Audiation Development System for Gugak's Fluid Musical Parameters Utilizing Audio Feedback Stimuli

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Abstract

Gugak, the traditional music of Korea, is defined by its distinctive musical characteristics, including flexible tuning, non-metric rhythms, and intricate ornamentation. These unique features, while artistically rich, pose significant challenges for novice learners, particularly when approached through conventional, textbook-based methods. To bridge this gap, we introduce the Audiation Development System for Gugak, an interactive platform that leverages algorithmic analysis to support both learning and teaching. Central to this system is the development of signal processing functions for rhythmic guidance, pitch detection, and additive harmonic synthesis—algorithms specifically designed to capture the expressive nuances of Gugak. These functions generate real-time auditory and visual feedback, providing a responsive learning environment aligned with the updated Korean music curriculum. The system not only enables student-centred exploration of Gugak's fluid structures but also supports educators through dynamic, visualized feedback tools. Beyond its technical foundation, this research sets the stage for future development of user interfaces and investigates the educational efficacy of computer-driven learning compared to traditional methods. By integrating music technology and pedagogy, this work contributes to both the accessibility and sustainability of Korea's musical heritage.

Keywords

Korean-traditional music genre, Gugak NIME, Educational controllers, Audiation, Audio stimuli, Feedback system, Initialized to current tuning

1 INTRODUCTION

Traditional Korean music, known as Gugak, encompasses a rich cultural and musical heritage that is both intricate and nuanced. Our research focuses on creating an interactive educational platform designed for both local and international novice learners. This platform aims to facilitate an accurate understanding of traditional Korean musical features while ensuring the preservation of its cultural and musical essence. In consideration of the recently revised nationally regulated Korean music curriculum, which is scheduled for full implementation across all South Korean public primary, middle, and high schools by 2026 [1, 2], alongside the historical foundations of viva voce education in Gugak, we explore effective methodologies for providing real-time digital feedback. This approach detailed in this paper is intended to enhance the individual learning experience by fostering a deeper practical comprehension of Gugak's flexible tuning, rhythm, and ornamentation parameters, ultimately contributing to lasting embodied learning effects.

Stage I involves unconsciously audiating a short series of notes just aurally perceived without giving them musical meaning.

Stage II includes consciously audiating tonality and meter while organizing essential note patterns from immediate aural impressions.

Stage III involves retaining and reassessing organized patterns of essential notes while audiating new series of notes.

Stage IV includes recalling patterns of essential notes from other pieces of music to assess and restructure current audiation.

Stage V involves predicting patterns of essential notes based on tonality, meter, and retained patterns, with accuracy affecting musical understanding.

Figure 1: Five stages of audiation development

Various related works by Pardue et al., Percival et al., Dyer et al., Suzuki, Kreitman, Kantoski, and Dai et al. demonstrate the effectiveness of providing audio stimuli to strengthen audiation and prevent intonation drift for beginner instrumentalists [3–9]. *Audiation*, a term coined by Edwin Gordon in the late 1970s, is defined as hearing music in one's mind when the sound is not physically present, distinct from aural perception [10]. The five stages of audiation, as outlined in Figure 1, are hierarchical and likely occur concurrently, involving patterns of notes, tonality, meter, and prediction. However, the last stage represents the point in development when the student musician can predict patterns of essential notes based on tonality, meter, and retained patterns, with accuracy affecting musical understanding. In settings characterized by a lack of instrumental accompaniment, the initial tonal reference may gradually be neglected. According to Dai et al. [9], unaccompanied intonation errors can be mitigated by instructing performers to internally model the commonly utilized tonal references through training that incorporates accompanying audio stimuli.

The findings from Pardue et al.'s user testing indicate that real-time auditory feedback is qualitatively more effective than real-time visual feedback [3]. Despite the ongoing discourse surrounding audio and visual feedback systems, it is argued that visual feedback is not a correction modality commonly utilized in performance contexts and may serve as a limiting habitual crutch that warrants significant consideration [4]. Pardue et al. asserts that among the school-age participants, the need for active allocation of visual attention between the feedback display and the score was beneficial in instances where the score was not critically essential (such as scales) [3]. Still, the challenge of dividing attention during practice sessions often resulted in sensory overload, particularly when visual cues changed at a pace too rapid for effective processing. Quantitative investigations reveal that humans process auditory stimuli more rapidly, at 40 milliseconds, compared to visual stimuli, which is processed at 50 milliseconds [3]. Consequently, it is easier for a learner to process auditory feedback in real -time than to process visual information.

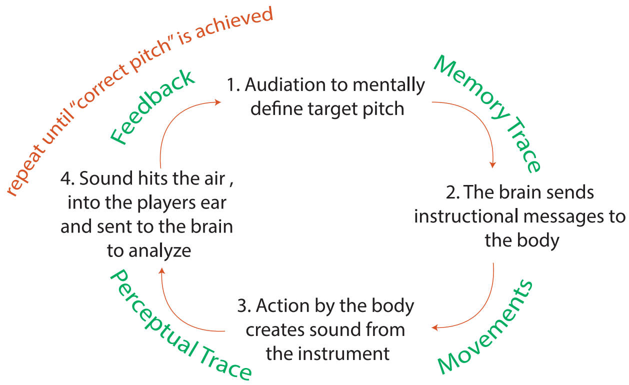

Figure 2: Kreitman's listening loop for intonation based on Adam's Closed-loop system for motor learning

The implementation of *Adam's Closed-Loop Theory*, a framework for motor learning that significantly relies on the availability of feedback to facilitate the acquisition of motor skills, is proposed [11]. Figure 2 illustrates *Kreitman's listening loop* developed for the aural perceptive pitch closed-loop theory process. Initially, this theory involves the development of motor memory traces, which are essential for the selection and initiation of a specific movement plan. Subsequently, through the advancement of the perceptual trace stage, the learner is afforded the opportunity to compare the ongoing movement with an accurate memory of the intended movement [7]. This process enables the learner to identify and rectify errors autonomously, thereby fostering a comparable long-term learning effect that is transferable across various levels of advancement and disciplines, including audiation.

The following sections of this paper clarify our system's requirements and methodology, share initial findings from user testing, and propose future work plans. We discuss key parameters that are essential for accurately representing the characteristics of Gugak and for the implementation of the revised curriculum regulations of 2022. Moreover, we will explain the mechanics of our system, detailing its initialization phase and the three stages of audiation development, including the audio and visual feedback stimuli involved. Lastly, a brief overview of the preliminary user testing carried out in our pilot study will provide insights for our upcoming initiatives.

2 ADJUSTMENTS REQUIRED FOR Gugak CLOSED-LOOP THEORY APPLICATION

Drawing upon prior research, our objective is to augment these findings to develop a feedback system specifically centred on Gugak. This system will take into account the fluid pitch parameters inherent to the genre, established musical frameworks, educational methodologies, and contemporary educational requirements necessary for implementation within public schools.

2.1 Revised Nationally Regulated Korean Music Curriculum

The General Music Education (GME) curriculum in South Korea has undergone ten revisions. It aims to foster a musical culture, nurture talent, and enhance educational outcomes through music for individuals aged six and older, while developing social-emotional skills. The 2022 Revised Music Curriculum marks a significant shift, wherein the focus transitions from goal-oriented achievement and prescriptive teaching strategies to a selection of core ideas and contents, thereby fostering an autonomous, student-centred music learning environment [1, 2, 12]. This aligns closely with Gordon's *Music Learning Theory* (MLT), which emphasizes the learning process of students, with teachers serving as guides who provide supportive environments and appropriate tools, all while adapting to the individual aptitudes of students [10]. One of the key transformations of this 2022 curriculum is the promotion of self-initiated learning, emphasizing application and performance while permitting the expression of creativity, emotions, and reflective thinking. This approach extends beyond traditional musical systems to embrace integrative and innovative creations that amalgamate various subjects.

Per the outlined guidelines pertaining to the 2022 revised music curriculum educational methodologies, we propose integrating innovative and creative digital technologies that impose minimal constraints on students' expression of Gugak music. Furthermore, this platform enables students to identify their errors autonomously and use reflective thinking to self-correct, enhancing their auditory and motor memory skills. While this system is primarily designed for novice Gugak students, due to the general lack of familiarity with nuanced Gugak practices resulting from a deficit of fully trained experts, this interactive feedback mechanism also aims to promote collaborative teaching, thereby enriching the comprehension of the subject matter for both students and instructors. The system primarily emphasizes the Gugak scale, tuning system, and sound characteristics. However, the interval intonation exercises and fundamental concepts developed through the study of Gugak can also enhance other non-Gugak music curriculum units, providing valuable insights and techniques that benefit a broader range of musical education.

2.2 Fluid Gugak Tuning

To effectively implement our Gugak audiation development system, our research has strategically selected a specific instrument that is widely utilized and plays a significant role in Gugak performances. However, this instrument presents educational challenges due to its physical attributes and performance techniques.

The haegeum, a vertical two-stringed bowed zither used in Gugak, is depicted in Figure 3. The arrangement of its strings and pegs, along with a fingering technique that requires the performer to apply and release tension from two strings affixed to wooden tension-held pegs, often results in tuning discrepancies during performances. However, professional haegeum players possess the ability to maintain accurate pitch despite these tuning variations by adjusting the pressure they apply to the strings. The absence of a fingerboard permits a broader spectrum of pitch control, as demonstrated in Figure 4. Nonetheless, this greater flexibility demands significant aural ear-training and refined motor skills to adapt to slight variations in intonation. Consequently, this genre and this instrument, the haegeum, present considerable challenges not only in the initial stages of learning but also in advancing proficiency.

Figure 3: Haegeum left-hand positioning and technique are not restricted by the use of a stationary fingerboard

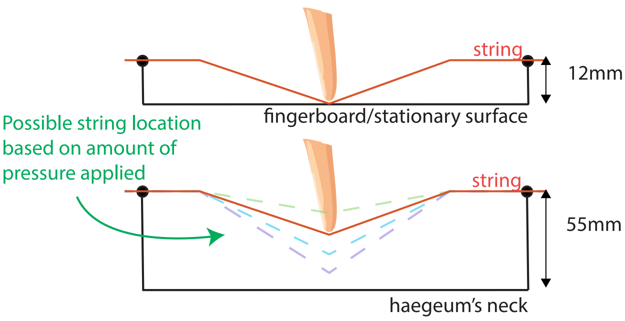

Figure 4: The distance between the string and stationary surface on viol-family instruments (top) and the haegeum (bottom)

Moreover, in addition to the specific design challenges presented by the haegeum for novice players, this traditional genre, in general, does not conform to the Western musical framework characterized by fixed tuning or pitch. Gugak relies significantly on relative pitch ear training, as opposed to fixed pitch and predetermined frequency values. This practice is centred around a fundamental root tone, referred to as the *hwang*, traditionally provided by an instrument within the ensemble. Consequently, this methodology results in a more adaptable and fluid approach to tuning and pitch. This intrinsic characteristic presents additional challenges when attempting to integrate the distinct qualities of Gugak, thereby underscoring the necessity for educational methodologies that equip players to adapt to unexpected scenarios related to tuning and intonation adjustments. A student's well-developed *Kreitman Listening Loop* practices can facilitate automatic intonation processes that operate without requiring conscious attention.

2.3 Traditional Gugak Score and Rhythmic Systems

Many facets of contemporary Gugak education have been endeavoured to be universalized through the implementation of the Western music system, leading to the transcription of pieces into five-line staff notation [13–15]. However, as previously discussed, the Western music system cannot encapsulate the full extent of Gugak musicality. In the field of symbolic music generation, Han conducts a comparative analysis of Western encoding schemes, including ABC and REMI (Revamped MIDI-derived events) notation, alongside their own Gugak notation system, as included in Figure 5 [16, 17]. This system facilitates the inclusion of additional details regarding note length within the "bar", as well as the types and directions of ornamentation that can be incorporated.

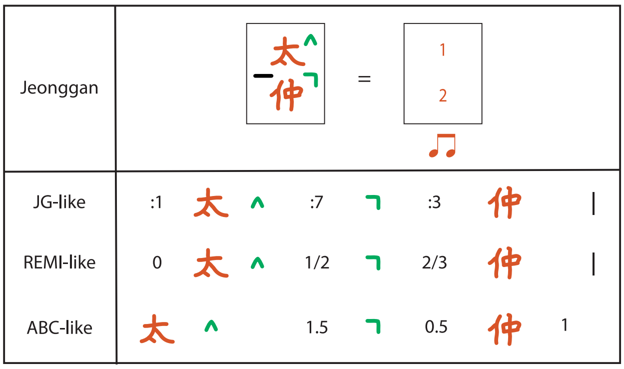

Figure 5: Han's comparison of encoding symbols to represent two Gugak Jeongganbo (orange) notes in a "bar" and the commonly used ornamentation (green) within the piece

Traditionally, most compositions not associated with court purposes were not notated at all. The *viva voce*, or oral transmission of music from teacher to student, was extensively employed. During these educational sessions, various methodologies for vocal representation of pitch and ornamentation were utilized, with the most prominent being a listening-and-repeating approach, whereby the teacher would perform from memory, and the student would echo the exact phrase [13, 15]. This practice is predominantly acknowledged within the context of Western music as the *Suzuki method* and exhibits comparable techniques to *audiation* [6].

In conjunction with the decline of traditional aural melodic transference practices within contemporary Gugak education, the fluid rhythmic system of Gugak has also been constrained to conform to the universal Western musical equal division of the meter. Given that Gugak emphasizes the breath-like fluidity and the allowance for time to incorporate expressive ornamentation as deemed necessary by the performer at that moment, it is essential to critically assess the practicality of integrating the Western *five-line staff score* in this digital educational platform when aiming to preserve and promote the inherent musicality of Gugak. The Gugak notation system known as *Jeongganbo*, which is a square-based scoring system included in Figure 9 and 10, will facilitate a more authentic expression of Gugak that aligns closely with the traditional genre. Nevertheless, numerous Korean students exhibit greater familiarity with Western notation, which necessitates additional time to acquire proficiency in the characters and structure of the Jeongganbo [15].

In light of the distinct characteristics inherent in Gugak, which warrant further investigation within the context of feedback system design, it is vital to acknowledge that the rapid and frequent variations in pitch may exacerbate the sensory overload experienced by students. Consequently, in circumstances where Jeongganbo is less familiar than Western notation, an increased emphasis on the unfamiliar score may result in heightened challenges in distributing visual attention between the feedback system and the musical score, subsequently leading to an ineffective feedback mechanism. This phenomenon is already prevalent within the fixed-pitch Western music system, as articulated by Pardue et al. Such sensory overload can be particularly pronounced in this genre due to visual stimuli that flicker at a rate too swift for proper processing [3]. Given the established tradition of the listening-and-repeating approach inherent to the Gugak genre, audio stimuli constitute the most appropriate feature of this digital Gugak education platform. More specifically, to promote and preserve the elements of this traditional genre, a seamless continuation of standard practices will facilitate the community's acceptance of a technologically assisted educational alternative. Consequently, the visual feedback system, a modality not typically employed in performance, becomes less qualitatively favourable for application within Gugak.

3 INTERACTIVE GUGAK AUDIATION EDUCATION SYSTEM

This section delineates the technological solutions requisite for the implementation of Gugak features, which encompass fluid tuning, pitch and rhythm practices, traditional score systems, and the stipulations outlined in the updated nationally regulated music curriculum guidelines. This system, outlined in Figure 6, is founded on previous research pertaining to audiation development, utilizing audio, visual, and multi-modal feedback systems targeted at novice instrumentalists.

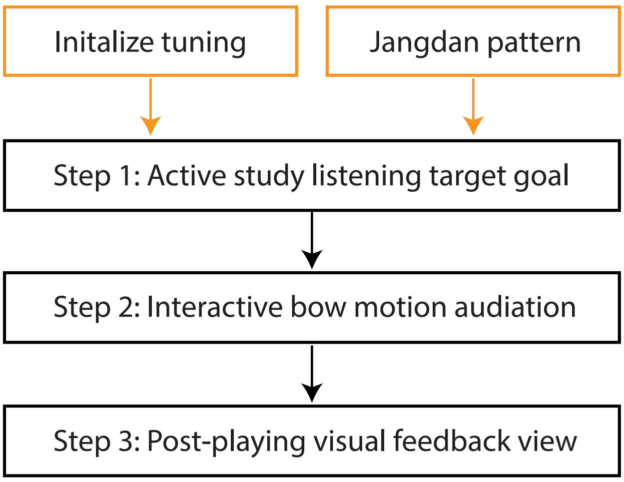

Figure 6: Overall flow of the interactive Gugak audiation education system

As previously indicated, it is essential to acknowledge the cultural importance of preserving fundamental traditional practices within the Gugak genre. At the same time, it should be acknowledged that this genre employs unconventional systems that diverge from the universal musical norms characteristic of more widely recognized Western music systems. Consequently, the students will predominantly use auditory stimuli to alleviate sensory overload and efficiently direct their attention to the feedback mechanisms, thus ensuring its sustained efficacy as an educational tool. Nonetheless, similar to the findings presented by Pardue et al. and Menzies [3, 18], the incorporation of non-real-time visual feedback will prove to be an invaluable resource for educators when facilitating discussions with students, particularly in situations where instructors lack formal training in Gugak.

3.1 Slipped Tuning: Initialize to Current Tuning

To integrate the intrinsic flexibility of Gugak tuning practices while mitigating the potential homogenizing effects associated with an emphasis on universal systems, this framework shall employ the current mean pitch estimation of the *hwang*, which serves as the tonic note within the Gugak scale, sustained for five seconds. As portrayed in Figure 7, this pitch estimation establishes the root pitch for determining the remaining fundamental frequencies (F0) of the other notes within the scale.

Jeongganbo scale name	Position on the haegeum		Fundamental frequency (Hz)
lower-jung	Inner string	1st finger	297.00
lower-yu		^ pressed	314.66
lower-yim		2nd finger	333.37
lower-yi		^ pressed	353.19
lower-nam		3rd finger	374.19
lower-mu		^ pressed	396.44
lower-eung		4th finger	420.02
hwang	Outer string	1st finger	445.00
dae		^ pressed	471.46
tae		2nd finger	499.49
hyeop		^ pressed	529.19
go		^ pressed (x2)	560.66
jung		3rd finger pressed	594.00
yu		^ pressed	629.32
yim		4th finger	666.74
yi		^ pressed	706.39
nam		^pressed (x2)	748.39
mu		^pressed (x3)	792.89
eung		^pressed (x4)	840.04
upper-hwang		^pressed (x5)	890.00

Figure 7: Example illustrating that when the hwang is set to 445 Hz, the remaining Hwangjong Pyeongjo scale F0 is determined to serve as the evaluation criteria for the pitch detection algorithms

Utilizing the initialized matrix of F0 calculations, any notes played beyond a range of ±100 cents from the defined note frequency will be deemed out of tune within this system. While further refinement of this pitch accuracy tolerance, specific to Gugak, requires additional testing, the established tolerance of 100 cents corresponds to the distance between each semitone. It is important to note that beginner pieces do not typically employ all semitones. The notes highlighted in blue in Figure 7 represent those that are commonly utilized, whereas the remaining semitones are utilized infrequently. If we disregard the infrequent pitches entirely from this system, this indicates a broader tolerance among the notes that are used. Additional testing is warranted; however, for beginners, a tolerance of ±150 cents may be considered for implementation in the future.

Given that technological tolerance for Gugak has not been widely researched and tested, this educational platform necessitates the rapid design of user interfaces for intermittent pilot testing. Due to its practicality of connecting other signal analysis software via OSC [19], MaxMSP software has been selected for this purpose. Among the various pitch estimator objects available within MaxMSP, such as `fiddle~`, `yin~`, `pitch~`, `iana~`, `transcribe~`, and `analyzer~` the `fzero~` pitch detector has been chosen for this component of the system due to its robustness in low-frequency resolution and its resilience against noise interference [20].

Although the MaxMsp objects `pitch~`, `iana~`, `transcribe~`, and `analyzer~` offer more detailed insights into partials, extensive spectral data, polyphonic signals, and other perceptual information, such details are not requisite for the current stage of the system. While `fiddle~` and `yin~` have demonstrated effectiveness for stringed instrument signals, the overall poor performance of `fiddle~` with single notes below approximately 200 Hz renders it an unsuitable option in this context. This is particularly relevant because we may encounter harmonic series frequencies below 200 Hz after initializing the current tuning of the haegeum, as seen in Figure 8. `Yin~` has been identified by Obin as a viable option for plucked or struck strings [21]; however, this consideration is not relevant in this instance, as the haegeum is classified as a bowed string instrument. The resilience of the `fzero~` algorithm against noise, particularly suited for bowed string instruments, is advantageous for filtering out segments of white noise that occur during changes in bow direction [20]. While most noise can be effectively filtered, fluctuations in pitch

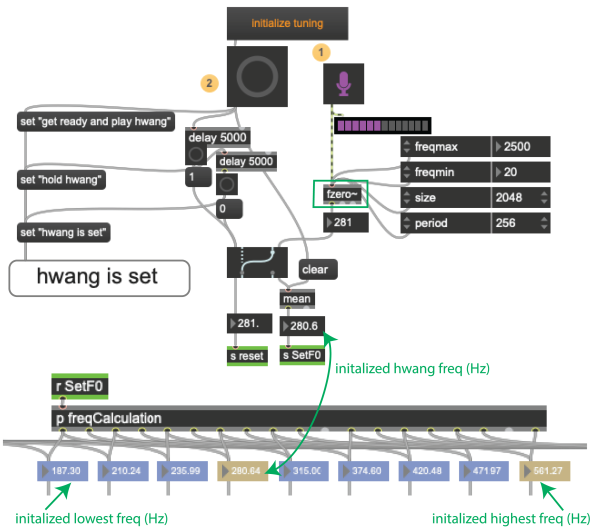

Figure 8: Initialization of tuning using Fzero prior to Stage One of audiation, illustrating establishing the mean hwang pitch estimation value to calculate the remaining scale frequency F0

estimation may arise due to the fingering and bowing techniques used by the haegeum player. To address this, as illustrated in Figure 8, we instruct the player to "get ready and play hwang". This approach helps to ignore any unintended preparation frequencies and allows the player to audiate and reach the intended hwang pitch with their left index finger. Next, we ask the player to "hold hwang" for five seconds to calculate the mean of the incoming `fzero~` pitch estimations. This average pitch is designated as hwang F0, used to calculate the remaining scale notes, as demonstrated in Figure 7.

This methodology of initializing the current tuning, in contrast to imposing a singular tuning value, underscores an interactive, student-centred approach outlined by the revised curriculum. Moreover, it accommodates the inherent fluidity associated with Gugak tuning. Furthermore, it addresses the challenges posed by initial tuning discrepancies that may emerge from the fingering techniques required for playing the haegeum. Each time students begin or revisit a score within the available corpus, they must initialize their current tuning as done in Figure 8. This practice assists novice individuals in accommodating and adjusting their pitch parameters, even when they may not possess sufficient ear-training to discern deviations from their prior tuning, vertical hand positioning, or finger pressure. Additionally, for the sake of audiation development, frequently changing the centre note along with the rest of the scale based on that note will improve the student user's relative pitch training. This approach is especially advantageous in the Gugak genre, more so than fixed or perfect pitch training.

3.2 Bow Motion Activation of Audio Stimuli

Two successive stages of audio stimulus techniques are introduced subsequent to the initialization of the current hwang tuning and the fundamental frequency (F0) of the remaining scale notes.

The first stage presents an exemplar of the target objective, akin to what an instructor might demonstrate during the listen-and-repeat viva voce practice, to implement what Sterne refers to as the *audile technique* [6]. This term is employed to denote the acquisition of knowledge through auditory experience as opposed to visual cues, analogous to utilizing a stethoscope for diagnostic confirmation. Aligned with the fundamental frequency of the scale note, this system, tailored for beginners, restricts itself to employing solely the most rudimentary *Hwangjong Pyeongjo* scale, which comprises nine scale notes. The requisite nine harmonic partials for each fundamental note and their corresponding amplitude ratios are calculated utilizing the method of additive harmonic synthesis [22]. The equation for bowed string physical modeling synthesis, `fn = f0 * ((2)^(1/12))^n`, is based on the most common additive synthesis method. The resulting additive fundamental and harmonic model is subsequently exported through the computer's speakers in accordance with the rhythmic cycle, as input by the student at the commencement of each session, serving as an exemplar of how the entirety of the current score selection's notes and rhythm is to be performed. This stage is intended as a period of study listening, necessitating full attention to create what Kendall describes as a *reference tonal image* [6].

The rhythmic cycle, also referred to as *Jangdan* within Gugak, does not necessitate a consistent equal division of the meter, as is customary in Western music. Instead, it places greater emphasis on replicating the performer's natural long-short breath-like motions. The Jangdan is traditionally regarded as the accompaniment part that cyclically progresses through an established pattern. While the fundamental pattern remains unchanged, additional ornamentation may occasionally be incorporated depending on the drummer's expressive intent [13, 14]. In this system, we address an alternative to the uncharacteristic, metronome-like

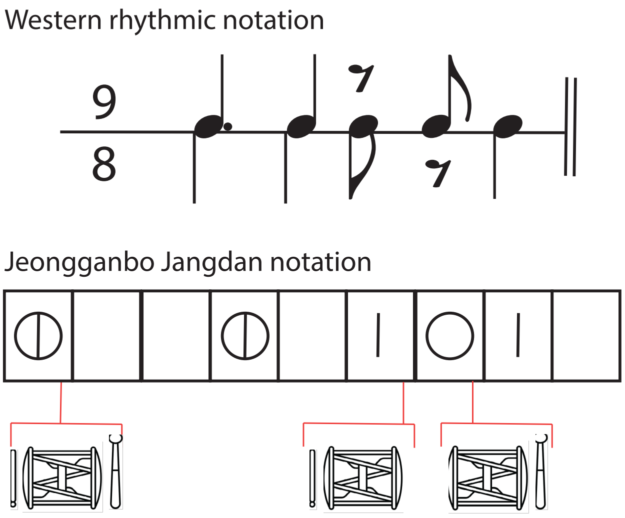

Figure 9: One the two Jangdan patterns of our platform are presented in a Jeongganbo score, which has been transcribed into Western music notation for specific purposes explanation

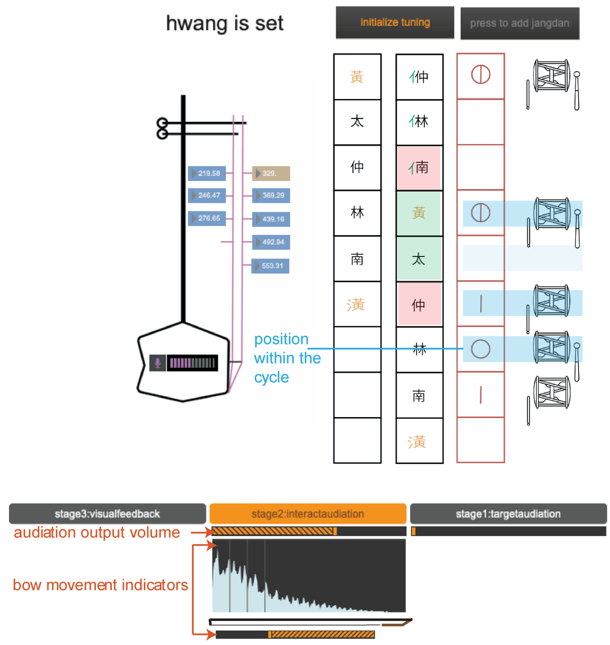

Figure 10: Stage two of the Gugak audiation system activates sound output exclusively when the bow sensor is in motion, as demonstrated in this preliminary UI

rhythmic feature within a bar. Figure 9 illustrates one of the two simple and commonly used Jangdan cycles that we implement. This allows students to explore Gugak expressivity between notes within a cycle pattern while maintaining rhythmic consistency by repeating the pattern as presented, without any modifications to the ornamentation. In general, provided that the rhythmic pattern is executed, the drummer possesses considerable flexibility regarding the spacing of the percussive strikes. For instance, the pattern illustrated in Figure 9 necessitates five hits of differing durations. As long as these five rhythmic elements are appropriately positioned based on the illustrated score pattern, the system will recognize the student's Jangdan cycle, thereby determining the duration of the score's pitches that are tuned to match the frequency of the student's physical instrument.

The second stage, which is similar to the first, utilizes additive fundamental and harmonic synthesis to generate the score note for audiation in accordance with the student's Jangdan cycle. However, while the initial stage involves the automatic playback of all notes within the score, the second audiation stage incorporates an interactive component that allows the student to engage with this auditory stimulus. The system produces sound only when the student manoeuvres their bow. Attached to the bow is a motion sensor that detects the horizontal position of the string contact point. We have recently implemented this feature by utilizing the compass sensor, which monitors the smartphone's position on the xy-plane when positioned face-up. This functionality is accessible in the complimentary Zigsim mobile application as a provisional measure for ideation and prototyping endeavours [23]. This strategic choice has permitted straightforward admissibility and established standardized conditions for pilot user testing of the system. Nevertheless, we anticipate the creation of a customized sensor attachment specifically designed for the haegeum bow in the foreseeable future. The Zigsim compass sensor generates values ranging from 1 to 360; however, the movement of the haegeum bow necessitates only a limited segment of this range. Furthermore, given that the primary objective of this sensor is to detect any movement of the bow, highly precise positional values are not requisite at this stage of the research. These values are calibrated to correspond with a horizontal slider on the user interface, as illustrated in Figure 10. Additionally, these values are depicted in the accompanying spectrogram, which visualizes the signal of detected motions.

To ensure the student maintains the correct timing, the notes progress according to the timestamps of the predetermined Jangdan cycle pattern. Figure 10 illustrates how the interface allows users to tap a Jangdan pattern, which is then applied directly to the score during audio feedback playback. Once the player starts the session, the Jangdan pattern is activated using the blue highlighted boxes. If the student does not keep to this rhythmic cycle, and delays in producing a new note, the duration of that note may be cut short, as the score follower automatically advances to the next note. This advancement requires a change in bow direction for the execution of the subsequent note. In contrast to Pardue et al.'s work on audio stimuli for violin students, which utilized a fixed beats-per-minute (BPM) audio feedback system for guidance [3], this approach offers a more distinct indication of rhythmic error while simultaneously facilitating expressive rhythmic exploration, an aspect integral to Gugak, and fostering continued audiation development practices.

Numerous related works have failed to quantitatively demonstrate the superior effectiveness of solely audio stimuli feedback systems [3–5], so we have integrated a secondary supplementary simple visual feedback component within the principal audio feedback system. We propose that audio stimuli will ultimately take precedence, particularly in the context of Gugak, owing to the previously mentioned characteristics. Nonetheless, it is plausible that as students become more familiar with the system, they may occasionally prefer a visual representation of their intonation accuracy. This hypothesis will be validated through forthcoming formal user testing. We implement this by employing the same `fzero~` MaxMsp object. Although this object may occasionally misidentify a strong partial rather than the fundamental frequency, we effectively leverage this for this secondary visual feedback component by cross-referencing against the calculations utilized for the additive synthesis model. As shown in Figure 10, we do not display the detected frequency value but instead provide a simple green and red colour graphic to indicate whether the student's pitch is within the ±100 cent accuracy tolerance previously established. Therefore, high accuracy in the numerical value of this `fzero~` pitch detection algorithm is not required.

3.3 Preliminary User Testing Results

A preliminary informal pilot study conducted with a limited number of participants indicates potential benefits associated with digital haegeum music pedagogy. Although the necessity to calibrate the system's tuning to the modified *hwang* centre pitch at the commencement of each round necessitated additional clarification and practice time for user acclimatization, the student participants successfully configured this feature and displayed qualitative enhancements in their ability to adjust their aural reference to the relative pitch. Given that Gugak music traditionally depends on interval intonation, the teacher pilot testers expressed gratification regarding the integration and training on this intrinsic approach to tuning and intonation. In alignment with Dai et al. and Kantorski's research [8, 9], the inclusion of musical accompaniment enabled participants to maintain their centre tone while performing. Furthermore, the second phase, which imposed limitations on performance based on time windows defined by a rhythmic pattern, afforded all participants the opportunity to investigate the flexibility of Gugak musicality, which is frequently unattainable through conventional BPM-based educational methodologies. User testers recommended further refinement of the visual representation of the features, observing that the frequent implementation of colour changes for visual feedback sometimes led to sensory overload when combined with the audio feedback. Nevertheless, particularly during the second phase and once the musical score's notes were sufficiently familiarized, they reported reduced dependence on visual colour feedback, relying more on aural cues. Although real-time pitch accuracy visual feedback was intermittently beneficial for monitoring their position within the score, as it updated closely after the note's conclusion, its utility was somewhat limited. Overall, the participants expressed enjoyment in the three-step progression process, which begins with establishing audiation using the *audile technique* through following the complete excerpt, transitions to a similar process with diminished assistance and additional effort requirements from the user, and ultimately concludes with a comprehensive visual overview of their performance for detailed reflective analysis.

3.4 Visual Feedback as Teacher Resource

While the visual feedback component of the real-time pitch detection algorithm may not provide users with precise quantitative assessments of their performance, Pardue et al. and Menzies emphasize the advantages of non-real-time summaries of individual student performances to guide the teacher's involvement in feedback [3, 18]. We utilise the signal processing libraries developed within Matlab to enable our system to obtain accurate numerical data.

While space prevents a comprehensive elucidation of the required algorithms for this post-playing feedback segment of our system, a succinct overview is provided below and in Figure 11. During the student's performance against the second audio stimulus stage, the system records their playing into an audio file. Subsequently, this file is transmitted to Matlab via Open Sound Control (OSC) for a comprehensive multi-layered pitch detection algorithm. The algorithm we have developed considers the inherent potential for greater frequency fluctuation caused by the instability of maintaining finger pressure, due to the absence of a fingerboard on the haegeum.

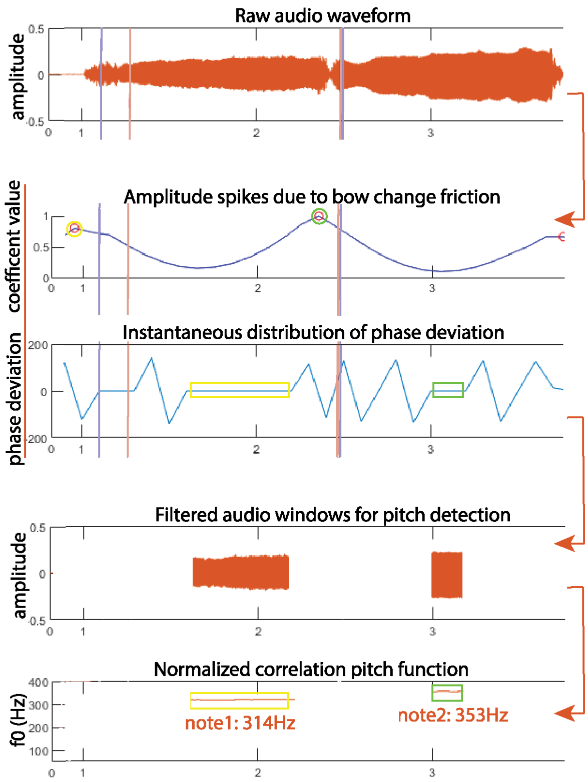

Figure 11: Multilayer filter process for establishing Gugak pitch detection windows within Matlab. The vertical lines indicate our ground truth onset positions, as accumulated by a group of Western (blue) and Gugak (red) expert annotators.

Consequently, we have devised a method for detecting the initiation of new notes through the identification of amplitude spikes present within the spectrogram. Simultaneously, we constructed a similarity matrix to pinpoint peaks that arise from increased noise levels attributable to friction associated with variations in bow direction. Given that our system requires single-note bowing techniques for each note, which is a vital practice for numerous beginners, this onset detection methodology accurately delineates the broadest possible window for each note. However, as is commonly observed with the majority of bowed string instruments, the transient phase of the haegeum's signal is significantly longer than that of its counterparts. The physical architecture of the haegeum introduces complexities pertaining to frequency fluctuations and the noise levels correlated with the onset of the initial bowed string sound, thus necessitating a more sophisticated approach to the established onset detection windows. This objective is accomplished through an analysis of the phase stabilization period. By employing an algorithm specifically designed to detect the common peak in the magnitude spectrum within subsequent, non-overlapping frames of 0.1 seconds, Figure 11 demonstrates a narrowed window within each onset interval, thereby effectively refining the zone designated for the most accurate pitch production for future pitch estimation.

Despite the existence of various pitch detection functions, we have chosen to utilize the normalized correlation pitch detection function. This function assesses the degree of similarity between a designated time series and its lagged counterpart across successive time intervals. In contrast to an autocorrelated function, the normalized correlation function yields superior results, as it is less susceptible to rapid amplitude fluctuations, which are frequently observed due to the haegeum playing technique [24, 25]. Upon the calculation of all four layers illustrated in Figure 11, the timestamps corresponding to the onset and phase windowing, in addition to the final pitch estimation values, are subsequently communicated back to MaxMsp for visual representation via user interface design, as demonstrated in Figure 12.

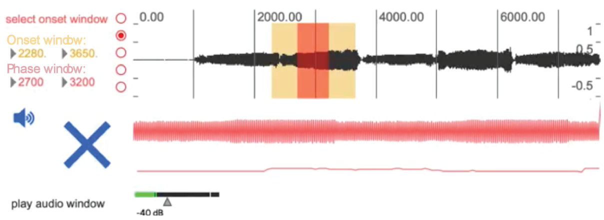

Figure 12: Visualization of stage three, featuring the MaxMsp interface for real-time interaction, with calculations in Matlab and data transmission via OSC.

As previously noted, this system is primarily designed for students as an alternative to conventional textbooks or one-dimensional instructional videos that have adapted their content for universal Western music comprehension [12, 13]. However, the updated curriculum has lessened the emphasis on teaching Gugak in music classes. As a result, many people have voiced their dissatisfaction with this change [15]. Since most music educators in these classrooms have completed programs that primarily emphasize Western music and have received minimal training in Gugak, they often lack a deep understanding of its unique characteristics. Nevertheless, by providing a thorough overview of students' performances, this initiative enables educators to participate more actively in the learning process, thus further aiding in the preservation of this diminishing traditional genre for future generations. As Neithsinghe observes, world music units are closely tied to cultural self-identity, rooted in an appreciation of their musical and historical heritage [26].

4 CONCLUSION AND FUTURE WORK

The Audiation Development System for Gugak signifies a progression in the educational methodologies pertaining to traditional Korean music. By utilizing real-time auditory feedback and integrating it within the revised Korean music curriculum, this system effectively addresses the distinctive challenges encountered by novice learners in grasping the fluid musical parameters inherent to Gugak. The platform's employment of pitch detection, additive harmonic synthesis, and interactive audio stimuli cultivates a more profound practical understanding of Gugak's adaptable tuning, rhythm, and ornamentation. Furthermore, the inclusion of visual feedback as an auxiliary resource for educators facilitates collaborative teaching strategies, thereby enriching the overall educational experience. This innovative approach not only empowers students to navigate the intricacies of Gugak but also plays an essential role in preserving and valuing this rich cultural heritage.

Future endeavours will concentrate on refining the system based on informal rounds of user feedback, assessing the validity of the established pitch accuracy tolerance, enhancing user interface design, and broadening the platform's capabilities to further assist the educational necessities of Gugak learners and educators. Additionally, collaboration with experienced South Korean music teachers will bolster our pedagogy and user testing, ensuring the system remains effective and relevant for future generations.

5 ETHICAL STANDARDS

All informal user testing and expert annotator participants have given their written consent to their participation in this research in accordance with the Victoria University of Wellington ethics standard.

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