Just intonation and inharmonicity in struck-string interaction

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21/04/24

Abstract

This paper explores the design of dynamic tuning mechanisms for struck-string interaction, focusing on the transition from equal temperament to just intonation for piano-based sounds. Inharmonicity, a natural characteristic of piano strings, presents challenges when employing exact harmonic intervals, particularly in the bass and treble registers. By leveraging dynamic tunings based on performance parameters such as key pressure, our proposal aims to tackle inharmonicity as a dimension of struck-string interaction in the context of just intonation, thus expanding the available timbre palette through tuning. Our project aims to dynamically modulate the inharmonicity of piano-like sounds, creating a continuum of tunings that incorporate harmonicity as a timbral dimension. This system is aligned with the characteristics of struck-string frameworks while providing musicians with tools to explore tuning as a tool for timbre design. Our research also aims to bridge the gap between theoretical tuning systems and practical implementations, offering new insights and techniques that can be applied in ubimus artistic practice and interaction design.

1. Introduction

Second-wave ubimus frameworks are providing interesting opportunities for the expansion of legacy practices. These threads complement the extant initiatives to push the boundaries of music-making beyond the acoustic-instrumental ways of thinking that have dominated technological developments since the early 1960s. These initiatives have unveiled the possibility of investigating unexplored aspects of well-established tools and resources, as exemplified by the archaeological work with software replicas [Lazzarini and Keller 2021], by the application of generative techniques for idiomatic aims [Lopes et al. 2021; Kramann 2021], or by the conceptual expansion of the basic units of music-making, embodied in the concept of musical stuff [Messina et al. 2022]. Surprisingly, tuning, a typical target of theoretical explorations throughout the last century, has not been approached from a ubimus perspective. This position paper attempts to address this gap.

Due to a focus on acoustic-instrumental thinking, equal temperament has been a predominant tuning system within the digital realm. According to Halewood (2015), “this model has become so ubiquitous that it is sometimes difficult to see it in its specificity [i.e.] as only one possible solution.” He mentions its practicality in accommodating a variety of tonal idioms and highlights the usefulness of having a well-established standard for group-based musical activities.

Along with other tuning methods, just intonation (also known as pure intonation) can provide a different strategy for pitch organization due to its ratio-based intervallic relationships. Many musical traditions employ just intonation [Vasudevan 2023]. Through an analysis and reinterpretation of problematic passages that have been used to demonstrate the supposed impossibility of just intonation, Duffin (2006) suggests that simple acoustical ratios may have been adopted as much as possible in Renaissance practice, while avoiding pitfalls such as progressive transposition or comma by comma in passages with overlapping pitches based on the circle of fifths. Complementarily, experimental findings indicate that pitches based on arithmetically exact intervals are neither better

nor worse than fractional approximations that “all of these experiments prove conclusively that singers and instrumentalists have no predilection for the so-called natural intervals, [...] the same is valid for the majority of listeners” [B, E., and J. Murray Barbour, July 1952].[1] Thus leaving aside purely practical factors, there is no perceptual justification for the widespread adoption of tempered tunings.

Given this state of affairs, we take a two-pronged approach to the exploration of tuning strategies for struck-string interaction. Firstly, we consider the expansion of pitch organization by means of alternative tunings. Just intonation is chosen as an initial target because of its ample (positive and negative) coverage in the music-theoretical literature. Subsequently, we address the conceptual underpinnings of tuning as a tool for timbre design. Our approach involves the usage of inharmonicity as a key parameter, pointing to links with the ongoing investigations of ubimus timbre-based semantics [Simurra et al. 2023; Zacharakis and Pastiadis 2021]. Our initial aim is to develop an interactive software toolkit that enables users to upload MIDI files and automatically convert them to just intonation based on the key signature of each segment of the MIDI file, thus yielding ratio-based pitches.[2] Later refinements will involve more flexible techniques that enable usage beyond the realm of strongly tonal idioms.

2. Methodology

Our work is in a preliminary stage of design, conceptual grounding and prototyping. We have developed a website that enables uploading MIDI or audio files, adjusting tuning parameters and rendering a sonic preview. If the outcome meets her expectations, the user can download the file.

First component: MIDI processing and key detection.[3]

- We utilize the Python mido library to parse MIDI files and extract musical data including pitches, timing and metadata.
- A tonal key detection algorithm was implemented using the music21 library [Cuthbert et al. 2020], which employs a combination of statistical and heuristic methods to determine the tonal center of each musical segment.
- Our current focus is piano music, handling asynchronous conversions from equal temperament to just intonation but keeping our techniques compatible with performance-oriented implementations.

Second component: Tuning adjustment algorithms.

- Develop algorithms to adjust the tuning of MIDI pitches from equal temperament to just intonation based on each segment-based detected key and using predefined just intonation ratios. By utilizing key detection, we can identify a reference key to apply tuning according to the ratios relative to a reference tonal center. This method, based on the user's specified window size (with 10 seconds as a

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[1] The studies cited include those from the Psychological Laboratory at the University of Iowa, such as Carl E. Seashore, ed, Objective Analysis of Musical Performance, University of Iowa Studies in the Psychology of Music 4 (1936) (see in particular, Paul C. Greene, "Violin Performance with Reference to Tempered, Natural, and Pythagorean Intonation," University of Iowa Studies in the Psychology of Music 4 (1936), 232-51); studies from the Harvard Psychological Laboratory by Austin M. Brues (1927); studies from the University of Washington by E. R. Guthrie and H. Morill (1928); James F. Nickerson, "Intonation of Solo and Ensemble Performance of the Same Melody," Journal of the Acoustical Society of America 21 (1949), 593-95.

[2] Instrumental events may lack pitch or may be heard as ambiguous pitches, thus in some cases they could be "untunable".

[3] When we say <key> we mean tonal center. This construct is not applicable to pitchless or inharmonic sounds (such as bells). It is also not applicable to nontonal harmonic idioms, such as those based on 4ths or other intervals.

default value), applies a windowing function for the detection of a tonal center.
- We are currently updating our prototype to enable manual tuning adjustments, allowing users to modify ratios and immediately hear the outcome. Parameters available for adjustment include window size, reference tonal centers, and base pitch for tuning adjustment.
- By implementing the music21 library and mido, our software can segment the MIDI file based on timestamps. Using ratio-based tuning algorithms, it successfully converts music from equal temperament to just intonation.

Third component: Interaction and audio support

- The current prototype allows users to upload their files, preview the tuned version, and download the outcome.
- We plan to design a simple and effective web interface using javascript and html, providing functionalities for file upload, playback controls, parameters changing, and visual and auditory comparisons.
- We also plan to include automated conversion of PCM audio files to just intonation.

3. Implemented prototype

We have implemented a first prototype of an interactive software toolkit that enables users to upload MIDI files and automatically convert them to just intonation based on the key signature of each segment of the MIDI file, thus achieving ratio-based pitches.

Website: https://just-tuning-0fe9a1e8597e.herokuapp.com

4. Musical examples

Original Fur Elise
https://drive.google.com/file/d/1o4qOxnlyrOr0CElFLrt7njI2aXZBqc4s/view?usp=share_link

Just-tuned Fur Elise
https://drive.google.com/file/d/1KIUv1NoiG3ax8wU_7fQkfmejlSYMVtx7/view?usp=share_link

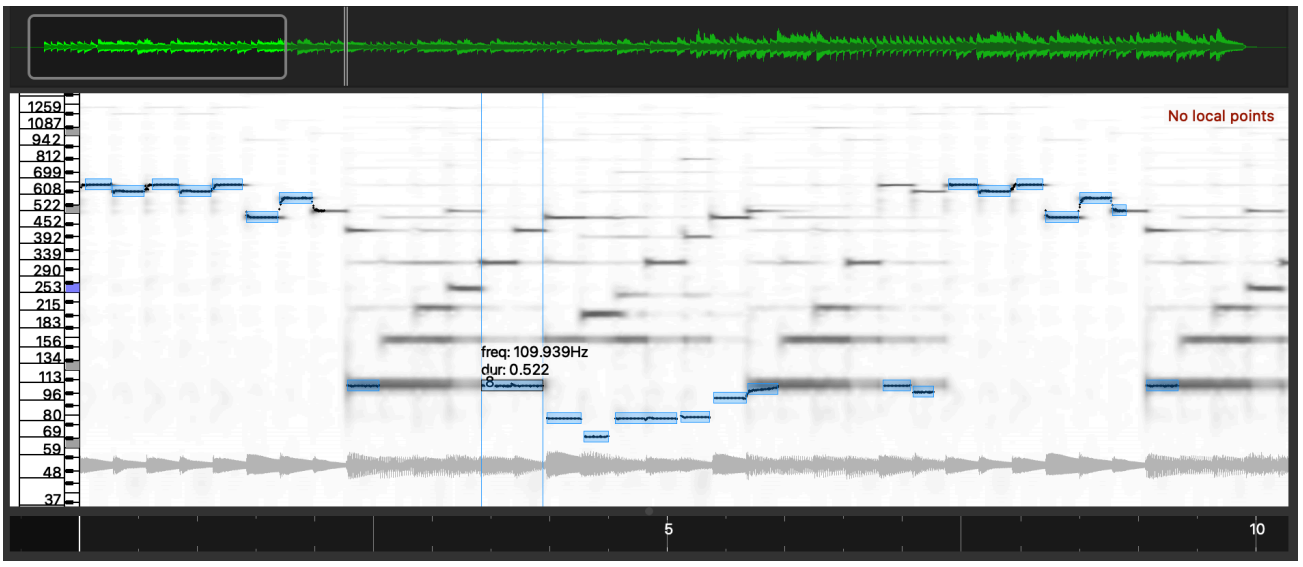

Fig.1. Frequency in equal temperament (Fur Elise).

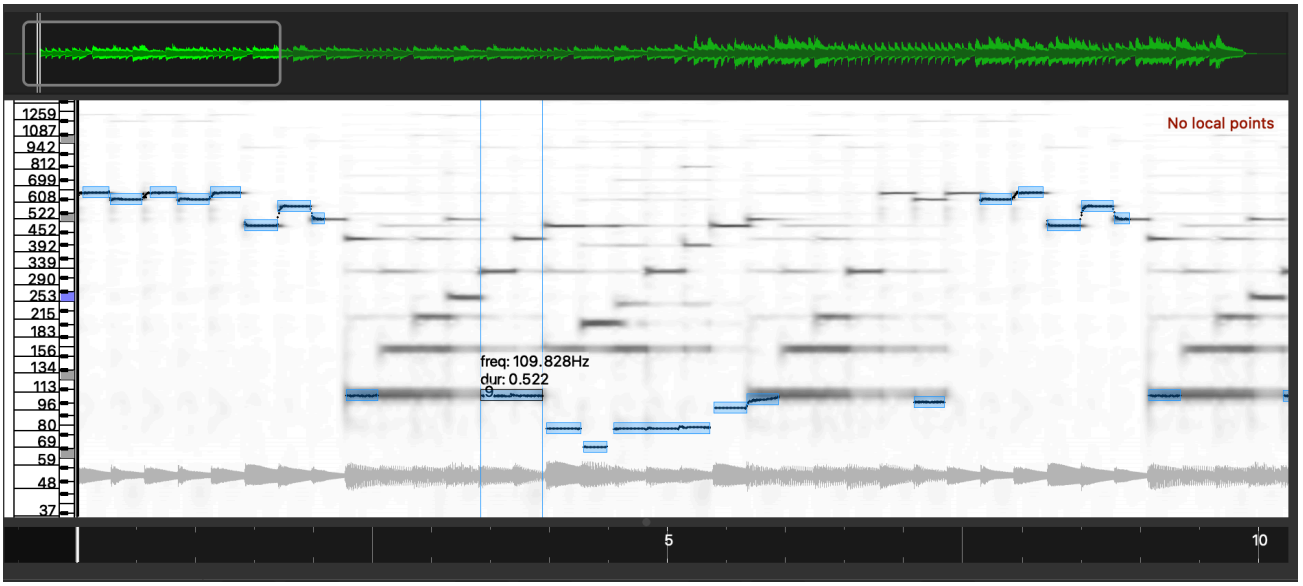

Fig. 2. Frequency by just intonation tuner.

Original Clair de Lune (Debussy)
https://drive.google.com/file/d/1IKR_7yZYS7O8YNe5tAqYusqGZWMgASqP/view?usp=share_link

Just-tuned Clair de Lune
https://drive.google.com/file/d/1r3arZo6uJpe7lvP3yJyBpXe9OMw1JcCj/view?usp=share_link

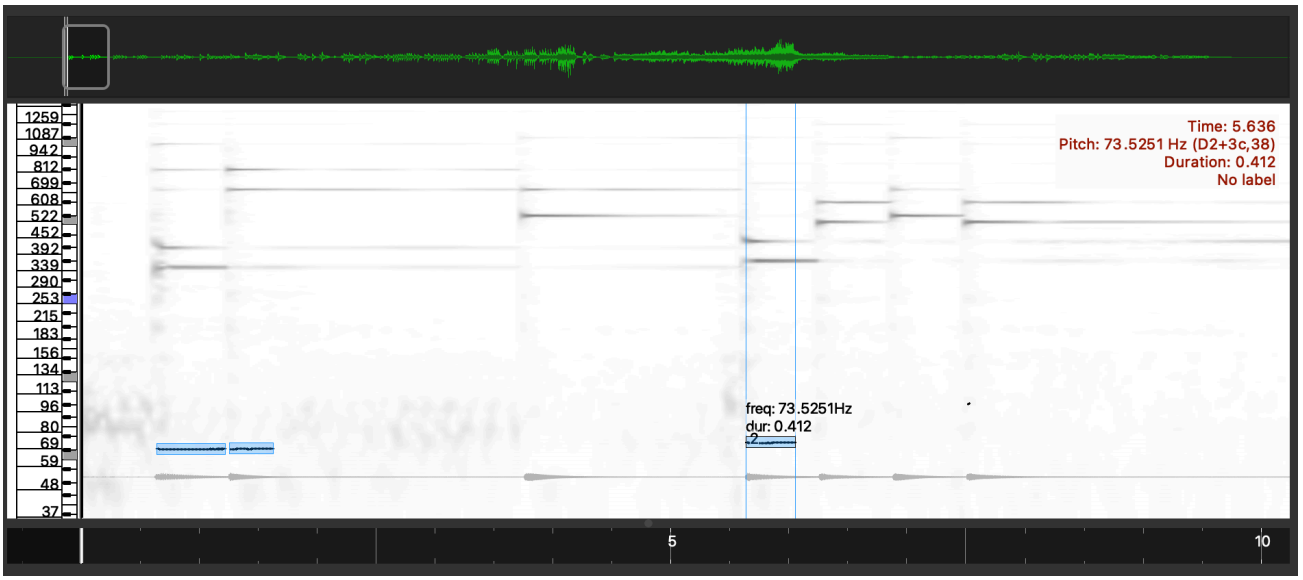

Fig. 3. Frequencies in equal temperament Clair de Lune Debussy

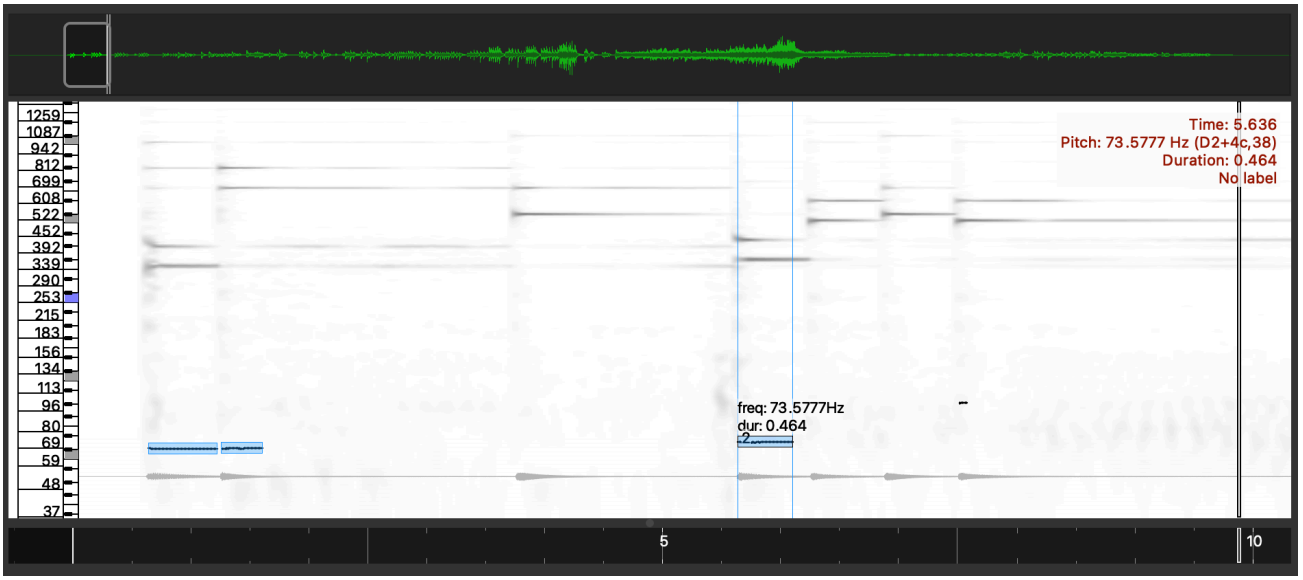

Fig. 4 Frequencies after just intonation.

5. Limitations

The results were partially impacted by practical barriers. First, just intonation cannot be practically achieved for every event, necessitating some compromises. As Jøran Rudi (2015) states, “the principle of just intonation is that intervals are described by integer ratios. However, due to the Pythagorean comma, the same pitches cannot be used in all keys. The small compromises in pitch that characterize equal temperament are unacceptable, thus the musician needs to have access to a much larger number of pitches to play with just intonation in all keys.” Additionally, the music21 key-detection method is not always precise, with an accuracy rate of about 78%, which in ambiguous tonal passages can result in jarring sounds. Lastly, the prototype’s interface is tailored for asynchronous usage, although the code is designed to allow real-time human input to enable tuning and display of musical outcomes.

6. Future developments

This project aims to bridge a gap in the design of tuning techniques in ubimus by providing a toolkit that makes the exploration of just intonation accessible to a wider audience. Through an interactive toolkit, users may gain a deeper understanding of the sonic differences between tuning systems unveiling the musical nuances they bring to performance and compositional tasks. Actual usage of alternative tunings may also provide a bridge between theoretical musicological speculations and practical design requirements.

Our toolkit yields sonic renditions showcasing the difference between equal temperament and just intonation renditions. It introduces a parametrically flexible technique that features an overall reference pitch for tuning adjustments, a time-windowed evaluation of tonal centers or an alternative predetermined reference pitch. The implemented library may be delivered both as an asynchronous and synchronous tool. We plan deployments to assess its limits within the context of expanded tonal idioms.

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