New Design Ideas
Vol.7, No.3, 2023, pp.648-661

CONTEMPORARY DESIGN AND STRUCTURAL ANALYSIS IN THE DEVELOPMENT OF A GAMELAN MUSICIAN ROBOT MODEL

P.N. Andono, G.F. Shidik, E. Noersasongko, A.M. Syarif*, R. Kadiasti

Faculty of Computer Science, Universitas Dian Nuswantoro, Semarang, Indonesia

Abstract. This study aims to design a model of gamelan music player robot. The challenge was creating a design for a robot model that has dimensions of length x width x height were targeted to be no more than 2 x 3 x 3 meters, a knock-down construction, consists of multi-instruments, and follows gamelan layout rules. Apart from aiming at preserving culture, gamelan robots are also being developed as industrial products, where the products combine local culture and technological functions in the design process. Contemporary design proposed to develop the design was focused on the installation of works of art through structural analysis to express the layout rules of instruments in one robot construction as a symbol of togetherness and unity in gamelan music. The robot was designed based on the shape of a sunflower consisting of four parts, which are stems, stalks, flowers, and leaves. The flower part is where the biggest instrument is placed, while the leaf part is where the other instruments are placed, including the control box containing the robot chip. After conducting a series of experiments, the robot model can fulfill the specified design characteristics. The contemporary design may erase original characteristics, however, the authenticity of the original form of the gamelan instrument with the attributes of their mallets can maintain the local culture information. Moreover, the performance evaluation conducted using expert test and user acceptance test shows that the ensemble gamelan automation algorithm can function well, and the gamelan robot can perform well.

Keywords: *Contemporary design, structural analysis, robot design, robotics, gamelan music.*

****Corresponding Author:*** *A.M. Syarif, Faculty of Computer Science, Universitas Dian Nuswantoro, 207 Imam Bonjol Street, Semarang, Indonesia, e-mail: arry.maulana@dsn.dinus.ac.id*

Received: *30 May 2023;* ***Accepted****: 9 October 2023;* ***Published:*** *8 December 2023.*

1. Introduction

This study aims to design a model of gamelan musician robot. Gamelan is a traditional musical ensemble from Java that has been acknowledged by The United Nations Educational, Scientific and Cultural Organization (UNESCO) as an Intangible Cultural Heritage. The challenge is assembling gamelan instruments which are generally relatively large in dimension into one robot construction while the size of the robot is targeted not to take up space. Therefore, a transformation of the instrument shape is also carried out to suit the robot construction design. Based on the design of the targeted gamelan musician robot model, proper design was needed as a solution for modeling gamelan musician robots. Some works by robotic musicians try to apply humanoid structural designs, while others apply designs that prioritize the work function of robots rather than duplicating the postures and poses of human musicians. Meanwhile, the gamelan musician robot model considers the right design based on its designation or

How to cite (APA):
Andono, P.N., Shidik, G.F., Noersasongko, E., Syarif, A.M., & Kadiasti, R. (2023). Contemporary design and structural analysis in the development of a gamelan musician robot model. *New Design Ideas*, *7*(3), 648-661.

function. On the other hand, the design is expected to maintain local cultural characteristics.

Robotic works that act as musicians attempt to form humanoid structures equipped with instruments to play. Robot design like this requires precision in implementing body mechanics so that the robot can move like a human. For example, a robot pianist named Xiaole who is able to move his fingers, arms, waist, head and legs to play an 88 key instrument (Hall, 2023), or a robot saxophonist by Lin et al. (2019). Moreover, Z-Machines designed by Yuri Suzuki Design Studio (Suzuki, 2023) is a rock band consisting of three robots with a humanoid design who play guitar, drums and keyboards. Compressorhead by Frank Barnes and Markus Kolb which displays a seriously impressive animatronics design (Stewart, 2022), is also a rock band consisting of a robotic drummer, guitarist, bassist and vocalist. Humanoid designs have high complexity in the algorithms implementation in order to create robots that can follow body mechanic rules while playing instruments. However, regardless of the existing complexity, the design of robots with humanoid structures in bands or orchestras or ensembles requires a relatively large area to present their performances.

Designs that focus on the working function of machines in playing instruments are also found in several musician robots. For example, robots playing traditional percussion instruments from Sri Lanka, which simply attach sticks to machines by placing them on top of the instrument by Goonatilleke & Hettige (2021), as well as robot drummers by Karbasi et al. (2020), or robot guitarists by Byambatsogt & Choimaa (2020), including a robot playing the theremin by Fryen et al., (2021), and a robot playing the angklung, a traditional musical instrument from Indonesia, by David et al. (2022). Contemporary design approach is appropriate for developing a robot that is focused on the work function of the machine in playing the musical instrument. This approach is to find solutions to challenge concepts with forward thinking including reflections on art history (Sirinkraporn, 2022), and tends to display designs that are asymmetrical, minimalist and lack of ornamentation, while traditional designs have a style of symmetry, ornamentation and are connected to history (Mouratidis & Hassan, 2020). Contemporary design emphasizes the creative process which does not require art to become an aesthetic work, but aesthetics is part of the creation of art (Sirinkraporn, 2022).

The development of the gamelan musician robot model was focused on the design process in trans-disciplinarity research. This type of research has a broader purpose that transcends disciplines, general methods and related domains of knowledge as a basis for exploring a problem or task (Engholm, 2017). The model development involves various domains of expertise, such as artificial intelligence, electronics, physics, visual communication design, gamelan music. Taking these conditions into account, the contemporary design approach was chosen to model a robot that can play multi-gamelan instruments. Moreover, gamelan, like any other musical ensemble, has different shapes and sizes of instruments, and rules for the layout of the instruments. Structural analysis for significant changes in shape which is part of the contemporary design (Taraszkiewicz, 2021). The analysis is needed to transform the ensemble's musical design into a robotic construction model. Therefore, structural analysis was conducted to design the gamelan musician robot.

Gamelan musician robots have become the object of research by Alimudin et al. (2021) and Siregar et al. (2021). Another example is the Gamelatron by Aaron Taylor Kuffner which has an inspiring contemporary design. The difference between the atmosphere in the Gamelatron performances and conventional gamelan performances was stated by McGraw (2016), where the Gamelatron cannot fulfill the atmosphere of felt-relation (attachment between the audience and performers) like the atmosphere of conventional gamelan performances. However, the element of feel is still a difficult challenge and has not been fully resolved in terms of the automation of art performances involving machines as performers.

The Gamelatron can be categorized as successful in art installations (McGraw, 2016), but the design has not applied a structural analysis that expresses the rules of instrument layout and the philosophy of togetherness or unity in music. Moreover, the contemporary design approach proposed in this research was focused on the installation of works of art through structural analysis to express the layout rules of instruments in one robot construction as a symbol of togetherness and unity in gamelan music.

2. Methodology and Materials

Gamelan consists of two musical scale systems, which are *pelog* and *slendro*. These two musical scale systems have different pitch frequencies. The *pelog* musical scale system consists of seven notes, which are 1, 2, 3, 4, 5, 6, and 7. Meanwhile the *slendro* musical scale system consists of five notes, which are 1, 2, 3, 5, and 6. Each gamelan musical scale systems consists of more than 10 types of instruments, and most of which are metallophones, some of which are idiophones, xylophones, aerophones and chordophones. Figure 1 shows an illustration of a gamelan ensemble set.

Figure 1. A set of gamelan ensembles

According to Supanggah (2002), gamelan instruments are grouped into three categories based on their function, which are the *balungan* (Javanese: skeletal), melodical and structural groups. Instruments in the skeletal group, such as *demung, saron, peking,* and *slenthem,* play notes which are categorized as the framework of the melody. Instruments in the melodical group, such as *rebab, gender barung, gender penerus, bonang barung, bonang penerus, gambang, siter,* dan *suling* (flute), play notes which are categorized as the melodical notes. Meanwhile, instruments in the structural group, such as *kethuk, kenong, kempul, gong*, play notes that categorized as the features that define the type of song.

2.1. Instrument Selection

In order to keep the size of the robot for not taking up space, not all gamelan instruments were used in the robot model. An interview with Mr. Supiyanto, a gamelan expert from the Pangreksa Budaya gamelan studio located in the city of Semarang, Central Java, was conducted in order to select instruments. As the results, six gamelan instruments were selected to be installed on the gamelan robot. The instruments selection was determined based on the dimensions of instruments and the types of instruments that can be collaborated in a limited number of instruments to play songs in a gamelan ensemble. Four of the selected instruments, which are *demung, saron, slenthem* and *peking*, belong to the skeletal group. The *demung* instrument is an instrument that produces basic melodic sounds. The *saron* instrument produces a sound one octave higher than the *demung*. The *slenthem* instrument produces a sound one octave lower than the *demung*. Meanwhile, the *peking* instrument produces a higher sound than the *saron* and is played twice on each beat. The remaining two instruments, the *gong* and *kenong*, belong to the structural group. The gong instrument consists of several sizes that represent the pitches. Still based on the interview with Mr. Supiyanto, simplification in numbers can be done by only using 1 or 2 pitched gongs. The *kenong* instrument in the *pelog* musical scale system consists of 6 *kenong* each for notes 1, 2, 3, 6, 7, while notes 4 and 5 are played in the same *kenong* instrument. All of the six instruments are metallophone instruments which are played using wooden mallets. Figure 2 shows an illustration of the six instruments selected to be installed on the gamelan robot.

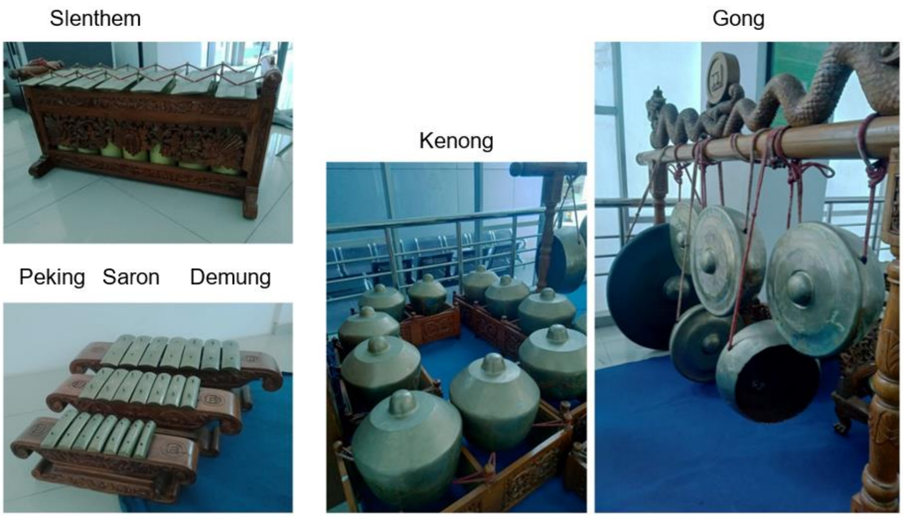

Figure 2. Six types of instruments installed on the robot

2.2. Instrument Placement and Arrangement

Based on its function, the hierarchy of placement of gamelan instruments is divided into three areas, which are the back area for instruments of the structural group, the middle area for instruments of the skeletal group, and the front area for instruments of the melodical group (Supanggah, 2002). Therefore, the placement and arrangement of the six instruments in the gamelan robot places the *demung, saron, peking* and *slenthem* instruments as skeletal instruments at the front, and then the *kenong* as the structural instrument is placed behind skeletal instruments, and the gong as the other structural instrument is placed at the back.

The gamelan robot model was designed not to take up space where dimensions of length x width x height were targeted to be no more than 2 x 3 x 3 meters. Therefore, the layout of gamelan instruments was transformed from horizontal to vertical instrument placement. The hierarchy of arrangement was set by transforming the position of the instrument from back-to-front layout to top-to-bottom layout. Figure 3 shows an illustration of the gamelan robot model with vertical placement and arrangement of instruments.

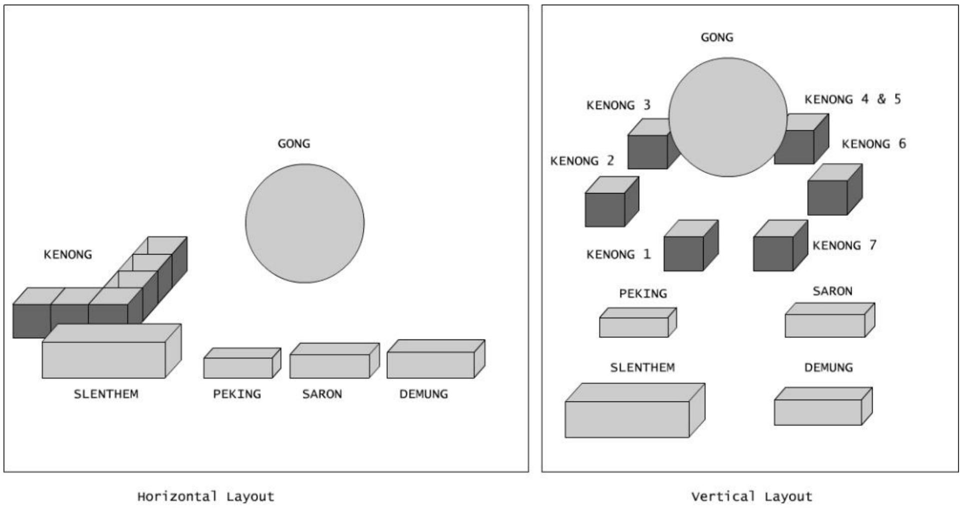

Figure 3. Illustration of the transformation of instrument placement and arrangement from horizontal layout to vertical layout

2.3. Instrument Material Selection

The analysis of the instrument material was to calculate the weight of instruments. The results were then used to measure the strength of the robot construction where instruments are hung in order to vertically placed and arranged them. The first analysis was targeted on the weight of the instrument's keys based on the material type. The metallophone gamelan instruments are made of iron or brass or bronze. The instrument made of bronze have the best sound quality, followed by the brass material, and then the iron material. However, compared to brass or iron materials, the bronze material has the heaviest weight. For example, in the *pelog* musical scale system, the *peking* instrument made of bronze weighs approximately 14 kg. On the other hand, the same instrument made from brass and iron weighs about 7 kg and 5 kg each. In addition, instruments made of bronze or brass have a natural luster, a luster that iron lacks. The instrument made of iron requires painting for the finishing process.

Analysis of instrument materials resulted instruments made of bronze and brass as candidates by considering sound quality, and these materials can emit luster naturally. Natural luster was needed to support the frame design of gamelan robots whose analysis is described in the Gamelan Robot Frame Design Analysis sub-chapter. Furthermore, the weight of the instrument and the design of the placement and arrangement of the instrument vertically were taken into consideration in selecting instruments made of brass. In addition, the transformation of the placement and arrangement of gamelan instruments from horizontal to vertical layout was carried out by leaving the body of the instrument. The material and shape of the instrument body were modified to make the instrument's dimensions more compact. The modification was conducted by installing the instrument keys on a steel frame designed to be as concise as possible. However, modifications to the *slenthem* instrument cannot be minimized optimally. Unlike the *demung, saron, peking* or *gong* instruments, the *slenthem* body contains tube resonators which must be included in the instrument. Figure 4 shows an illustration of a modified *peking* instrument body, and a modified *slenthem* instrument body.

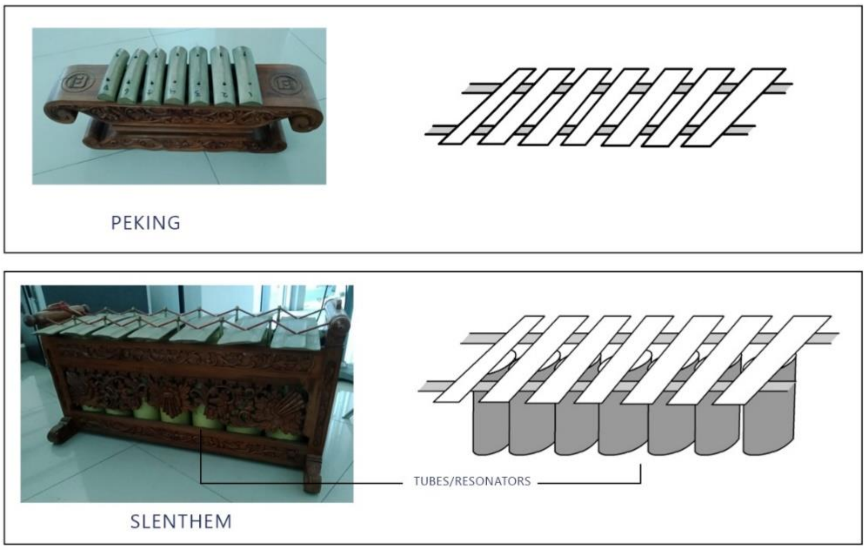

Figure 4. Illustration of a modified *peking* instrument body (top), and a modified *slenthem* instrument body (bottom)

2.4. Gamelan Robot Frame Design

Stainless steel was the chosen material for the robot frames based on its strength, easy to clean and can be bent. Stainless steel 304 series was selected with consideration of its good corrosion resistance. Stainless steel which also emits luster is one of the reasons in determining brass as an instrument material. The shape and size of the *gong* instrument, which is large, makes it stand out, so the position of the gong which is placed at the top of the robot makes the construction of the robot look like a sunflower. The robot was designed based on the shape of a sunflower with the *gong* instrument being the flower element, and other instruments being the leaf element. The robot construction was designed into four parts, which are stems, stalks, flowers, and leaves. The flower part is where the *gong* instrument is placed, while the leaf part is where the *demung, saron, peking, slenthem* and *kenong* instruments are placed, including the control box containing the robot chip. The stem is the crutch for all the robot elements, so the diameter of the stainless steel used has the largest size. The part of the stalk that is linked to the stem is used as a place to hold the flowers and leaves, in which the flowers and leaves are the places for instruments. Figure 5 shows an illustration of the frame design of the gamelan robot with an inset image of a sunflower as its inspiration.

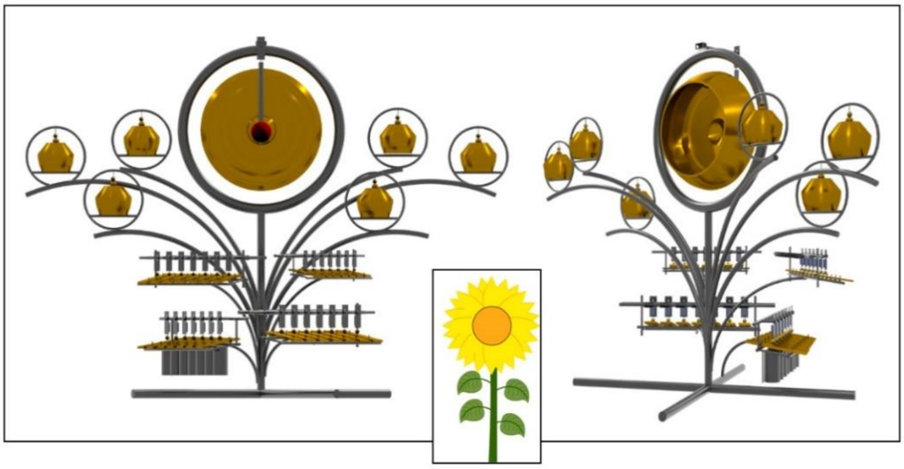

Figure 5. The gamelan robot frame design

The *gong* instrument which is hung using a rope to the instrument body made of wood was modified by changing the instrument body to use a stainless-steel material which was formed in a circle with two holes at the top right and left to be used as a place to attach the instrument hanging rope. Likewise with the body of the *kenong* instrument which was modified like the body of the *gong* instrument but with a smaller diameter. Two holes at the bottom right and left are made to be used as a place to attach the instrument rope. This construction follows the construction of the original *kenong* which is installed using ropes attached to the body of the instrument. In addition, the knock-down technique was applied to the robot so that each part can be separated so as to facilitate its mobility.

2.5. Instrument Mallet Design

The placement of the instrument mallet follows the sitting position of the gamelan musicians when playing the instrument, which is behind the instrument and facing the audience, and each instrument is played using its mallet. Modifications were made to support robotic engineering in bats, where each key has its own mallet. The size of the instrument mallet was reduced to 40-50% of the original size so as not to fill and cover the appearance of the instrument key. Next, crutches for placing the mallets were added to the body of the instrument.

3. Results and Discussion

A model of a gamelan music player robot was developed using a contemporary design approach. Six metallophone instruments made of brass, which are *demung*, *saron*, *peking*, *slenthem*, *kenong* and *gong*, were chosen to be installed on the robot. The size of instruments was reduced from its original size. Stainless-steel with series 304 was used for the robot frame and as a place to hang and hold instruments. The layout and arrangement of the instruments used in gamelan performances are used as a reference with a modified transformation from horizontal to vertical layouts. As the results, the developed robot model has a width x length x height dimensions of 1.2 x 2.1 x 2.3 meters. Figure 6 shows the results of the gamelan robot model development.

Figure 6. Results of gamelan robot model development

The sunflower-inspired robot construction design consists of four parts, which are stems, stalks, leaves and flowers. The stem is used to hold stalks, including flowers. The stem part is for placing the *demung, saron*, *peking* and *slenthem* instruments, as well as the control box which contains the robot chip. The flower part is used as a place to put the *gong* instrument. The sunflower design implemented in the robot construction can fulfill the aesthetic principle. Instruments that are an integral part of a traditional musical ensemble can be installed on the robot. The unity of color can be shown through the visuals of the instrument and the robot frame which can emit a natural luster based on the materials used, which are brass for the instrument and stainless-steel for the robot frame. The different shapes and sizes of the instruments show harmony and harmony. The visible motion or direction of the Gamelan robot design is able to represent order and dynamics as rhythm. The different shapes and sizes of the instruments can show harmony in the robot. The emphasis in gamelan robot design is shown through the grouping of instruments based on shape which basically follows the rules of layout and arrangement of gamelan instruments.

The weight and dimensions of the instrument hung on the robot frame have an impact on the balance of the robot construction when it is placed on an uneven floor. The robot's front or rear legs can be lifted up to 3 to 4 centimeters. This problem was solved by placing four ball-shaped shoes on each end of the robot's legs. Each ball can be threaded to adjust the height of its position. The position of the two rear balls can be lowered if the back of the robot is raised, and vice versa. The implementation of the knock-down technique in robot construction was used to separate the parts of the robot so as to facilitate its mobility when the robot is moved. The stretched robot legs with a size of 1.2 x 2.1 meters were designed to be two separate parts. The installation of the two parts of the legs is done by linking them to the stem and tightening the links using bolts. Figure 7 shows an illustration of the installation of robot legs.

Figure 7. Illustration of assembling the robot's left and right legs on the stem

Figure 8. Illustration of the assembly sequence of robot stalks, flowers and leaves

A hollow stainless-steel rod is installed around the stem to place the robot stalks using a technique like in pipe fitting. This technique of installing the stalk on the stem supports the rotational arrangement of the stalks. Furthermore, the *gong* instrument which acts as a flower is installed at the very top of the stem. Finally, the *kenong*, *demung*, *saron*, *peking*, *slethem*, and control box instruments which act as leaves are placed at the end of the robot's stem using the same technique to support its rotation settings. Figure 8 shows an illustration of the assembly sequence of robot stalks, flowers and leaves.

3.1. Gamelan Ensemble Automation

Gamelan ensemble automation was developed based on a rule-based method for gamelan instruments play automation proposed by Fanani et al. (2020). This method implements a set of four-instrument game rules for instruments of the skeletal group, which are *demung*, *saron*, *peking* and *slenthem*. The *demung*, *saron* and *slenthem* instruments have the same playing rules, which are played on every beat in the song, or one stroke on a certain key based on the selected note of a note sequence per beat. Meanwhile, the *peking* instrument is played twice on each beat, or two strokes with the same distribution of tempo on certain key based on the selected note of a note sequence per beat. The four instruments are installed on the gamelan robot with two other instruments, which are the *kenong* and *gong* instruments. The *kenong* instrument is played every even beat, and the *gong* instrument is played every multiple of eight beats. Thus, the developed gamelan ensemble automation algorithm is described in the following pseudocode:

```
INPUT: notes is an array of a note sequence
       tempo is time interval between beats
       counter is timer in tempo
       n is the length of notes
       instrument1 is demung
       instrument2 is saron
       instrument3 is kenong
       instrument4 is peking
       instrument5 is kenong
       instrument6 is gong

counter: ← counter + 1
FOR k ← 0 TO n Do
  IF counter < tempo/2 THEN
    play s of instrument4
  ELSE IF counter > tempo THEN
    s: ← notes(k)
    play s of instrument1
    play s of instrument2
    play s of instrument3
      IF s = mod 2 THEN
        play s of instrument5
      END IF
      IF s = mod 8 THEN
        play instrument6
      END IF
    counter: = 0
```

```
      k: ←  k + 1
    ELSE
      IF k ≥ n THEN
        counter ← 0
      END IF
    END IF
  END FOR
```

3.2. Performance Evaluation

The performance of the gamelan robot was evaluated based on the quality of the sound produced, the quality of the gamelan ensemble automation, and the level of audience acceptance of the gamelan robot. Evaluation of the sound quality produced by gamelan robot playing involved two expert gamelan musicians from two different gamelan studios. The experts are Mr. Supiyanto from the Pangreksa Budaya gamelan studio, and Mr. Yoyok from Suko Raras gamelan studio. The experts were asked to assess the sound quality produced by the gamelan robot playing on each instrument separately and as an ensemble. Assessment was carried out using questions:

R1: How does the sound of the instrument played by the gamelan robot match the sound of the instrument played by humans?

R2: How does the ensemble sound played by the gamelan robot match the ensemble sound played by the gamelan studio?

The experts were asked to assess based on Likert scale measurements with a range of 1-4 which represents very not suitable, not suitable, suitable and very suitable. Table 1 shows the results of evaluating the sound quality produced by the gamelan robot on each instrument.

Table 1. Results of the sound quality evaluation on each instrument (R1)

Instruments	Expert I	Expert II
Demung	3	3
Saron	3	3
Slenthem	2	1
Peking	3	3
Gong	3	3

In the R1 evaluation, each expert gave a score of 3 (suitable) for the sound quality produced by the gamelan robot playing on each instrument except the slenthem. Expert I gave a rating of 2, and Expert II gave a rating of I for playing the slenthem instrument. Slenthem has a low humming sound produced by the resonator under each key, but this characteristic sound was a problem to be produced by the gamelan robot. The slenthem mallet has a cylindrical tip covered with cloth on the outside. The thickness of the layer affects the quality of the sound produced. The same striking machine working mechanism is applied to each instrument. On the other hand, slenthem is the only instrument on the gamelan robot that is played using resonator support. Instead of modifying the working mechanism of the slenthem mallet machine, the alternative solution is to modify the shape of the slenthem mallet machine. The shape of the slenthem mallet was modified to resemble a gong mallet, an instrument that also produces a low humming sound. The ball-like shape of the gong mallet made from layers of cloth is used to beat the slenthem instrument with a reduced size to suit the size of the slenthem instrument. Both experts stated that the solution can produce a better low hum sound. However, modifications to the shape of the slenthem mallet that change the characteristics of the original shape are not recommended by both experts. Therefore, the gamelan robot still uses a slenthem instrument mallet that matches its original shape, and the problem of the sound quality of the slenthem instrument is an important note for future improvements.

In the R2 evaluation, initially, each expert gave a score of 2 (not suitable) for the sound quality produced by the gamelan robot ensemble playing. Both experts gave the same statement that the level of loudness produced by playing all the instruments as an ensemble was less than harmonious, especially when playing the kenong instrument which sounded weak, and playing the peking instrument which sounded dominant. The solution to this problem was conducted by resetting the distance between mallets and their keys on each instrument. The distance between the mallet and the key is set lower to reduce the loudness of the sound from the instrument. Setting a lower distance reduces the level of pressure when hitting the instrument so that the loudness of the sound produced also decreases. Adjusting the distance between the mallets and their keys was done with the help of the two experts, and the results can increase the assessment of the two experts to score of 3 (suitable).

The next evaluation was to measure the level of audience acceptance of the performance of the gamelan robot. 30 respondents were selected by screening 'have seen a gamelan performance in the last two months'. Respondents were asked to saw a gamelan robot performance accompanying a *sinden* (female singer) performing three songs, then make an assessment based on the question 'How good is the performance played by the gamelan robot?'. The assessment uses a Likert scale measurement with a range of 1-4 which represents very not good, not good, good and very good. User assessment results are processed using the Mean Opinion Score (MOS) technique, which is a subjective assessment from users to measure the quality of an event or experience. The MOS measurement formula is:

$$\text{MOS} = \frac{\sum_{n=1}^{N} R_n}{N}$$

The results of the user acceptance test showed that two users gave a score of 1 (very not good), four users gave a score of 2 (not good), 19 users gave a score of 3 (good), and five users gave a score of 4 (very good). Based on user assessment, the MOS value obtained is 2.9 which shows that the gamelan robot performance is at a good level.

4. Conclusion

After conducting a series of experiments, the robot model can fulfill the specified model characteristics, which are a robot consisting of six instruments, the layout and arrangement of the instruments on the robot follow gamelan layout rules, the robot has dimensions of no more than 3 x 3 x 3 meters, the robot construction is knock -down follows the shape of a sunflower. Moreover, overall, the results of expert testing and user acceptance testing show good performance of the gamelan robot. The gamelan robot design is focused on modern technology and materials for practical, fast and inexpensive designs. These design characteristics are a preference in modern life and are not long-term designs, and erase national characteristics (Margarita & Elena, 2019). However, although modifications to the body of the instrument were made, the authenticity of the original form of the instrument with the attributes of the instrument mallet can maintain the local culture information.

Apart from aiming at preserving culture, gamelan robots are also being developed as industrial products, where industrial design aims to develop products that combines local culture and technological functions in the design process as in the contemporary expressions. Future research will focus on developing a robot chip that implements the gamelan ensemble automation algorithm.

As information addition, the performance of robot gamelan can be seen through the YouTube Channel as follow: https://www.youtube.com/@RobotSekarNuswantoro/featured

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