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Measurement methodology for the acoustic scattering of a single tree

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ABSTRACT

Scattering of sound by trees is either wanted or unwanted, depending of the application. Behind noise barriers, trees have a positive effect on the wind field, but could decrease barrier performance in absence of wind. In a street canyon, the presence of trees increases the diffusivity of the sound field. However, little is known about the inter-species differences with respect to scattering. In this paper, an in-situ and easy-to-deploy measurement methodology is presented to estimate the amount of acoustic scattering by a single tree, by using a pulse generator (e.g. alarm pistol) and a single microphone. By performing time-domain analysis, the direct sound path and scattered waves can be separated. Furthermore, early and late scattering by the tree crown can be distinguished. Example measurements are presented, and the degree of scattering is linked to geometrical crown properties.

INTRODUCTION

The interaction between sound and vegetation has been the subject of many studies. Already in 1946, Eyring [1] carried out experimental studies for sound propagation in tropical jungles. Since then, researchers found large reduction for road traffic noise by applying vegetation [2], while others concluded that influence of vegetation is limited [3].

Vegetation has direct acoustical effects like reflection (mainly on stems) [4, 5], absorption by leaves [6, 7], and scattering by tree elements [8]. There are also a number of important indirect effects. The increased porosity of ground under vegetation (by the presence of roots, and by forming a humus layer) will lead to a significantly different ground effect [9]. Trees also influence the micro-meteorology, and this can be used in a positive way e.g. near noise barriers. It is well known that for downwind sound propagation, barrier efficiency can be largely reduced. The use of a row of trees was experimentally shown to increase shielding in the presence of wind along a highway noise screen [10]. However, in absence of wind, scattering by the tree crown could lead to increased high frequency scattering into the acoustic shadow zone behind a barrier, compared to a barrier without trees.

On the other hand, scattering by trees can be wanted. The presence of scattering objects and façades was shown to decrease sound levels in a street canyon [11], and also for propagation to nearby canyons or courtyards [12, 13]. It could therefore be beneficial to place trees with a high degree of scattering in such situations.

In literature, there is however very few information on the scattering properties of various species. Therefore, research to the topic of scattering by vegetation is conducted. A first step is developing an adequate measurement methodology, which is the main subject of this paper. Focus is on an in-situ and easy-to-deploy methodology. From a theoretical point of view, it is interesting to do research to the scattering of an individual tree. When performing measurements near belts of trees or forest, there is a complicated interaction of multiple effects, which makes conclusions often difficult.

MEASUREMENT METHODOLOGY

The measurement requires a pulse generator (sound source), a microphone (receiver) and a sound meter. The setup for the measurements is given in Figure 1. In the present study, the Italian made Bruni alarm pistol was used as the pulse generator, which was located at 15 m away from the tree. The reproducibility of this source was tested in anechoic environment. Figure 2 shows the source reproducibility. The sound was recorded by SVAN 959 through a microphone (MK250B, Microtech Gefell) and a preamplifier (SVANTEK). The SVAN 959 is a digital, Type 1 sound & vibration level meter along with analyser, and its sampling frequency is 48000 Hz. The microphone was located at 15 m away from the tree. The tree is located at the center of the circle passing pulse generator and microphone. The heights of the pulse generator and the microphone were 1 m and 0.9 m above the ground, respectively. Measurements were performed both on a straight line connecting source, tree, and microphone (180 degrees connecting line) and on an angle of 150 degrees (150 degrees connecting line). This measurement configuration is a compromise that allows optimal separation of the direct sound from the scattered sound and limits the influence of background noise and reflections from the wider environment. To validate source reproducibility in situ and sample micrometeorological differences all measurements were repeated at least 3 times. The recorded wave data will be analysed in time domain and example results will be shown in the following section.

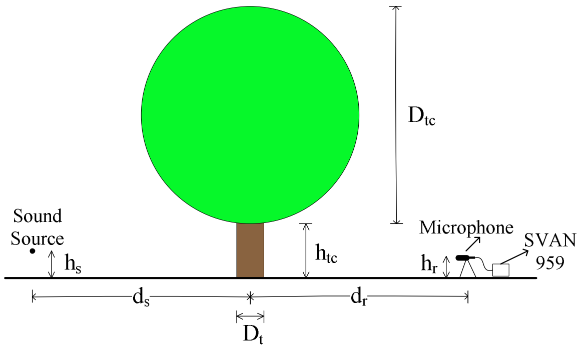

Figure 1. Setup for measurements about acoustical scattering of a single tree. D_{tc} is the diameter of the tree crown; D_t is the diameter of the tree trunk; h_{tc} is the height of tree crown; h_s and h_r are the heights of sound source and receiver, respectively; d_s is distance from sound source to tree and d_r is the distance from receiver to tree.

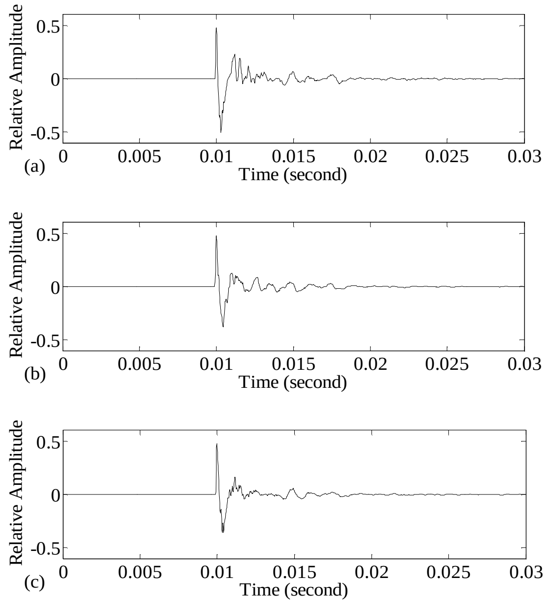

Figure 2. Wave form of 3 gunshots in anechoic chamber

MEASUREMENT AND DISCUSSION

Test measurements were carried out on several trees in Gent and in Brussels, Belgium in 2010. In this proceedings paper we will consider one of the trees as an example. The tree considered is a 22 m high black willow. The diameter of stem of this tree is 1.3 m. The diameter of tree crown is 20 m, and the lowest part of the crown is 2 m high above the ground. The ground is flat grass land. The closest other trees are around 40 m away from this tree.

The measurement discussed here as an example was performed from 2:30 pm to 3:30 pm on April 22, 2010, when the tree had no leaf. The weather was sunny and there was a slight wind. The temperature during the measurement was around 11 degrees centigrade; the relative humidity was close to 100%; and the atmosphere pressure was 101685 Pascal. Figure 3 shows gunshot signals recorded during outdoor measurement and in the anechoic chamber. The scattered sound waves by the individual tree can be noticed.

In the test setup where the angle between the source-tree line and the tree-recorder line is 150 degrees, the direct sound comes just over 3 ms before the first scattering from the tree. Since most of the high frequency content of the gun shot comes within 3ms of the initial peak, the direct sound (and ground reflection) can now easily be distinguished. Therefore, in the data analysis, all acoustic energy arriving within a time interval of 6 milliseconds (simplified as ms) centered at the peak of the signal is attributed to the direct sound and early ground reflection. After the direct gunshot, the recorded signals include the scattering signals by the individual tree and background noise. In the present study, the time interval for analysing the scattering signal is 25 ms; and only the scattering within 0.3 second after the gunshot is considered. A 1 second excerpt of the signal arriving 1 second after the direct sound is selected as representative for the background noise. Fast Fourier transform (FFT) is used to analyse these signals. To allow comparing tree scattering measurements recorded at different environmental conditions, atmospheric absorption calculated according to the formula given by ISO9613-1 [14] was removed from the measurements. No correction was made for differences in ground condition. Figure 4 shows the changes of relative sound pressure level (SPL) of scattering signals with time. The SPL is given in 1/3 octave band; and the results of 6 central frequencies (500Hz, 1000Hz, 2000Hz, 4000Hz, 8000Hz and 12500Hz) are shown in 25ms time intervals. It can be observed that for low frequencies, the SPL of the scattered signal is much smaller than that of the direct gunshot. This is due to the fact that the size of the stems, branches and twigs of the tree is much smaller than the wavelength. For high frequencies, the wavelength becomes smaller and more scattering occurs. For the 150 degrees connecting line (Figure 4 on the right) the observations are slightly different. Firstly, the direct sound has a higher level because it is no longer partially screened by the tree and because the distance between source and observer is somewhat lower. Secondly, the initial decay of the sound level looks smoother. When considering the dimensions of the tree, it can be expected that scattered sound starts arriving shortly after the direct sound and keeps flowing in until about 70ms later. Sound arriving later has either undergone multiple reflections within the crown or comes from reflections from trees in the wider neighbourhood.

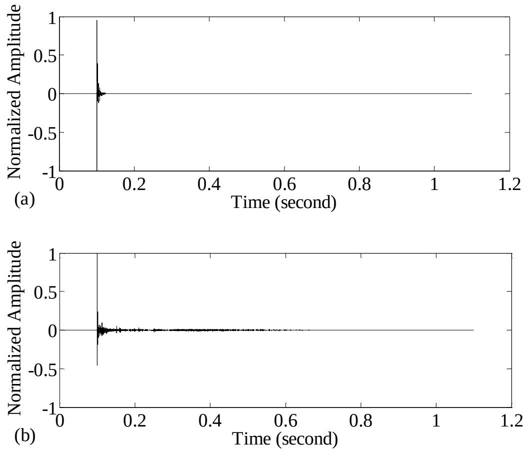

Figure 3. Example of recorded wave forms: (a) in anechoic chamber; (b) outdoor with an individual tree for 180 degrees measurement line.

Spectral characteristics of the scattering become clearer when comparing the average sound pressure level of the direct sound to the average sound pressure level during the first 25ms after the direct sound shown in Figure 5. The screening of the direct sound by the tree at high frequencies becomes obvious when comparing the 180 degrees measurement setup to the 150 degrees measurement setup. Above 1000 Hz, the scattered field is very simular in both directions while there seems to be an additional increase at lower frequencies for the 150 degrees measurement setup. The origin of this additional effect could be related to a ground effect but this could until now not definitely be proven.

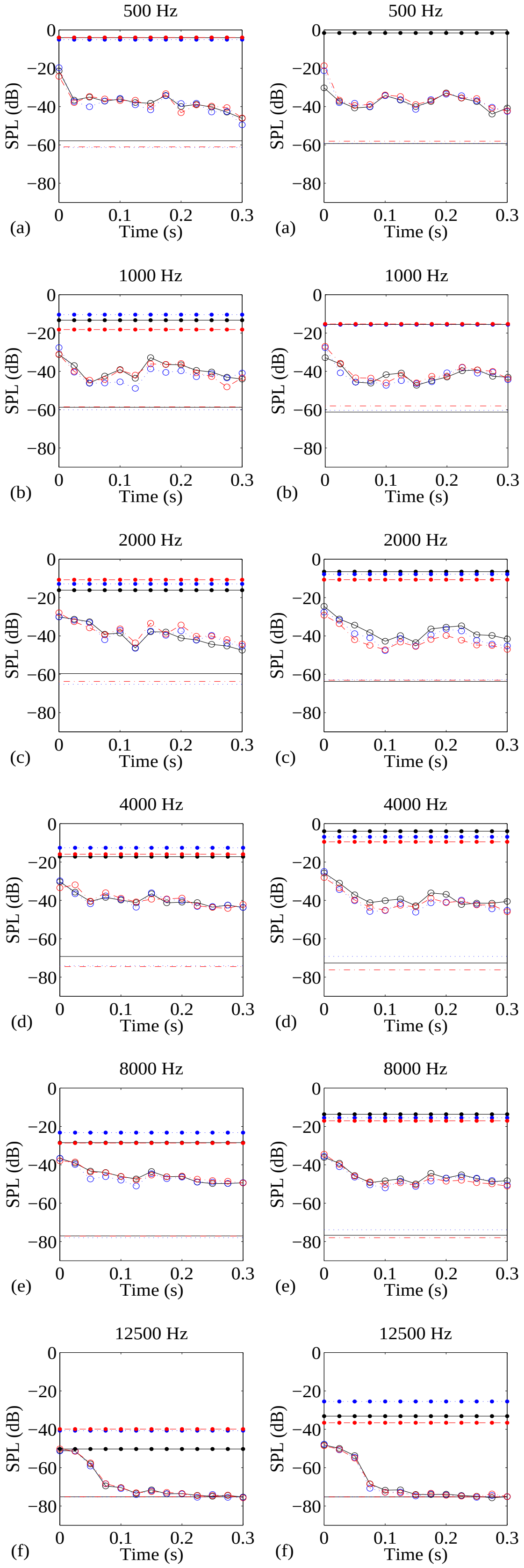

Figure 4. Relative sound pressure level (SPL) for the direct gunshot, scattering signals and background noise. The figures in left column show the results for 180 degrees measurement; the figures in right column show the results for 150 degrees measurement. The black, blue and red lines indicate three different repetitions of the test. The lines with solid dot denote the SPL of direct gunshot; the lines with hollow circle denote the SPL of scattering signals; and the lines without marker denote the SPL of background noise.

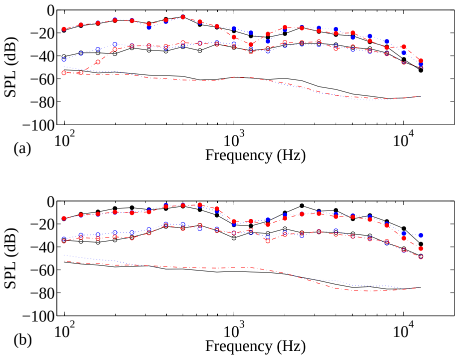

Figure 5. Relative sound pressure level (SPL) in frequency domain for the direct gunshot, scattering signals and background noise. (a) results for 180 degrees measurement; (b) results for 150 degrees measurement. The black, blue and red lines indicate three different tests. The lines with solid dot denote the SPL of direct gunshot; the lines with hollow circle denote the SPL of scattering signals; and the lines without marker denote the SPL of background noise.

CONCLUSIONS

This paper presents an experimental method to study the scattering properties of an individual tree. By using an impulsive source and by selecting suitable observation points, the scattered signal can be distinguished from the direct signal in time domain. First measurements show good reproducibility of the test. At high frequencies, scattering by the twigs and branches in the crown of the tree could clearly be observed in the screening of the direct sound and in the reflection at a moderate angle. Although not shown in this article, the proposed measurement method has also successfully been applied to investigating the effect of leafs and the influence of tree species on the amount of scattering in situ.

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