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THE PREFERRED INITIAL TIME DELAY GAP AND INTER-AURAL CROSS CORRELATION FOR A JAVANESE GAMELAN PERFORMANCE HALL

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This paper discusses the application of a method based on human subjective preference to the acoustic design of a Javanese *gamelan* performance hall. Some important distinctions between Javanese *gamelan* ensembles and Western classical orchestra are the tuning system, orchestral blending process, and technique of playing. The results of subjective preference test using the rank order method showed that the subjects preferred 24·25 ms for the initial time delay gap (*ITDG*) and the smallest value of the inter-aural cross-correlation (*IACC*). The preferred *ITDG* agree with the *ITDG* from the room response measured in a traditional *pendopo* in Indonesia, which is not a common concert hall but an open-sided hall. However, the preferred *IACC* is not in agreement with the measured *ITDG* in the *pendopo*.

1. INTRODUCTION

Javanese *gamelan* is one of the Indonesian traditional music ensembles. There are several important differences between the *gamelan* and the Western symphony orchestra including tuning systems, orchestral blending systems, and playing technique.

According to Ando [1], by using a human preference approach through a psycho-acoustic test, four orthogonal factors for designing concert halls can be determined. Those four factors are the listening level (*LL*), the initial time delay gap (*ITDG*), the subsequent reverberation time (T_{sub}) and the magnitude of the inter-aural cross-correlation (*IACC*). So far, this theory has mostly been applied for designing concert halls for Western classical music.

This paper will discuss an application of the approach to design the preferred acoustic conditions for performing Javanese *gamelan* in an enclosed hall. Two preferred parameters *ITDG* and *IACC* will be discussed in this paper. Measurement data from a *pendopo*, an open-sided hall where Javanese *gamelan* is usually played in Indonesia, will be provided as comparison.

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2. JAVANESE GAMELAN

Gamelan gets its name from the low Javanese word *gamel* [2], which refers to a type of hammer, like a blacksmith's hammer. The name "*Gamelan*" actually refers only to the instruments themselves, which are predominantly percussion. Javanese have a separate word for the art of playing *gamelan* instruments namely *karawitan*, a noun formed from the word *rawit*, meaning "intricate" or "finely worked".

In a complete *gamelan* orchestra there are about 20 different types of instruments. However, the total number of instruments maybe as high as 75, as there needs to be at least two of most of the instruments, one for each of the two tuning systems. Some instruments (for example, the *kempul*) also exist as a set and each item of that set may be counted separately.

The bringing together of *gamelan* instruments from various types of ensembles to form the full modern Javanese *gamelan* orchestra has taken place only over the last two centuries. As the instruments have come together, so has the music changed and developed. The type of *gamelan* music one hears today, performed on a full modern orchestra, is certainly different from what is known of *gamelan* music even at the end of the 19th century, which is the earliest period for which there are any relative complete records. What *gamelan* used to sound like in earlier times is still a mystery.

One thing is clear, however. Within *gamelan* music today, the distinction remains between what one can loosely term "loud" and "soft" styles. Central Javanese *gamelan* music has found its own unique blending of the two. Perhaps one key to appreciating Javanese *gamelan* lies in being able to understand the relationship between these two styles, for which there are still distinct repertoires. But much of the subtlely and complexity of *gamelan* lies in the change of focus from the loud to the soft style even within the performance of one piece of music [2].

Karawitan is broadly synonymous with *gamelan* music, in other words it is the conceptual framework and theoretical content of the *gendhing* (gamelan music pieces). The main condition for *karawitan* is that it is one of the two Javanese tuning systems, or *laras*. Although a complete Javanese *gamelan* is regarded as a unit, it is usually two *gamelan* placed together, one for each *laras*, with most of the corresponding instruments placed adjacently at the right angles, and this contributes to the impression of one large *gamelan*. The two *laras* are called *slendro* and *pelog*. As the tuning of the *gamelan* cannot be altered in performance it is necessary to have complete sets in each *laras* [3].

The basic information about *laras* is easy to grasp and it should never be a problem to distinguish one from the other. *Slendro* is defined [3] as an anhemitonic pentatonic scale. This means it has five notes and no semitones, which would also describe the scale obtained on the black notes of the piano. The crucial difference is that the five notes of *slendro* are more or less equally spaced, while the black notes have clear differences between whole tones and minor thirds. The problem for the Western ear is relating the pitches of such a subdivision. Divisions of the octave into 12 equal intervals (semitones), six (whole tones), four (minor thirds: diminished seventh chord), three (major thirds: the augmental triad) and two (tritones) are familiar, but the "missing" division between one and six is not used in Western music, and this is the territory of *slendro*. If the octave is divided into five equal parts, the resultant interval will lie between a whole tone and a minor third. The somewhat elusive quality of *slendro* is that we cannot say exactly where the interval is, because in practice the octave is not divided into five precisely equal steps. The Western love of standardization (or familiarity with the equality tempered scale) means that such a situation could be regarded as unsatisfactory, but the Javanese attach great important to *embat*, or intervallic structure. Much of a *gamelan*'s unique personality depends on its *embat*, and a good ear will appreciate the subtle differences between the notes of *slendro* or *pelog* from one *gamelan* to another.

Pelog is readily distinguished from *slendro*. For one thing it has seven available notes and differing sizes of interval varies far more than in *slendro* and including semitones.

An important distinction is often made between the *gamelan* and the Western symphony orchestra. The *gamelan* is a set, housed in a special place. The players come to it empty-handed and depart likewise. They will probably remain anonymous, whereas the set of instruments will usually bear a name—a personality which is special to it and serves to identify the whole musical event. The Western orchestra is a collection of individuals (even of individualists) most of whom bring their own instrument. The musicians are generally specialists in one instrument, whereas a good *gamelan* player is expected to be proficient in most, if not all, instruments. The cohesion of the ensemble in a symphony orchestra depends on the conductor's ability to blend the instruments into a unit; such a need does not arise with the *gamelan* since the blend was ensured first at the manufacturing stage, and then by special rapport between the musicians who know everyone playing in the ensemble [3].

3. PENDOPO

Pendopo, a large hall, open-sided square veranda [4], sheltered the functioning of Javanese states, with specific ones allotted to the law courts, the clergy and the king and his ministers for their public appearances. The symbolic importance of the buildings to the legitimacy of the rulers was carried out to new lengths in the late 18th century, when the court of *Pakubuwono II* of *Mataram* at *Kartasura* was transferred to a new capital near the village of *Solo*.

Today the courts of Java preserve the ancient forms, though the trim is often modern. In the layouts of the *kratons* in *Yogyakarta* and *Solo*, some scholars see echoes of *Majapahit*. Ceremonials are still important to the *kratons* and there is a busy life of courtiers as court-supported arts. Although they may not have any official roles in the running of the state today, the palaces are still places of prestige, still able to arbitrate Java Style.

The Javanese houses are classified according to their roof forms (Figure 1) and houses are organized by the placement of the columns, which support roofs. Walls are secondary: their placement is determined by the roof-carrying columns. In the simplest Javanese

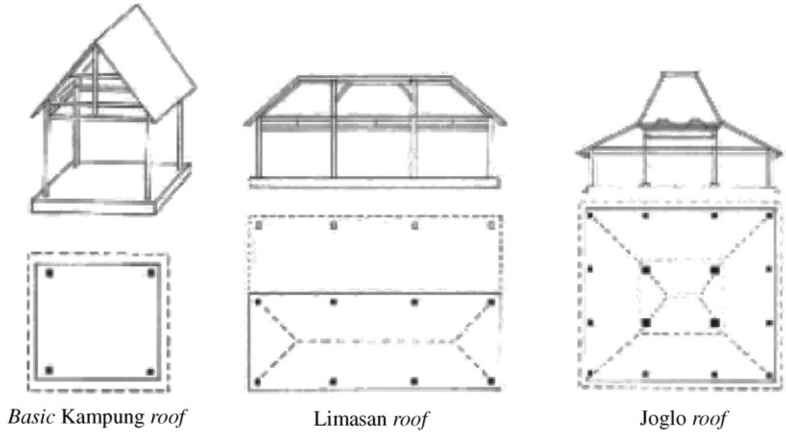

Figure 1. Roof shapes of Javanese house.

Figure 2. A typical interior of *pendopo*.

house, four columns of equal height are braced in a double layer of trusses. From the center of two of the trusses rise two columns, which in turn support a roof beam. This *kampung* roof falls away in two directions on either side of the beam. Of course, this simple shape may often be extended, added to and combined with other roof shapes [5].

The most common roof type in Javanese houses is the *limasan*, created by extending the *kampung* model to a rectangular plan, with additional pairs of columns at either end. The basic shape is created by the fact that the roof beam does not run the full length of the rectangular building, rather it extends over the inner most set of columns. This means the *limasan* roof has four slopes, two along the shorter axes. The typical *limasan* has four slopes and five ridges, which emphasize the central area between the innermost four columns [5].

The most characteristic Javanese roof form for houses (and the most complex), is the *Joglo*. The portion of the roof that sites over the innermost four columns, is much steeper, almost a pyramid, except that it comes to two points rather than a single one. The *joglo* does not use king posts as does the *limasan* or *kampung* roof. Rather, the master pillars are sometimes taller than the outer ones. Resting on the top of the central four pillars are layers of wooden blocks, which step back into the center, and out to the sides. The outermost blocks support the roof that rises steeply above, the inner layers form a stepped pyramidal ceiling. The timbers of the inner layers are often heavily worked, carved, and gilded. This ceiling of stepped timber, the *tumpang sari*, is usually the most intensely decorated area of the traditional Java house [5].

The *pendopos*, palace audience hall, or the kind of pavilion which usually houses at least one set *gamelan* [4], feature in many wealthier homes, including the *kratons*. Most of their roof shapes are the *Joglo*, however some of them are *Limasan*. A set of *gamelan* is usually placed in one corner or side of *pendopo*. The center, under the *tumpang sari*, is kept clear for the dancer. The audience area is placed in the main hall, left and right sides, or in the veranda. In some crowded urban areas, masonry walls might be erected around the *pendopo*. A typical interior of *pendopo* is shown in Figure 2.

4. METHOD AND EXPERIMENT SETUP

The research used three methods for the investigations. Computer-based analysis was used to determine and select the characteristics of the appropriate *gendhing* for the subsequent subjective preference test, while computer simulation process was used for preparing the test samples. *In situ* measurements were conducted in a *pendopo* in Indonesia to provide a comparison to the subjective preference tests. Subjective preference testing in an anechoic chamber was used to determine the preference.

4.1. SAMPLES SELECTIONS AND PREPARATIONS

Studio recordings of Javanese *Gamelan* music pieces—*Gendhing*—in a CD format was captured into a PC using 16-bit data width and 44·1 kHz sampling rate. Each sample was 6–9 s in duration. The effective duration, τ_e, of the autocorrelation function (ACF) of those samples was then computed using ACF Analysis software [6]. Several samples of Javanese *gamelan gendhing* were analyzed. All of the samples were classified as a fast type *Gendhing*. It is expected that they all have a small effective duration of ACF. They are considered to be representative of all other types of Javanese *gamelan gendhing*. The fastest *gendhing*, in this case with the smallest τ_e, will be chosen as the sample for future subjective measurement. A sample from the *closing* part of *Kebogiro Glendeng*, with minimum $\tau_e = 27{\cdot}59$ ms ($2T = 2$ s, interval 100 ms), was chosen and used in the subjective preference test. The duration of the stimulus was 9·3 s. τ_e values of the stimulus as a function of running time is shown in Figure 3. All the samples in all the subjective preference tests were derived from this sample. These were achieved by convolving the sample with room impulse responses of a simulated room in an ODEON package software. Simulation to produce suitable acoustic parameters was then organized using Cool Edit pro in a PC combined with a configuration of loudspeakers in an anechoic chamber (see later section for details).

4.2. IN SITU MEASUREMENTS

In situ measurements were carried out in *Pendopo Mangkunegaran* in Solo Indonesia, using a MLS signal and Binaural Room Impulse Response technique. The MLS signal was

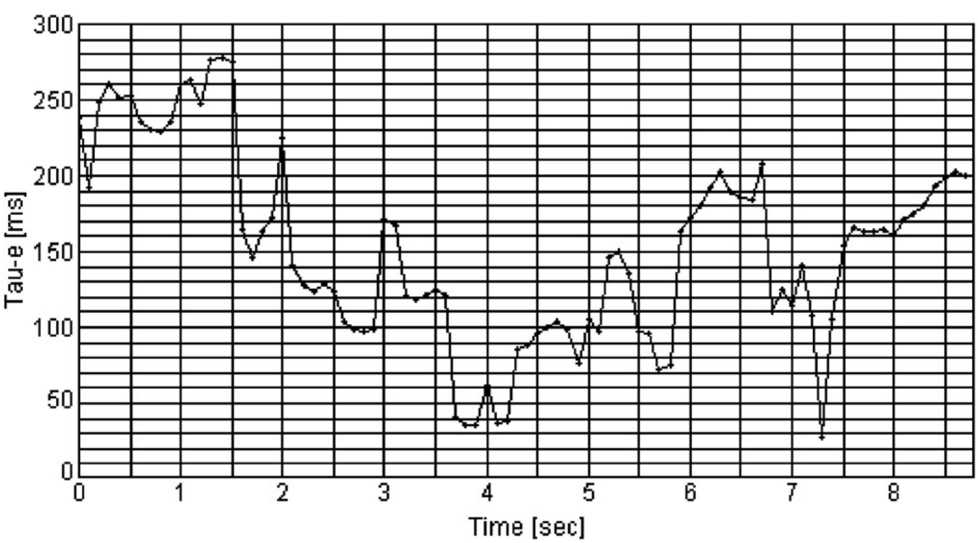

Figure 3. τ_e values of the stimulus as a function of running time.

sent to an omni-directional loudspeaker through a full duplex sound card, and the room response recorded by using two tiny *Electret Condenser* microphones, *Knowles* EK 3132, which has a flat broadband response from 100 to 10·000 Hz, in human ears, then fed back to the PC through the same sound card. Five points in the *pendopo* were chosen to represent three main locations: dance floor, audience area, and VIP audience area. Averaging was made for each measurement at each point to annul the effect of wind since the *pendopo* is an open-sided hall. The calculation of *ITDG*, *RT*, and *IACC* was carried out off line according to reference [6].

4.3. SUBJECTIVE PREFERENCE TESTING

All the subjective preference tests were carried out in an anechoic chamber, using a configuration of seven loudspeakers to simulate several sound field conditions to be judged by listeners. The values of the simulated parameters were chosen according to the minimum effective duration of ACF of the samples in an attempt to determine its relationship with the preferred values of the simulated parameter.

Tests were completed by between 6 and 17 listeners depending on the test. All the listeners were university students of several nationalities, of both genders and varied in age from 20 to 35 years old. They had no known of hearing problems. The subjective preference test has been carried out using the rank order method. In this method, subjects are asked to rank several stimuli starting from the most preferred to the least preferred. They may listen to each stimulus as long as they wish before they rank the stimuli. Subjects were not allowed to give equal rank to each stimulus. Tests were completely double blind, in that neither the subjects nor the experimenter knew the order of presentation of the stimuli. At the beginning of the research, the paired comparison method had been used instead of the rank order method. It was found [7] that subjects had difficulties to differentiate samples with a small different value of parameter, for example, *ITDG* 20 and 30 ms.

All stimuli were stored in a PC, which was also functioned as stimuli player. For both tests, the number of stimuli was 5. Seven identical loudspeakers, *Genelec 1029A*, were used to produce the sound field in an anechoic chamber. All loudspeakers were placed at distance of 1·35 m from the listener. The horizontal angles of the loudspeakers were 0, ± 45, $\pm 67{\cdot}5$, and $\pm 135°$. The vertical angles of the loudspeakers were 0°, except the rear loudspeakers for the *ITDG* test, which were elevated 6°, relative to the subject's ears. The frontal loudspeaker was used to simulate the direct sound. The reflection sounds came from the $\pm 45°$ loudspeakers, while the $\pm 67{\cdot}5$ and $\pm 135°$ loudspeakers were used for reflections and reverberant sounds. The *ITDG* was reproduced through the $\pm 45°$ loudspeakers, which both have slightly different time delays (1 ms). The time delay of the first reflection was varied from 15 to 160 ms for the *ITDG* test, and kept constant at 30 ms for the other test. The reverberation decay were reproduced by the $\pm 67{\cdot}5$ and $\pm 135°$ loudspeakers starting 80 ms after the direct sound. The exact time delays of these four loudspeakers were set slightly differently (± 2 ms). The *RT* was kept constant at 1 s for both tests. The total reflection amplitudes for the *ITDG* test was set to 1 dB relative to the amplitude of the direct sound. This total amplitude was varied in the *IACC* test. The *LL* was set constant to 73 dBA for both tests. The detailed configuration of both tests is shown in Table 1, while the schematic configuration of loudspeakers in an anechoic chamber is shown in Figure 4, where PC is a personal computer and ADAT (from *Alesis*) is a multichannel audio output, which is basically an analogue–digital–analogue audio converter. The unit is an A/D D/A converter that uses optical cables to connect to and from the PC sound card.

TABLE 1

Detailed configuration of subjective preference test

Test	Direct sound (deg)	Reflection sound (deg)	Reverberant sound (1 s)	Reflections amplitude	Reverberation amplitude	Stimuli	Listening level (dBA)	Subject
ITDG	0	±45	±67·5°, ±135°	1 dB	−3 dB	15, 30, 50, 80, 160 ms	73	6
IACC	0	±45	±67·5°, ±135°	Varied	Varied	0·3, 0·4, 0·5, 0·75, 1	73	10

5. RESULTS AND DISCUSSION

Only two parameters *ITDG* and *IACC* are discussed in this paper. The reason for choosing these parameters was mainly because this research was carried out to find out whether the western approach of designing a concert hall can be used to design an enclosed performance hall for a Javanese gamelan which is usually played in an open-sided hall. Those two parameters were used as a starting point of the work as there are no available results for enclosed room design for these particular music instruments. Since there are no available data of acoustic design for a Javanese gamelan performance hall, subjective preference experiments were considered as the most appropriate approach to start the research work and measurements in the original performance hall were then used as comparison. With regards to other parameters, those two (along with the *LL* and T_{sub}) have been considered enough to represent a basic design of an enclosed performance hall for a Javanese gamelan.

All the following preference results were plotted as the listeners' mean preferences, with 5 = most preferred and 1 = least preferred, and 95% confidence limits (shown as error bars). All results were statistically tested using the *Friedman* test which shows they are highly significant ($p < 0{\cdot}001$). Figures 5 and 6 show that there was a low value preference for *ITDG*, with the most preferred value of 24·25 ms. This value was calculated using a polynomial fitting of $y = 6{\cdot}9823x^3 - 39{\cdot}736x^2 + 69{\cdot}882x - 34{\cdot}766$, with a high correlation value $R^2 = 0{\cdot}9933$, as shown in Figure 6. This means that the subjects preferred good clarity with an intimate sound field for listening to Javanese *gamelan* in an enclosed hall.

Comparing with the results from *in situ* measurements in an open-sided hall, preference test results agree with the *ITDG* of *pendopo* Puro *Mangkunegara*n [8], as shown in Figure 7. It shows the *ITDG* and *RT* of the *pendopo* at 5 measurement points, including the centre of the hall (centre), the audience area (10, 11, 15), and the VIP area (king). The measurement points are shown in Figure 8. It is shown that the value of measured *ITDG* is in the range of 20–30 ms, while the measured *RT* is in between 600 and 900 ms. The reflection surfaces at the centre of the hall and the audience area are the ceiling and the floor, while for the 'King' place (VIP) there are additional reflections from the wall.

Using a sample of classical music for his subjective preference tests [1], Ando discovered an approximate relationship for the most preferred *ITDG* in terms of the ACF of source signals and the total amplitude of reflections, as follows:

$$[ITDG]_p = \tau_p$$

with $\tau_p \approx (\log 1/k - c \log A)\tau_e$. (envelope of the ACF is exponential), where c and k are constants depending on the subjective attributes, and A is the total amplitude of reflections.

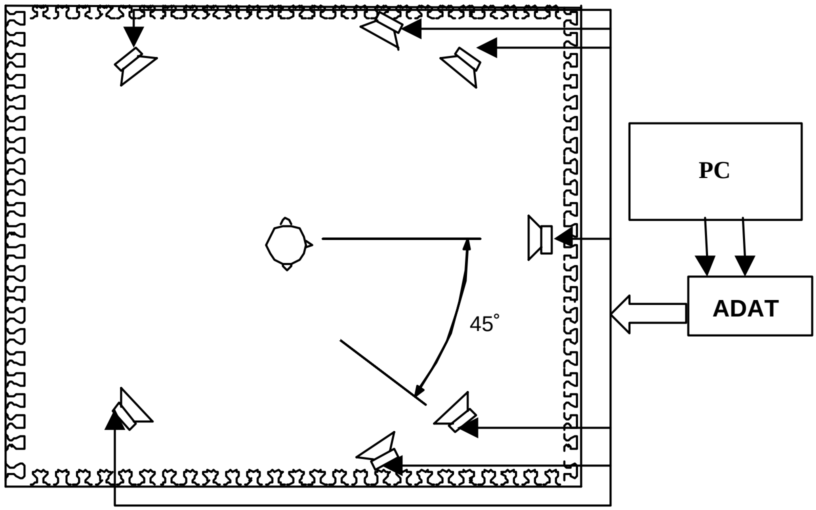

Figure 4. Loudspeaker configuration in anechoic chamber.

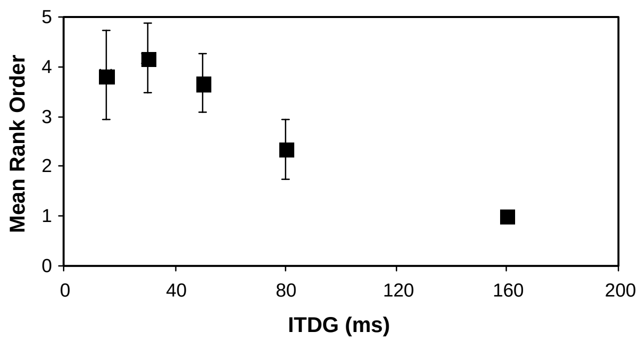

Figure 5. Preference for *ITDG*.

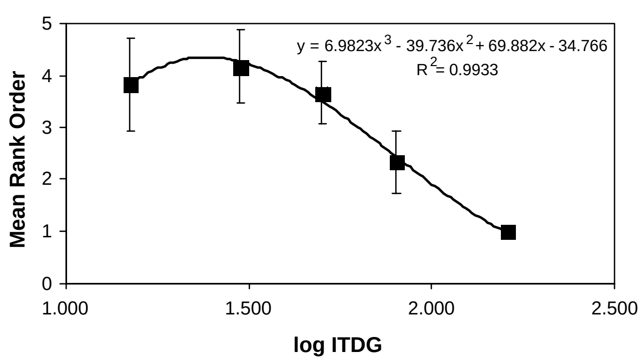

Figure 6. Calculation of $[ITDG]_p$ by polynomial fitting, with $x_{max} = 1{\cdot}384727$, which is equal to $ITDG = 24{\cdot}25$ ms.

Calculating the result using the constants related to the ACF-envelope of source signals for calculating various subjective responses to sound fields with a single reflection, in relation to the ACF-envelope, with $k = 0{\cdot}1$ and $c = 1$ (range of amplitude $7{\cdot}5 \geqslant$

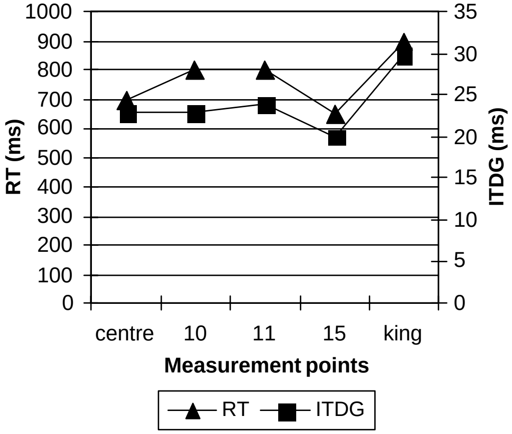

Figure 7. *ITDG* and *RT* of *Pendopo Mangkunegaran*.

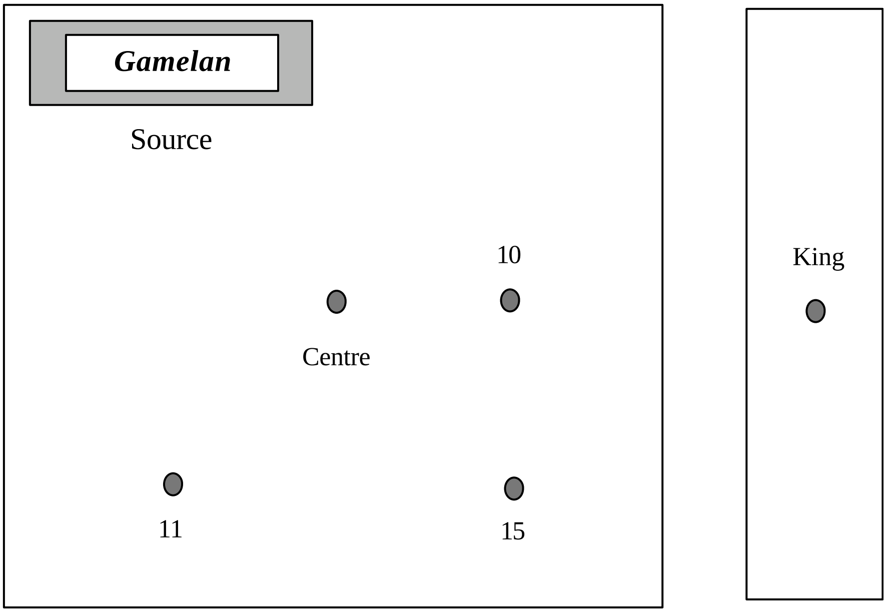

Figure 8. Measurement points in *Pendopo Mangkunegaran*.

Amplitude of source signals $\geqslant -7{\cdot}5$ [1], and $A = 1$,

$$\tau_p = \tau_e \quad \text{and} \quad [ITDG]p = \tau_e.$$

From the result of the preference value for a Javanese gamelan, the $[ITDG]_p = 24{\cdot}25$ ms, while the $\hat{o}_e = 27{\cdot}59$ ms, or that $[ITDG]_p \approx \hat{o}_e$ in this test.

These calculations show that the preference values of *ITDG* for the Javanese *gamelan* obtained by subjective testing agree with Ando's suggestion, which was developed originally for Western music. This finding also suggests that preferences of other parameters related to the *ITDG* are expected to be similar with the preference values for classical music in a common concert hall.

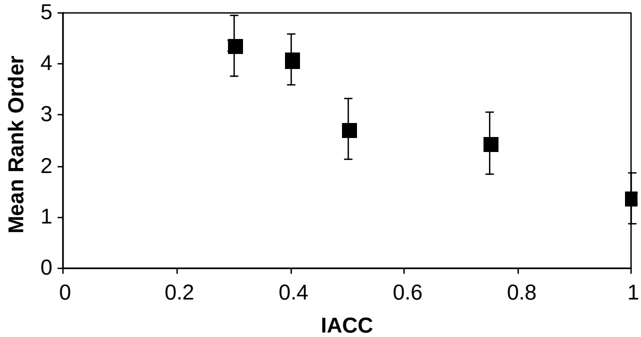

Figure 9. Preference for *IACC*.

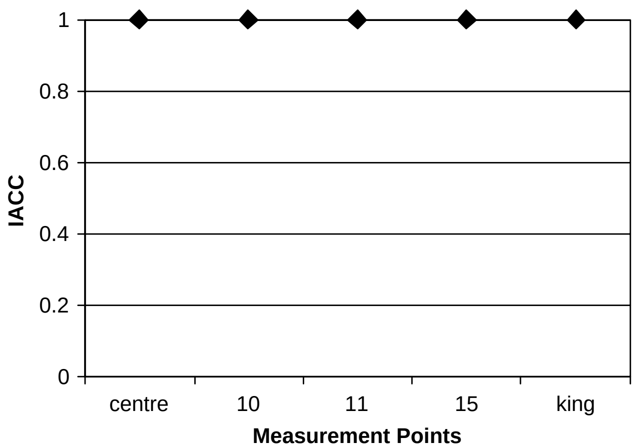

Figure 10. *IACC* of *Pendopo Mangkunegaran*.

Figure 9 shows that the lower the *IACC* the higher the subjective preference. This shows that a spaciousness and enveloping sound field is preferred for listening to Javanese *gamelan* in an enclosed hall. This finding is similar to those found in listening to classical music in a concert hall. However, this is not in agreement with the measured *IACC* of *pendopo Puro Mangkunegaran*, ($IACC = 1$) as it is an open-sided hall, as shown in Figure 10. The *IACC* of the *pendopo* may be improved by use of the ceiling and floor, since the *pendopo* has no walls. The optimization of ceiling shapes and floor surface may be useful. More measurements are needed to confirm this finding.

6. CONCLUSION

The preferred parameters for Javanese *gamelan* performance hall were 24·25 ms for *ITDG* and the smallest value of *IACC*. The preferred *ITDG* agrees with the ITDG from the room responses measured in a traditional *pendopo* in Indonesia, which is not a common concert hall but an open-sided hall. However the preferred *IACC* is not in agreement with the measured value, although the *IACC* of *pendopo* may be improved by use of the ceiling and floor. It is also shown that the preference of the *ITDG* confirmed Ando's suggestion in the case of Javanese gamelan music.

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