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Sound dispersion and reverberation by a single tree

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ABSTRACT

In urban spaces such as streets and squares trees may be effective in dispersing sound energy due to multiple reflections between building façades. This phenomenon can affect computer predictions of acoustic parameters such as RT and sound attenuation in such spaces. Therefore, basic research on the acoustic effect of a single tree has been conducted in this study. Field measurements were carried out for three single trees standing at sufficient distance from obstacles. Selection criteria were species, canopy size and the amount of leafs. The effect of receiver distance from the tree was also investigated. Frequency analysis of the results showed that a single tree can disperse sound energy effectively, especially above 1000Hz. Results for large and small trees with fully grown leafs suggested that RT for a large tree is higher than for a small tree – at about 0.2s at high frequencies. Results for different amounts of leafs showed noticeable changes in RT at high frequencies, above about 2kHz. With increasing receiver distance from the tree, RT decreased at high frequencies. The experiment on back scattering by trees suggested this effect is considerable.
Keywords: Tree, Reverberation, Sound dispersion, Scattering, Vegetation, Street canyon

1. INTRODUCTION

Trees contribute to the features of an urban setting that affect the characteristics of the sound field. Multiple reflections between building façades in street canyons and courtyards may increase the significance of trees. Sound energy dispersed by trees can lead to variations in acoustic parameters including reverberation time (RT) and sound attenuation, especially in such reverberant spaces.

Research on the effect of trees on sound dispersion and RT has been limited while most studies have focused on the reduction of sound transmission through trees in open fields [1-5]. Some experiments were carried out to investigate the acoustic characteristics of individual plants in terms of absorption by leaves [6-9]. The acoustic effect of a single tree is expected to depend on many factors such as the species and size. In this study, in-situ measurements were carried out to investigate the effect of a single tree on sound dispersion and RT by considering various factors mentioned above.

2. MEASUREMENT METHODS

Measurements were carried out in the park at Chatsworth House near Sheffield in September 2010 and April 2011. Three individual trees of different species, size and shape were selected to examine the importance of these factors for sound dispersion and RT. To suppress the effect of late reflections, the trees selected stood alone with sufficiently large distances (over 70m) to other trees and obstacles.

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Table 1 describes the cases considered. The oak tree measurement was performed twice to compare RT as influenced by the amount of leafs in two different seasons (seven month interval). The result of RT between the oak and cherry tree is compared to examine the effect of tree type since they have a similar height. In Figures 1, 2 and 3, the condition and location for each tree is presented.

Table 1 – Tree condition used in the measurements

Species	Tree size	Date	Leaf size (approx. [10])
Oak	10.5m(H)x15m(W)	Sept'10, Apr'11	15cm(L)x7.5cm(W)
Lime	20m(H)x18.5m(W)	Sep'10	10cm(L)x5cm(W)
Cherry	13m(H)x15m(W)	Apr'11	6cm(L)x3cm(W)

(a) Oak tree with leaf (Sept. 2010) (b) Oak tree without leaf (Apr. 2011) (c) Satellite view

Figure 1 – Measurement condition of the oak tree with and without leaf

(a) Lime tree (Sept. 2010) (b) Satellite view

Figure 2 – Measurement condition of the lime tree

(a) Cherry tree (Apr. 2011) (b) Satellite view

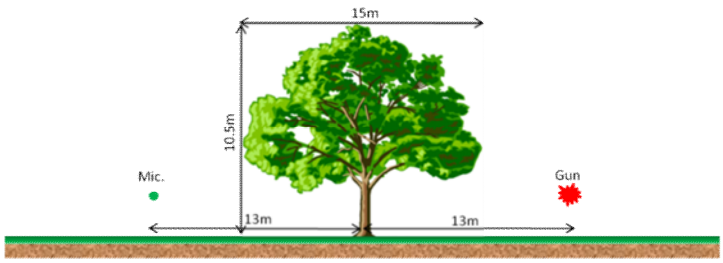
Figure 3 – Measurement condition of the cherry tree

Shots from a start pistol were used as acoustic excitation. Five shots were released and averaged out afterwards to catch variations in the emitted source powers. This measurement methodology was assessed earlier [11]. Microphones were connected to an Edirol R-44 multi-channel recorder and a 01dB Symphonie system. Temperature and relative humidity were 20.3°C and 62% on the first measurement day in 2010, and 28.2°C and 34.1% during the measurement in 2011. The wind speed (measured at microphone height) was in the range 0.02-1.40m/s.

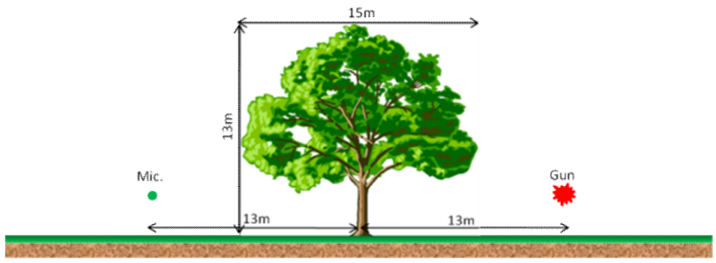
3. RESULTS

3.1 Frequency analysis of sound scattered by a single tree

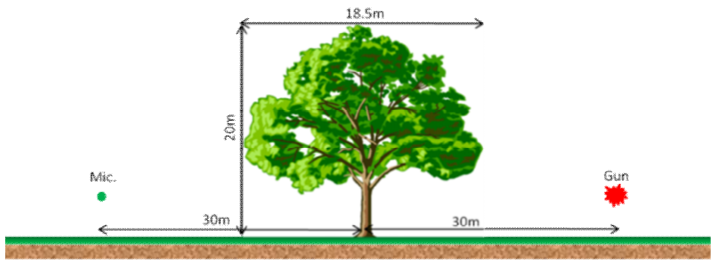
Impulse responses were obtained at a 145cm high microphone receiving sound scattered by a single tree. The source was at 13m from the tree for the small oak and cherry tree, and at 30m for the large lime tree. Figure 4 shows the experimental conditions for each tree.



(a) oak



(b) Cherry



(c) Lime

Figure 4 – Measurement condition for each tree (tree figure from downtoearthservices.co.uk)

The impulse responses for each condition are shown in Figure 5. For relative comparison, the amplitude of direct sound is adjusted to be equal. Impulse responses of a gunshot measured in open field are also presented to compare the later part of the sound energy by dispersion. The results in Figure 5 show that impulse responses for each tree measurement are all considerably longer in comparison with open field measurement due to sound energy dispersed by tree structures such as trunks, branches and leaves. For the impulse response of the large lime tree, it can be seen that sound energy in the later part is stronger than other tree situations.

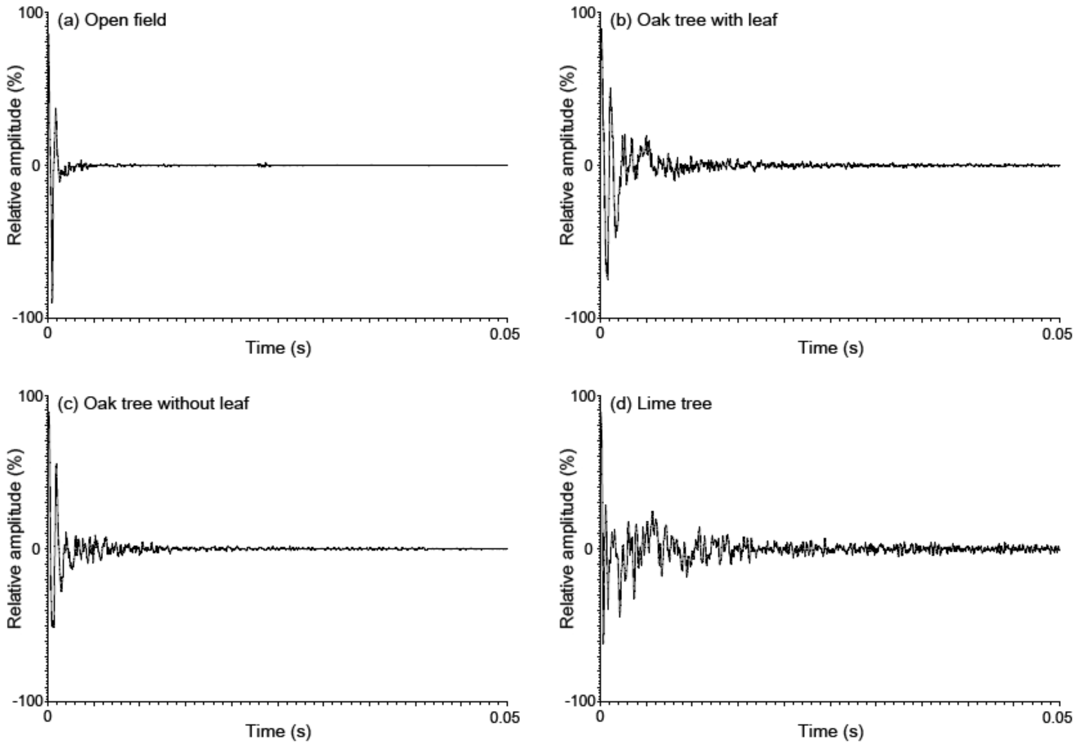


Figure 5 – Impulse responses for open field, small oak tree with and without leaf, and large lime tree with the same amplitude of direct sound

To analyse sound energy for each frequency band, the impulse responses are filtered using the graphic equalizer function in the DIRAC analysis programme. The result in Figure 6 shows that sound energy propagating through the small oak tree with leaf can be observed within 0.02sec up to 250Hz. These results indicate that a single tree has an insignificant effect on sound dispersion at low frequency, and it is dominated by direct and ground reflection sound. On the other hand, the later part of impulse response mainly by the dispersed sound energy can be seen above 500Hz. This result indicates that RT is strongly influenced by the dispersed sound energy at high frequency.

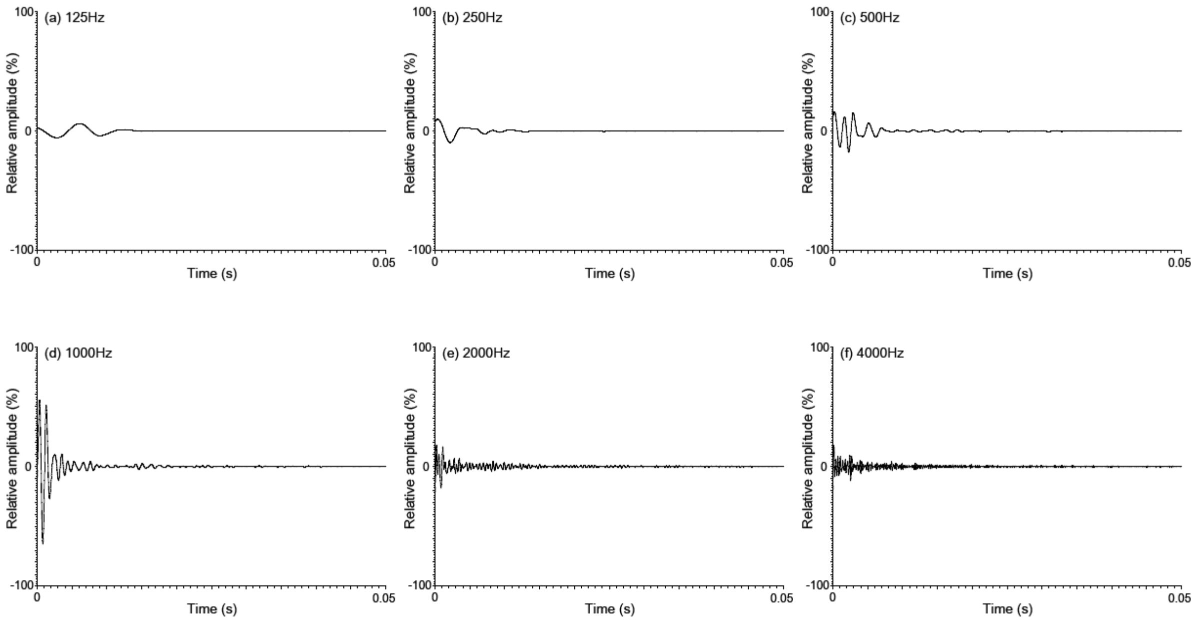
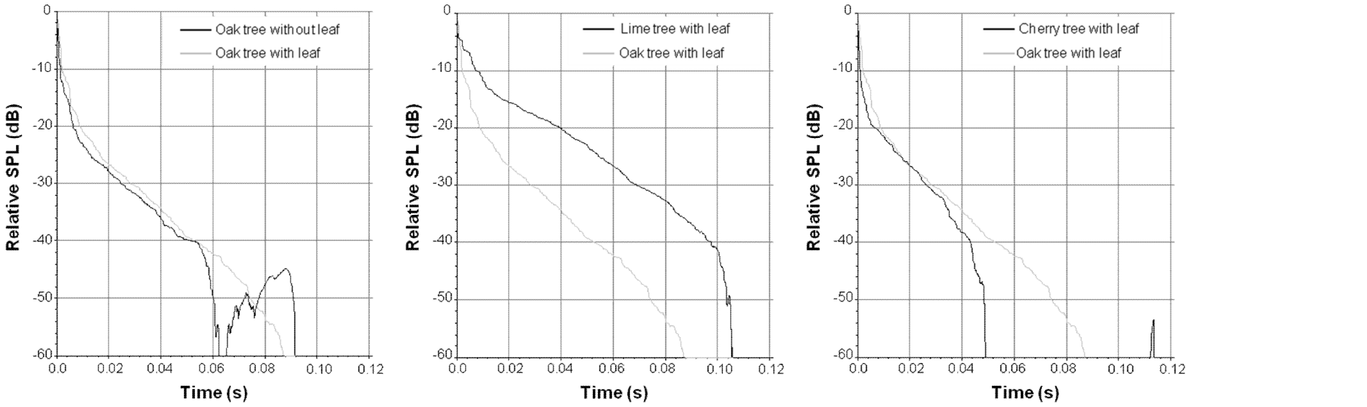


Figure 6 – Frequency analysis of impulse response for the small oak tree with leaf

3.2 Decay curves and reverberation effect

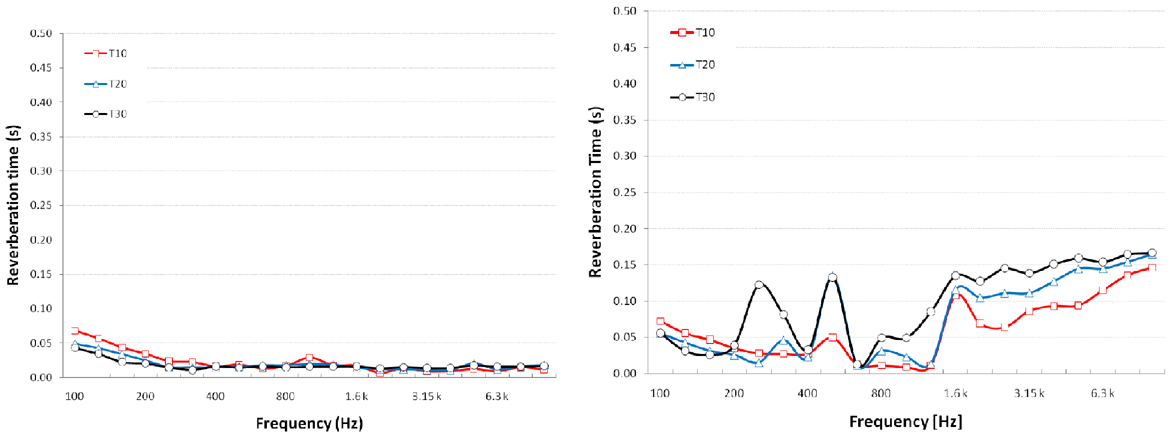
The late arrival of sound energy dispersed by a single tree can affect RT. RT depends on the characteristics of decay curves, and there are different ways of calculating RT, including T10, T20 and T30. Figure 7 shows the decay curves for each measurement and allows examining the effects of tree type/size and leaf effects. The result shows that the decay curve for the large lime tree with leaf is significantly different in comparison with that for the small oak tree with leaf, which indicates the effect of tree size on RT. On the other hand, the difference in decay curves for the oak tree with and without leaf, and the cherry and oak with leaf is rather insignificant, which suggests a minor effect of the amount of leafs and type of tree on RT.



(a) Oak tree without and with leaf (b) Lime and oak tree with leaf (c) Cherry and oak tree with leaf

Figure 7 – Decay curves for different tree conditions, to examine the effects of tree type/size and leaf effects

Three different decay ranges (T10, T20 and T30) are calculated using the DIRAC programme to verify the effect of calculation methods. In Figure 8, the results according to RT calculation methods are presented for the small oak tree with leaf. The RT of impulse responses measured at an anechoic chamber is also shown to verify the accuracy of the analysis programme.



(a) Anechoic chamber (b) Small oak tree with leaf

Figure 8 – RT of anechoic chamber and the small oak tree with leaf according to calculation methods

The result for the oak tree indicates that RT generally increases with increasing frequency. This means that sound energy dispersed by a single tree is effective in increasing RT at high frequencies rather than low frequencies. However, RT is rather short, less than 0.2sec. The comparison result according to T-value shows that RT increases with increasing T-value, especially at middle and high frequencies. RT measured in an anechoic chamber represents that the DIRAC programme is accurate for calculating impulse responses with very short RT, but it is noted that below about 200Hz the RT effect may not be caused by the tree since the results with the tree and the anechoic results are rather similar.

3.3 Reverberation time by tree sizes

RT according to the tree size is compared in one-third octave bands using the T10 calculation method considering that this was an open field measurement. Figure 9 shows the comparison results of RT for the small oak and large lime trees with fully grown leafs. It can be seen that the tree size can significantly affect RT, although leaf type and tree structure could also be affecting factors, but this is relatively minor, as discussed below. In particular, the difference in RT between the small and large tree is significant with a difference of about 0.2s at high frequencies. On the other hand, the effect of the tree size is insignificant at low frequencies.

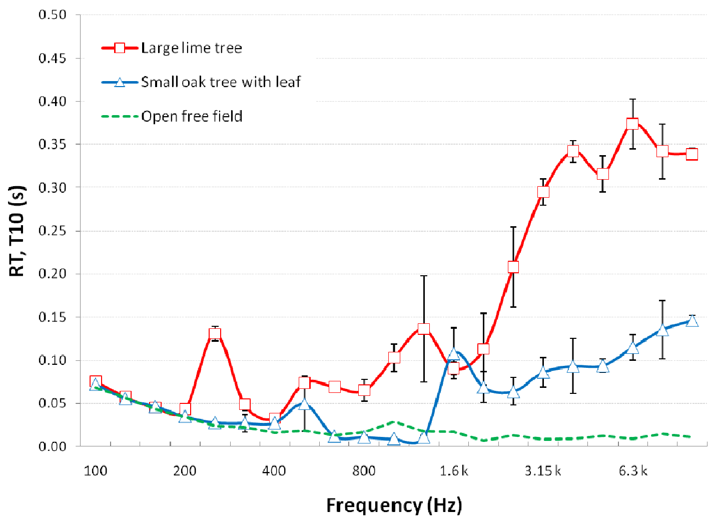


Figure 9 – Comparison of RT according to the tree size

3.4 Effect of the amount of leaf and tree type

Measurement for the small oak tree was carried out for two different leaf conditions. The oak tree had fully grown leaf in September 2010. On the other hand, very small spring leaf has been grown in April 2011 as shown in Figure 1. To investigate the effect of tree type, RT between the oak and cherry tree is also compared. The shape of leaf for the oak and cherry trees is shown in Figure 10.

(a) Leaf of the oak tree (b) Leaf of the cherry tree

Figure 10 – Leaf condition of the oak and cherry trees

RT according to the amount of leafs on the oak tree is compared in Figure 11. The result indicates that the presence of leafs has an influence at high frequencies, above about 2kHz. On the other hand, this effect is rather insignificant at middle and low frequencies.

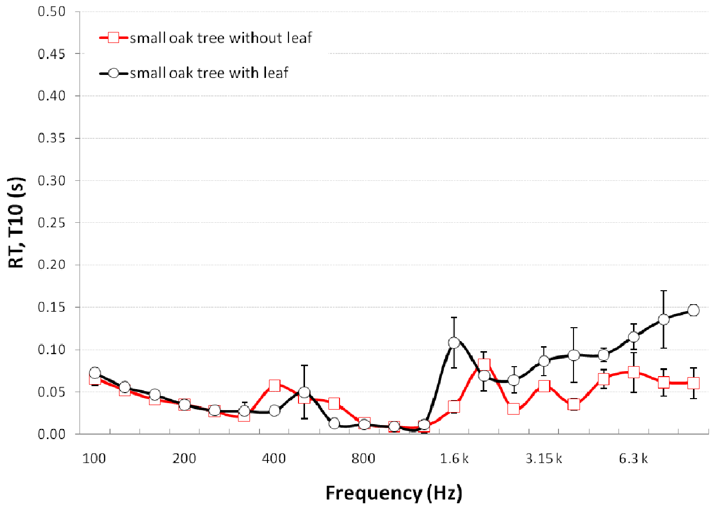


Figure 11 – Comparison of RT according to the amount of leafs at the oak tree

The type of tree is one of the possibilities to change RT due to different characteristics of tree structures such as leaf, branch and bark. In this study, two different types with a similar size were selected to compare RT. The leafs on the oak tree are relatively large compared to the cherry tree. Figure 12 shows that the RT curves for both trees are however similar. This suggests that in the studies range, tree type is of minor significance for RT in contrast to the effect of tree size.

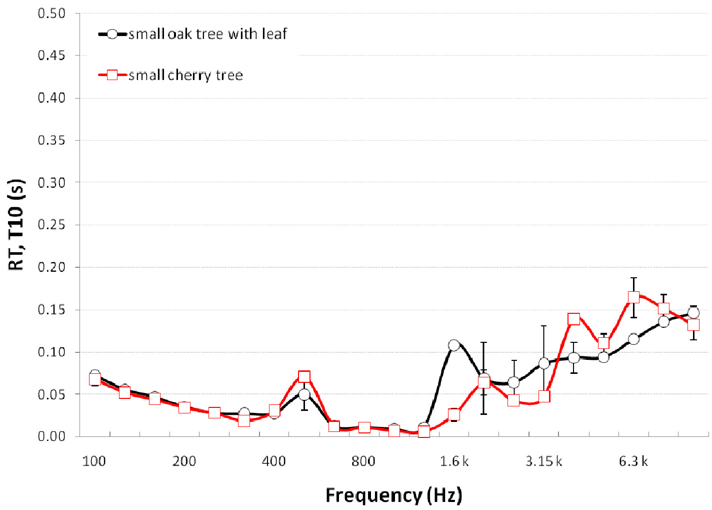


Figure 12 – Comparison of RT between the oak and cherry tree

3.5 Tree reverberation according to distance

Measurements were performed at four different distances relative to the tree column (2m, 5m, 10m and 20m). The distance between the sound source and the tree was 20m. The measurements were carried out near the small cherry tree and oak tree without leaf. Figure 13 shows the measurement arrangement for both cases. In Figure 14, measurement results of RT are presented. The results for the cherry tree with leaf indicate that RT decreases with the increase of distance. On the other hand, the effect of distance relative to the oak tree without leaf is less significant than in case of the cherry tree.

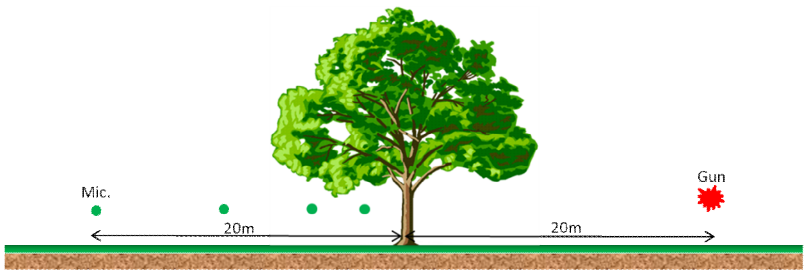
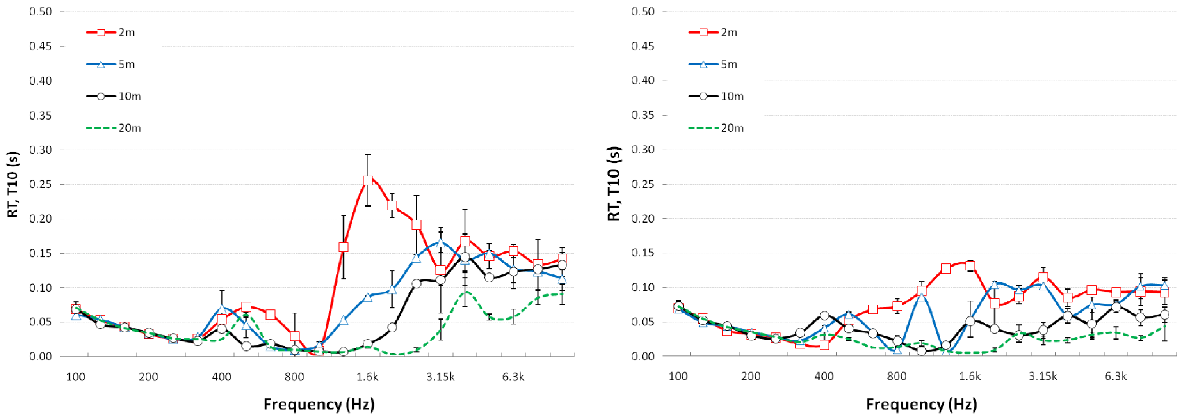


Figure 13 – Arrangement to investigate the effect of distances on RT



(a) Cherry tree with leaf

(b) Oak tree without leaf

Figure 14 – RT according to the distance

3.6 Frequency analysis for back scattering by a single tree

Back scattering, which means that sound energy is reflected and scattered towards the source side, can play an important role in creating a reverberant field, especially in the near field? To examine the effect of back scattering, impulse responses were recorded at 10m from the cherry tree at the source side. The source was located at 30m from the receiver. Figure 15 shows the experimental set-up to measure back scattering. In Figure 16, impulse response without frequency filtering within 0.2seconds is shown. The result in Figure 16 indicates that strong back scattered sound energy at the later part. To analyse the effect of the back scattering accurately, sound energy for each frequency is filtered using a graphic equalizer from 125Hz to 4kHz based on octave band centre frequencies. The result of each frequency band is described in Figure 17. The results show that the back scattered sound energy appears from 500Hz.

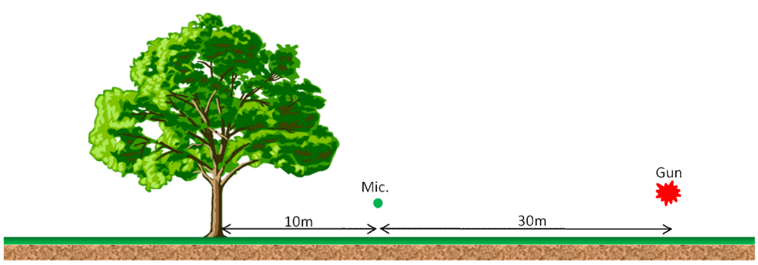


Figure 15 – Experiment set-up to measure the back scattering

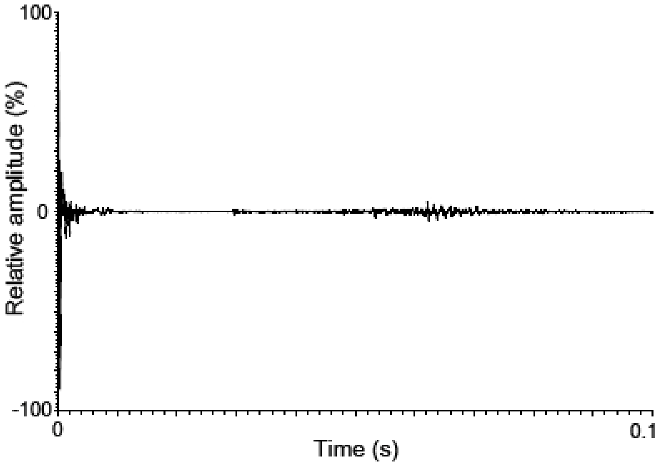


Figure 16 – Impulse response of the back scattering without filtering

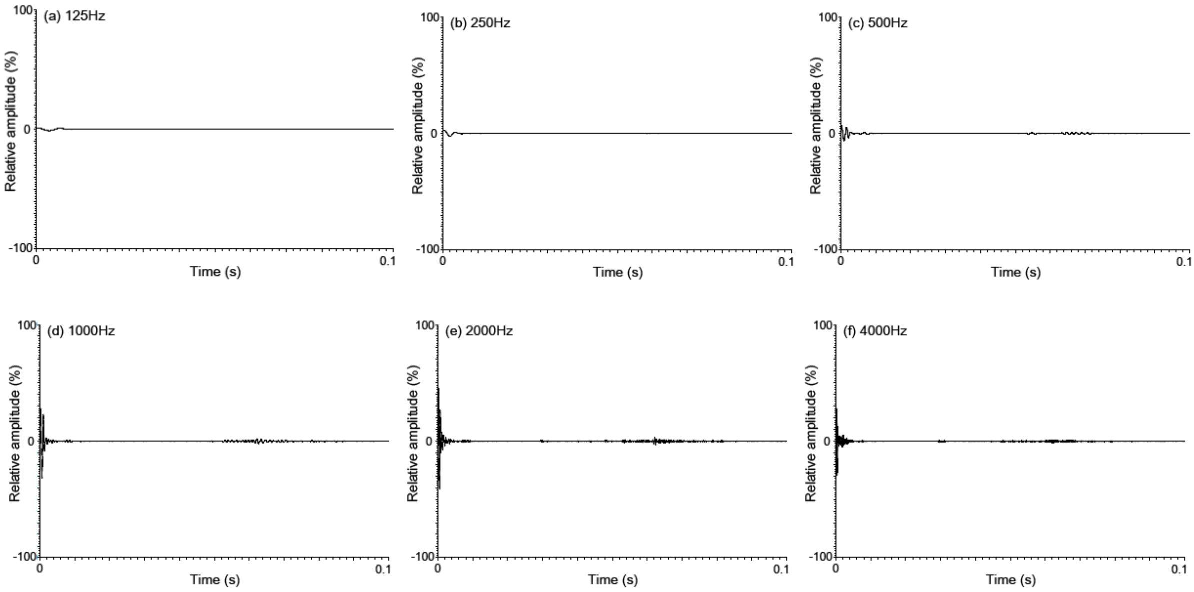


Figure 17 – Filtered impulse response for each frequency band

4. CONCLUSIONS

This study investigated how the sound energy dispersed by a single tree affects RT according to the size and type of tree, amount of leafs, and distance from the stem axis. The overall results showed that a single tree increases RT, especially at high frequencies. The maximum RT measured near a single tree at high frequencies can amount up to 0.4sec. At low frequencies, the effect of dispersed sound energy on RT is insignificant. From the result of frequency analysis, it is shown that the dispersed sound energy appears in the later part of the impulse responses, which increases RT. In particular, the effect is obvious above 1kHz. The size of the tree has a significant effect on increasing RT, by about 0.2s at high frequencies in the studied cases. It has also been shown that RT increases with an increased amount of leafs, especially at high frequencies. The measurements set up to clarify the effect of receiver distance show that RT decreases with increasing distance. In terms of the back scattering effect, it has been shown that a tree has a significant effect on increasing sound energy at high frequencies.

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