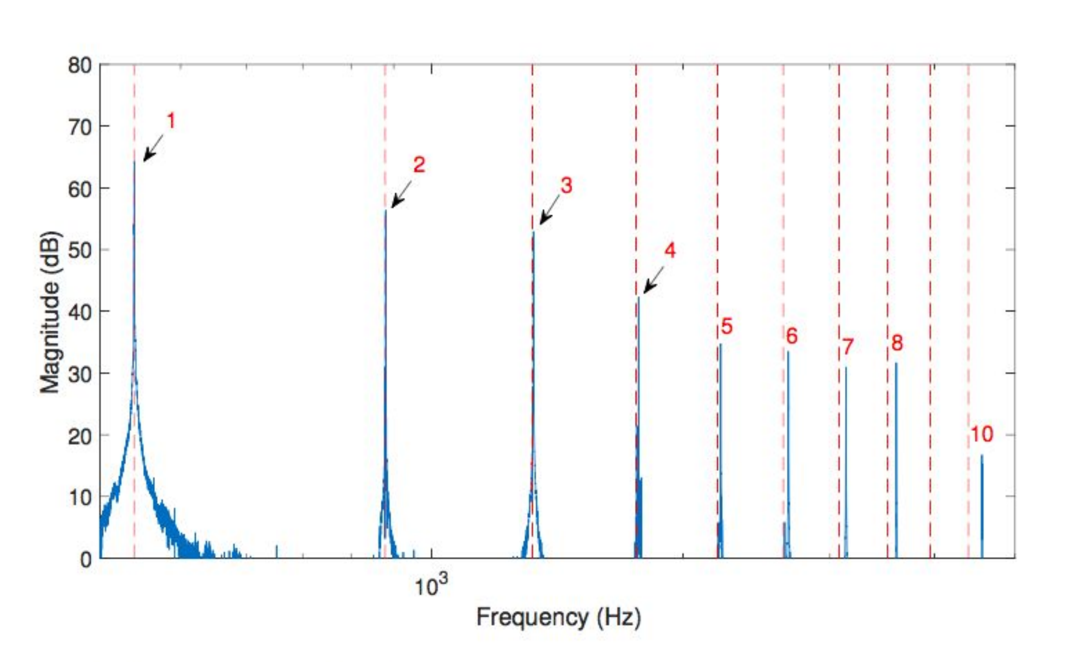
Automatic Tuning

- Steps
  - Input: Recorded untuned piano tones
  - Intermediate: New fundamental frequencies of tones
  - Output: Amount to turn tuning pin for tuned tones
  - Action: Turning the tuning pin

Automatic Tuning

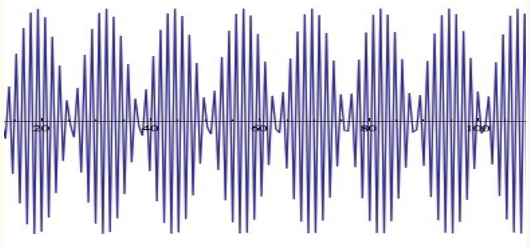
- Main challenge
  - Finding new fundamental frequency
  - Imitating results of aural tuning
- What makes it hard
  - Inharmonicity of piano strings
  - Subjectivity in aural tuning

Inharmonicity in the partials of A4



Past Approaches

- Minimising beating by Lattard [1]
  - First 5 partials of each tone used
  - Frequency found by equating beats to that for ET
  - It is unknown how the results were verified



- Matching partials by Tuovinen et al. [2]
  - Used tone spectra to try and match partials
  - Was tested with and without weights for partial amplitudes
  - Results were quantified as deviation from professional tuning

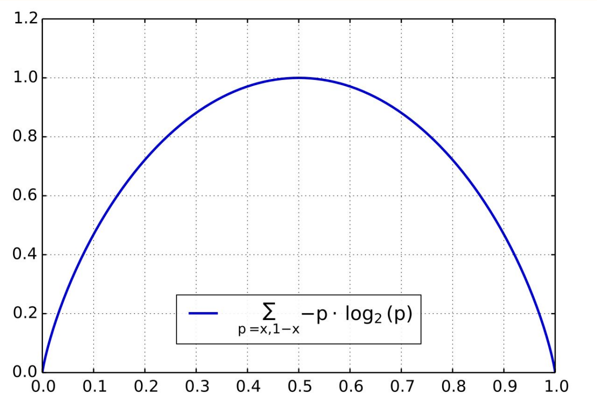
$$w_i = \frac{M_i}{\sum_{n=0}^{N-1} M_n}$$

Past Approaches

- Minimizing Sensory Dissonance by Giordano [3]
    - Model for dissonance between two piano tones proposed
    - Used to tune intervals
    - Results compared with professional tuner

$$D_{\text{total}} = \frac{1}{2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} B_{i,j} d_2(f_{1,i}, f_{2,j})$$

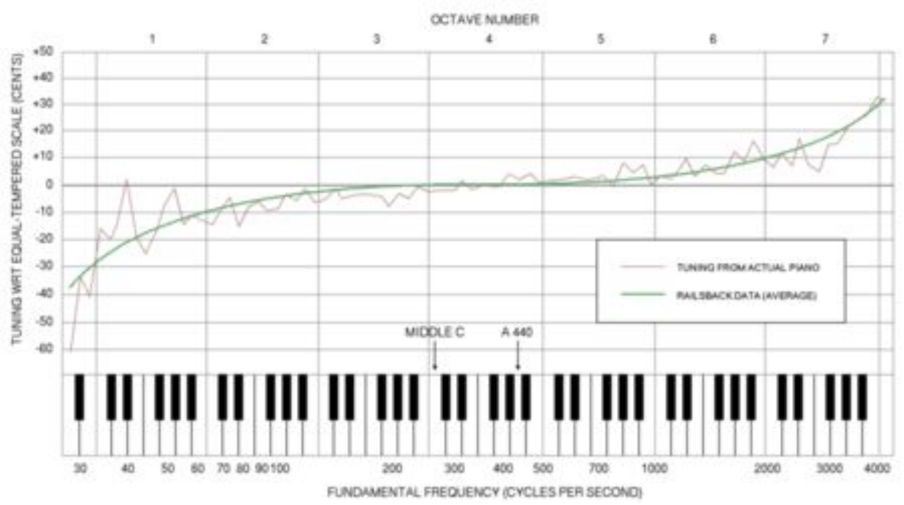
- Minimizing Entropy by Hinrichsen [4]
    - Shannon entropy calculated for all tones together
    - Minimized by arbitrarily tuning each tone up or down
    - No concrete explanation to why this method works



Shortcomings of Previous Studies

- Quality of tuning compared with professional tuner
  - Visually using Railsback curves
  - Calculating deviation of fundamental frequencies

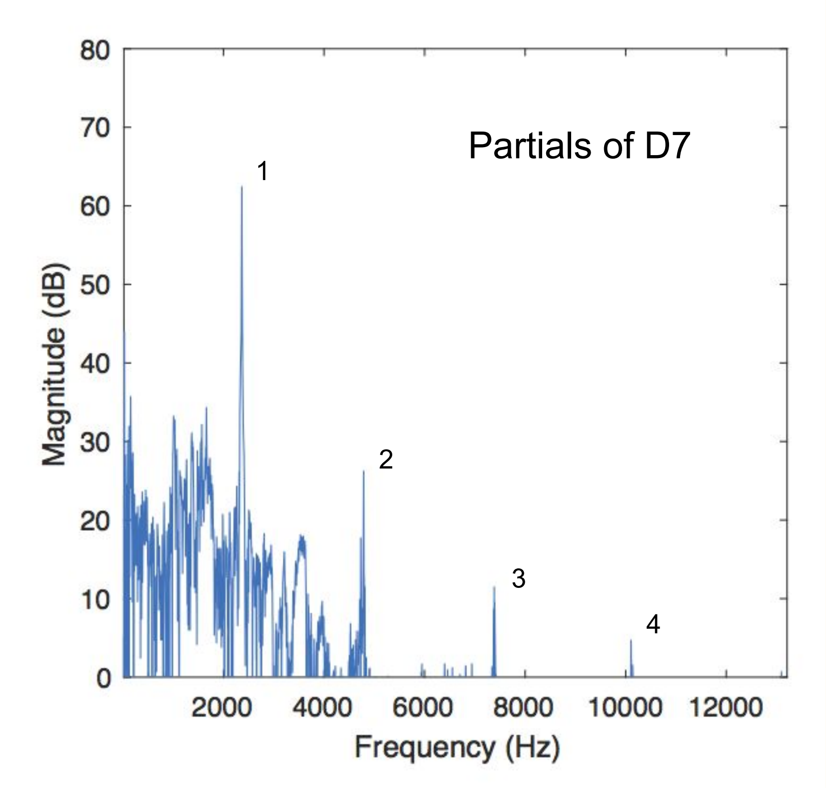
- Drawbacks
  - Subjectivity of professional tuning
  - Compounding effect of tuning mistakes
  - Not backed by any listening tests



Contribution

1. High Frequency Tones

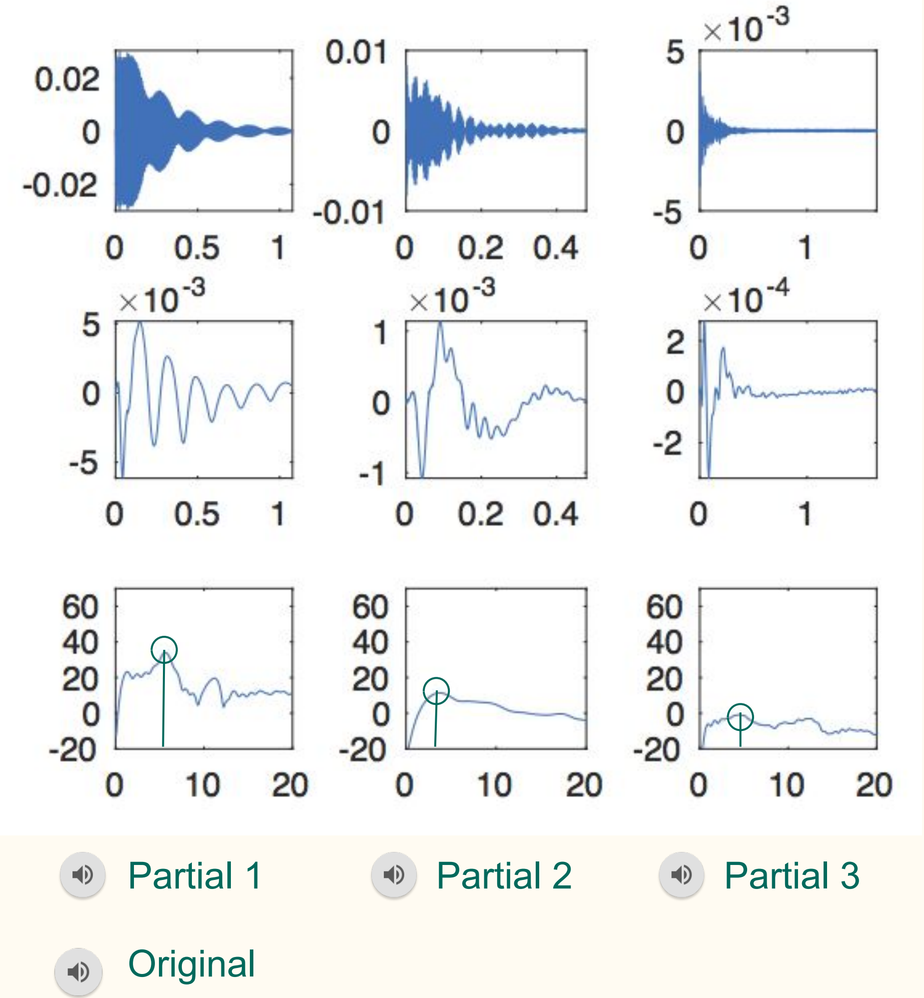
- All analysis and results are for high piano tones
- Properties
  - Have very high inharmonicity
  - Few significant partials
  - Fast decay
  - Resonance in recording due to absence of damping
  - Tuned using octaves



Contribution

2. New Evaluation Method

- Beats based analysis
- Analyse beating effects for each octave
- Advantages
    - Close to what professional tuners do
    - Correlates with listening study



Contribution

3. New Set of Recordings of Tuned Piano Tones

- Tones recorded on a Yamaha Disklavier

Contribution

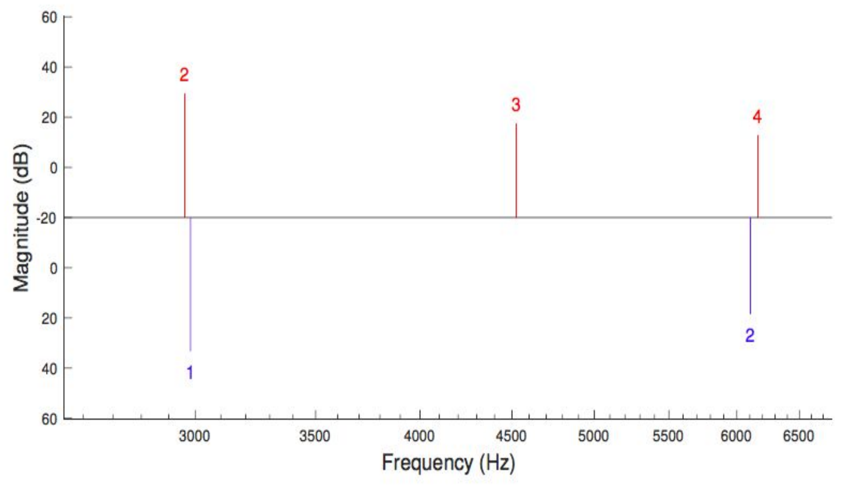
4. Listening Study

- To find a simple tuning rule for high tones
- Compare different tuning analyses with results
- 4 tuning rules tested near 6th octave
- Multi Stimuli test with anchor
- 16 participants

Tuning Rules

- Matching the first partial (m1)
- Matching the second partial (m2)
- Anchor: matching the third partial (m3)
- Matching the geometric mean of first two partials (gm)

Also compared with professional tuning (n)



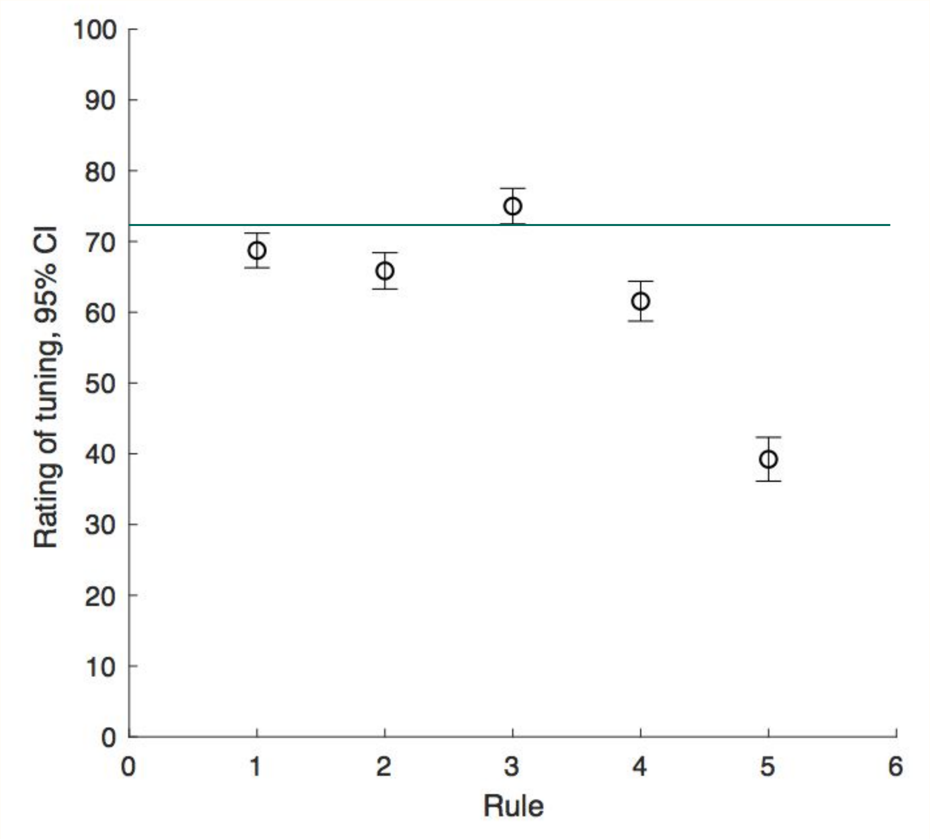
Partials of A4 (above) and A5(below)

Results

Results for all octaves

Methods:

1 - Professional tuning (n)
2 - Geometric mean rule (gm)
3 - Matching first set of partials (m1)
4 - Matching second set of partials (m2)
5 - Matching third set of partials (m3)

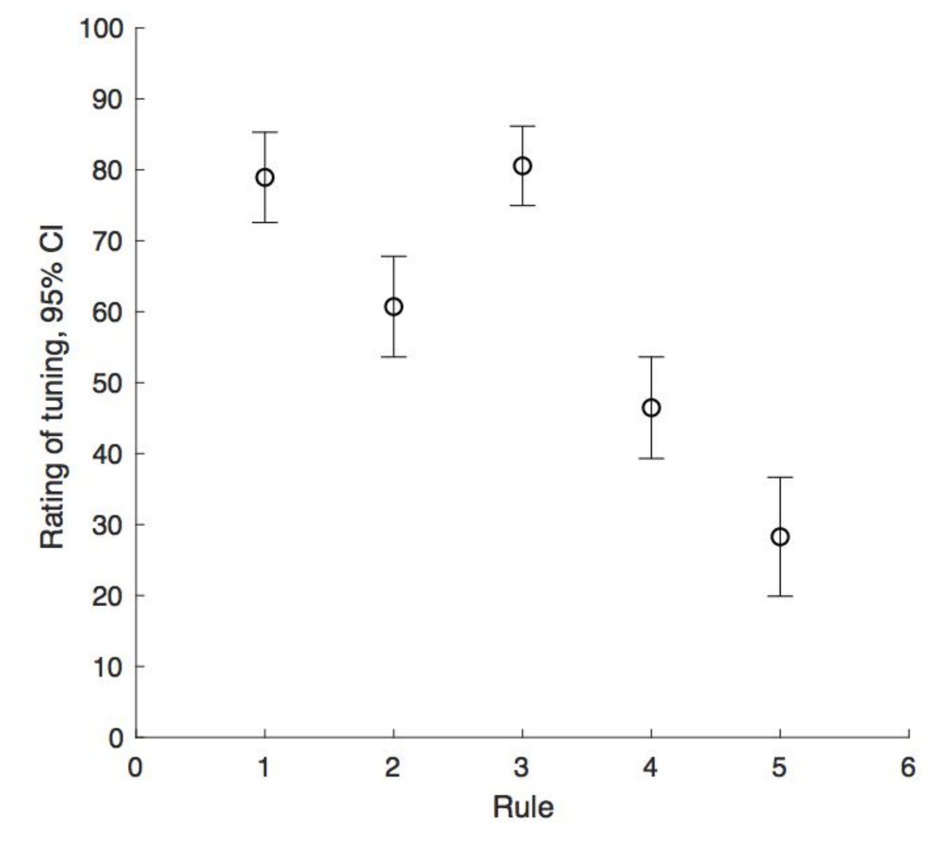


Results

Results for octave D5 D6

Methods:

1 - Professional tuning (n)
2 - Geometric mean rule (gm)
3 - Matching first set of partials (m1)
4 - Matching second set of partials (m2)
5 - Matching third set of partials (m3)

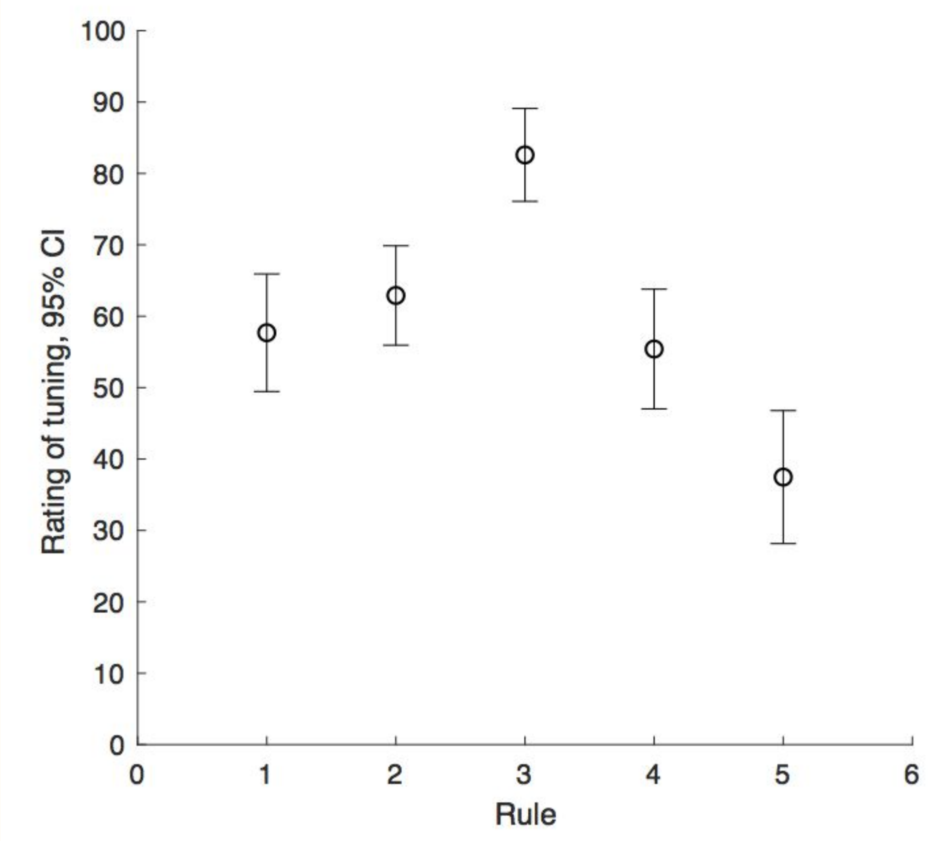


Results

Results for octave G5 G6

Methods:

1 - Professional tuning (n)
2 - Geometric mean rule (gm)
3 - Matching first set of partials (m1)
4 - Matching second set of partials (m2)
5 - Matching third set of partials (m3)

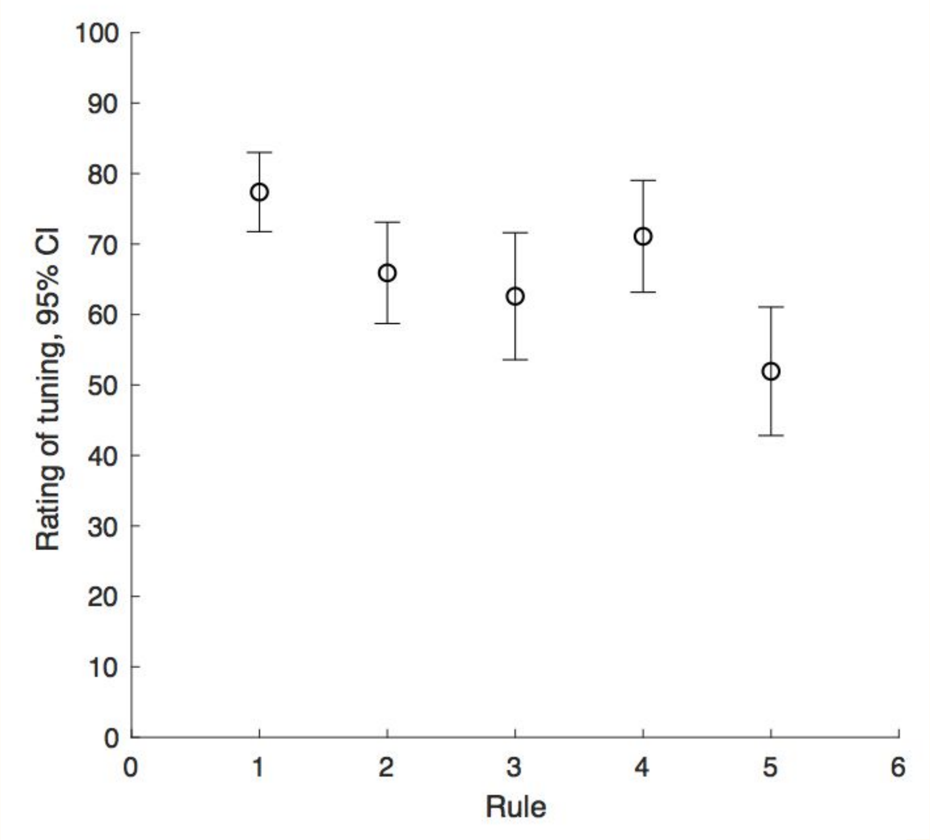


Results

Results for octave D6 D7

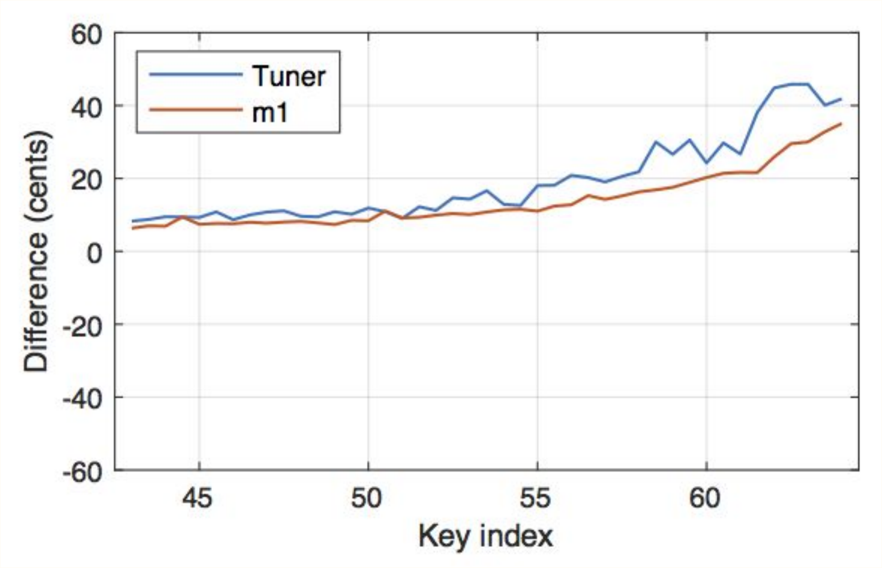
Methods:

1 - Professional tuning (n)
2 - Geometric mean rule (gm)
3 - Matching first set of partials (m1)
4 - Matching second set of partials (m2)
5 - Matching third set of partials (m3)

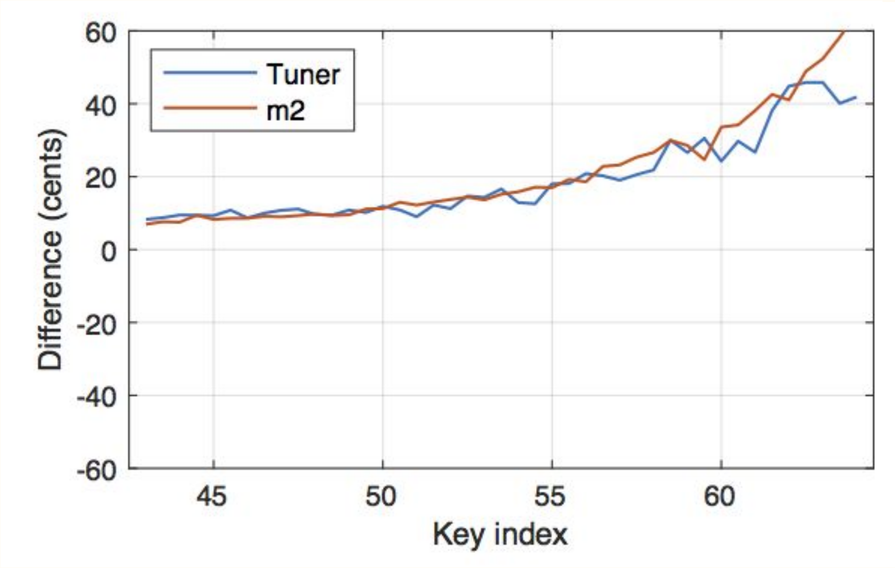


Comparison - Railsback Curves

Results of rule m1

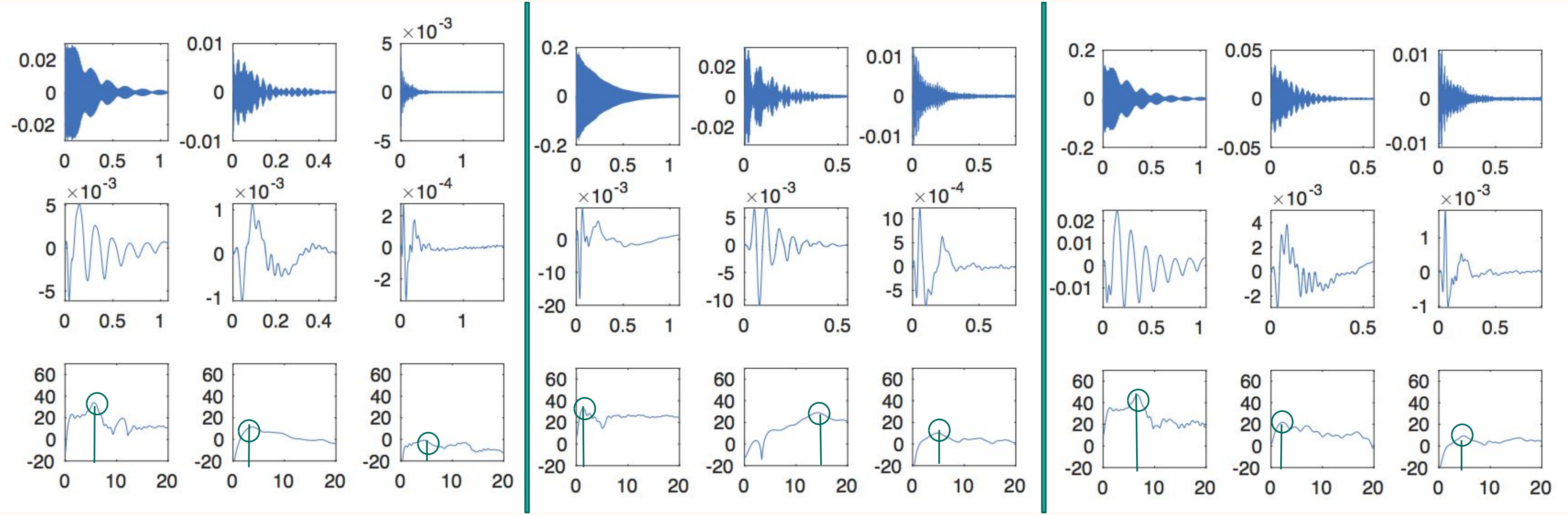


Results of rule m2



Comparison - Beats Analysis (Key 62)

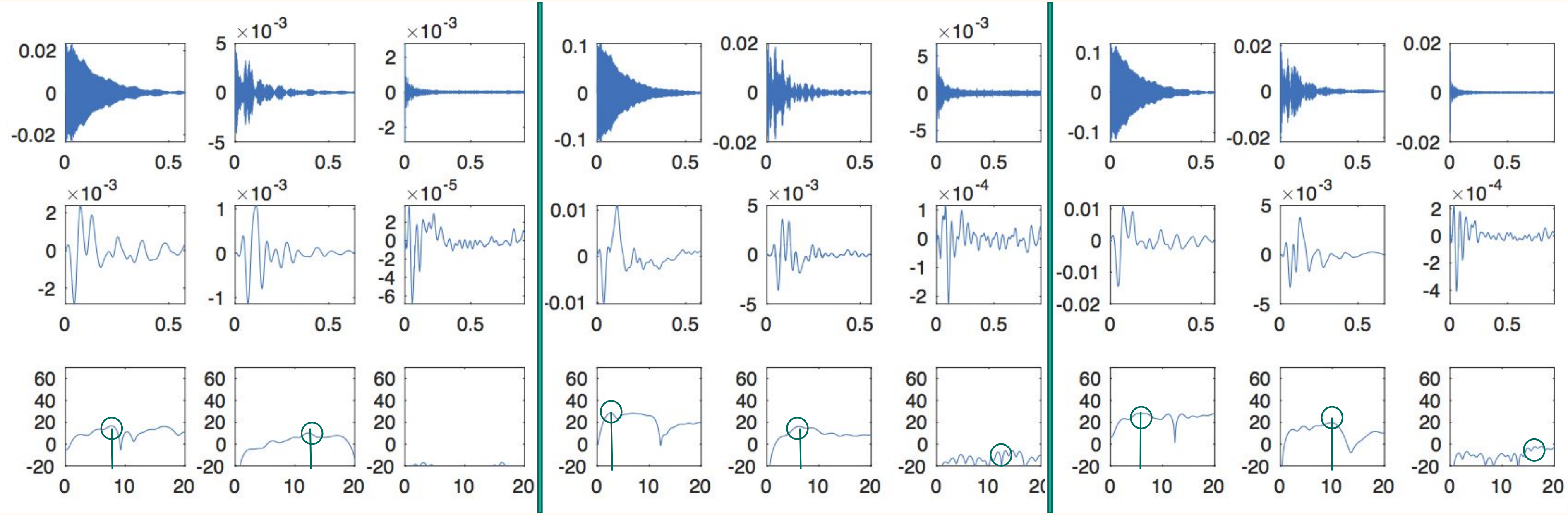
Professional Tuner			Matching 1st Partial			Matching 2nd Partial		
Partial 1	Partial 2	Partial 3	Partial 1	Partial 2	Partial 3	Partial 1	Partial 2	Partial 3



Comparison - Beats Analysis (Key 66)

Professional Tuner | Matching 1st Partial | Matching 2nd Partial

Partial 1 | Partial 2 | Partial 3 | Partial 1 | Partial 2 | Partial 3 | Partial 1 | Partial 2 | Partial 3



Conclusions

- Found simple rule for tuning high partials
- Proposed new method to evaluate tuning
- Both results confirmed by listening test

Future Work

- Extend Beat Analysis
- Create a complete automatic piano tuning system

Reference

[1] J. Lattard, “Influence of inharmonicity on the tuning of a piano—measurements and mathematical simulation,” The Journal of the Acoustical Society of America, vol. 94, no. 1, pp. 46–53, 1993.

[2] Tuovinen J, Hu J & Välimäki V, “Toward Automatic Tuning of the Piano,” in Proceedings of the Sound and Music Computing Conferences, Malaga, Spain, pp. 143-150, 28/05/2019

[3] N. Giordano, “Explaining the Railsback stretch in terms of the inharmonicity of piano tones and sensory dissonance,” The Journal of the Acoustical Society of America 138, 2359 (2015).

[4] H. Hinrichsen, “Entropy-based tuning of musical instruments,” Revista brasileira de Ensino de Física, vol. 34, no. 2, pp. 1–8, 2012.