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Initial Time Delay Gap for Javanese Gamelan Music Concert Hall : An Auto-correlation Function Approach

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1. Introduction

Javanese *gamelan* is one of the Indonesian traditional music ensemble. Despite founded as an outdoor music, now a days it is mostly played indoor. A good indoor sound field design for performing the Javanese *gamelan* music, as an ensemble of its music pieces – simply called *gendhing* – or to accompany other performance like shadow puppets and dance, is needed.

By analysing the auto-correlation function of a *gendhing*, its effective duration (τ_e) can be obtained. According to Ando[1], by analysing τ_e of classical music and Japanese traditional music, the four orthogonal factors for designing concert hall can be determined. Those four factors are the listening level, the initial time delay gap (early reflection after direct sound), the subsequent reverberation time, and the Inter-Aural Cross-Correlation (IACC). This paper will only focussing on obtaining the preferred initial time delay gap for Javanese *gamelan gendhing* concert hall, using subjective preference judgement. The paired comparison method was used for the subjective preference testing.

1.1. Javanese Gamelan

Gamelan gets its name from the low Javanese word *gamel*, which refers to a type of hammer, like a blacksmith's hammer. The name '*gamelan*' actually refers only to the instruments themselves, which are pre-dominantly 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'.[2]

The bronze *gamelan* instruments are made from a mixture of tin and copper; three parts tin to ten parts copper. The word for '*gamelan*' in high Javanese is *gangsa*, a word in common Javanese etymology supposed to be formed from the two words ***tembaga*** (copper) and ***rejasa*** (tin), or from the numbers ***tiga*** (three) and ***sedasa*** (ten) expressing their proportions.

In a complete *gamelan* orchestra there are about twenty different types of instruments. However, the total number of instruments maybe as high as seventy-five, as there need to be at least two of most of the 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.

Unlike the Western concert tradition where traditionally the function of the orchestra is to accompany the voice, in the Javanese *gamelan* orchestra the singing is no more or less important than any other instrument; its function is yet another melodic layer in the overall structure of music. A piece of *gamelan* music is usually complete when the singing is present, but it is possible, and quite satisfying musically, to play the same piece without it.

1.2. Auto Correlation Function

The Auto Correlation Function (ACF) is defined as [1] :

$$\Phi(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} x(t)\,x(t+\tau)\,dt \qquad (1)$$

where :

τ	: time delay
T	: integration interval
x(t)	: time domain signal

Equation (1) shows that the ACF is a sum average of a product of a signal and its delay over a time interval 2T. Physically, this represent the correlation of a signal at a certain time x(t), with the same signal at $t+\tau$, $x(t+\tau)$. If signal x(t) and $x(t+\tau)$ are highly correlated, the amplitude of the ACF will be larger, and vice versa. In acoustics, the ACF is a measure of correlation between sound signal p(t) and $p(t+\tau)$.
If the delay time, $\tau = 0$ and x(t) = p(t), equation (1) become

$$\Phi(0) = \lim_{t\to\infty} \frac{1}{2T} \int_{-T}^{+T} p^2(t)\,dt \qquad (2)$$

It means that the ACF when the time delay equals to zero, $\Phi(0)$, is the intensity of the signal in time interval 2T. This is also the maximum value of the ACF amplitude. Therefore, the ACF is often normalised to $\Phi(0)$:

$$\phi(\tau) = \frac{\Phi(\tau)}{\Phi(0)} \qquad (3)$$

If sound signal p(t) reaches the human ears then processed by the auditory system, the ACF of the signal that is heard can be written as

$$\Phi(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} p'(t)\,p'(t+\tau)\,dt \qquad (4)$$

where $p'(t) = p(t)*s(t)$. The function s(t) is the ears sensitivity, and for practical convenience it is represented by an impulse response of A-weighted function.

The decay characteristic of the ACF becomes an important part in auto correlation analysis.[4] A parameter called effective duration is defined in terms of the decaying process. The effective duration of ACF, τ_e, is defined as the delay time at which the envelope of the normalized ACF becomes 0.1. This parameter has two important meanings:[5]

1. τ_e related to the bandwidth of the signal. The wider the bandwidth, the shorter the τ_e. As an illustration, τ_e of a white noise ≈ 0, and τ_e of pure tone (ideal sine) $\approx \infty$. Other types of sound signals will have τ_e value in between 0 and ∞.
2. τ_e is a measure of correlation

1.3. Subjective Preference

Subjective preference testing is carried out to obtain the preferred initial time delay for Javanese *gendhing* concert hall. The method used in the testing is paired comparison method. In this method, subjects are asked to choose which stimulus they preferred better than the other for every pair of stimulus. All stimuli have a specific characteristic from a parameter being observed. In each pair,

each stimulus becomes a standard. With n stimuli there will be ½n(n -1) pairs of stimuli. Subjects are not allowed to give equal judgement to each pair.

One of the special characteristics of paired comparison methods is that this method does not limited in data transitivity. Therefore, if in a measurement a subject preferred A stimulus than B stimulus and preferred B stimulus than C stimulus, it is possible to preferred C stimulus than A stimulus. It is useful for experiment with uncertainty of transitivity level.[5]

The next step of testing is to make a subjective preference scale which have the same interval thus the stimuli can be marked objectively. One of the methods to calculate scale value of stimuli is law of comparative judgment. This law is represented by equations which are associate subjective preference proportion to stimulus k compare with stimulus j for a physical parameter with scale value and discriminal dispersion of each stimulus k and j in a psychological continuum.[5]

2. Data Collection

2.1 Sample Selection

The Javanese *Gamelan* music pieces - *Gendhing* - in a CD format was played using CD player which was connected to personal computer (PC) through a sound card. Samples were made using of 16 bit data width, mono with 44.1 kHz sampling rate, 6 seconds of length, and were recorded in a RIFF WAV format.

The effective duration of ACF of those samples was computed using Auto Correlation Function Analysis software developed under MATLAB 5.1. The integration interval for all samples was 200 ms. Sample with the shortest effective duration is chosen for subjective experiment.[1]

2.2 Subjective Preference Testing Configuration

Eleven subjects were involved in the subjective preference testing. Two loudspeakers were used in the testing, one speaker producing direct sound and the other one for first reflection. The direct sound loudspeaker is placed in front of the subject and the reflection sound loudspeaker is placed at 35° CW as it is shown in figure 1. The amplitude different of direct sound and reflection sound was set to 3 dBA. This configuration will produce IACC around 0.5. The level of listening was set to 78 - 79 dBA in average.

There were 4 (four) different stimulus, each of them has initial time delay 25, 50, 100, and 200 ms, respectively. These stimuli were presented in pair, thus there were 6 pairs presented to each subject. Each pair of stimuli was presented 20 times for every subject.

3. Results and Discussion

3.1 Sample Selection

Some samples of Javanese *gamelan gendhing* were analysed to choose a single sample for subjective preference testing. All the samples are classified as a fast type *gendhing*. It is expected that they all have a short effective duration of ACF or have a wide Bandwidth. They are considered to be representative of all other types of Javanese *gamelan gendhing*. The fastest *gendhing*, in this case with the shortest τ_e, was chosen as the sample for subjective preference testing measurement.

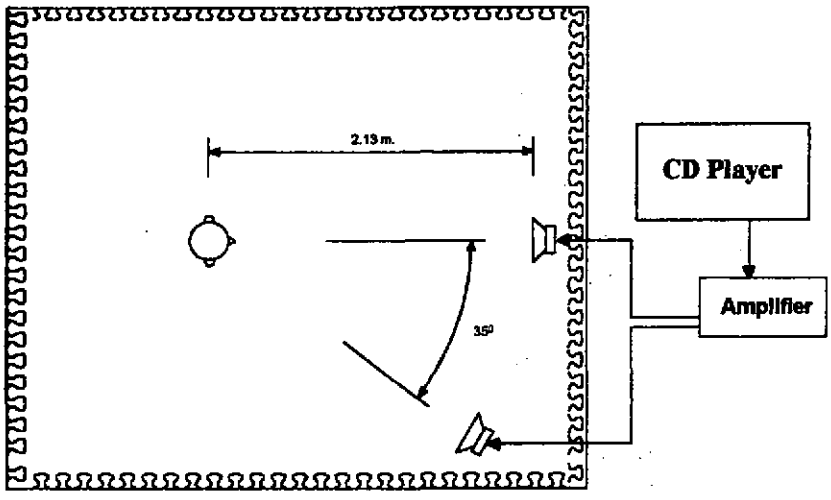

Figure 1. Experiment Configuration

Based on equations (1) to (4), the ACF for all samples was computed using integration interval 200 ms. This integration interval value was chosen to get the best fined structure of ACF of samples. With 200 ms integration interval, each sample was divided into 30 time frames. The τ_e of each sample was determined from the minimum effective duration of all time frames.

By looking at the delay time in which the amplitude of the ACF envelope become 10% of its amplitude at zero delay time, the effective duration of ACF of each samples can be obtained. Since the samples are music pieces, - not white noise signal nor pure tone -, the effective duration of its ACF would be in between 0 and infinity. The ACF of *Sampakan* part of *Ranjapan Abimanyu Gugur* has the shortest effective duration. This *gendhing* has effective duration of 48.75 ms as it is shown in figure 2. With a similar research using western classical music as sound samples, Ando et al [1, 3] have found that for the fast type music, called music motif B, from *Sinfonietta Opus 48 III Movement* composed by Arnold, the effective duration of ACF was 40 ms.

The *gendhing* from *Sampakan* part of *Ranjapan Abimanyu Gugur* with τ_e = 48.75 ms at interval 200 ms, was used for the subjective testing to determine the preferred initial time delay and subsequent reverberation time. From those two parameters, the preferred dimension (surface area and volume) of a room for performing the Javanese *gamelan* music, can be obtain.[1]
The decay characteristics of ACF, τ_e, has a close relation with the subjective listening to the total sound field. According to Ando's result [1, 3], τ_e can be used to determine two important parameters for designing acoustics condition in a room, that is the preferred time delay of first reflection related to the direct sound (Δt_1) and the subsequent reverberation time (T_{sub}), according to the following relationships :

$$\left[\Delta t_1\right]_p = \tau_e \qquad (5)$$

$$\left[T_{sub}\right]_p = 23\,\tau_e \qquad (6)$$

The delay time of first reflection or initial time delay gap plays an important role in subjective qualities of room acoustics. One of the qualities, intimacy, is influenced by initial delay time gap and listening level.[7] Intimacy is an identification level, which is sensed by the audience while listening to music. This intimacy is related to the perception of audience to room dimension where music is played. Music can be heard intimately if the audience feel close to the music, and perceiving that

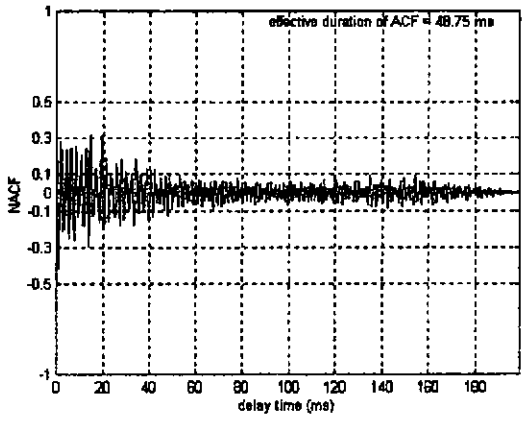

Figure 2. ACF of *Sampakan* Part of *Ranjapan Abimanyu Gugur*

the music played in a "small" room. Therefore, the room should be properly design for such a particular music.

3.2 Subjective Preference Judgement

Five Indonesian students were involved in the subjective testing. All of them are familiar with the music. The scale value of their preference is shown in figure 3. It can be seen that all of them preferred the smallest initial time delay. Their preference slightly increasing at the initial time delay longer than 100 ms. Since there only two loudspeaker were used in the testing configuration, the

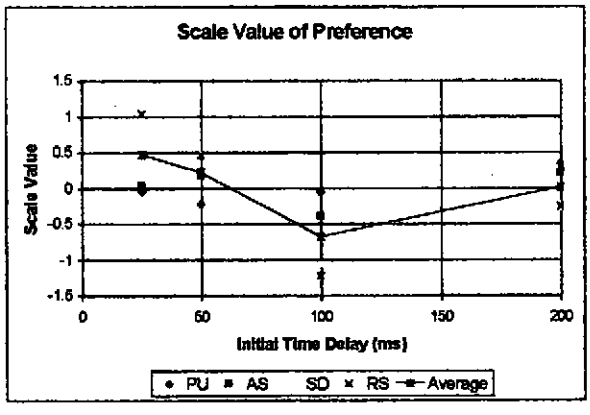

Figure 3. Scale value of preference of 4 (four) Indonesian Subject

longer the initial time delay gap, the spatial effect, such a stereo effect and image shift, exist. According to the interview with the subjects, this effect sometimes influenced the judgement. The influence is sometimes positive and some other times negative. Positive influence mean that the subject prefer longer initial time delay, since they heard the music has wideness or they perceive the music played in outdoor environment.

To assure the subjects consistence, analysis of variance (ANOVA) has been carried out. The ANOVA result can be seen in table 1 below. It is shown that all the subject have clearly distinguished all the presented pair of stimuli. Two of the subjects also asked to do subjective preference testing using other music source, Balinese *gamelan* music pieces. The scale value of preference of this testing is shown in figure 4. It can be seen that all the subjects preferred longer initial time delay gap for this type of music. This result is consistent with the similar testing result

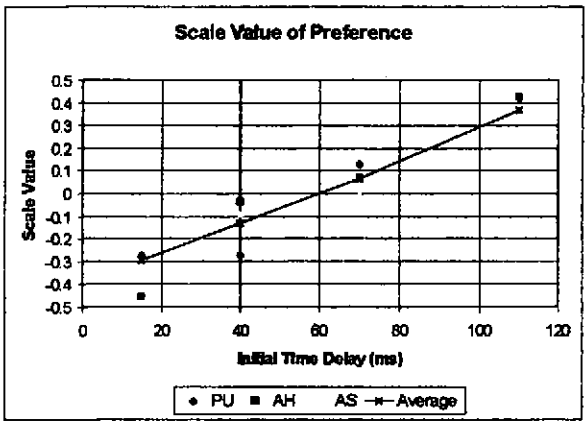

Figure 4. Scale value of preference of 3 (three) subjects.

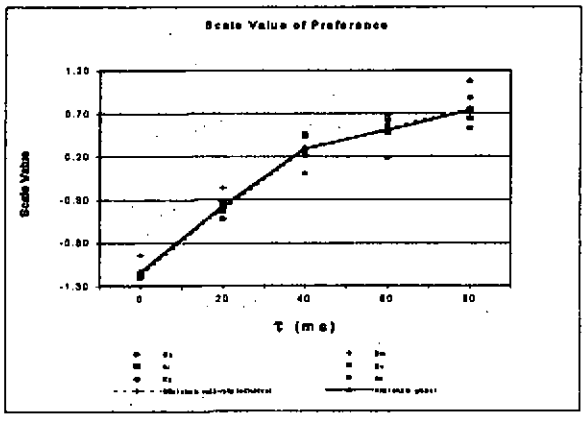

Figure 5. Similar testing result of 6 (six) subjects in Indonesia[8]

conducted in Indonesia[8], as shown in figure 5.

Since these two music pieces are played using two different instruments, it can be physically heard that these two music pieces are different. By analysing them using ACF approach, it is found that their effective durations are almost the same. The Javanese *gendhing* has τ_e = 48.75 ms, while the Balinese one 49.41 ms. According to Ando result using a fast type classical music[1], the preference to both of them should be similar. But, as it is shown in figure 3 and 4, the preference are opposite to each other. It means that the ACF approach might not be suitable to these kinds of music.

Table 1. ANOVA of subjective preference testing

Pair	*F*	*P-value*	Significance Difference
25 - 50	1.4636	2.7185E-01	72.82%
25 - 100	21.8968	3.3980E-03	99.66%
25 - 200	5.1203	6.4300E-02	93.57%
50 - 100	20.0727	4.1912E-03	99.58%
50 - 200	2.1064	1.9688E-01	80.31%
100 - 200	12.1868	1.2968E-02	98.70%

4. Variation of Testing

Some non-Indonesian students have also been involved in the subjective preference testing. From 6 subjects involved, 2 of them have similar preference of what Indonesian subject did, but 4 (four) of them have opposite preference. The scale value of preference of these subjects is shown in figure 7 and 8.

Besides the possible effect of testing configuration, there is one important parameter that should be considered here. It is the fact that all the non-Indonesian subjects never heard the music before. Thus, when they asked to make judgement to the stimuli, their preference to the music itself might become more dominant rather than to the sound field condition of the music.

To validate these results, more subjective preference testing will be conducted, with some changes on the testing configuration and parameter involved.

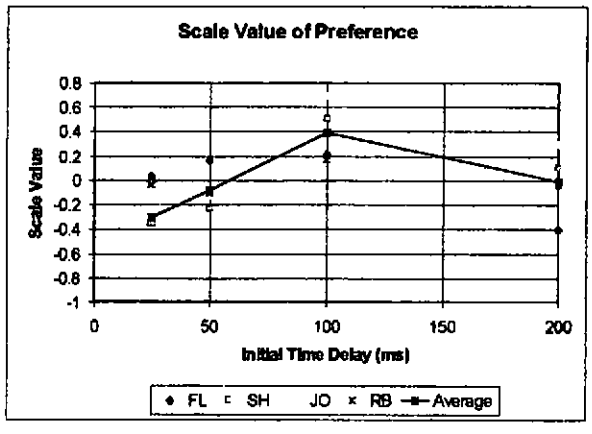

Figure 7. Scale value of preference of 4 (four) non-Indonesian subjects

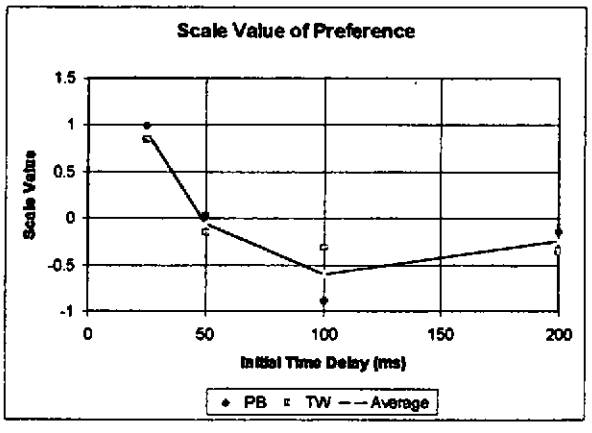

Figure 8. Scale value of preference of 2 (two) non-Indonesian subjects

5. Conclusion

It was found that the ACF of the *Sampakan* part of shadow puppet performance *Ranjapan Abimanyu Gugur*, has the shortest effective duration, that is 48.75 ms, and was used as sample for subjective preference testing.

The subjective preference testing shown that all the Indonesian subjects and two non-Indonesian subjects preferred shorter initial time delay gap, while four non-Indonesian subjects preferred 100 ms. It still need more subjective preference testing to confirm or disprove equations (5) and (6) in the context of *gamelan* music.

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