2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Piano Duo: Haptic Sharing System Supports Two-Piano Practice

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***Abstract*—Two-piano performance is a beautiful form of musical collaboration where two pianists create a dynamic dialogue by blending their unique styles. However, the performers' inability to see each other often leads to synchronization issues, requiring significant practice time. This study proposes "Piano Duo", a practice support system for two-piano performances. By sharing sensory information through performance videos, core body movement sensing, and tactile feedback, the system aims to improve timing accuracy and practice efficiency. The results suggest not only enhanced synchronization and efficiency but also potential for more advanced artistic expression.**

***Index Terms*—two-piano, center of gravity, performance support, haptic design, embodiment, sensory sharing**

I. Introduction

In classical music, a "Duo" refers to an ensemble performed by two musicians, where both players engage in a musical dialogue on equal footing to create a unified work. Among various duo formations, the two-piano setup—where two grand pianos are placed facing each other and played as independent instruments—is considered one of the most sophisticated forms of artistic expression in classical music. This format allows both pianists to contribute equally, shaping the music as co-creators rather than as leader and accompanist.

While there is a distinction between the roles of the first and second piano, the relationship is not a simple hierarchy. The first piano typically carries the main melody or thematic material, while the second piano supports the overall structure through harmony and rhythm, creating a rich musical texture. This complementary interplay results in a multilayered composition that balances individuality with cohesion, enabling the pianists to merge their unique interpretations into a harmonious performance.

However, two-piano performance presents unique challenges. The presence of sheet music and music stands creates visual obstructions, making it difficult for performers to see each other's movements and subtle musical cues. As a result, they must rely heavily on auditory and physical awareness to synchronize their playing. Additionally, securing an appropriate practice environment—one that accommodates two grand pianos—is a significant logistical hurdle, further complicating ensemble coordination.

This study focuses on these distinctive challenges of two-piano performance, with particular attention to the issue of timing synchronization. Given the visual limitations and practice constraints, discrepancies in timing can easily arise, making synchronization a crucial aspect of successful duo performance. By addressing these timing inconsistencies, this research aims to enhance the performers' ability to coordinate with one another. Furthermore, beyond technical improvements, the study explores how heightened awareness of body movements and timing adjustments can foster a more natural and cohesive musical interaction, ultimately enriching the

*This research is supported by the JST Moonshot R&D Program "Cybernetic being" Project (Grant number JPMJMS2013).

sense of unity and the quality of musical communication between performers.

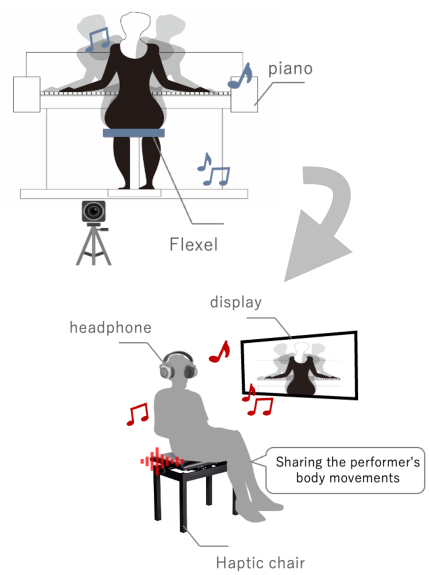

Fig. 1. Sharing torso movements, breathing, and rhythm via visual (performance image) and tactile (center of gravity) presentation.

II. Related Work

The way pianists move their upper bodies during performance is not merely a habit or unconscious motion. For instance, Laberge et al. [1] have demonstrated that core stability and hip movement contribute to the control of tone color and dynamics, with smooth, coordinated body movements enhancing the overall quality of performance. Similarly, Turner et al. [2] analyzed how emotional expression is conveyed through body motion and reflected in sound, concluding that physical movement plays a crucial role as an aesthetic element in musical performance.

While large ensembles, such as orchestras, rely on conductors for coordination, smaller ensembles require musicians to achieve musical synchronization autonomously. As a result, performers must rely on nonverbal communication—such as eye contact and body movements—to maintain synchronization and expressive cohesion [3]–[6]. In the case of piano duos, it has been shown that predictable and fluid movements enhance synchronization, whereas irregular movements can disrupt it. Thus, body motion serves not only to improve technical precision but also as a vital medium for conveying musical cues and intentions [7].

The coordination of timing and tempo among ensemble musicians has long been a critical challenge. Various approaches have been developed, including visual feedback systems that provide intuitive cues [8] and innovative technologies such as AI-assisted ensemble systems [9]. Soundbrenner[1] and tactile feedback devices [10] have also been introduced to facilitate timing synchronization without relying solely on visual or auditory cues. However, achieving synchronization in ensemble performance goes beyond mere rhythmic alignment; it requires a shared musical interpretation. These tools alone struggle to foster a nuanced mutual understanding of musical expression among performers.

Touch is a unique sensory modality based on physical contact. Beyond merely receiving external information, it plays a fundamental role in perceiving bodily presence, movement, and self-awareness. In recent years, many wearable devices have been developed to enhance skill transmission and motor control through haptic feedback, including those that provide natural haptic sensations [11].

Furthermore, full-body haptic interfaces are being integrated with visual and auditory modalities, enabling cross-modal sensory connections that create immersive experiences [12], [13]. Among these technologies, those utilizing skin shear deformation have been particularly effective in providing realistic and intuitive tactile feedback, contributing to enhanced movement perception and spatial awareness [14]. These advancements in haptic technology hold promising applications across diverse fields, from entertainment and education to rehabilitation.

III. Concept

The difficulty in achieving synchronization during two-piano performances arises from the lack of non-verbal communication between performers due to visual limitations. For performers to synchronize autonomously, they must understand each other's playing styles, body movements, and breathing. However, securing sufficient practice time and space for this understanding is challenging. This study introduces a system that shares the performer's core body movements, breathing, and sense of rhythm through visual (performance video) and tactile (center of gravity) feedback. By implementing this system during the 2nd pianist's individual practice, it aims to improve timing discrepancies and make it easier for performers to intuitively sense each other's habits and intentions, leading to natural synchronization of timing.

IV. System Design

This system is broadly composed of hardware that performs sensing and feedback, as well as software that connects them (Fig.1). The details of these components are explained below.

A. Hardware for Haptic Feedback

In this system, we employ the distribution of skin stretch elements induced by rotational motion as a haptic feedback method. Previous studies have used skin stretch feedback to present force dynamics, such as those observed in bodily movement [14], [15]. As in prior studies [14]–[17], the stimulation is conveyed through clothing; Section V presents a validation study confirming sufficient stimulus transmission. Given this context, skin stretch stimulation is considered an appropriate mode.

The device incorporates 36 rotating skin stretch elements, similar to those used in the prior work by Horie et al.

[1]Soundbrenner https://support.soundbrenner.com/hc/ja

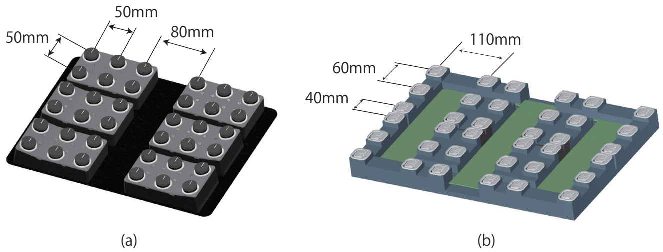

Fig. 2. The dimensions of the haptic (a) and sensor (b) devices.

[14] The spatial arrangement of these stimulation elements is illustrated in Fig.2a). The inter-element spacing is smaller than the two-point discrimination threshold on legs, allowing for the spatially continuous haptic presentation through the phenomenon of phantom sensation by simultaneously controlling adjacent elements [18]. Each element has a diameter of 25 mm, which ensures sufficient pressure for effective deformation while minimizing the risk of pain. The adequacy of this deformation is validated in the experimental study presented in the following section. Each element is actuated by a servo motor (RS204MD, Futaba), and the user's body weight is structurally supported by the device enclosure via thrust bearings. A single control board (SSP 001-UA-S, commissure Inc.) is assigned to every four motors, and all motors are synchronously controlled through a daisy-chain connection.

To facilitate practical use as a piano bench, the base structure was designed to match standard piano bench dimensions, minimizing discomfort for the pianist (Fig.3a).

Fig. 3. A haptic feedback device (a) and a sensor device (b) designed to replicate the conventional shape of a piano chair.

B. Hardware for Haptic Sensing

The load distribution sensor used in this system is equivalent to the Flexel [19] system and consists of 36 load cells, each capable of withstanding a load of up to 50 kg as shown in Fig.2b. This setup allows for the measurement of the load distribution applied to the casing. Although the load cells are arranged non-uniformly—optimised for installation in standard commercial raised OA flooring—Flexel's algorithm [19] can still process their readings to calculate the centre of gravity. By placing this sensor on the seat surface of a chair, we constructed a system that enables the acquisition of time-series changes in the center of mass of the upper body. Additionally, similar to the system on the presentation side, the device was designed to resemble the shape of a conventional piano bench to minimize discomfort for pianists during actual performances (Fig.3b).

C. Software

The software was designed using TouchDesigner. Raw data obtained from the sensors is transmitted to the control PC via UDP in JSON format. The received JSON data is parsed to obtain a matrix of sensor values. After performing sensor calibration, the resulting matrix is transmitted as a stimulus intensity distribution to a haptic generation module with a maximum rotation angle of 40 degrees with liner function. In the haptic generation module, a gaussian filter is applied to the spatial distribution of the pressure data to ensure spatial continuity. Additionally, a gaussian filter is applied in the temporal direction with a time window of 0.05 seconds to smooth out noise present in the sensor data.

V. System Validation

To verify whether the developed system functions as expected and to identify its effectiveness and challenges, we quantitatively observed the impact of system implementation on motion sharing and timing synchronization. Specifically, we quantitatively evaluated the subjective intensity of different levels of haptic stimuli perceived by the participants and confirmed whether the system could present the intended stimulus intensity.

A. Procedure

In this experiment, a haptic-feedback chair delivered rotational stimuli at five angular levels: 6.4° (Level 1), 12.9° (Level 2), 19.1° (Level 3), 25.6° (Level 4), and 32.0° (Level 5). The upper limit of 32° was chosen because the prior study used under 50° as the stimulations [18] and a preliminary pilot assessment confirmed that this amplitude could be experienced without pain. The stimuli were separated to right half 18 points and left half 18 points. Ten participants (men and women in their twenties) participated, and each session lasted roughly 5–10 minutes per person.

Before the main task, participants familiarised themselves with the stimuli: the five left-side and five right-side patterns were played in random order for a total of 30 presentations. With the participant seated, the experiment proper began by replaying each of the five right-side stimuli twice to establish a reference. Thereafter, stimuli from the left (L1–L5) and right (R1–R5) were presented in random order. After every presentation, the participant assigned the perceived intensity to one of the five levels (1–5). Ten such trials constituted one session, and the session was repeated three times, yielding 30 trials per participant.

B. Result & Discussion

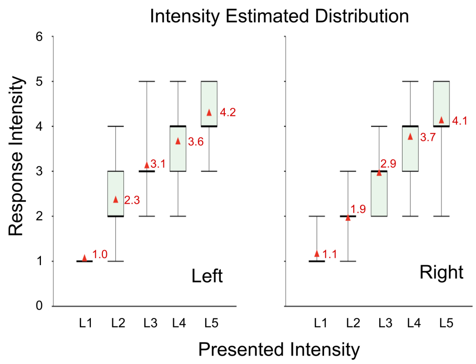

Fig. 4. The intensity estimation distribution for the left side and the intensity estimation distribution for the right side based on the verification results.

The validation results are shown in Fig.4. This validation used the magnitude estimation method to assess how participants subjectively evaluated different stimulus intensities. Overall, stable evaluations were obtained; however, variability was observed for mid- to high-intensity stimuli, with individual sensory differences and sensitivity influencing perception. The findings highlight individual variability and limitations in recognizing stimulus intensity. Future evaluations should consider personalized stimulus calibration as well as the effects of trial repetition and habituation.

VI. User Study

The goal of this experiment is for the performer to recognize and understand the "habits" of the partner's center of gravity and posture. This understanding will help the performer consciously transform unconscious body movements and habits during two-piano performance. As a result, the goal is to improve synchronization accuracy in two-piano performances by achieving better coordination of body movements and timing between the performers.

The experiment proceeded according to the steps outlined in Fig.5 and Fig.6. Data from the 1st pianist (leader) performance, including performance videos and center-of-gravity data was recorded. The 2nd piano performer uses this data during practice. The subjective experience of the performers during individual and joint practice sessions was evaluated, and the change in the frequency of timing discrepancies after using the system was investigated.

A. Evaluation Method

The evaluation was based on the performers' subjective assessments of timing discrepancies. Specifically, both the 1st and 2nd piano performers marked on the score the areas where they felt discrepancies during the recorded performance. They then discussed these areas and reach an agreement on the final discrepancies.

We defined two categories of the discrepancies and instructed to participants to use the categories in the assesment; "misalignment" is timing discrepancies that most classic piano players may easily notice, while "subtle discrepancy" refers to more subtle timing deviations that are acknowledged and agreed upon by the performers themselves. Through these assesments, the impact and effectiveness of the system on performance accuracy and practice efficiency will be evaluated.

This study is an initial case study focusing on how the system was evaluated by pianists playing specific musical pieces with the system for the first time. The assignment of pieces to the system condition was not counterbalanced. Although we selected two well-known pieces that typically require time to achieve synchronized performance, this user study was not designed to explore generalizability across factors such as piano skill level, age, prior experience with the system, or repertoire variety.

B. Procedures

The first author performed the 1st piano, while three pianist acquaintances from music universities took on the role of the 2nd piano, designated as P1, P2, and P3.

Two music pieces were introduced with repeats excluded: Piece A, performed using the system, and Piece B, performed without the system.

A: Brahms: Sonata for 2 Pianos, Variations on a Theme by Haydn Op. 56b, Choral St. Antoni - No.7

B: Brahms: Sonata for 2 Pianos, Variations on a Theme by Haydn Op. 56b, Choral St. Antoni - Final

The experiment took place over approximately one month, following the schedule below. The total number of joint two-piano performances was three, with the first session being the initial rehearsal without the system. Individual practice during the experiment was done only by the 2nd piano performers, while the 1st piano performer practiced individually outside of experiment hours. The experiment was carried out in a practice room at a music university, where a two-piano joint rehearsal took place, and individual practice sessions were conducted using the system. The session details are as follows.

First session:

1) Initial joint rehearshal
2) Recording of misalignment: assesing timing discrepancies and marking them on the score, confirming interpretation of Pieces A and B, annotating the score
3) Practice only by 2nd pianist (For Piece A and B approx. 1.5 hours each)
   - With system, annotating the 1st player's performance style and tendencies on the score
   - Practice with visual, tactile, and auditory presentation
   - Multiple practice sessions with tactile and auditory presentation only
   - Practice without system: Focusing on areas identified during previous joint rehearshal (approx. 30 minutes to 1 hour)

Second and Third sessions:

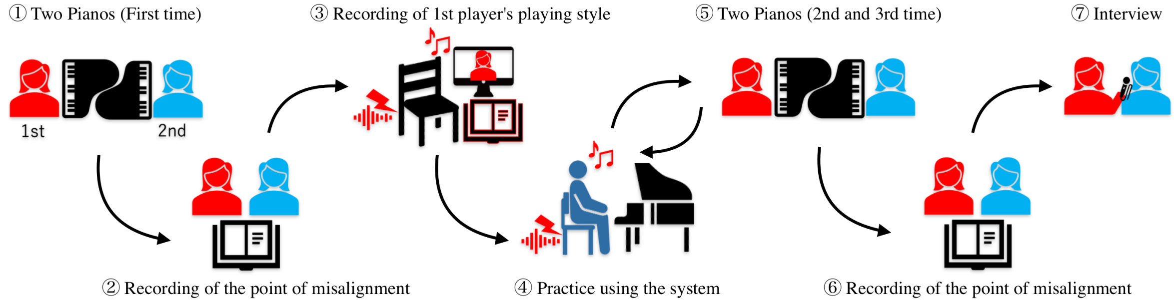

Fig. 5. Overview of the Experimental Procedure

Each step corresponds to the same step in the first session.

1) Practice by 2nd pianist
2) Joint rehearshal
3) Recording of misalignment

Fig. 6. The joint rehearsal (a), 2nd pianist marking the 1st pianist's performance tendencies on the score using CoE replay by the system (b), experiencing the system while playing the piano (c), and the participant sitting on the haptic feedback device (d).

C. Results

The results are shown in Fig.7. Changes in the amount of discrepancies are shown on the right. Here, we report the pianists' evaluations. All participants agreed that the timing discrepancies identified through these assessments reflected subtle deviations in rhythm, phrasing, and expression—nuances that technical measurements may fail to capture. Due to space constraints, we omit detailed descriptions of the specific score sections each evaluation refers to.

For Piece A, the system reduced rhythm discrepancies and timing shifts between performers. This suggests that visual and tactile feedback improved synchronization by making timing errors more noticeable and enhancing the sense of rhythm. On the other hand, in Piece B, even simple rhythmic sections showed noticeable discrepancies, demonstrating that without the system, efficient improvement in synchronization was difficult. In particular, fluctuations in tempo and the complexity of the rhythm in Piece B created new discrepancies, even in simpler sections.

In the interviews, there were positive responses such as ”I didn't feel much effect during individual practice, but it was easier to predict the sense of tempo and phrasing when actually playing with a partner” and ”By understanding my partner's habits, I became more aware of my own movements, and it seems useful for self-analysis.” However, there were also some doubts raised about the system and its usage, such as ”The sense of breathing is not conveyed” and ”For actual performance, a more realistic setting is essential.”

VII. Discussion

In Piece A, the use of the system led to a gradual reduction in discrepancies with repeated practice, making it easier for performers to synchronize their rhythm and counting. However, in Piece B, discrepancies persisted even in simpler rhythmic sections, with more noticeable timing issues occurring in complex rhythms and call-and-response parts.

Furthermore, feedback from interviews revealed that the system helped performers become more aware of their own and their partner's physical characteristics, making it easier to recognize performance habits or ”quirks.” This deeper understanding allowed them to reduce mismatches in rhythm and phrasing, improving the overall ensemble accuracy. Thus, the system proved to be a valuable tool not only for synchronization but also for fostering a deeper understanding of the performers' physical movements and performance habits.

However, the current system revealed several challenges, including the inability to adequately reproduce the ”breathing feel” in real time, as well as uncertainties regarding the selection of musical pieces and methods of use. In ensemble performances, sharing the sense of breathing and tempo is crucial. Therefore, future improvements should focus on achieving more accurate real-time reproduction of the breathing feel.

As described above, this study is the first case study of the system, involving three pairs of pianists (with one pianist fixed), and we did not randomize the order of the musical pieces or their combination with haptics. How the system would be received by other pianist pairs under different conditions was beyond the scope of this study. It is possible that the system may not be effective for other performers or contexts. The contribution of this study lies in demonstrating that the system can be effective in certain cases, and in providing a detailed report of those cases. Further validation using a wider

Fig. 7. Analysis of the performance by the players themselves. (Left, Middle) Full annotations by the players. (Right) Changes in discrepancies. In Piece A, with haptic sharing, all discrepancies decreased with each iteration, whereas in Piece B, no such tendency was observed.

variety of musical pieces, randomized conditions, and a larger participant pool is left for future work.

VIII. Conclusion

The two-piano is the epitome of dialogue in music performance. The sound it produces is a grand conversation between two performers, intertwining fiercely or gently as they shape a single piece of music. However, it comes with unique challenges. Limitations in visual field and practice environment often hinder coordination between performers, leading to moments when their music may miss each other.

In the user test using the "Piano Duo" system, it was demonstrated that the discrepancies in performance were reduced, and the performers could more clearly recognize their partner's rhythm, tempo, and body movements. Furthermore, through tactile feedback, performers were able to simultaneously become more aware of both their own movements and their partner's, enhancing coordination. Incorporating tactile feedback in practice encouraged performers to become more aware of their movements and offered a type of feedback different from traditional methods, making the practice more efficient. Based on these findings, it can be concluded that the objectives of this research have been successfully achieved.

The sharing of sensory information through tactile feedback represents a new dimension for performers who have traditionally relied on sight and sound. It allows them to feel their partner's breath and body movements, facilitating a deeper understanding and resonance that transcends words and sound. We hope this new form of collaboration, enabled by tactile feedback, not only offers a new option for piano duo practice but also enhances the joy of mutual resonance—making it more tangible—and opens up new horizons in music.

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