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Research paper

Designing an Expressive Virtual Kompang on Mobile Device with Tri-Axial Accelerometer

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Abstract

The paper presents an expressive virtual percussion instrument for Kompang on mobile devices that closely replicate the actual instrument. In nowadays, most available applications are lacking expressiveness control as these applications only use trigger-type event to play corresponding sound. This paper is therefore implemented a simple extraction method by extracting percussive features from embedded sensors to map with the output sound with minimum delay. Multiple features related to the shape of the drum hit are extracted by using tri-axis accelerometer sensors of the mobile device. These features provide an expressive percussion experience that closely imitates playing an actual instrument. An application of the virtual instrument for Kompang is described with an evaluation of the system with ideas for future developments. Result from the study showed that the feature extraction algorithm had an accuracy of 86.78% at detecting drum hit at its peak acceleration value. The questionnaire results also indicated the participants were satisfied with the system in overall.

Keywords: *Gesture Recognition; Mobile Music; Music Interaction; Natural User Interface.*

1. Introduction

With technology advances at a rapid pace, the way we interact with computer machines has evolved tremendously. In the beginning, there are limited choices of input device such as keyboard and mouse interact with the computer. Today, a growing list of devices is built with natural user interface (NUI) in making the human-computer interaction to be much more natural and intuitive. These interfaces accept input in the form of taps, swipes, gestural motions, and body movement. Touch User Interface (TUI) is one of the most popular that widely used since the appearance of touchscreen mobile device.

During the last decades, with the ubiquity of mobile devices by the public, applications and games had been developed to support various musical activities. Some of these applications intend to provide users the ability to play virtual drum via their mobile devices. As noted by Dolhansky [1], these percussion applications had limited control of musical expressiveness as the sound was triggered based on the touch input on the screen. In fact, a musician able to do more than trigger sound on an actual instrument, by adjusting certain parameters to directly change their playing styles. These parameters are including the energy possessed on each drum hit, the material of the drum membrane and the location of the hit on the drum.

The study describes a virtual percussion application, namely *Virtual Kompang*, which simulates Kompang, a traditional percussion instrument in Malaysia. The application allows user to control the expressive qualities of the *Virtual Kompang*. The features that related to timing and energy of each drum hit are extracted from the accelerometer sensor, which commonly embedded on the mobile device. The extracted expressive qualities are then mapped to an output sound. An illustration of a musician playing with the *Virtual Kompang* is shown in **Fig. 1**.

Fig. 1: A musician was playing the virtual instrument on mobile device.

The design of *Virtual Kompang* aims to achieve several goals. Firstly, the study wants to create an expressive musical instrument on mobile device, which is portable in size. Secondly, it is hoping that the physical interaction of the actual instrument can be preserve by leveraging the technology to extend the instrument in potentially useful ways. This paper details the journey into the exploration of designing interface for the *Virtual Kompang* that offers expressive natural experience to the musician, similar to the one playing with a physical instrument.

2. What is a Kompang

The inspiration for this study is a hand percussion drum known as Kompang, which is particularly popular among the Malay communities in Malaysia. It is a membranophone instrument which produces sound by hitting the membrane with bare hands. It is a single-headed frame drum that makes with animal skin as the membrane.
To play a Kompang, a musician must hold the instrument with one hand and hits the membrane with another hand. Generally, each drum hit can only trigger sound at once, either 'Pak' or 'Bum'. A 'Bum' is produced by hitting the edge of the Kompang with closed fingers while hitting the middle of the membrane with palm will produce a 'Pak'. **Fig. 2** shows the playing style and hitting position on an actual Kompang for producing sounds.

Fig. 2: Hand position when player hit (a) 'Pak' and (b) 'Bum'.

The study attempts to create a digital version of Kompang on mobile platform for several reasons. Firstly, surface of the mobile device can act as the membrane of an actual Kompang. It offers an intuitive form of interaction experience by using hand motion to trigger output sound. This form of experience is similar to playing the actual instrument. Meanwhile, the number of the population who own a mobile device is increasing from time to time. The development of *Virtual Kompang* helps to preserve the instrument and allows users to easily access to it.

3. Previous Work

Several studies were focused on using input device together with various type of sensors, in attempts to replicate the motions used to play a physical instrument. Motion controller is one of the popular interaction devices that used for designing natural musical interface. An early example of such research work was done by Marrin et al. [2] as a baton with embedded sensors such as infrared LED, accelerometer, and force sensors was designed to be used as the real baton. Another example was the AoBachi system, that designed by Young et al [3]. A pair of 'bachi' drumsticks were made with accelerometers sensors placed on each stick. Heise et al. [4] used a standard Wii Remote to simulate the playing of percussion instruments such as the maraca and rainstick.
Some research works are conducted to discover the capability of replicating musical instrument in its' virtual form on the mobile device. The idea of designing musical interface in mobile platform started taking shape before the introduction of smartphones. Dial Tones [5] was probably the first project to explore the concept of using mobile devices for performing musical performance. It used dialing and ringing audiences' mobile phones to perform polyphony music. Williamson et al. [6] explored the possibilities of using haptic feedback on mobile phones to notify user of certain events. The ShaMus system, developed by Essl et al. [9], implemented accelerometer and magnetometer of mobile phones to control a virtual drum.
More recently, gestural interaction catches into the eye of researchers as it offers more intuitive and natural way to interact with the computer. As noted by Norman [7], gestural interaction is more practical to deploy late since the introduction of powerful and inexpensive technology for sensors and processing. Leap Motion is one of the popular products among the inexpensive hand tracking technology. Various research studies have done with using Leap Motion to control the virtual musical instrument. For example, Hariadi et al. [8] implemented it to capture users' fine hand motion for playing their virtual traditional instrument. Enkhtogtokh et al. [9] used Leap Motion to play virtual piano as it has technical benefit to identify fine finger gestures.
This study is conducted designed on mobile device, rather than the motion capture controller. This is because the controller has technical limitation in terms of tracking constant moving hand motion. As proven, Silva et al. [10] notified the motion controller is not able to track constant fast hand movement in real time during melodic performance. Additionally, Han et al. [11] also mentioned similar experience when using Leap Motion in their study. The issues addressed were in terms of occasionally mis-tracking and lost fingers, due to fast hand motion.
A musician cannot play a sequence of music if the controller kept lost tracking of the hand motion. Thus, the designed system in this study extends the work presented in mobile music studies by capturing percussive motions on mobile device and mapping these gestures to module the output sound. The mobile device is acting as the membrane of Kompang, users' percussive motions are extracted when fingers touch on the screen. The study uses a low latency method for obtaining multiple features per swing, to improve rhythmic accuracy while enjoying expressive playing experience.

4. Overview

To implement expressive control on *Virtual Kompang*, the system used embedded accelerometer sensors to extract percussive features and then mapped to the output sound. It is important to ensure the extraction process to operate quickly enough to provide an experience of imitates playing a real instrument. Thus, methods for extraction must keep simple to reduce computation time, and at the same time, it must also provide enough expressive control to make the playing experience an interesting one.
The proposed system has three main features, which are feature extraction, feature mapping, and orientation detection. The mobile device records the accelerometer value in real time when user is playing. The system checks whether user touches on the screen, while receiving new accelerometer sample from the sensor concurrently. When the system detected a drum hit, the output sound should produce by mapping with the acceleration data provided by the accelerometer sensor. Output sound can be modified accordingly, based on the accelerometer profile of a drum hit. For example, when the greater the force hit on the device, the louder the sound should produce. The system is expected to be able to provide expressive playing experience. It is therefore latency must be addressed to provide a consistent playing experience.

4.1. Feature Mapping

To design a virtual percussion instrument, it is important to reduce the lag between the detection of a hit and sound production. This is because the amount of latency will affect both the rhythmic accuracy and the playing experience. Regardless of experience in playing percussion instrument, it makes intuitive sense that hitting a drum harder should produce a louder noise. Thus, the mapping between the linear acceleration and the output sound should be directly proportional. The solution presented in this study is a hit detection method that can operate quickly the accelerometer profiles from the sensors to get the magnitude acceleration value of each sample with low latency issue.
The overall process of extracting percussion gesture feature is depicted in **Fig. 3**. Each sample of acceleration data is composed of the concatenation of the tri-axis accelerometer data (x, y, z), one for each direction. In general, the raw data captured by the accelerometer sensor is a combination of the acceleration magnitude with the frequency noise, due to the accelerometer hardware

and accidental user input. At every sampling time, acceleration

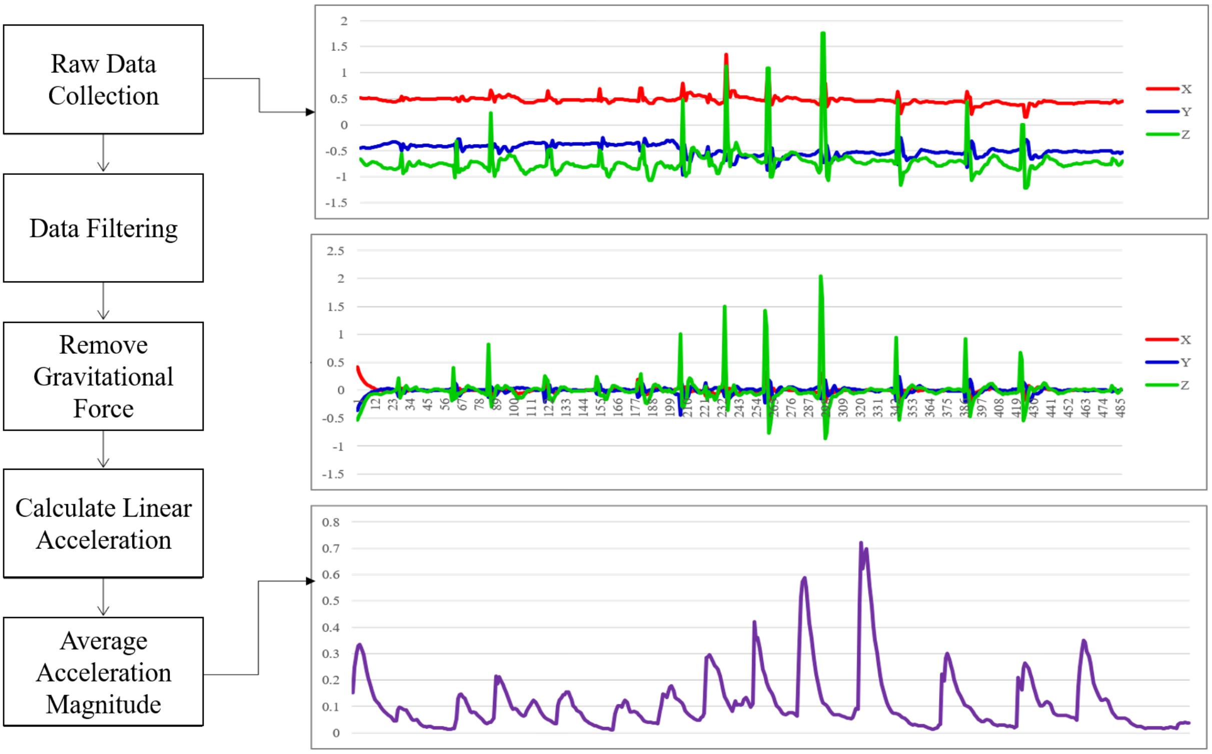


Fig. 3: Overall Procedure of Filtering Tri-Axial Accelerometer Sample

signals of the mobile device are extracted from the accelerometer sensor. A simple low-pass filtering method is implemented to filter the noise from the acceleration data. A smoothing process is applied to isolate the force of gravity. The collision between hand touch on the device should produce obvious peak value at the sum acceleration M which has magnitude as:

$$|M| = \sqrt{x^2 + y^2 + z^2}$$

where x, y, and z present accelerometer measurement of three axes.

4.2. User Interface Design

A good user interface design is the one that the user feels comfortable and can easily understand how to interact with the system. Throughout reviews on past research works, a gap was identified between the software designers and the end users as the designed interface made by the designers might not reach users' expectation. Hence, the users' opinion on the use of the system as virtual instrument is important. The current prototype of *Virtual Kompang* consists of five user interfaces for users to experience. The study intends to know which interface are preferred the most by users. In general, the interfaces display both 'Pak' and 'Bum' sounds as buttons.

The *Virtual Kompang* provides two distinctive modes for users to try out, namely normal mode and expressive mode. Users are presented with the normal mode on application startup. A mode switching button is shown on the button left of the screen (see **Fig. 4**). The application is quickly toggled into the other mode when the switch button is touched. In the expressive mode, accelerometer sensors are activated. Users are required to grab the mobile device in the orientation like they were holding the acoustic Kompang instrument. Accelerometer sample is mapped to produce various output sound that is differed by the force of contact. This preserves the physical interaction of hitting the actual instrument to the *Virtual Kompang*.

Fig. 4: Design Schematic for the Interface Design.

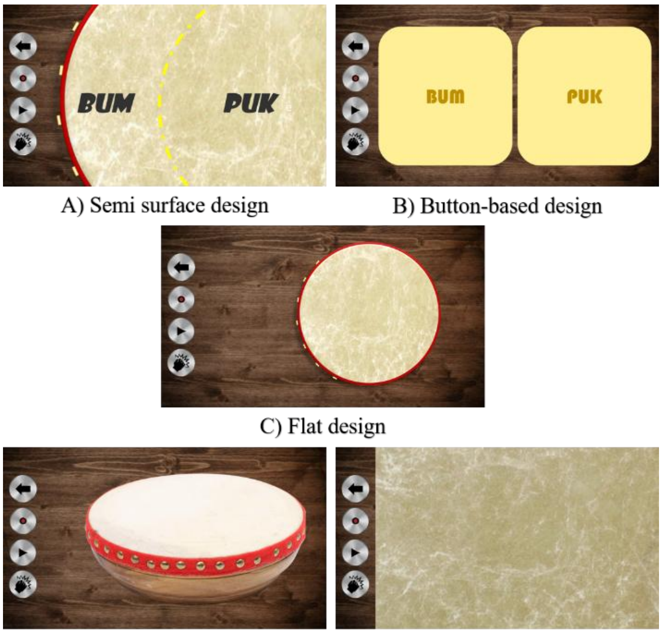
5. Experiment Setup

Ten participants (four males and six females) from the University Putra Malaysia were recruited in the study. The ages of participants ranged from 20-59. The number of participants who had or had no experience in playing Kompang were equally distributed. Three were experienced Kompang players (with more than 5 years of experience playing Kompang), two had at least 3 years of playing experience, and five had no experience with Kompang. All of them had prior experience in using mobile devices. There were ten sessions with only one participant per session. Each session took approximately 20 minutes to complete.

The *Virtual Kompang* is developed on the Android mobile device and deployed on the Huawei P10 phone, with Octa-core HiSilicon Kirin 960 processor, 4 GB of RAM and embedded sensors such as fingerprints, accelerometer, gyroscope, and compass. All sessions were video recorded using SJCAM SJ500 action camera recorder and took place in a lab setting as shown in **Fig. 5**.

Upon arrival, participants were informed about the purpose of the study. They were first introduced with all five interfaces (see **Fig. 6**) and how they worked. Subjects were given up to 10 minutes to become familiar with the interfaces before they ranked the one they preferred from most likely to the least likely one.

Fig. 5: Experiment Setup for User Study



A) Semi surface design
B) Button-based design
C) Flat design
D) Three-dimensional based design
E) Full width design

Fig. 6: Screenshots of the User Interface of the *Virtual Kompang*.

Participants were also required to perform between 16 to 32 strikes in expressive mode until they were satisfied with their performance. Two drumming rhythms were drawn with audio playback to act as reference rhythms. Participants could choose to follow the provided rhythms or compose new rhythms, depending on their capabilities. Information related to the percussive motion of each drum hit was also collected via the interaction log file to evaluate the real-time performance of the algorithm in extracting percussive features. Throughout the session, subjects' experience on the prototype were observed with video recording. A post-questionnaire was administered to them at the end of the experiment.

6. Results

The study identifies users' preference on the interface design and evaluates the effectiveness of the algorithms with extensive experiment. In this section, the findings of the study will be briefly discussed, alongside with the video recordings questionnaires data and log files.

6.1. User Interface Preference

To determine which interface design was the most preferred overall, mean ranking of each interface was calculated. The mean ranking is calculated as follows, where:

$$\mu = \frac{x_1w_1 + x_2w_2 + x_3w_3 \ldots + x_nw_n}{Total}$$

w = weight of ranked position
x = response count for answer choice
Among the suggested interfaces, 50% of the participant selected interface (a) as the first choice, and 40 % as the second choice. In terms of mean ranking score, interface (a) also had the highest score with 4.4 in average. It was then followed by interface (b), interface (c), interface (e) and interface (d) respectively. The mean score obtained for each interface is shown in **Fig. 7**.

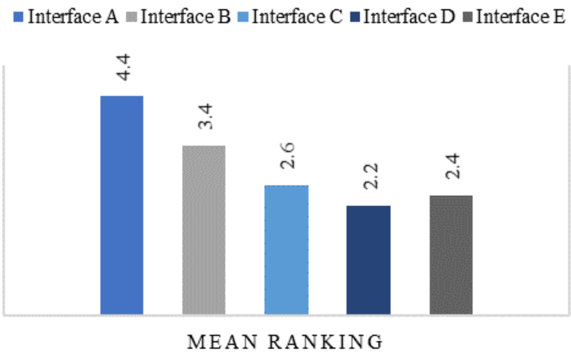


Fig. 7: Mean of Ranking Score on User Interface Preference

Based on participants' opinions, interface (a) was better for several reasons. The advantages of this interface were including:

- Wide distance between sound trigger buttons
- Similar interface to an actual instrument
- Animated visual feedback on each drum hit

6.2. Timing Accuracy of Strikes

Throughout the study, a generalized striking gesture was observed. A user first made a backswing away from the device to prepare for a drum hit. The participant then accelerating the hand towards the device in the vertical plane. In meanwhile, the hand which holds the device tend to move towards the striking hand. The point in time when participant began to move device towards the striking hand caused a growing pattern in acceleration. As shown in **Fig. 8**, participant correlated a peak in acceleration magnitude when the striking hand touched on the device. At the same time, percussion sound was produced when hand touch is detected. Result obtained in this study was similar as the findings from Dolhansky et al. [1] as the act of touching the device, which mimics hitting an acoustic Kompang, is corresponds to a peak in acceleration magnitude.

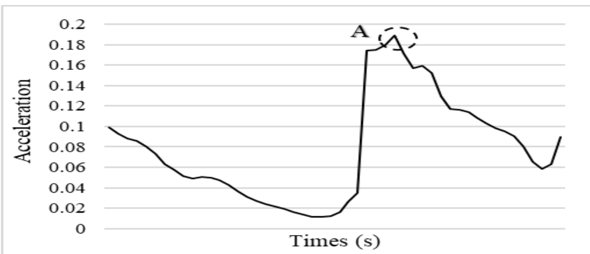


Fig. 8: Accelerometer Profile for a Drum Strike. Point A Indicated the Peak Acceleration when a User Touch on the Instrument Surface.

The study followed similar approach presented as Collicutt et al. [12] by calculating timing accuracy to evaluate performances of the system in detecting drum hit. Log files were recorded while participants were playing with the expressive mode. A log file records the acceleration magnitude and the timing of onset detection that occurs when participants were interacting with the virtual instruments. Hence, the accelerometer of over 300 percussive strokes made by participants were recorded and saved as log files during the study.

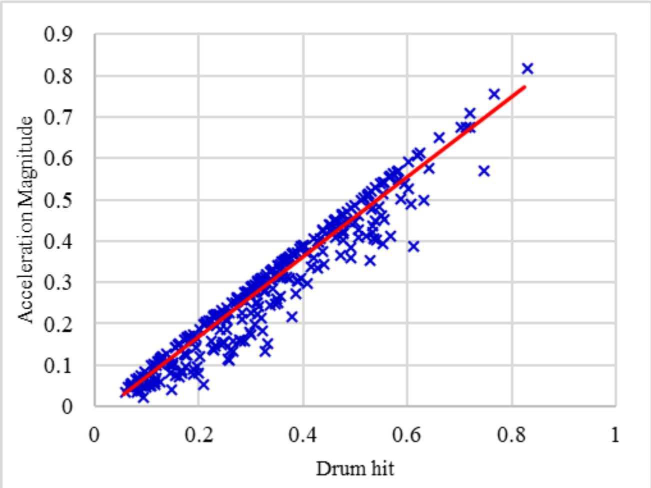


Fig. 9: Visual Representation of the Time Between the Peak Acceleration and Drum Hit.

Fig. 9 shows the correlation between time of detecting drum hit and the peak acceleration. Results showed that the accuracy of detecting drum hit at peak magnitude is 86.78%. The study observed that the accuracy of the system was affected in several situations. Results showed that the system was unable to recognize soft hits at low peak acceleration value. The second scenario is that hit detections occurred on several samples before it reached the actual peak. This is most likely due to the rebounding force that happened after participant touched on the screen. It was then resulting in continuous rise in acceleration value. An illustration of such an effect is illustrated in **Fig. 10**.

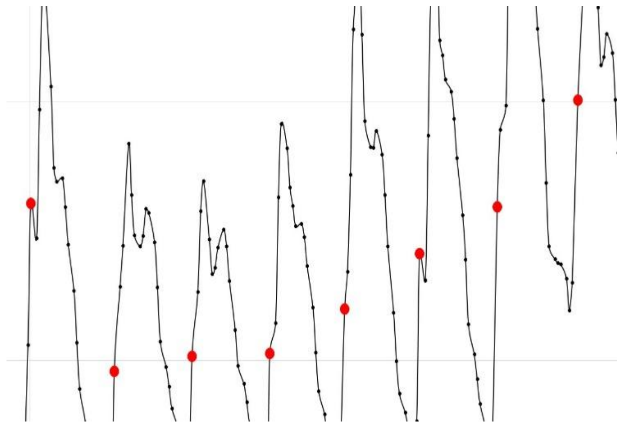


Fig. 10: Visual Representation of Striking Hit. Red Spot Indicated the Point of Drum Hit Before It Reached the Actual Peak Acceleration Magnitude.

6.3. Post-Test Questionnaire Results

Following the completion of tasks given to the experiment, participants were asked to rate the application with statements on a five-point Likert scale. The Likert scale had a variation between strongly disagree to strongly agree, which indicating complete satisfaction with the design criteria. The following questions were asked regarding the evaluation on the instrument and interface:

- *Easy to use*: "I am satisfied with how simple the instrument is designed and yet allows me to create complex rhythm."
- *Controllability*: "I feel in control of the instrument when playing with it."
- *Engagement*: "I thought it was interesting and engaging when playing with the instrument."
- *Learnability*: "I need to learn a lot of things before I could get going with this application"
- *Consistency*: "I think that the instrument is able to respond consistently."
- *Interface Design*: "The interface of the application is pleasant."
- *Enjoyment*: "I feel enjoy when I am playing with the application."
- *Natural*: "I feel natural to use hand motion as input to play the instrument."
- *Expressiveness*: "I feel that myself could expressively control the virtual instrument when playing with the application."
- *Mapping*: "I feel that the output sound produced by the application is corresponding to the sound produced by the acoustic Kompang."
- *Realistic*: "I feel that the application has nearly replicates the experience of playing an acoustic Kompang."

Results showed that the views of participants towards the virtual instrument as used in the study were generally positive as none of the statements had a mean score that were lower than 3. A summary of questions that were asked in the questionnaire is shown in **Table 1**.

From observations and comments on the post-questionnaires, it seems that participants with various background had different expectations towards the application. A short interview was conducted right after participants done their questionnaire. When asked about what they liked about the application, participants with no musical background in Kompang often said that the interface was easy and simple to use. They were not interested in the expressive control in manipulating the output. Instead of that, they felt interested to see the application in becoming a rhythm-based game that challenge their rhythm skills. It is believed that these games instead give the user the feeling of having control towards the instrument, regardless of their knowledge level in playing Kompang.

Table 1: Summary of Questionnaire Responses for *Virtual Kompang*

Statement	Mean
Ease to use	3.4
Controllability	3.7
Engagement	3.5
Learnability	4.1
Consistency	4.3
Interface Design	4.3
Enjoyment	4.1
Natural	3.4
Expressiveness	3.4
Mapping	3.3
Realistic	3.4

Meanwhile, some participants who experienced in Kompang commented that playing the application alone is not as fun. They explained a Kompang music is played when at least two rhythmic parts were played alternately to form a complete rhythm. They suggested to add pre-record rhythmic parts into the application, so they could play rhythm even when they were alone. Participants were also fine with the expressive features in manipulating sound sample. However, a few of them dislike using finger touch to trigger sound as they stroke the Kompang with their palm.

In overall, it is believed that the results of this study demonstrate players were desired for the ability to have creative control in the virtual instrument. Despite of their musical background, participants showed a clear preference in expanding more features that implemented in music-based games nowadays.

7. Conclusion

The study presents the *Virtual Kompang*, a prototype mobile application that uses touch interaction for simulating an actual Kompang. The system closely mimics the actual instrument in function, sound, and playing style with the use of embedded sensors such as accelerometer. The system granted expressive control to user by extracting percussive features and mapped to the output sound in real time. Results showed that the implemented algorithm has high accuracy in extracting acceleration profile to map with the output sound in real time. Meanwhile, the study also observed perception of the user seems to be the more important factor, whether they willing to spend time on using it. The findings of the study suggested that the application should has abilities to create music, and have the feeling of being in control, so that it can fulfill user expectations regardless of their musical background.

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