Improvement of Soundscapes Based on Noise Control in Urban Forest as an Effort to Fulfill Quality of Green Open Space Standards

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Abstract: Urban forests play an important role in green open spaces. Urban forests have aesthetic functions and social functions that refer to the quality standards. Urban noise causes city forest soundscapes to be less comfortable and less aesthetic so that its function as a green open space is not fulfilled. This study aims to improve the quality of sound in urban forests (soundscape) based on the quality of green open space standards through noise control and find out the type of improvement most preferred by visitors. The quality of standard of green open space is pursued through sound masking, active noise cancellation, and convolution in sound signal conditioning. The convoluted sound signal is traffic noise with a convolved signal in the form of bird noise, water rush, and relaxation music. From the results of the improvement of the sound signal then tested on 30 respondents through a comparison test method. The subjective acoustic parameters of the environment are identified, which includes the value of the autocorrelation function (τ_1, ϕ_1) and dynamic range (D_R). Efforts to improve the quality of acoustics based on the quality of green open space the most preferred by respondents were sound masking and ANC with birdsong with successive scores 4.44 and 2.78. The results of identification of traffic noise treated by ANC and sound masking with songbird obtained values D_R = 32.35 dBA, τ_1 = 0.73 s, and ϕ_1 = 0.03. These parameters describe these sounds tend to be preferred because the human ear is more sensitive with high pitch and D_R.

Keywords: Noise; Noise control; Sound masking; Pshycoacoustics test

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I. INTRODUCTION

Noise is defined as unwanted noise that arises from certain activities and has the potential to cause hearing loss. Meanwhile, the sound is defined as varying pressure that propagates in the medium so that it reaches the human ear [1]. In urban areas, one of the causes of noise in population activity is traffic, industry, offices, and so on. The noise can have a bad influence on human health and activities. It has a negative impact on human health, such as sleep disturbances and cardiovascular disease [2]]. In order not to reduce the visual aspect (aesthetics), one of the efforts to control noise is through building barriers in the form of vegetation in the landscape or often called urban forests. The existence of urban forests is inseparable from environmental problems, such as noise caused by traffic noise and other urban activities. According to Kepmen-LH 48/MENLH/1996 concerning Noise Level Standards, the standard quality of green open space noise is set at 50 dBA. The impact of urban noise causes a negative soundscape for individuals and causes the shifting of urban forests from their ecological and social functions. Based on this, it is necessary to make efforts to control noise to traffic noise and other urban activities to create better soundscapes based on the quality of the standards and individual perspectives. The term soundscape is used to describe a person's perception of the environment they occupy. To be able to describe the state of the environment through various physical attributes [3]. Understanding soundscape includes objectively sound composition and factors that influence whether soundscape brings about positive or negative perceptions. These perceptions can be identified with certain parameters to determine the improvements that will be made. The several parameters that must be considered in soundscape are frequency patterns, temporal patterns, spatial patterns, and interactions [4]. These patterns can be obtained from environmental acoustic parameters consisting of objective parameters and subjective parameters that describe the characteristics of soundscape. If these characteristics give rise to negative perceptions, then certain methods need to be improved.

The handling effort ever offered to overcome the problem of noise is the application of sound absorption and noise barrier technology. However, it is considered ineffective and difficult to do in noise conditions due to complex sound sources, such as urban noise. This happens because urban noise has variable frequency content and fluctuating levels, so it will be difficult to find material specifications that act as passive noise control. Another alternative that can be done is by other active noise control methods, such as ANC (active noise cancellation), convolution and sound masking. ANC is an effort to eliminate unwanted noise from the environment. ANC is done

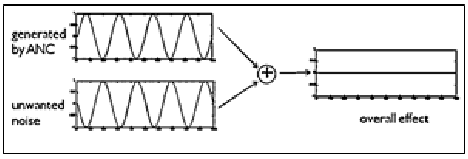

FIG. 1: Signal cancellation of two waves with different phases 180°.

by generating noise that is identical to the noise that arises. Then through some calculations, the noise is produced in the opposite phase. This condition allows for the cancellation of unwanted signals or noise [5]. The concept of noise cancellation in ANC depends on the principle of superposition of waves. The work scheme for the occurrence of ANC can be seen in Fig. 1.

Based on Fig. 1, noise cancellation is done by generating an identical signal as a secondary sound source. The two coherent signals will interact so that there is a mutually attenuating wave interference or referred to as destructive interference. This process can reduce noise levels in large enough quantities. However, after canceling the signal residual noise is still found. So, to get the optimal signal cancellation result, further identification of the main sound source is needed [6].

Sound masking is done to cover up unwanted sounds. Besides, sound masking also aims to give a more comfortable impression to the listener and give satisfaction to the environment [7]. Sound masking can be applied for various purposes, one of which is on an urban landscape. In contrast to other noise control methods, sound masking is more dynamic for the sound to be covered. Sound masking is able to adapt to sound objects that have varying levels and fluctuate with time. In addition, the sound masking working area is focused on the listener's ear and is not affected acoustically by the structure of the building [8].

Sound convolution is a method that combines two audio sources in certain parts proportionally. In general, convolution is carried out in the frequency domain and simply, convolution can be described mathematically in the following Eq. 1.

$$y\left(n\right) = x\left(n\right) * h\left(n\right) = \sum_{k=-\propto}^{\propto} x\left(k\right) * h\left(n-k\right) \qquad (1)$$

where $y(n)$ is the output signal, $x(n)$ is the input signal, and $h(n)$ is an impulse signal that acts as a convolution. If $x(n)$ is a signal with length N, *i.e.* from 0 to N-1, and $h(n)$ is a signal with length M (from 0 to M-1), then convolution of $x(n)$ and $h(n)$ results $y(n)$ with length N + M-1, from 0 to N + M-2. Based on Eq. 1, convolution is carried out in the form of a frequency domain. One of the methods used in convolution is the Fast Fourier Transform (FFT) which starts with the transformation of the input signal into the frequency domain. Then the result will be multiplied by the convoler signal to produce an output signal. This output signal will be returned in the time domain [9].

Sound characteristics of the improved results can be reviewed with several environmental acoustic parameters, namely ACF (autocorrelation function). These parameters are related to temporal, spectral, and spatial aspects that describe the different time signals arrive at the two ears. The τ_1 is defined as the first time delay, while ϕ_1 is defined as the amplitude of the first peak. ACF is obtained from the geometric mean of energy at the time s and s+τ. So the ACF value is in the range 0≤ $\phi_{(11)}(\tau)$ ≤1. The ACF parameter gives a physical meaning that, the higher the value $\phi(\tau)$, the stronger the pitch and the higher τ, the lower the pitch [10]. Another subjective parameter used is related to the sound level, namely D_R (Dynamic Range). These parameters represent the maximum difference from SPL (L_{max}-L_{min}). D_R parameters used in fluctuating sound signals can be used to predict the perception of urban soundscape [11]. The subject acceptance category for sound level changes can be seen in Table I.

TABLE I: Subject acceptance of sound level changes

Changes in Sound Level (dB)	Subject Acceptance
6	Barely perceptible
10	Clear perceptible
20	Twice louder
40	Very louder

Based on Table I, subject acceptance is influenced by changes in sound level. The greater the change in sound level, the difference felt by the subject becomes clearer. This also applies to the DR parameters used to predict subjective perceptions of soundscape [12]. Jin Yong Jeon and Joo Young Hong (2015) classifying city park soundscapes based on the perception of environmental acoustics in three different city parks. Data were collected using soundwalk and questionnaire methods, while data analysis was carried out using Hierarchy Cluster Analysis which classified the soundscape into three parts, namely, natural sound, human sound, and traffic noise. Meanwhile, Tanoni *et al* (2018) conducted a soundscape mapping in Surabaya's Bungkul Park using the auditory perception of blind disability as a reference to auditing the quality of city parks audibly. The result is the need for the addition of the sound of the fountain as an element that makes it comfortable. This paper discusses efforts to create a positive soundscape in urban areas through noise control with active noise control, in the form of ANC (active noise cancellation), sound masking, and convolution. The results of improved soundscapes are objectively and subjectively characterized. Objective characterization is done by autocorrelation function and dynamic range parameters, while subjective characterization is obtained based on individual perspectives through questionnaires.

II. METHOD

A. Soundscape Measurement

Spectral patterns, temporal patterns, and spatial patterns in soundscape can be obtained through measurements of environmental acoustic parameters consisting of objective parameters and subjective parameters referring to ISO 1996/1. Mea-

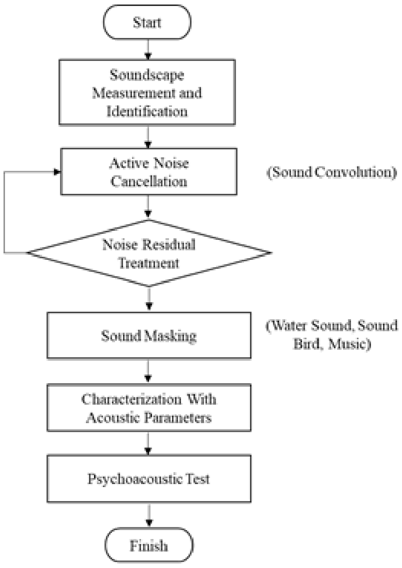

FIG. 2: Flowchart of Noise Control Methods with ANC and Sound Masking.

surements were made to obtain L$_{Eq}$, D_R and ACF sound levels. L$_{Eq}$ measurements are carried out using a Sound Level Meter whose height is adjusted by the height approach of the human ear. ACF analysis is done through field recording at the soundwalk using the H1 microphone with an identical position to the human ear. The recording results are then processed and calculated using the Realtime Analyzer and Sound Analyzing System. ACF in soundscape contains psychoacoustic elements that are used in evaluating sound quality especially based on green open space standards. While the DR is obtained by calculating the difference between L_{max} and L_{min} to find out the sound dynamics.

B. Soundscape Improvements

As stated in Part I, efforts to control noise in this research are ANC (active noise cancellation), convolution, and sound masking. Figure 2 shows the stages in carrying out noise control in this study.

Based on Fig. 2, acoustic improvements will be made based on the results of measurements and soundscape identification. Improvements will be made to the sample of the soundscape that respondents dislike the most. There are two methods namely, active noise cancellation (ANC) and sound masking. ANC is carried out by the convolution method using a single frequency such as Eq. 1. In this step there is residual noise that must be minimized. To obtain optimal results, sound disguises are made with natural sounds, such as birdsong, gurgling water, and relaxing music. The ratio of masking sound level to soundscape is set with a difference of 3 to 5 dBA. This is because the change in the character of the new sound can be felt by listeners with a difference of at least 3 dB. Meanwhile, soundmasking failure can occur if the soundscape cannot be covered up and can still be heard clearly. While the failure of ANC is the emergence of residual sound due to an imperfect process. The combined method aims to provide optimal repair results and complement each other from the two methods. The results of these improvements are then characterized using acoustic parameters. To get the perception of the results of the improvement of the soundscape, psychoacoustic tests were carried out on 30 respondents.

The improvement in soundscape quality was assessed using a psychoacoustic test using a comparison test method for the winding signal. In this method, the respondent (listener) hears a pair of sounds and then chooses the one he feels is most appropriate (comfortable). Through this method, it can be seen that the voice that has the highest score is the voice that is most preferred by the respondent. The sound source tested came from a Lenovo PC IP-330 and the respondents listened with Sennheiser headphones. A pair of sounds will be selected in a combination of water sounds, birdsong and relaxation music. The sound source tested came from a Lenovo PC IP-330 and respondents listened with the Sennheiser headphone. Sound pairs will be chosen in combination from the sound of water, birds chirping, and relaxation music. From each sound installation can be calculated the distribution of preference values (S$_{i(k)}$) with the Eq. 2.

$$S_{i(k)} = \sqrt{2\pi}\left(P_{i(k)} - 0.5\right); i = 1, 2, 3 \quad (2)$$

where i is the type of sound being tested and k is the number of respondents who gave an assessment. Then the probability value given by the respondent ($P_{i(k)}$) can be calculated by the Eq. 3.

$$P_{i(k)} = \frac{1}{M}\sum_{j=1}^{M} Y_{ij(k)}; i, j = 1, 2, 3 \quad (3)$$

where M is the number of sounds tested on each respondent [13]. Comparison test conducted on 30 people aims to get the sound composition of the respondents most liked. The composition can be known through the scores obtained.

III. RESULTS AND DISCUSSION

A. Objective Identification

Measurement of L_{Aeq} parameters and field recording on five routes are done by soundwalk. The visualization of the intended routes can be seen in Fig. 3.

Refers to Fig. 3, the measurement results on routes that include L_{Aeq}, τ_1, ϕ_1, and D_R values can be seen in Table II.

Based on Table II, the L_{Aeq} measurement results on all routes show a sound level that exceeds the threshold of green open space noise by 50 dBA. It can also be seen that route A has the highest sound level compared to other routes. This is caused by the position of route A which is close to the dominant source, namely traffic noise. The dominance of traffic noise also occurs on route C so that the characters are almost

FIG. 3: Soundwalk route: (a) Route A, (b) Route B, (c) Route C, (d) Route D, (e) Route E (source: personal collection).

TABLE II: Soundscape measurement results with environmental acoustic parameters. WIT: West Indonesian Time.

Route	Time	L_{Aeq} (dBA)	τ_1(s)	ϕ_1()	D_R (dB)	Score
A	16.00 - 17.00 WIT	62.87	2.79	0.39	7.8	-0.75
B		57.79	2.9	0.02	10.5	1.67
C		58.08	1.36	0.63	8.3	-
D		57.24	2.97	0.3	9.3	5.83
E		55.71	2.49	0.31	10.8	-

the same as route A. It can also be seen that the parameter values of routes D and E are close to each other so that the characters can be said to be similar. In this regard, routes C and E are eliminated at the respondent subjectivity testing stage.

In subjective testing, the number of respondents who assessed through the comparison test was 30 respondents. The comparison test results can be seen based on the scores in Table II. Thus it can be seen that the type of original sound that most respondents disliked is route A. This is indicated by a lower score than the other route. When viewed from its equivalent sound level, the route has the highest sound level. Other parameters measured are ACF and D_R to predict how someone's perception of soundscape. Route A has τ_1 which is lower than other routes. This shows that route A has a relatively shorter delay time and has a higher pitch. This condition causes the sound of route A to tend to be preferred because the human ear is more sensitive with a higher pitch. For parameter $\phi(1)$, this route (route A) is positive, which indicates the sound source is coming from the right direction. The direction is the position of the dominant sound source, namely traffic on one-way streets that cross from the right to left to the H1 microphone position. As for the D_R parameter, the greater the D_R value, the sound is said to be more dynamic. The amount of change in sound level will affect subjective reception. Thus, this parameter can be used to predict the subject's perception of soundscape. Whereas continuous sound indicates a relatively lower dynamic range, such as route A with single dominance by continuous traffic noise [14].

B. Signal Control Based Acoustic Improvements

The high intensity of the sound caused by traffic noise makes acoustically reduced comfort in Joyoboyo Forest. For this reason, noise control in this study is focused on traffic noise signals. ANC control is done by generating the same

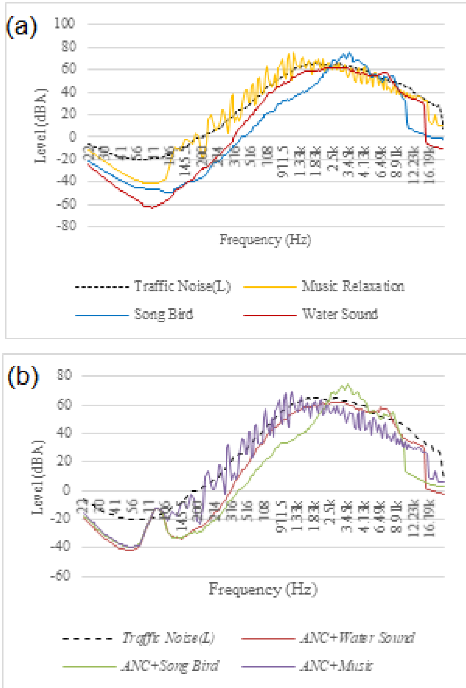

FIG. 4: Characteristic of traffic noise improvements result: (a) sound masking and (b) sound masking + ANC.

new sound signal, but the phase is reversed with the first sound signal. The two sound signals combine to form a new sound signal and cancel each other out due to destructive interference. However, in the final results of the process, there are still residual sounds as a byproduct. After the ANC, sound masking is carried out as an effort to improve sound quality with an easy method by combining masking signals to traffic noise in the time domain. In this study, sound masking was performed using song bird, gurgling water, and relaxation music. Based on the experiments that have been carried out, sound masking cannot cover overall traffic noise. This is caused by sound levels that fluctuate with frequency. Following this, a joint formula was carried out to optimize noise control in traffic noise, namely sound masking and ANC. The ANC method will cancel the traffic noise signal, but a residual sound with a lower level still occurs. Furthermore, the residual sound will be covered by sound masking using the other sounds mentioned earlier. Thus, the results of noise control will be optimized. The

TABLE III: Sound pair in the comparison test.

Sound Pair	Mask
1.2	(1) : Water sound
1.3	(2) : Song Bird
2.3	(3) : Relaxation Music

TABLE IV: Result of soundscape improvement.

Masking	τ_1(s)	$\phi_1(\tau)$	D_R (dB)	Skor	Masking+ANC	τ_1(s)	$\phi_1(\tau)$	D_R (dB)	Skor
Water sound (1)	5.33	0.59	11.96	0.61	Water sound (1)	1.9	0.04	10	-0.22
Song Bird (2)	4.1	0.69	23.25	4.44	Song Bird (2)	0.73	0.03	32.35	2.78
Music relaxation (3)	0.73	0.5	8.18	1.67	Music relaxation (3)	6.05	0.51	6.86	-0.56

results of the engineering of sound control can be seen in Fig. 4.

In Fig. 4b, it can be seen that the masking closure of the traffic noise sounds is more significant than before the ANC performed on the sound as Fig. 4a. The ANC method can reduce the sound level with residuals that will be covered by masking. Decreasing the sound level can benefit the sound masking process because the traffic noise level is lower. Benchmark of the success of the results of soundscape improvements can be seen in several objective parameters and also subjective parameters. The effort to get subjective parameter values is done through a comparison test, which is to choose one of each sound pair listed in Table III.

From the tests conducted in Table III, certain scores of each type of sound were obtained based on the subjective preferences of the respondents. The score results and objective parameters of the sound improvement results can be seen in Table IV.

Based on Table IV, the results of sound quality improvement are identified by several parameters. The higher the value $\phi(\tau)$, the stronger the pitch, but the higher the value τ results in decreased pitch. While the dynamics of the songbird are high enough to make the subject feel the change in sound level very clearly. This can be seen from the D_R value. Also, when viewed from the parameter τ_1 the results of the improvement of sound with ANC and birdsong have a higher pitch than other sounds. From the subjective test results as in Table IV, the highest score is owned by the type of birds singing masks. So that traffic noise engineered with bird song is considered by respondents as the most comfortable sound composition, both before and after ANC. This can be seen from the relatively short value of τ_1, so it has a high pitch. This shows the characteristics of bird sounds tend to be preferred by respondents because the human ear is more sensitive to high pitch and this also applies to other sounds. Besides, engineering carried out by bird song has a fairly large D_R, which is > 20 dB. The magnitude of these changes affects the subject's acceptance of sound engineering results. A change of 20 dB defines that the songbird is twice as loud as the sound of traffic noise.

IV. SUMMARY

The improvement of quality of acoustics based on the quality of green open space standards can be done with ANC, sound masking, and convolution. The result most preferred by respondents were sound masking and ANC with birdsong with scores of 4.44 and 2.78, respectively. The dentification results on traffic noise treated by ANC and sound masking with birds chirping were obtained D_R values = 32.35 dB, τ_1 = 0.73 s, and ϕ_1 = 0.03. Meeting the quality of green open space standards in Joyoboyo Forest can be done by reducing noise, especially traffic noise. Besides, it also requires the addition of elements that can create natural nuances, such as fountains and bird song.

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