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Playing Gamelan *Bonang* in the Air: User Requirements for Designing a Digital Musical Instrument for the *Malay Bonang*

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Abstract

In recent years, computer technologies have been impactful in the design and development of Digital Musical Instruments (DMIs). As music interaction became prominent in the Human-Computer Interaction (HCI) field, emphasis on user requirement upon the design of musical interfaces has also grown since the last decade. Although designing new DMIs is becoming very popular, it is often determined by the designers and often not reflective of users' needs. In this study, we explored user requirements for the design of a virtual musical instrument of the Malay *bonang*, an instrument found in the Malay gamelan ensemble. The requirements were elicited from a group of gamelan experts to establish the bonang playing techniques to be mapped to the virtual instrument which we called Air Bonang. Findings revealed that in designing the Air Bonang that is natural and expressive, the fundamental playing techniques of the bonang should be integrated into the system using mid-air interaction. In addition, exploratory techniques might also be integrated into the Air Bonang to leverage musical expression. The outcome of the study proposes design criteria that encompass three aspects of a natural Air Bonang, namely, embodiment, expressiveness, and feedback.

Keywords: Digital Musical Instruments, Human Computer Interaction, Malay gamelan, music interaction, user requirements, virtual *bonang*

Introduction

Computational technologies have profoundly influenced many aspects of music. The interaction between humans and Digital Musical Instruments (DMIs), known as music interaction, is prominent in the field of Human-Computer Interaction (HCI). Discourse on music interaction is taking place progressively highlighting the trends in various aspects of music interaction including philosophy, design, development, methodology, and evaluation. Designing new DMIs has become very successful and popular among researchers, musicians, and developers, however, they are determined by the designers (Bowen, 2013; Cohé & Hachet, 2012; Wobbrock et al., 2009) and are often exploratory and in a constant state of development (Morreale et al., 2018). This is probably due to various motivations and purposes when designing DMIs such as to develop new sounds, improve audience experiences, as well as making DMIs accessible for novices to make musical performances (Emerson & Egermann, 2020; McPherson et al., 2019).

In this study, we wanted to reimagine a traditional musical instrument, the *Malay bonang*, in a virtual environment. We aim to preserve its traditional identity and naturalness by simulating its playing gestures as well as to explore affordances of the bonang DMI. To realize this, we gathered requirements from potential users, namely professional gamelan musicians to give insights into designing the virtual bonang. In music interaction, user requirements are elicited in various types of projects such as mid-air interaction (Brown et al., 2018; Leng et al., 2018), gesture recognition (Françoise & Bevilacqua, 2018), motivations for building new DMIs (Emerson & Egermann, 2020), user-defined gestures (Leng et al., 2017), as well as evaluations of DMI (Brown et al., 2020). In our work, we seek to find out the requirements to design a natural virtual musical instrument of the Malay bonang. Our motivation stemmed from the unique playing gestures of the bonang and the lack virtualization of traditional Malay musical instrument. We hope to design a bonang DMI that is meaningful, engaging, and relevant for all users.

The Malay bonang is a knobbed-gong instrument found in the Malay gamelan ensemble, also known as gamelan *Melayu*. Made from bronze, iron, and wood, in terms of physicality, it is a relatively large, heavy, often custom-made, and expensive instrument as shown in Figure 1. Its unique gestures and playing techniques, often deemed to be technically challenging among beginner learners, has never been explored for the design of a digital musical instrument (DMI).

There is a variety of virtual gamelan bonang developed namely mobile applications (Anshori, 2014; Hassan et al., 2020) and hardware-based DMIs (Naber, 2016), however, there is little discussion on how the bonang's playing gestures and techniques are incorporated in these designs. For example, the mobile application of the bonang would be ubiquitous and accessible. However, the touchscreen interaction of the application does not simulate the hand movements of the bonang gestures due to the limitations of mobile devices (K. A. Saffian & Norowi, 2021). With hardware-based digital gamelan (Naber, 2016), although the striking gesture of the bonang is physically done with the hands, it is only designed as one gong instead of the complete set of gongs found in the bonang. In this study, the roles and techniques of the Malay bonang are explored by gathering user requirements in determining possible mappings for the bonang DMI.

The Malay bonang has unique gestural playing techniques where it requires good coordination of both hands, which can be potentially simulated to a DMI. Once a court ensemble, the Malay gamelan has evolved over the last decade where innovations are taking place on its composition, performance, instruments, as well as playing techniques (Mohd Shah & Poheng, 2021). Furthermore, playing techniques from the Western and other non-Western musical instruments have also been explored and incorporated into the Malay bonang, challenging its affordance (Tanaka, 2010), as well as appropriation where performers came to define the identity of the instrument through their working relationships with it (Zappi & McPherson, 2014). These can be further explored in the design of the Air Bonang. From this study, we propose the design criteria for a virtual Malay bonang which we call the Air Bonang to help guide other research in developing a natural yet explorative DMI for the Malay gamelan in general.

Figure 1. The Malay bonang also known as *keromong*

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The Malay Bonang

The gamelan is a type of orchestra that originated in Indonesia. There are various types of gamelan ensembles within the Southeast Asia region including the Malay gamelan, which is the gamelan music in the style of Malaysia. Its origin was traced back to 1811 when a group of gamelan musicians and dancers from Riau-Lingga was brought to the state of Pahang to perform at a royal wedding. The Malay bonang, also known as *keromong*, is a five-tone knobbed-gong instrument found in the Malay gamelan ensemble. It consists of 10 gongs (known as *canang*) made from iron or bronze which are arranged in two rows, with five pots in each row. In reference to Figure 2, the bottom row is arranged from left to right with ascending tones (12356) while the top row is arranged from left to right with descending tones (65321). The top row gongs have higher pitches than the bottom row gongs, almost in an octave-like relationship but with slight variations in frequencies due to their non-harmonic spectral content (K. Saffian, 2014). The five-tone scale of the Malay bonang is often loosely described as a major pentatonic, known as slendro (Hamdan et al., 2020). All of the bonang gongs are hung on stretched strings across a wooden frame and raised a few inches above the floor. This physical structure of the bonang requires the player to sit on the floor to play it. The bonang gongs are struck with a pair of wooden mallets in unique left-and-right-hand coordination, for example, striking two gongs on different rows simultaneously or alternately. Traditionally, the bonang leads the gamelan ensemble by playing the introduction of the song and giving cues to other gamelan instruments before going into new sections of the songs.

Figure 2. Bonang gongs and pitches.

Teaching and learning of gamelan music are heavily rooted in oral tradition which differs from location to location and from teacher to teacher (Shah, 2013). Hence, there is no standardization of terminologies pertaining to its playing techniques unlike learning Western musical instruments. The hand gestures made when playing the bonang are not necessarily given names but rather to realize gamelan melodies. Therefore, to design the Air Bonang, gathering user requirements from the gamelan experts will determine and establish the bonang techniques and gestures so that they can be simulated into the Air Bonang. The size and dimension of the bonang are also not standardized and vary from one gamelan maker to another. Despite this, replicating the size and dimension of the bonang instrument as shown in Figure 3a and 3b, will ensure a natural transition from the virtual instrument to the acoustic counterpart.

Figure 3a. Bonang wood frame dimensions.

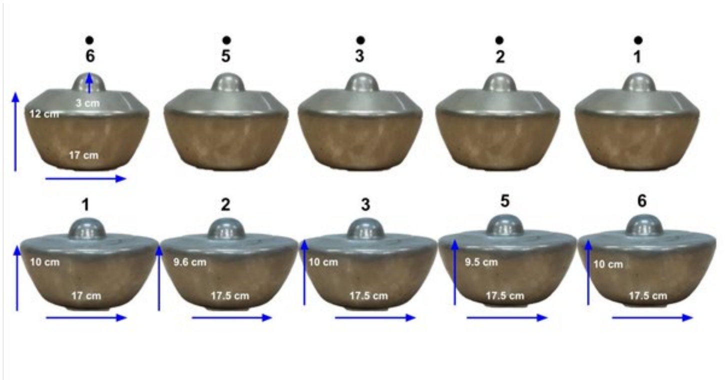

Figure 3b. Bonang gong dimension. All the top gongs have similar dimension while the bottom gongs vary slightly.

Existing virtual gamelan instruments are mostly based on variations of the Indonesian gamelan ensembles, namely the Balinese gamelan (Aryadana et al., 2019; Diatmika et al., 2015; Dwipayana et al., 2019) and Javanese gamelan (Permana et al., 2019; Revana et al., 2020). Virtualizing the Malay gamelan instrument has mostly been focused on the mobile application of the *bonang* instrument developed for the learning of the instrument (Hassan et al., 2020). Many of these virtual gamelan systems are mostly focused on the learning aspects of the ensemble where the systems are developed to provide only general information about the gamelan, rather than as DMIs. Not much has been discussed about the musical expression aspects as well as the naturalness of these gamelan virtualizations. Despite integrating the different types of technology in developing these virtual gamelans, such as mobile technology, augmented reality, and virtual reality, however, the mapping of users' gestures is not fully leveraged to optimize natural musical expression and interaction. For example, the virtual reality *Gong Kebyar* (Aryadana et al., 2019) is a mobile application based on the Balinese gamelan *'gong kebyar'* ensemble. This VR-Android-based application is developed as a learning tool to introduce the Balinese gamelan through visual displays rather than interactive ones, where the users get to play the VR instruments. Meanwhile, a game-based VR application called the Go-Byar (Dwipayana et al., 2019) incorporated gestural aspects of playing the gamelan instruments where the users can either choose to play in freestyle mode or with accompanied music. Despite being interactive, the details of the gestural interaction are not discussed especially pertaining to its mid-air interaction.

Mid-Air Interaction in Musical Performance

Mid-air interaction in musical performance is anything but new. It goes back to the invention of the theremin, an electronic musical instrument controlled without physical contact developed in 1920. In recent times, technological advancement as well as commercial production of motion capture and gesture tracking technologies such as the Leap Motion, Microsoft Kinect, and virtual reality displays such as Oculus Quest, has taken mid-air interaction to a new level where it can be experienced by a wider group of people.

Mid-air interaction in DMI performances have been explored by many researchers. Some related works include user-defined mapping of musical performance using data glove (Brown et al., 2018), using the Leap-Motion sensor to design a piano-based and a percussion-based DMIs (Han & Gold, 2014), and exploring haptic feedback in AirPiano (Hwang et al., 2017). Considered as a natural and an intuitive interaction, it provides an unmediated form of control with no constraints on human movement (Brown et al., 2018). Despite being unconstrained in movement, other issues arise with mid-air interaction such as lack of control, feedback, tactility, and latency. In terms of feedback, haptics technology has been coupled with mid-air interaction as it can recreate real physical sensations (Rakkolainen et al., 2020). Mid-air technologies such as hand controllers and data gloves, for example, can make up for the lack of tactility, and head-mounted displays (HMD) can provide visualization for more effective mid-air interaction. Many of these technological advancements are constantly addressing latency issues to ensure a more fluid interaction. Mid-air interaction research often includes user requirements study, typically on gesture elicitation to identify appropriate gestures suited to the context of use and design issue (Koutsabasis & Vogiatzidakis, 2019). This becomes the central of this study where the simulations of the potential bonang gestures are determined through this user requirements study which forms the proposed design for the Air Bonang.

Methodology

A user study was conducted to elicit user requirements on playing techniques and gestures of the Malay bonang that can be mapped to the DMI that will be developed. The study aims to answer three research questions: (1) what type of bonang playing gestures can be mapped for a DMI, (2) how users determine effective bonang gestures in terms of spatial, angle, and distance with mid-air interaction, and (3) how to design an Air Bonang that is natural.

Participants

Six gamelan experts were recruited through the purposive sampling technique (Palinkas et al., 2015) together with the snowball sampling technique (Coss, 2018). They comprised gamelan instructors, practitioners, and musicians from various universities, music academies, and gamelan performance groups. The experts involved were three males and three females with a mean age of 42.7 years old. The criteria in recruiting the experts are they must have at least five years of experience playing the gamelan and have played both traditional and contemporary gamelan music, presented in Table 1. The mean years of experience of the experts recruited are 18.3 years. The gamelan experts were invited via text messages using the WhatsApp application. This medium was chosen over other types of invitation as it is the most direct and convenient way of sending and receiving messages. The study was conducted in a remote setting via online interview, due to the restricted movement order of the Covid-19 pandemic. The interview sessions took two days to complete with a duration of an hour for each respondent.

Table 1

Profiles of the gamelan experts

Expert (E)	Sex	Age	Related Formal Education	Gamelan Background (in Years)	Gamelan Experience
E1	F	46	Doctoral of Education (Music)	23	Musician, judge, facilitator
E2	M	32	Bachelor Degree of Music (Arranging and Composition)	25	Music director, musician, lecturer, composer, arranger, tutor
E3	F	57	PhD in Music Education	31	Musician, music director, judge, organizer, and researcher
E4	F	42	PhD in Ethnomusicology	17	Musician, tutor, judge, lecturer, and organizer
E5	M	31	Bachelor Degree (Malay Gamelan)	18	Musician, lecturer, tutor, composer, and arranger
E6	M	49	-	26	Musician, reference expert, tutor

Interview

The study began with an interview followed by a request for the respondents to demonstrate basic techniques of the bonang. The semi-structured interview had three following themes: (1) respondents' musical background, (2) background and techniques of the Malay bonang, and (3) design ideas and requirements for the Air Bonang. This interview structure was chosen so that a deeper understanding of user requirements can be obtained from the respondents (Lazar et al., 2017).

Observation

For the demonstration, the experts were requested to demonstrate the hand gestures of playing techniques of the bonang. The hand gestures are video recorded within the same session of the interview displayed in Figure 4. All the respondents had given consent for their participation. The study has also been given an ethics clearance. There were two tasks involved: (1) playing single notes of the bonang in ascending (12356) and descending (65321) in mid-air, and (2) playing the notes along with singing the melody of a Malay gamelan tune entitled *Timang Burung* in mid-air. For both tasks, the experts were asked to repeat their hand movements three times so that movements can be compared. The music notation for the tune was provided.

Figure 4. Recorded interview of the study.

Data Analysis

For the interview, the grounded theory method (Corbin & Strauss, 2014) was used to analyze the interview data to explore any themes from the overall feedback of the respondents. Based on the interview questions, several themes emerged pertaining to the fundamental techniques of the bonang, as well as design requirements which are discussed in the following section.

As multimedia information can provide a rich pool of data (Lazar et al., 2017), the images of the experts' hand gestures were screenshotted and edited using an online photo editor (https://overlay.imageonline.co/) to produce image overlays of the hand poses. This was done to see the difference in alignment of the note-striking position in terms of spatial, angle, and distance between repeated bonang notes. Two images of the hand poses representing two corresponding bonang notation were digitally laid on top on one another. Static objects in the images such as cabinets, chairs, or tables, were used as reference points when overlaying the images to ensure that the alignment is accurate. To measure the difference of alignment between the note-striking positions, an application to measure angles on images called *Angulus* was used.

Results and Discussions

The results are discussed and divided into three sections namely the fundamental techniques of the Malay bonang, ergonomic issues in the bonang, and mapping design for the Air Bonang.

Fundamental Techniques of the Malay Bonang

The study aims to gain experts' feedback in terms of the roles of the Malay bonang as well as its fundamental playing techniques. Due to its oral tradition, there was no standardization in its technique nor terminology that comes with it. From the experts' feedback, it is important that the fundamental bonang techniques are clearly established so that they can be simulated into the Air Bonang. From the interviews, four fundamental playing techniques of Malay bonang are identified as the following: *serentak*, *berselang*, *bertingkah* (or *meningkah*), and *bunga* which are displayed along with music notation in Figure 5. Each technique may be introduced to beginner players in a sequence displayed in Figure 6 where the level of difficulty of the technique increases.

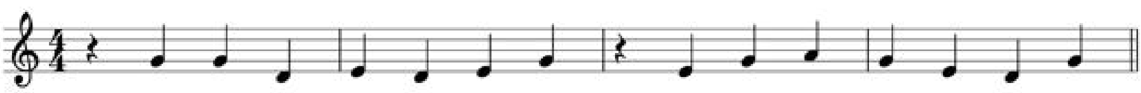

Figure 5a. The first four measures of basic melody for the gamelan tune *Timang Burung*.

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Figure 5b. *Serentak* technique. Playing two notes simultaneously with both hands.

Figure 5c. *Berselang* technique, demonstrated by the alternating left- and right-hand movements.

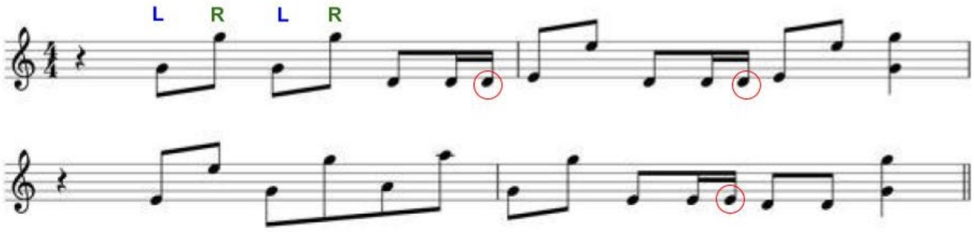

Figure 5d. *Bertingkah* technique with additional repetitive notes in circle to create rhythmic variations from the basic melody.

Figure 5e. A variation of the *bunga* technique.

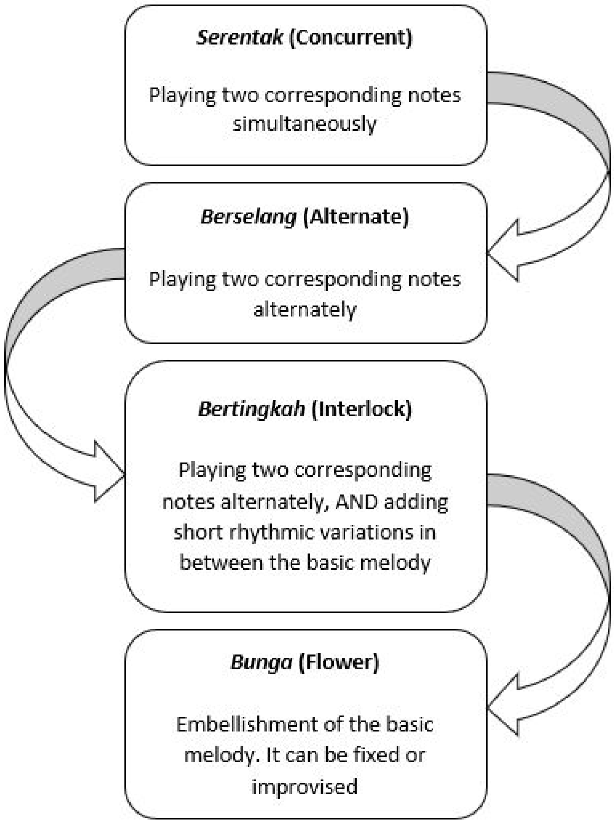

Figure 6. Fundamental bonang techniques.

Ergonomic Issues in Bonang

The bonang is played using a pair of mallets, hence, the way the mallets are held by the player influences the way the knobbed-gongs are struck. The bonang mallet is made of wood with curvatures and wrapped in thick red thread at the tip. The bonang knob is struck using the threaded part of the mallet. Two mallets are flexibly held with both hands to ensure that the desired tone can be produced. According to the experts, there is no specific way of holding the bonang mallet, however, one has to be flexible enough to ensure appropriate grip control, force of strike, arms' reach as well as agility to ensure the desired tone is produced and meet the musical demands of the song. Most of the experts prefer to hold the mallet in the middle displayed in Figure 7 to ensure balance with some variations depending on their styles in Figure 8.

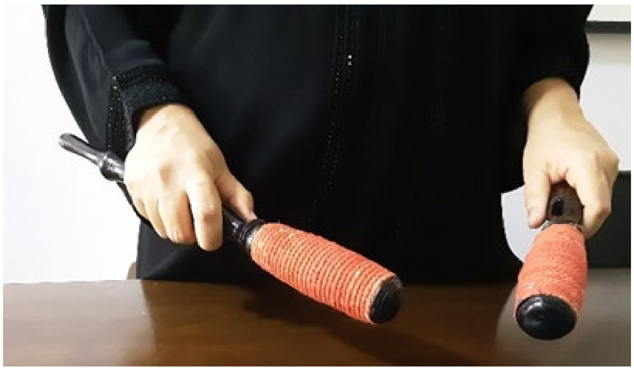

Figure 7. The most common and preferred way of holding bonang mallets.

Figure 8. One variation of holding the bonang mallet, by using the index fingers to further secure the grip

As with many acoustic musical instruments, the bonang is notorious for being unergonomic. It is played in a sitting position where the player sits on the floor or on a custom-made stool. In this position, both arms are extended in front of the player to strike the gongs as shown in Figure 9. The player's body tends to bend forward to reach out to the bonang gongs which causes a 'stress position' and 'overuse' when playing in a fast tempo manner (León et al., 2015). To accommodate people of smaller sizes or with shorter arms, an extension might be added to the mallets so that the gongs can be reached. This was practiced in the past during gamelan lessons at the courts.

Figure 9. Sitting position of playing the bonang.

Other than the shape and size of the instrument, factors such as instrument quality and musician's technique could also contribute to ergonomic issues (Fogliano, 2020). Traditional bonang techniques require both hands to move in a contrary motion, according to how the gong pitches are laid out in Figure 10. This hand coordination is deemed to be challenging where the player must ensure striking accuracy only of the knob, therefore moving outward and inward while playing could potentially cause fatigue to the arms and wrists which is known as the 'gorilla arm syndrome'. The 'gorilla arm syndrome' refers to arm fatigue caused by prolonged unsupported arm position commonly found with vertical touchscreen and mid-air input gestures in human-computer interaction (Hansberger et al., 2017; Hincapié-Ramos et al., 2014). Furthermore, contemporary gamelan music challenges this practice by demanding a higher level of playing skills for manipulation of playing techniques to meet the requirement of certain compositions (Mohd Shah & Poheng, 2021) which would implicate more ergonomic issues.

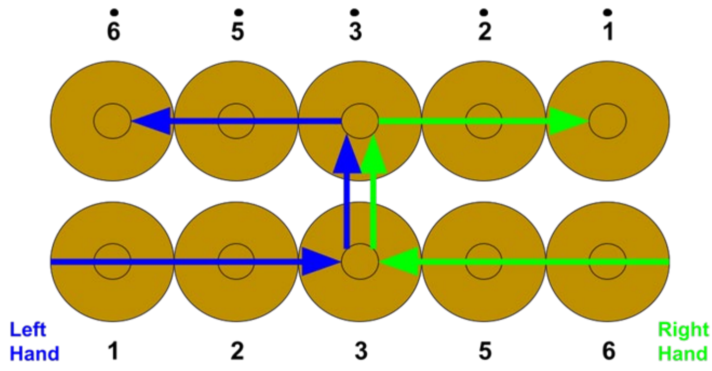

Figure 10. Left- and right-hand movement of playing the *bonang*.

Mapping Design

The mapping design of the Air Bonang is divided into mapping gestures, design features, mid-air interaction, and bonang dimensions.

Mapping Gestures

In understanding user requirements pertaining to the bonang gestures that will be mapped into the Air Bonang, all the experts agreed that it is important to keep the techniques or gestures to the fundamentals. The experts saw the Air Bonang to virtually preserve and sustain the bonang instrument especially for users who want to learn to play it, therefore, it should incorporate the four basic playing techniques mentioned previously (serentak, berselang, bertingkah, and bunga). It must also allow for users to incorporate the left- and right-hand coordination of playing the *bonang* as this will be the natural way of playing on the real instrument. Some of the experts are more open to integrating contemporary gamelan techniques such as moving the individual gongs around the wooden frame for exploratory purposes, especially to cater for composers, arrangers, and professional gamelan musicians. However, it must be carefully designed as contemporary techniques are ambiguous depending on the composition.

Design Features

The experts interviewed were also asked about design features that they would like to include in the Air Bonang. Visuals of the bonang gongs seemed to be the most important feature to have as this will be helpful for novice users to learn to play the Air Bonang along with video tutorials with basic information on the gamelan instruments. Three experts suggested that the system should have a play-along feature where the Air Bonang can be played with pre-recorded gamelan tracks. They believed that this can be an effective way of educating the users on the traditional repertoire of the Malay gamelan. Since the bonang is not a solo instrument, unlike the violin or piano, having a play-along feature will give the user the sense of playing in the gamelan ensemble. In order to design a virtual bonang that is natural, some experts suggested considering the sitting position of the system as well as having control for dynamics. In addition, other features that can be integrated into the Air Bonang include detection of wrong notes or movements, customization features such as changing the key/tuning and/or layout of the gongs, as well as being able to provide physical feedback.

Mid-Air Interaction

The key feature of the proposed Air Bonang is a DMI that is natural, hence, we believe that the mid-air interaction would be the most suitable interaction as the hand movements are not restricted. With technology such as virtual reality displays, hand controllers can be used to represent the bonang mallet which gives control of the striking gestures. From the interview, the experts agreed that the bonang gestures can be effectively executed with mid-air interaction. In terms of the dimensions of the mid-air gestures, two experts emphasized keeping the dimension of the gestures according to the real bonang instrument. They believed that this would ensure a natural transition from virtual playing to playing on the real bonang. Others were opened to the flexibility of re-sizing the dimension of the bonang gestures according to the users' arms' reach and body sizes.

Mapping of Bonang Dimensions

To determine the dimension of the *bonang* gestures in terms of spatial, angle, and distance with mid-air interaction, the images of the experts' hand demonstration were analyzed using the image overlays technique. With respect to the expert own self, the overlaid images of him/her 'striking' on the same bonang pitches are compared to see if he/she can 'strike' on the same note position at every single round of the demonstration or that there is a misalignment of the striking position. Using the angle measuring application, *Angulus*, the hand positions of the first image and the second image, identified as the hypotenuse and adjacent respectively, determined the cosine (cos θ) or the angle of the misalignment. The angles measured will give an insight into mapping the appropriate dimensions of these gestures into the Air Bonang shown in Table 2.

Table 2
Angle (in degrees) of experts' hand positions

***Bonang* Pitch**	**E1 (Without mallet)**	**E2 (Without mallet)**	***E3 (With mallet)**	**E4 (With mallet)**	***E5 (Without mallet)**	***E6 (Without mallet)**
1	4.9	10.8	2.2	11.9	7.8	24.9
2	7.2	2.7	11.8	28	8.7	23.5
3	3.1	27.8	12.5	15.4	9.3	4.6
5	10.5	4.9	7.8	14.3	19	16
6	3.2	-	4.6	16.5	48.6	11.8
Mean	5.78	11.55	7.78	17.22	18.68	16.16

Out of six experts, only two experts (E3 and E4) used a pair of bonang mallets to demonstrate the bonang techniques as shown in Figure 11. By using the bonang mallets, a clearer position of where the strokes ended can be seen compared to bare-handed as the threaded part on the mallets must touch the bonang knob for effective striking as displayed in Figure 12. For E1 and E2, the angles are measured from their shoulders to their fists which mimic the gestures of holding the mallets as shown in Figure 13. Meanwhile, E4's angles are measured from the arm to the tip of the mallet where it should represent the mallet touching the bonang knob. This explains the larger angles for E4 in general as holding the mallets requires some control. As the demonstration was done via online video calls, the positioning of E3, E5 and E6 cameras of the interviews had hindered them from displaying the bonang gestures at the proper playing positions, hence the angles might not be accurate.

Having been trained to play the bonang for many years, the experts have probably developed some kind of "muscle memory" or automatic motor control, which had enabled them to gauge the positioning of the bonang gongs even when there is no physical bonang presented (Lam, 2020). This explains the relatively small angles of ≤ 28° across all hand positions, which is an accepted value for the hand positions. From this data, it can be concluded that it is rather difficult for the experts to maintain consistent note-striking positions at every round, perhaps also due to the absence of visual cue.

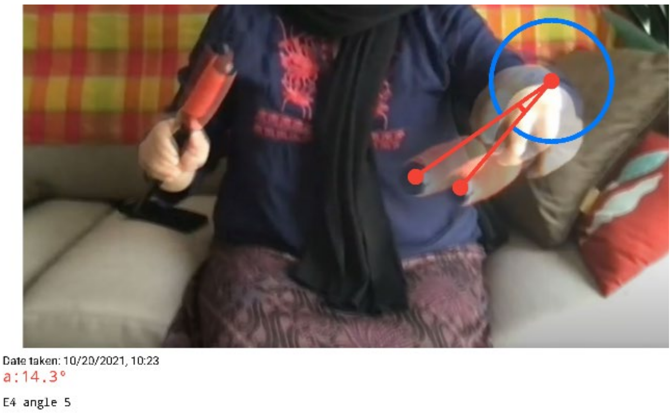

Figure 11. E4 hand demonstration using bonang mallets.

Figure 12. Threaded part of the mallet (in red) touching the bonang knob.

Figure 13. E2 hand demonstration without bonang mallets.

Proposed Design Criteria

From the user requirement study, a set of criteria for designing the Air Bonang is proposed. The experts believed that it has to embody the musical and practical essence of the Malay bonang instrument. The proposed design criteria for the Air Bonang highlight three aspects, namely, embodiment, expression, and feedback.

Embodiment

Embodiment in DMIs refers to the desired transfer of physical energy into a sound-producing device, typically accomplished through the incorporation of a more nuanced, continuous form of control (Emerson & Egermann, 2020). With the Air Bonang, the embodiment is represented through the bonang playing techniques using the proposed mid-air interaction. We believe it can represent the natural gestures of these techniques more effectively compared to other types of interaction. At this point of the study, the embodiment is imagined through muscle memory when performing the bonang gestures. In addition, the mid-air interaction captures a three-dimensional spatial mapping of the bonang gestures according to the bonang's size and dimensions. Here, the x-axis is mapped to the width of the instrument and the movements between the bonang gongs for different pitches, the y-axis is mapped to the dynamics of the 'striking force' in relation to its loudness, and the z-axis is mapped to the different top and bottom bonang registers as shown in Figure 14. In comparison to other forms of interaction such as touch screen, button, or switch, mid-air interaction is not constrained by these components. This way, gestures can be mapped and tracked more naturally and intuitively.

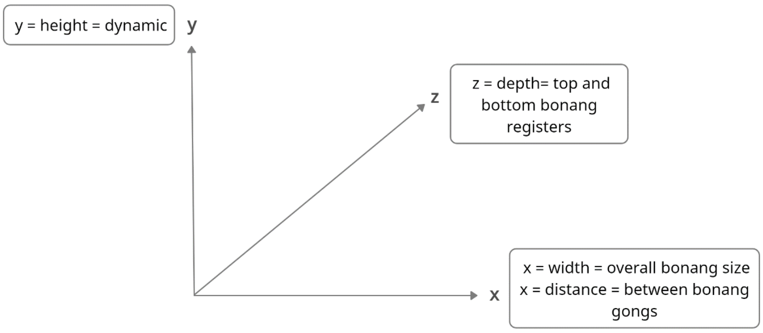

Figure 14a. Mapping of gestures for the Air Bonang

Figure 14b. 3-dimensional *bonang* gestures that will be mapped into the Air Bonang

Expressiveness

Expressiveness refers to aspects that can be controlled by the user in making the Air Bonang more intuitive and expressive. In most DMIs, controllable expressive parameters are mapped to musical elements, such as dynamics, timbre, vibrato, and time (Brown et al., 2018; Tanaka, 2010) which are realized by the gestures made. In the Air Bonang, there are three aspects of expressiveness of the system that is controllable, namely music, visual, and customization. Being able to control the music means having control of the bonang's musical dynamics by the amount of striking force, as well as having a realistic timbral quality of the Malay bonang that is responsive to the striking gestures and the location of strike. Visuals refer to the visualization of the bonang gongs and users' preferences on UI/UX of the system. Both music and visuals will influence the third aspect of expressiveness in the sense that the user can customize the system according to their preferences.

Feedback

Feedback refers to the feedback that can be provided through haptics to ensure accuracy of strikes on different bonang gongs as well as to mimic the tactile sensation of hitting on the bonang knobs. The haptic feedback is responsive to users' gestural input in terms of force, spatial, time, and position.

One of the important questions raised by the experts of the Air Bonang is the purpose of the DMI as well as the target users. The experts foresee the Air Bonang as a virtual musical instrument that is intended for the preservation of the Malay gamelan's tradition and identity, hence, the mappings should be kept to its fundamental techniques. This is to ensure that the users will have a seamless and natural transition to play the bonang instrument. In addition, to make it more intuitive and expressive for those who are already skilled at the bonang, additional or borrowed techniques that are practiced in contemporary gamelan such as using the Balinese mallet as well as applying the Javanese gamelan techniques on the Malay gamelan instruments, which can also be integrated into the Air Bonang so that it can be utilized not only as a musical learning tool but also for creative purposes such as music composition and performance.

Conclusions and Future Work

In this study, six gamelan experts were interviewed to elicit user requirements for the design of the Air Bonang, a DMI based on the Malay bonang instrument. The main findings of the study highlight the fundamental techniques of the Malay bonang along with mid-air gestures that can be mapped to the virtual Air Bonang. Four fundamental bonang techniques were established to be mapped and simulated into the Air Bonang, namely, serentak, berselang, bertingkah, and bunga. We proposed mid-air interaction as an effective and natural way to execute these bonang gestures. In designing DMIs based on traditional musical instruments, we believe that preserving the original identity of the instrument has to be put as a priority. In the meantime, more flexibility and accessibility can also be offered through explorations of new techniques and gestures to leverage musical expression. The design criteria were proposed for the Air Bonang: embodiment, expressiveness, and feedback, cover the naturalness aspect of the DMI as well as provide expressive features for the users. The current design of the Air Bonang is being developed into a virtual reality musical instrument with two modes of playing: (1) natural mode, where user can play the VR bonang similar to its acoustic counterpart, and (2) exploratory mode, where users can customize the settings of the bonang pots and playing technique in 3-D. These two modes will be able to cater to users of different levels of expertise, namely the novices for basic playing and gamelan experts for more advanced musical creation.

Throughout the study, we faced some challenges. The inability to conduct face-to-face observation in a controlled environment had hindered us from obtaining a more detailed observation of the hand demonstrations. From the analysis of the image overlays, although most experts were able to maintain their hand positions of the bonang gestures, however, there were inconsistencies in the demonstration methods as they had to adapt to their surroundings. There were also some issues with camera position and angle, internet connection, study equipment used, and physical environment. Future work will involve prototype testing to determine effective bonang gestures in terms of spatial, angle, and distance with mid-air interaction.

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