A Multi-User Interface for Real-Time Intonation Monitoring in Music Ensembles

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Abstract

Intonation is a crucial aspect of musical ensemble performance. Yet maintaining accurate tuning among multiple musicians remains a persistent challenge, particularly in variable rehearsal and live performance settings. While intonation monitoring systems have been explored previously, most focus on single-channel processing, lack real-time capabilities, or do not support ensemble-specific functionality. In this work, we explore the possibilities of a real-time, multi-user intonation monitoring system specifically developed for music ensembles. It provides immediate, role-specific feedback to both musicians and conductors, supporting collaborative rehearsal practices and ensemble tuning processes. We conducted an initial experiment in a rehearsal setting with four musicians and a conductor, focusing on a qualitative evaluation of usability, interpretability, and musical relevance. The preliminary findings indicate that the system offers clear and practical feedback, promotes awareness of intonation, and has the potential to enhance interaction and facilitate communication within the ensemble.

CCS Concepts

• **Applied computing** → **Sound and music computing**; • **Human-centered computing** → *User interface programming*; • **Information systems** → **Music retrieval**.

Keywords

Pitch Estimation, Real-Time, Intonation, Monitoring, Music Processing

1 Introduction and Related Work

Motivation and Challenges. In amateur wind music ensembles, addressing intonation is often one of the most time-consuming aspects of rehearsal and concert preparation. While musicians typically tune their instruments to a reference pitch at the start, this does not guarantee that all members remain in tune throughout the session. Each instrument and player has unique intonation tendencies, and some pitches are inherently more difficult to tune accurately [4]. Musicians must make continuous adjustments during rehearsals and performances, especially as the musical context changes and affects how notes should be intonated.

Intonation in Wind Ensembles. Many wind instruments allow for continuous pitch adjustment through playing techniques, air support, and tuning slides. As a result, intonation in wind ensembles is not fixed to 12-tone equal temperament and often gravitates toward just intonation [16]. Musicians adjust their tuning to the harmonic context, such as lowering major thirds, to achieve more consonant intervals within chords. These micro-adjustments require heightened awareness and real-time adaptation, especially when the harmony or chord structure changes rapidly.

Related Work. To help musicians with intonation, computer-aided feedback systems have been explored in various music teaching contexts. For example, in [11], auditory and visual feedback was used to guide violin students in improving their intonation. In [2], real-time feedback was based on combined sound and motion analysis to support the development of sound quality. Similarly, [12] focused on assessing sound quality, but relied solely on acoustic features. A web-based user interface for supporting choral singing practice was introduced in [13], and a software tool for multi-channel audio analysis of singing voices was presented in [6], offering pitch-related feedback for singers.

2 Intonation Monitoring System

In this section, we describe the technical components and design principles of our real-time intonation monitoring system. Additional materials and resources are available on a supplemental website.[1]

System Overview. Our system enables real-time intonation monitoring for music ensembles, combining multi-channel audio input, robust pitch estimation, and intuitive visual feedback for both musicians and conductors. As illustrated in Figure 1a, microphones capture each instrument and transmit audio to a central server, which performs pitch analysis and distributes results to client devices for visualization.

Definition of Intonation. In this paper, *intonation* refers to the accuracy of the fundamental frequency in relation to a selected tuning system — specifically, the 12-tone equal temperament based on a reference tuning (e.g., 442 Hz). However, our approach can be easily adapted to consider the harmonic structure of the input signal [15], accommodate different tunings [7, 16], or make relative measurements between musicians [17].

Pitch Estimation. Pitch estimation is performed using a real-time implementation of the `SWIPE` algorithm [3, 9]. `SWIPE` estimates the fundamental frequency by comparing spectral templates to the

[1] https://www.audiolabs-erlangen.de/resources/MIR/2025-ICMI-Intonation

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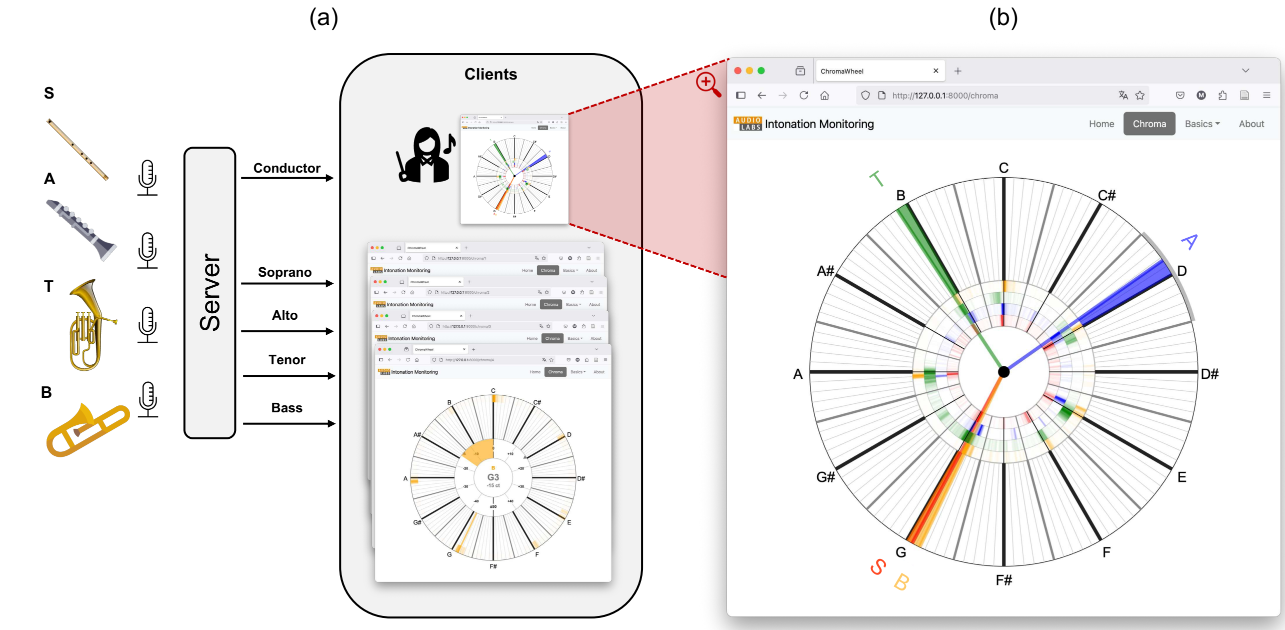

Figure 1: Overview of the real-time intonation monitoring system. (a) System architecture: microphones capture audio from each musician, connecting to a central server for real-time pitch analysis and web-based visual feedback. (b) Conductor view: main visualization for intonation monitoring, showing pitch class, cent deviation, and tuning stability for each musician.

input signal and selecting the best-matching template. Because these templates incorporate harmonic structures similar to those produced by wind instruments, the algorithm performs well in this context. Moreover, in previous work, it was found that `SWIPE` is not only computationally efficient but also robust in the presence of acoustic cross-talk, a common challenge in multi-track ensemble recordings [8]. These properties make `SWIPE` especially well-suited for real-time, multi-channel pitch tracking in live ensemble settings. The estimated pitches are processed on the server and then distributed in real time to multiple client devices, such as mobile computers or tablets, where they are visualized through a web-based application.

User Interfaces. Our intonation monitoring system provides two main views: a *single view* for individual musicians and a *conductor view* for ensemble-wide monitoring. Both use a circular layout, specifically a *chromatic circle* [10], which resembles the *circle of fifths*, a concept familiar to most musicians. The grid is divided into 12 segments for the chroma classes, arranged clockwise with C at the top, condensing pitch information across octaves. In the *conductor view*, intervals and chords form recognizable patterns, enabling quick visual identification. The circular arrangement also supports smooth transitions across notes and octaves, minimizing abrupt jumps in the visualization of estimated pitches.

Single View. The *single view* (Figure 1a, right side) is designed to provide each musician with real-time feedback on their own intonation, functioning similarly to a standard tuning device but enhanced with a circular layout for improved musical context. The outer circle displays the current pitch class as a pointer, allowing musicians to quickly identify which note they are playing. Within the inner circle, cent deviations from -50 to $+50$ cents are visualized, referencing the 12-tone equal temperament system and helping users recognize subtle tuning differences. To further support musicians, the interface incorporates pitch histograms that reflect tuning stability over time, enabling users to observe trends and fluctuations in their intonation during sustained notes or passages. Triangle markers highlight key musical intervals, such as major and minor thirds at -14 and $+16$ cents, respectively, providing visual cues for context-sensitive tuning adjustments.

Conductor View. Figure 1b shows the *conductor view* for ensemble-wide monitoring, visualizing each musician's current note and cent deviation as colored pointers and areas. In our example, the ensemble plays the notes G, B, and D, which form a G-major chord. The soprano (red) and bass (yellow) play the G; however, the bass is slightly lower than the soprano, as indicated by its position on the outer ring. The B is played by the tenor (green), also a few cents lower. It is important to recall that in just intonation, the major third should be played at -14 cents. Finally, the alto (blue) is playing an A, which is also too low. The inner rings display a histogram for every connected device in their respective colors. This setup enables the conductor to make informed judgments about ensemble intonation that go beyond the capabilities of traditional isolated tuning devices.

3 User Experiment and Evaluation

Experiment Setup. The initial user experiment aimed to assess usability and inform future design of the intonation monitoring

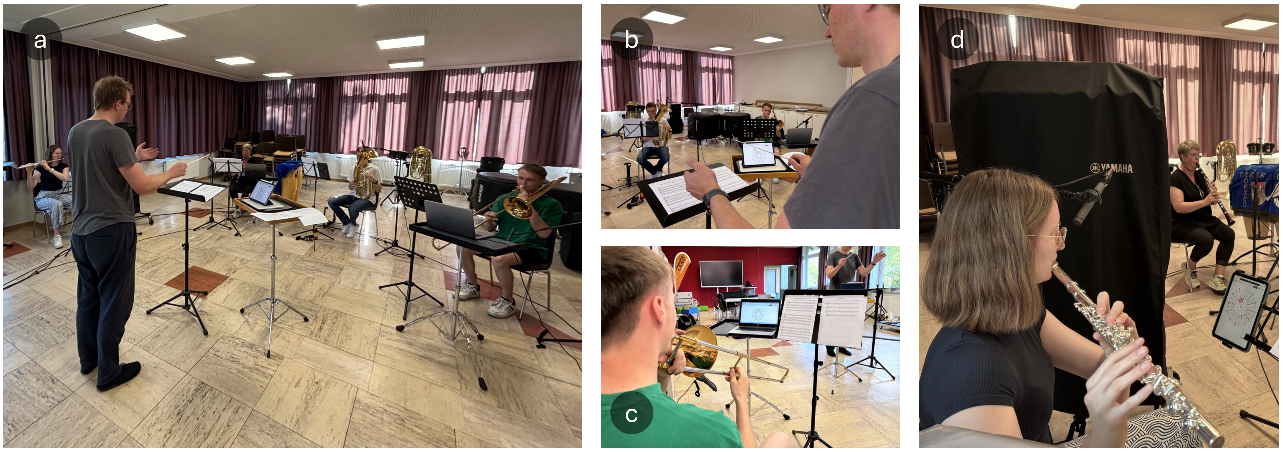

Figure 2: Impressions from the user experiment: (a) The ensemble seated in a semi-circle during rehearsal. (b) The conductor view with a multi-channel interface. (c) The trombone player's setup using a notebook. (d) The flute player using a tablet for the single view interface. All musicians agreed to make the photos available.

system in a real-world setting. It was conducted in the rehearsal room of the Weserberglandorchester (WBO) Bödexen, Germany, with four amateur musicians (flute, clarinet, baritone horn, trombone) and a conductor. The session, including discussion, lasted about two hours. As shown in Figure 2a, musicians were seated in a semicircle with approximately 2 meters between them. Each had a music stand and a display device (notebook or tablet) running the intonation monitoring interface — role-specific for musicians and a full overview for the conductor (Figure 2b–d). Four identical cardioid condenser microphones (Schoeps MK 4) were placed about 15 cm in front of each instrument.

Procedure. The experiment session was organized into five sequential parts: instrument tuning, scale playing, chords, cadences, and chorales. Initially, all musicians tuned their instruments simultaneously using the intonation monitoring system, followed by individual pitch recordings and verification with the conductor's tuning device. Next, the ensemble played scales together, with the conductor indicating note changes; this was performed both with and without the monitoring system to compare experiences. The third part focused on B major and B minor chords in various inversions, with each musician taking turns playing the third and adjusting their intonation based on system feedback. In the fourth part, the group performed four different cadences, and finally, two chorales (DR1 and TE1) from the ChoraleBricks dataset [1] were played. For each musical task, recordings were made both with and without the system, enabling direct comparison of intonation accuracy and ensemble interaction. After the musical session, all musicians completed a structured questionnaire covering three areas: personal and musical background, impressions of the intonation monitoring system, and open feedback.

Results. Two participants were female and two were male, with ages between 19 and 50 years. All had been playing their main instrument for over ten years, practiced approximately two to three hours per week, regularly participated in at least one ensemble, and also played additional instruments. The impressions of the intonation monitoring system was assessed through statements rated on a 5-point Likert scale (from strongly disagree to strongly agree). Most participants reported a clear understanding of the information presented, and they generally found the interface to be familiar. The display was not found to be distracting during playing, and participants noted an increased awareness of intonation while using the system. Ratings regarding the alignment between the display and their own auditory perception of intonation were neutral. Participants also expressed a neutral stance on using the system in future rehearsals, pointing to both interest and opportunities for further development.

User Feedback. Overall, the participants considered the intonation monitoring system as a helpful tool, particularly appreciating features such as cent markers for thirds, the histogram visualization, and visual support for stabilizing pitch especially during sustained notes. They reported that the system enhanced their intonation awareness, revealing unexpected tendencies to play sharp or flat and helping them adjust pitch more accurately within chords. However, limitations were noted, especially with display instability during fast passages. Users suggested improvements including a refresh button, octave-specific histogram views, faster pitch display response, and overall stability enhancements. Although the conductor view was not specifically evaluated, initial impressions indicated that it was helpful for assessing ensemble stability and understanding the harmonic context, especially during long sustained notes. A more detailed discussion on the musical impact of the system is provided in the Section 4.

4 Conclusion and Future Work

Technical Challenges. Our initial user experiment provided valuable insights into the real-time intonation monitoring system for music ensembles and highlighted technical and musical challenges for future iterations. A major issue was acoustic cross-talk, particularly with the flute, which is difficult to isolate from nearby instruments. The flute's smaller size and quieter sound are often overshadowed by larger, louder instruments like the baritone horn, complicating fundamental frequency estimation — a limitation noted in previous studies [8]. Acoustic room reverberation and ensemble spacing introduced further complexities. To improve signal isolation, future systems could combine better microphone selection, pre-processing techniques (e.g., low-pass filtering or source separation), and alternative input devices based on vibration sensors [5], similar to using larynx microphones in vocal applications [14].

Musical Impact. Beyond technical aspects, the field study was highly rewarding. Musicians were patient, curious, and engaged, providing valuable feedback and appreciating the technology's novel perspective on their practice. The system increased their sensitivity to intonation and encouraged musical reflection. Such tools can support not only tuning but also deeper engagement with ensemble playing. For conductors, the interface translates abstract instructions into concrete visual cues. For example, lowering the third in a major chord is often difficult for amateur musicians to internalize. Real-time feedback helps them intuitively understand and apply such adjustments, improving listening skills and intonation over time.

Future Directions. Throughout the experiment, various ideas for future development emerged. Unlike default tuning devices, our system is a connected solution that enables advanced signal processing pipelines—for example, to address cross-talk and other ensemble-specific challenges discussed above. This connectivity allows for richer, context-aware feedback and collaborative features that go beyond isolated tuning support. Currently, only the conductor has access to the full ensemble's tuning data. However, musicians could benefit from context-aware feedback on their individual devices. This feedback might include which notes are being played by others, an estimate of the current chord, who is playing the root of that chord, their own harmonic role within the chord (e.g., major third), and a corresponding intonation target. Furthermore, if the ensemble drifts in pitch collectively, musicians could make informed adjustments rather than adhering rigidly to a fixed reference grid. Such contextual awareness could foster a more responsive and musically sensitive approach to ensemble intonation beyond what individual tuners offer.

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