Encouraging Improvisation in Piano Learning Using Adaptive Visualisations and Spatiotemporal Models

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ABSTRACT

The process of learning the piano for novices is usually difficult and time-consuming. Several approaches in augmented reality such as piano-roll visualizations have been explored but have not garnered enough success and adoption. These piano roll prototypes have introduced several features and modules that assist novices on aspects such in sight reading, timing and many others. However, improvisation, the act of allowing the piano user to incorporate their *personal touch* into their performance, and personalised learning have not been much explored in this domain. In this PhD, we are going to explore how we can encourage piano learners to improvise with the use of adaptive piano roll visualisations. Specifically, we are going to investigate how heuristics defined by experts and spatiotemporal models can be used to design visualisations that motivate and encourage learners based on their personalised learning patterns. Using these models and inputs, we will design and build a piano roll training system integrated with adaptive visualisations that serve as intervention helping learners. We will evaluate and compare these visualisations in various user studies where they get to play piano pieces and develop their improvisation skills. We intend to uncover whether these adaptive visualisations will be helpful in the overall training of piano learners. Additionally, we wish to explore whether these adaptive visualisations will allow us to discover affordances that can potentially improve piano learning in general.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; visualisation.

KEYWORDS

extended reality; spatiotemporal moving target selection; heuristics; piano roll; visualisation; piano learning

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1 RESEARCH PROBLEM, QUESTIONS AND GOALS

The process of learning a musical instrument such as the piano is usually tedious, repetitive and overwhelming. It requires keen hand-eye coordination, mastery of music sheet notation and more importantly, hours of continuous practice. All this can highly increase the cognitive load of learners. Having a tutor or a maestro usually provides an improved learning experience since novices can receive immediate feedback during their practice. However, tutors are usually expensive and are not always readily-available (e.g. when practicing alone). The learning process also varies depending on the type of a music instrument and its availability (portable vs. stationary) and costs. All of these are some of the known factors that make learning a music instrument a challenging task.

Several technology interventions have been introduced to assist in one or some of the challenges in learning music instruments ranging from supportive tutoring prototypes, ergonomics, groupware and others [6, 8]. Even cultural and societal factors have been considered along with technological interventions [4, 5]. More recently, Augmented Reality (AR), the approach of overlaying digital elements to the physical world, has been introduced as a tutor substitute for music instrument learners. The availability of AR Standard Development Kits (SDKs) lead to a rise of AR prototypes being developed and studied [28]. Most of the innovations introduced by these AR piano systems are either in hardware [1, 11], learning modes [27] or visualisations [2].

Some of these piano prototypes have focused on seemingly short-term goals such as (1) teaching users the mechanical ability to press and (2) teaching users how to play a song but not necessarily how to play the piano properly. In turn, most of these systems may have lacked on focusing on providing long-term or scalable support to learners in the form of skills such as (1) understanding the learner and where in piano learning they struggle, (2) teaching harmony and the ability to listen and identify melodies, (3) providing recommendations and other intervention that encourage the user to practice and improve, and many others.

While reporting on improvements in the learning process of novices, very few prototypes [3, 12] focused on enabling improvisations as part of its features. They are on their early stages and have introduced improvisation through gestures and other sensors. At the best of our knowledge, no existing work has encouraged improvisations from the users through the use of augmented projections such as piano roll visualisations. Understanding how novices perform and improvise during the learning process plays an important role in this research. When a novice tries to learn the piano, it is ideal for a system to understand the important parts (in terms of music features and didactics) that they should be learning and provide interventions based on these areas for improvement. These features have not been observed in aforementioned prototypes and traditional piano learning, as well as in piano improvisation.

General studies on learning systems have explored cognitive load (and other factors) to potentially assist in developing expertise of learners. Yuksel et al. [33] introduced an adaptive learning interface that adjusted itself based on the current brain state (EEG signal) of the learner. He posits that having a dynamic and adaptive interface led to an increased accuracy and speed of learners while doing brain-based adaptive tasks. Cognitive load has also been explored in music learning. The work of Klepsch et al. [15] measured the cognitive load of learners, and how the piano roll as a visual stimuli may potentially overwhelm the user, however, with inconclusive results. Studies that explored the understanding of cognitive load, user personalities and their effect to the user's spatial memory also exist [9, 16]. Despite the extensive body of research on using technology in learning, none of the studies have explored and tested these technologies in the context of piano improvisation and piano roll visualisations.

Music also has a temporal component described by the rhythm and other factors such as time signature, length of beat/rest, etc. It has been observed that introducing irregularities in temporal component has a negative effect on the listening experience [23]. However, introducing small, systematic temporal irregularities in the music sheets have led to improvements in playing a piano [17, 18]. While these improvements have been observed on a traditional piano, they have yet to be explored in the domain of adaptive AR piano prototypes. In the context of AR piano roll visualisations, users having to press the right key at the right time given a visual stimuli would then describe the spatiotemporal applicability of music.

In this work, we will focus on designing and modelling adaptive piano roll visualisations based on learner's spatiotemporal data and expert heuristics on improvisation (beyond what has been introduced in [7]). More specifically, we are going to investigate whether these interventions affect learning especially on the skill of piano improvisation. It will also consider other factors namely (i) the user's internal time keeping mechanism, and (ii) the effects of visualisations in Cognitive Load Theory (CLT) [13, 15]. We chose two approaches to build the models described. The first one will be based on the spatiotemporal modelling work by Kim et al. [14], Lee et al. [20], Lee and Oulasvirta [21], Liao et al. [22] where they have modelled and predicted error rates of users executing spatiotemporal tasks such as batting a virtual baseball, clicking on a moving and tricky target, and pressing a tactile button at the right time.

Spatiotemporal modelling is based on internal time-keeping mechanism when given an external stimulus following the Wing-Kristofferson (WK) model. This model deals with synchronisation and performance given a sequence of external events such as the metronome [31, 32] that enables a linear phase-error correction mechanism among users [25, 29] allowing them to reduce errors in pointing activities such as pressing. Existing previous work on spatiotemporal models have focused on single-target moving objects only and have not explored multi-targeted scenarios such as piano key-pressing.

Our second approach will be based on the heuristics defined by experts marking various difficult parts of songs, and deciding on specific interventions and improvisation recommendations needed for these marked parts. For both approaches, we will build an AR projection-based piano roll system that will allow us to collect the usage data of its users. These data will be then used to design adaptive visualisations (changing for example the speed, movement, amount of the visualizations).

We propose *PIANO 2.0* inspired and built on top of the work by Rogers et al. [27] that will take into account the models described. We believe that such a system can support piano learning through visualisations as an intervention to assist learners of varying skills. Participants will be invited to train with our piano roll prototype while we will observe its effects on the piano learning experience especially on improvisation.

The focus of this research will be on exploring augmented piano systems anchored on the general research question: *"How can we encourage piano learners to improvise with the help of adaptive visualisations based on spatiotemporal models and expert heuristics"*? The models will not only allow us to adapt visualisations to individual learners but also to understand how users differ in the way they use the piano. We divide this general research problem into more specific research questions:

RQ0: What technological interventions have been introduced to support piano learning? AR presents an effective supporting piano learning technology. However, in order to proceed with the succeeding RQ's we also need to survey and review the landscape of technology that supports piano learning as well as interview piano teachers and teachers of piano didactics. By doing this, we can draw more inspirations towards designing better adaptive visualisation systems beyond the scope of the domain of interesting AR prototypes, and firmly position our contribution in the existing landscape of technology for supporting learning.

RQ1: How to build multi-target pointing models to predict user errors while using the piano roll? We predict that based on the success of earlier studies on a single-target spatiotemporal pointing and moving target selection in AR [20, 21, 24], models of learners usage can also be used to build adaptive visualisations that support piano learning. Similarly, heuristics-based models should also be possible to build for such multi-target pointing.

RQ2: How to improve the learner performance, user experience and sound quality of novices when learning the piano using adaptive visualisations designed on spatiotemporal and/or heuristic models? We believe that if we consider spatiotemporal data of learners or heuristics, we can anticipate errors and design adaptive visualisations (e.g. change the speed of the visualisation, emphasise possible hard to play parts) that will serve as intervention to better support learning [26]. Lee [19] states that determining the appropriate level of difficulty in game design is essential to ensure player experiences in an environment. By predicting error rates from player's activities in a game, we could better support learning experiences in general. We believe that the same should be true in similar learning scenarios such as playing musical instruments. We will evaluate this in terms of improved student performance (measure accuracy), user experience (usability tests and Attrakdiff [10, 27]), and sound quality (with the help of expert rating). We predict that novices will progress differently if they use adaptive visualisations of our AR piano prototype compared to using non adaptive static visualisations or not using any technological intervention. We will explore this in the learning process of piano novices.

RQ3: How do piano players learn improvisation using adaptive visualisations designed on spatiotemporal and/or heuristic models? Based on the results of our expert interviews, improvisation is a least-focused on but equally-important skill for piano learners. We will tackle this RQ in a similar way as RQ2. We believe that adaptive visualisations can aid as a learning supplement/intervention in encouraging piano learners to improvise during their performances.

The work presented will provide the following contributions to the field:

(1) a survey of prototypes exploring the existing landscape of augmented piano technologies and piano roll visualisations;
(2) multi-target spatiotemporal pointing models to predict user errors while using the piano roll;
(3) adaptive visualisation methods for piano roll based on spatiotemporal and/or heuristic models;
(4) modification of the existing piano roll designed to develop users' improvisation skills;
(5) several user studies involving: (i) expert interviews eliciting current gaps and design recommendations; (ii) a study exploring how different adaptive visualisations will affect users learning if compared to the baseline (static piano roll); (iii) a study exploring novel piano role visualisation for developing improvisation skills;
(6) design guidelines/rules for implementing adaptive visualisations in piano learning.

2 INITIAL RESULTS AND KEY FINDINGS

We have defined four (4) distinct phases of this research namely (1) **Explore**, (2) **Develop**, (3) **Model** and (4) **Assess** phases [7]. In **Explore**, we already reviewed existing prototypes and modalities that support teaching and learning piano. This phase also included expert interviews (piano teachers and teachers of piano didactics), literature review and prototype design. A systematic literature review of 61 augmented piano prototype papers using the PRISMA and open coding technique was done on a set of augmented piano prototypes introduced within the last 15 years. We highlighted the extensive contribution of prototypes with respect to specific themes in piano learning as well as the gaps such as the lack of adapting the technology interventions to individual users in order to better support their learning needs. The second part of this is based on interviews with piano teachers and teachers of piano didactics (currently $N = 5$, 22.5 average years of experience). In these interviews we discussed the teaching process, design ideas and validated our assumptions with regards to the design of the prototype and the results of the survey. Their insights were considered in the design of the piano prototype and the design of experiments. The findings of this phase revealed that there are two gaps in the field: the lack of adaptive technologies for piano learning and the lack of support for developing improvisation skills.

In the **Develop** phase, we decided to build upon the **P.I.A.N.O.** prototype by [27, 30], which will be a scalable version of the former to accommodate dynamic adaptive classical visualisations and improvisation visualisations. This prototype will initially be developed with static piano roll visualisations that will be projected on the top. It will be equipped with sensors and modules that enable spatiotemporal data collection and/or heuristic-based rules and features. This will be equipped with an *Improvise* module which will allow students to learn the piano beyond the already-available *Practice*, *Listen* and *Play modes* from the current version of the prototype. In the *Explore* phase, the majority of interviewees revealed that the current piano teaching approaches in music schools have not put enough emphasis on the improvisation. Our modified piano roll for improvisation will be, to our knowledge, the first visualisation of its kind. An open-source documentation of the project will also be shared. A modified MIDI keyboard is currently being prepared and equipped with plugins that should be able to capture spatiotemporal moving target data. This prototype is also being bundled with an AR projection module that will help in the data collection phase of this study.

3 FUTURE WORK

Currently we are in the middle of the **Develop** phase as described in previous section. This will be followed by the **Model** and **Assess** phases respectively. In the **Model** phase, we will investigate whether it is possible to build spatiotemporal models from users' movements, key presses and patterns while using PIANO 2.0. This will be done by collecting their usage data and building an initial model, which will then be updated on continuous use. This will allow us to analyse and predict users' error rates used to build and optimise adaptive visualisations that will encourage improvisation. We will explore different configurations of the model such as one model per finger, one model per hand or one model for two hands. An additional model will be based on the heuristics from the experts marking various difficult parts of songs, and deciding on specific interventions needed for marked parts. These models will be trained and validated hand on hand during this phase. When we will achieve desirable parameters, these will be used to augment the visualisation engine that will support novices and our experimentation.

During the **Assess** phase we will explore how adaptive visualisations encourage novices to improvise and have better learner experiences. We will invite novice participants to learn using our PIANO 2.0 prototype specially-equipped with spatiotemporal sensors following a between-subject study design. Participants from a local secondary school aged 12 and up will be invited to train using our prototype using classic piano roll and improvisation piano roll visualisations following our specified training programme. The participants will be exploring four conditions: (i) no visualisation, (ii) static visualisation, and (iii) two adaptive visualisations. Participants will be using PIANO 2.0 for multiple, succeeding sessions. We will measure if there is an improvement in terms of user experience and piano playing. If possible, the recordings and outputs of the participants will also be assessed in a separate study with the help of experts who will give their rating on musical output.

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