The Development of a Web-Based Urban Soundscape Evaluation System

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Abstract. Acoustic quality is one of the important aspects of urban design. It is usually evaluated based on how loud the urban environment is. However, this approach does not consider people's perception of the urban acoustic environment. Therefore, a different method has been developed based on the perception of the acoustic environment using the concept of soundscape.

Soundscape is defined as the acoustic environment perceived by people who are part of the environment. This approach considers the relationship between the sound source, the environment, and the people. The analysis of soundscape considers many aspects such as cultural aspects, people's expectations, people's experience of space, and social aspects. Soundscape affects many aspects of human life such as culture, health, and the quality of life.

Urban soundscape management and planning must be integrated with the other aspect of urban design, both in the design and the improvement stages. The soundscape concept seeks to make the acoustic environment as pleasant as possible in a space with or without uncomfortable sound sources. Soundscape planning includes the design of physical features to achieve a positive perceptual outcome. It is vital to gather data regarding the relationship between humans and the components of a soundscape, e.g., sound sources, features of the physical environment, the functions of a space, and the expectation of the sound source. The data can be measured and gathered using several soundscape evaluation methods. Soundscape evaluation is usually conducted using in-situ surveys and laboratory experiments using a multi-speaker system. Although these methods have been validated and are widely used in soundscape analysis, there are some limitations in the application. The in-situ survey needs to be done at one time with many people at the same time because it is hard to replicate the acoustic environment. Conversely, the laboratory experiment does not have a problem with the repetition of the experiment. This method requires a room with a multi-speaker reproduction system. This project used a different method to analyse soundscape developed using headphones via the internet. The internet system for data gathering has been established; a website has enabled to reproduce high-quality audio and it has a system to design online questionnaires. Furthermore, the development of a virtual reality system allows the reproduction of virtual audio-visual stimulus on a website. Although the website has an established system to gather the required data, the problem is the validation of the reproduction system for soundscape analysis, which needs to be done with consideration of several factors: the suitable recording system, the effect of headphone variation, the calibration of the system, and the perception result from internet-based acoustic environment reproduction. This study aims to develop and validate a web-based urban soundscape evaluation method. By using this method, the experiment can be repeated easily and data can be gathered from many respondents. Furthermore, the simplicity of the system allows for the application by the

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stakeholders in urban design. The data gathered from this system is important for the design of an urban area with consideration of the acoustic aspects.

1. The soundscape concept to evaluate the urban sonic environment

City planners have developed many concepts to create adequate urban areas, which mainly focused on the visual aspect [1]. The acoustic aspect is usually neglected by urban designers although it has an important role in shaping the environmental quality of a city [2]. Furthermore, the analysis of the acoustic aspect only considers the negative aspects of sound as represented by noise [3].

The aspect of sound has become an important issue in city development [4]. ITU-T-FG-SSC has defined the Smart Sustainable City as "A Smart Sustainable City is an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life; efficiency of urban operation and services; and competitiveness; while ensuring that it meets the needs of present and future generations with respect to economic; social; environmental as well as cultural aspects" [5]. The aspect of the sound environment is important in three elements of the definition of the Smart Sustainable City: social, environmental, and cultural.

The Smart Sustainable City is explained in detail using six dimensions: Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, and Smart Living [6]. The dimension of the smart environment includes four characteristics: attractivity of natural conditions, pollution, environmental protection, and sustainable resource management. In here, the sound environment aspect is related to the noise pollution of a city and the environmental protection.

The dimension of smart living also highly relates to the acoustic aspect. It has seven characteristics: cultural facilities, health conditions, individual safety, housing quality, education facilities, tourist attractivity, and social cohesion. The study by Berglund shows the effect of soundscape on human health [7]. The soundscape also affects the tourist attractivity of urban parks [8][9] and the other tourist attractions [10].

The urban sonic environment is usually evaluated using the concept of noise measurement. This concept relies on sound level measurement and comparing the result to the available standard. If the sound level exceeds the standard than the noise must be reduced regardless the sound source as shown in Figure 1.

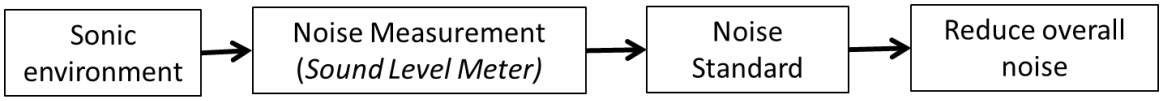


Figure 1. Sonic environment management based on noise measurement

The Indonesian government has developed some policy regarding the level of permissible noise in different areas. The Indonesian Ministry of Environment and Forestry has a policy for noise standards according to KEP-48/MENLH/11/1996 as shown in Table 1.

Table 1. Noise Standards according to the Indonesian Ministry of Environment and Forestry

Area	Noise Level (dBA)
Residential Area	55
Commerce and Services	70
Office and Trading	65
Green Open Space	50
Industry	70
Government and Public Facility	60
Recreation	70
Port	70
Cultural Heritage	60
Hospital	55
Schools and Education Facilities	55

Area	Noise Level (dBA)
Place of Worship	55

The standards seek to establish quiet places, which is considered a better sonic environment. A problem arises from the standard, namely that most areas in Indonesia exceed the noise standards and people still doing their activities there.

The standards and the noise measurement concept only consider the noise level with no consideration of how the people who use the space perceive the sonic environment. The noise control of a noisy space is focused on reducing the overall sound level [11], although it is found that the noise level does not necessarily affect the perception of a space [12] [13]. The perception of a space is affected by the subjective preference of sound sources rather than only the sound level [14].

Soundscape is a different approach to analysing the sonic environment by considering the human perception. Soundscape is defined as the "acoustic environment as perceived or experienced and/or understood by people, in context" and the acoustic environment is defined as "sound from all sound sources as modified by the environment" [15]. The concept tries to integrate three aspects in the analysis: people's perception, sound source, and the environment, as shown in Figure 2.

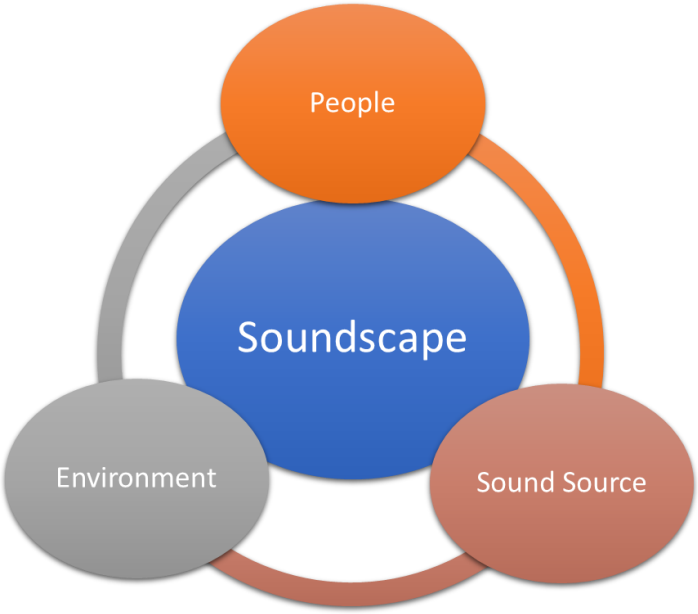


Figure 2. Three Aspects of Soundscapes

The soundscape concept mainly applies to the urban soundscape [16–18] and it must be implemented in the design stage and for urban sonic environment treatment [19]. The concept tries to understand the positive aspects of the sonic environment, not only the negative aspects and noise [20]. The soundscape approach conducts the treatment of the sonic environment in two ways: reducing the negative sound and adding positive sound.

The soundscape approach tries to analyse the sonic environment by focusing on how people perceive the sonic environment, not only based on noise measurement [21]. Table 2 presents the differences between noise management based on noise measurement and the soundscape concept.

Table 2. Sonic environment management based on the noise concept and the soundscape concept

Sonic environment management based on the noise concept	**Sonic environment management based on the soundscape concept**
The evaluation result is generalized for similar functions of space	The evaluation result cannot be generalized for similar functions of space
Based on noise measurement	Based on perception evaluation

All sound sources contribute to the overall noise	The sound sources are categorised into positive and negative sound sources
Managed by reducing the overall sound level	Managed by reducing the negative sound sources or masking the sonic environment using positive sound sources

2. Soundscape analysis method

According to Aletta et al., the method of analysing soundscape can be divided into based on three approaches as shown in Figure 3: in-situ experiment, laboratory experiment, and recalled in memory.

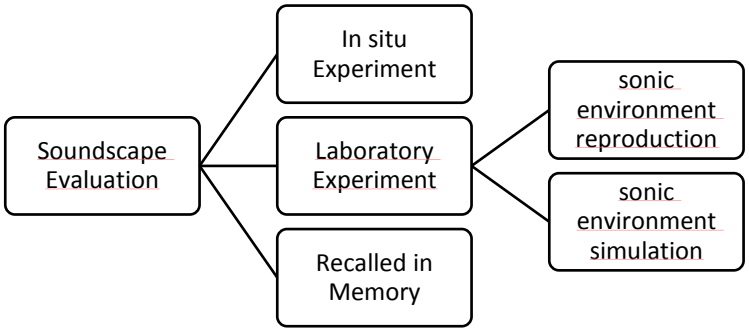


Figure 3 Soundscape evaluation method according to Aletta et al [22]

The in-situ experiment usually comprises three methods: behavioural observation [23], soundwalk [24–27], and narrative interview [21,28]. The soundwalk is an empirical method used to identify a soundscape and its sound objects in-situ [14]. Figure 4 shows a snapshot of the soundwalk. Although the in-situ experiment is one of the most common methods to analyse the urban soundscape, this method has the issue of repeating the experiment. Semidor suggested that a soundwalk should be conducted more than once, in order to minimise the temporal change effect [25]. Time effects are an important aspect of soundwalks since soundscapes are always changing. The in-situ experiment also needs to be done in a group with a limited number of participants. Another problem with the in-situ experiment is the limited variation of the sonic environment, making it difficult to model the interaction between the sound source and the perception.



Figure 4. Soundwalk in an urban area

The laboratory experiment usually involves sonic environment reproduction and sonic environment simulation [29][30]. The sonic environment is commonly reproduced using a multi-speaker system, as seen in Figure 5. This system has been validated using semantic differential analysis [31,32] and semantic categorization [33]. The reproduction by using a headphone has also been implemented but there is limited information about the validity of the system. The sonic environment simulation using a multi-speaker system also has been validated using semantic differential analysis [34].



Figure 5. Sonic reproduction system using speakers

The laboratory experiment has the advantage of the repeatability of the experiment; the sonic environment can be repeated as often as possible. However, since the sonic environment needs to be reproduced using a multi-speaker system, the system requires a room with acoustic treatment. The experiment must also be conducted individually in the room where the system is installed. Another problem is that the variation of the actual sonic environment limits the variation of the sonic environment.

The soundscape evaluation method based on memory is usually conducted using interviews or questionnaires. This method aims to identify the sound sources and to understand the expectation of the sonic environment [35]. This method is also commonly used for a soundscape research where the in-situ experiment and the sonic environment recording cannot be done such as in an Intensive Care Unit [36]. The limitation of this method is that the participants must have experienced the actual space since the context of the sonic space cannot be provided by a recording.

Apart from these three methods, a method is developed to analyse soundscape using the soundscape composition concept and internet-based tests as shown in Figure 6. These two methods are developed to deal with the limitations of the common methods.

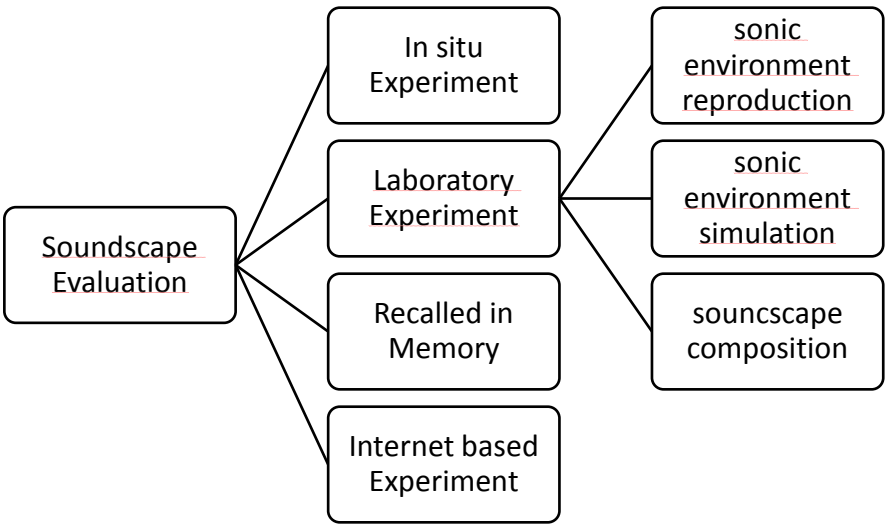


Figure 6. The Development Soundscape evaluation method

The soundscape composition concept is proposed by Bruce et al. [37] by developing a sonic environmental simulator that allows the addition of sound sources in a sonic environment. Sudarsono et al. [34] further developed the simulator, enabling the composition of a sonic environment using only the sound sources. This simulator can also simulate the movement of moving sound sources and the position of the sound sources. By using the simulator, the participant can easily compose the expected soundscape and the model that represents the interaction between sound source and people's perception has been determined [38].

The internet-based experiment is developed to increase the participation in soundscape experiments. The internet-based experiments have become an alternative for various reasons. The first reason is the increasing internet speed, which allows playing high-quality audio and even videos. The system for soundscape evaluation can be developed using internet easily.

The second reason is the development of virtual reality technology [39]. This technology allows us to make immersive virtual environments using three-dimensional audio video. The reproduction system also has been available using Facebook 360 and YouTube 360. The virtual environment can be easily reproduced in a laboratory and even by using the internet. This system has become an alternative for soundscape research [40]. The limitation of this system is that the reproduction needs using specific tools such as mobile phones or virtual reality devices and the sonic environment needs to be evaluated after the participant experiences the sonic environment.

The aim of this study is to develop a soundscape evaluation tool using the internet. The tools will be developed without virtual technology to simplify the experiment. By using this system, the participant can fill in a questionnaire while listening to the sonic environment. In addition, the system is developed using simple recording and a reproduction system allowing everyone to use this system easily. This system will allow the soundscape experiment to be conducted anywhere with more participants compared to the existing methods. The experiment also can be conducted only using headphone and laptop/mobile phone.

3. Development of an internet-based urban soundscape evaluation system

An internet-based urban soundscape evaluation system allows the soundscape experiment to be reproduced anywhere. Using this system, the data can be collected through an online form and can be shared easily. The key element of this system is how to reproduce the sonic environment in a valid way regarding the variation of experimental conditions. In the internet-based experiment, the selection of headphones and the tools to fill in the questionnaire cannot be controlled. Regardless the variation, the data from the questionnaire must be valid. Moreover, the system must be made as simple as possible in making the recording and the questionnaire.

The concept of participation in soundscape analysis has been analysed by Laso et al. [41] who state that urban design must consider the acoustic problem in the society and that participatory analysis has become an important tool in data collection. The smart city concept also includes the aspect of participation in decision-making which is can be done easily using an internet-based soundscape test.

The soundscape evaluation system is based on an online questionnaire form. The online form is selected because of its simplicity and low cost. By using this online form, the questionnaire can be made easily for free. The questionnaire consists of several soundscapes recording and the problem is how to reproduce the soundscape by using headphone, which can give the similar perception to the actual soundscape via the internet.

The focus of this study is to find a recording technique that is simple but provides valid reproduction; find out the effect of different headphones to the sonic environment perception; and establish the calibration of the reproduction system.

3.1 Recording technique

The recording technique has been developed quickly. The recordings in soundscape study are commonly made using a Soundfield microphone, which records in B-Format (4-channel signals). This method is also known by ambisonic recording technique. The B-format signal is then reproduced using speakers in a laboratory. Although the system has valid results [42], the application using a headphone has not been determined. Furthermore, the system is a little bit complex since the signal needs to be recorded simultaneously and decoded before the signal reproduced. The signals can be decoded into various systems such as an ambisonic reproduction system, surround system, or stereo system. Figure 7 shows the ambisonic recording system for stereo reproduction.

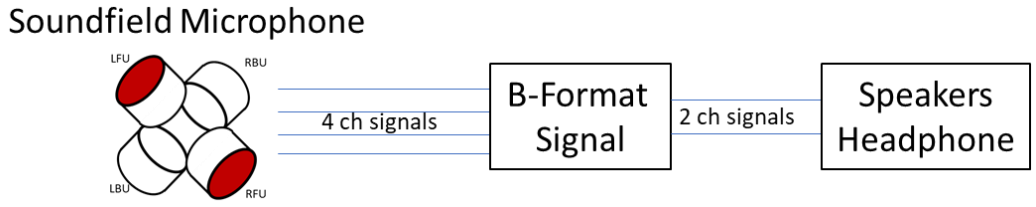


Figure 7. Ambisonic Recording System for Stereo Reproduction

Another study uses binaural recording with an in-ear microphone or dummy head to make an impressive sonic environment reproduction. The system is much simpler than using a Soundfield microphone since the output is already in stereo. Figure 89 shows the recording system. The disadvantages of this system are that the validity of binaural reproduction using a headphone for a soundscape experiment has not been determined. Moreover, the microphone used for this recording is not widely available.

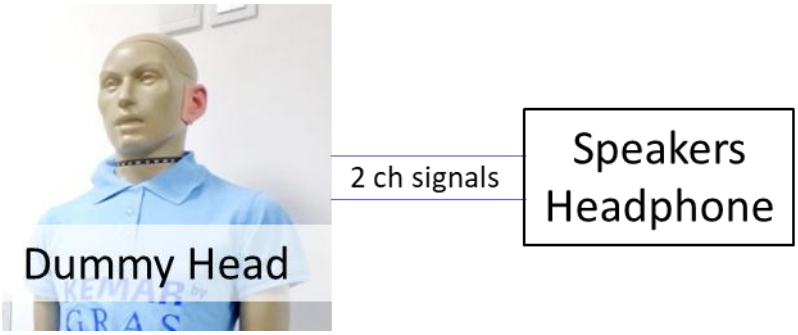


Figure 8. Binaural Recording System for Stereo Reproduction

The focus of this study is to find a simple stereo recording technique that is widely available and easy to use. Our study found out that the Mid Side recording technique is suitable for soundscape recording.

Mid Side recording is a recording technique using two types of microphones (cardioid and figure of eight microphone) as shown in Figure 9. This is one of the most common recording techniques in hand-held recorders beside the XY recording technique. The Mid Side signal must be decoded into left and right channel before the signal can be reproduced but some hand-held recorders include the decoder inside so the output signals are ready to be reproduced.

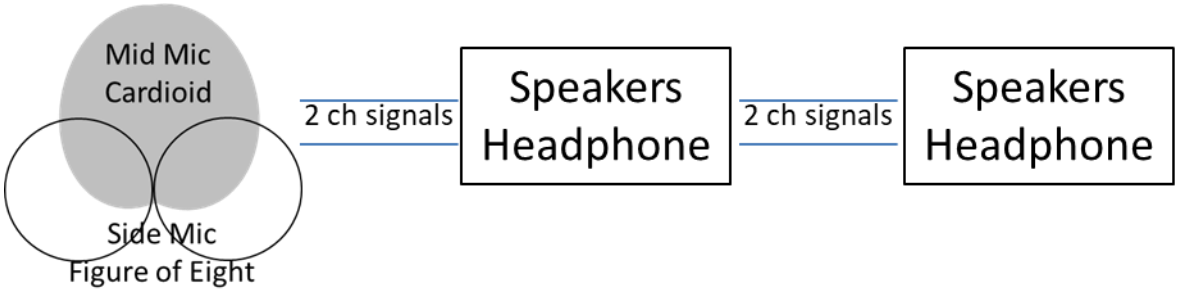


Figure 9. Mid Side Recording System for Stereo Reproduction

The validation in the laboratory using semantic differential analysis shows that the recording with Mid Side technique could give the similar perception to the in-situ experiment and the reproduction using multi-speakers reproduction system [31]. Three soundscape dimensions emerge from the experiment using MS recording: Relaxation, Dynamic, and Communication. The detailed result for this part is presented in another paper about the validation of soundscape reproduction using headphone.

3.2 Headphone variation

The headphone variation is analysed to understand the difference in perception between three different types of headphone, the over-ear, on-ear, and in-ear headphones. Figure 10 shows the different types of headphones used for the experiment. Our study shows that there is no significant difference (sig<0.05) between the types of headphones. Furthermore, the same soundscape dimension also emerges from these three types of headphone. A detailed result is presented in another paper about the validation of soundscape reproduction using headphones.



Figure 10. Headphone used in the experiment. A is the over-ear headphone, B is the on-ear headphone, and C is the in-ear headphone

3.3 Calibration system

One of the important aspects of the soundscape reproduction is the calibration of the reproduction. Sudarsono et al. showed that sound reproduction at the wrong level could affect the perception [43].

Furthermore, their study indicates that when the participants of the experiment are given the opportunity to adjust the sound level, which represents the actual sounds, they adjust it to a similar level.

The results of the study indicate that it is possible to develop a calibration system for soundscape reproduction using people's perception. This method could prove to be useful since the calibration usually requires an instrument that is not widely available.

Figure 11 shows the calibration system. Before the experiment, the participants listened to a sonic environment recording and were requested to adjust the sound level of the gadget (laptop, tablet, mobile phone) that represented the actual level. After the calibration, the experiment could be started. Since the other recordings were made with the same microphone and the same sensitivity, the calibration applied to the other recording. The detailed results of this experiment are presented in another paper about the development of web-based soundscape reproduction calibration.

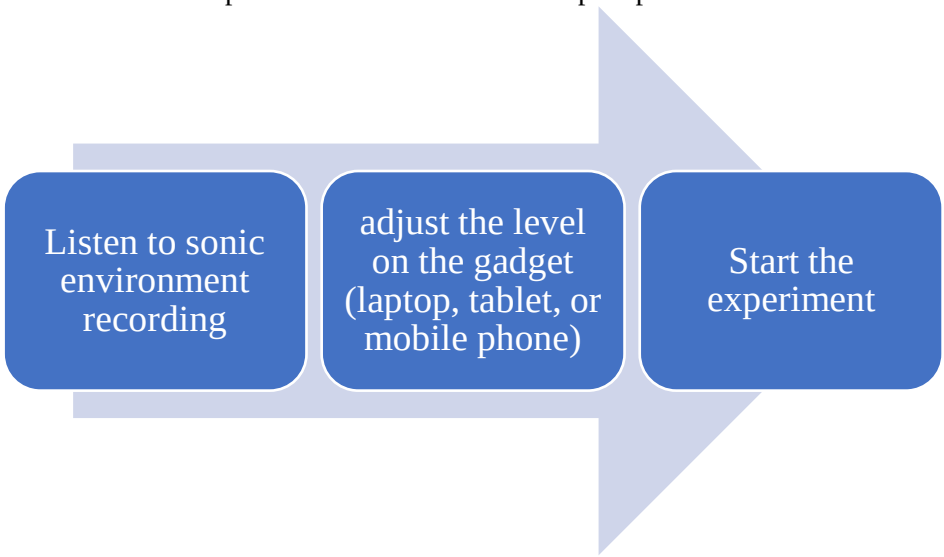


Figure 11. Internet-based sonic reproduction system's calibration based on perception

4. Conclusion

The internet-based sonic environment simulator using a headphone has been developed based on the principles of simplicity, low-cost, and validity. The study demonstrated a suitable recording technique, which is simple and relatively cheap, namely the Mid Side Stereo Recording Technique. This recording technique can provide a perception similar to the actual soundscape. The experiment also demonstrates that the type of headphone does not significantly affect the perception of the soundscape. The calibration system also has been developed based on perception. This alternative calibration method can be used for calibrating the internet-based reproduction system anywhere.

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