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TRANSMISSION LINE MATRIX METHOD FOR SOUND PROPAGATION MODELLING IN FORESTS: COMPARISON WITH IN-SITU MEASUREMENTS

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ABSTRACT

The current efforts to adapt a numerical method to the modelling of sound propagation in forests are presented in this paper. It is relevant to professionals and researchers in environmental acoustics and those interested in studying sound propagation in complex outdoor environments using numerical modelling techniques. The study aims to demonstrate the applicability of the method in complex media in which sound waves undergo multiple reflections combined with ground effect during their propagation from a sound source and a receiver point. The Transmission Line Matrix (TLM) method is used to perform numerical modelling of sound propagation in a 3D forest geometry generated based on a real tree distribution case. Results are discussed qualitatively in this paper. Their validation by comparison with in situ measurements will be presented at the conference.

Keywords: *Transmission Line Matrix (TLM), Numerical method, Forest*

1. INTRODUCTION

Forests are complex acoustic environments that pose unique challenges for sound propagation modelling. Accurately predicting the behaviour of sound waves in forests is crucial for a range of applications, from environmental noise monitoring to wildlife conservation [1, 2]. In particular, the preservation of quiet zones in forested areas is becoming an increasingly important issue, as human activities encroach on natural habitats.

Literature on forest sound modelling encompasses various methods. The Green Function Parabolic Equation (GFPE) with effective medium theory [3–5] accurately captures the macro-scale drag of forests on atmospheric sound. A comparison of a ray-tracing method with measurements reveals the forest's impact on sound propagation [6]. Additionally, modelling methods for individual trees in urban areas have been implemented [7, 8]. Numerical methods such as the TLM method have shown promise in modelling sound propagation within complex outdoor environments, including forests [9]. However, Accurately modelling sound propagation at the scale of living beings within the forest necessitates careful validation to ensure model accuracy and reliability [10]. This study aims to address this need by presenting a methodology for the comparison between TLM simulations and in-situ audio measurements in forests. While this evaluation does not address all the factors that can affect sound propagation in forests, such as topography, weather conditions, and tree leaves, it provides an important step towards developing more accurate and reliable models for these environments.

The remainder of the paper is organized as follows. In the next section, the TLM method is briefly presented. Then, the methodologies used for forest geometry modelling, TLM simulations, and in-situ measurements from [1] are presented. The results of TLM simulations are presented and discussed in the subsequent section. Finally, a conclusion with a summary of the findings, contributions, and limitations is given and suggest avenues for

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**Corresponding author*: gwenael.guillaume@cerema.fr future research are presented.

2. TRANSMISSION LINE MATRIX (TLM) MODEL

2.1 Numerical method origin

The TLM method is based on Huygens' principle for wave propagation and an electro-acoustic analogy [11]. This approach exploits the recursive discretization of wave fronts into secondary sources and applies it to a structured mesh, modelling sound propagation as pressure pulses traveling along transmission lines. This allows for an analogy between the diffusion of pulses between mesh nodes and the progression of a sound wave.

2.2 Formalism

In the current study, a d-dimensional spatial generalization of the TLM model is adopted, it has been used in previous works [12]. The spatial domain is subdivided into a Cartesian mesh with a step size of $\Delta\ell$, and time is decomposed into steps of Δt. The nodes on the grid are identified by an index vector $\mathbf{r} = (j_1, \ldots, j_d)$. At each time step n, each node in the volume instantaneously receives and emits incident and scattered pulses along m transmission lines connecting the nodes. By modelling these pressure pulses, an approximated value of the exact acoustic pressure, ${}_nP\mathbf{r}$, at the point $(x_1, \ldots, x_d)$ at time t_n can be calculated. It should be noted that the iterative process of TLM pulses has been detailed in previous literature [10], and has been intentionally omitted from the current discussion.

3. METHODOLOGY

3.1 Configuration of in-situ measurements

The TLM numerical simulations aim to reproduce the experimental campaign conducted by the French National Museum of Natural History (MNHM) [1] at the 'Nouragues' CNRS scientific station. The measurements consisted in recording audio signals at different distances from a source emitting a sound sequence composed of various types of signals (white noise, sweep, etc.) emitted successively. The source-receiver distance was varied between each measurement from 0.5 meter to 100 meters by displacing the microphone. The GPS positions of the source and of the microphone for each source-receiver distance were registered. According to their analysis, the useful signals for which the signal-to-noise ratio is satisfactory are limited to a maximum source-receiver distance of 40 meters and a maximum frequency of 4000 Hz. The GPS positions of the trees were recorded over the experimental site and reported in a spreadsheet file.

3.2 Forest geometry modelling

Forest geometry modelling is an essential step in the TLM simulation process. To generate a 3D forest model, a CSV file containing the x_1, x_2 coordinates of the trees and their diameter at breast height (DBH) is read and processed using Python scripts. The FreeCAD API is used to generate a triangular surface mesh representing the scene and containing data about the boundary materials. Figure 1 displays the result of this step, using the data from the 'Nouragues' CNRS research station in French Guiana. Then, a custom package (FastVoxel [**?**]) is used to voxelize the mesh and generate a matrix of indexes pointing to a JSON file that contains the material data required by the TLM solver. This voxelization process produces a Cartesian mesh where each voxel has an index associated with a material type. The index-to-material mapping is stored in the JSON file for the TLM solver to read.

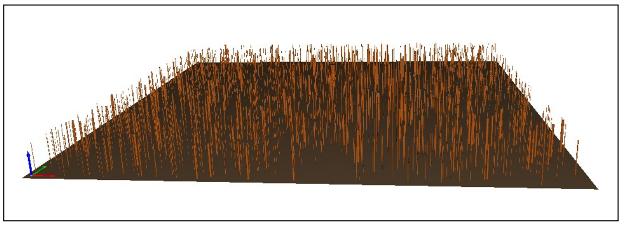

Figure 1. Example 3D view of an area of the 'Nouragues' forest, French Guiana. Representation built with the MNHM data from the CNRS research station.

3.3 Simulation setup

The simulations are carried out using the block-splitted implementation of the TLM method, as described in [13]. The simulation domain is 80 meters by 50 meters by 20 meters and contains a punctual source in front of a microphone line, spaced 10 meters apart from each other on the x-axis. The TLM method uses impedance boundary conditions on the trees, which are modelled as cylinders with a height of 13 meters and a diameter determined from the geometrical measurements described in the previous section. The ground is also modelled with acoustic impedance boundary conditions, using the 'slit-pore' [14] model. Absorbing matched layers [15] are implemented on the outer sides of the domain to prevent reflections and reduce numerical artifacts.

3.4 Analysis of results

Based on the simulation results, the pressure field is analysed and presented in Figures 2, 3, and 4. White dots represent the trees. Figure 2 shows the pressure field at the initial pulse. As the wave propagates through the forest, it undergoes scattering from the trees and generates multiple reflections on the trunks, as illustrated in Figure 3. The figure also reveals the reflected wavefront from the ground. Finally, in Figure 4, the pressure field appears to be a low-energy diffuse field. This is confirmed by the changing colorbar on the right of both Figures 3 and 4, which indicates a decrease in the pressure amplitude as the wave travels through the forest.

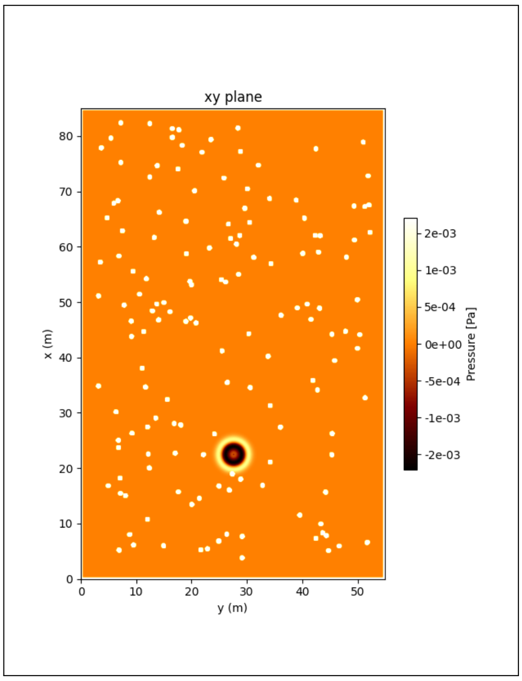

Figure 2. Pressure [Pa] field at time step 6.

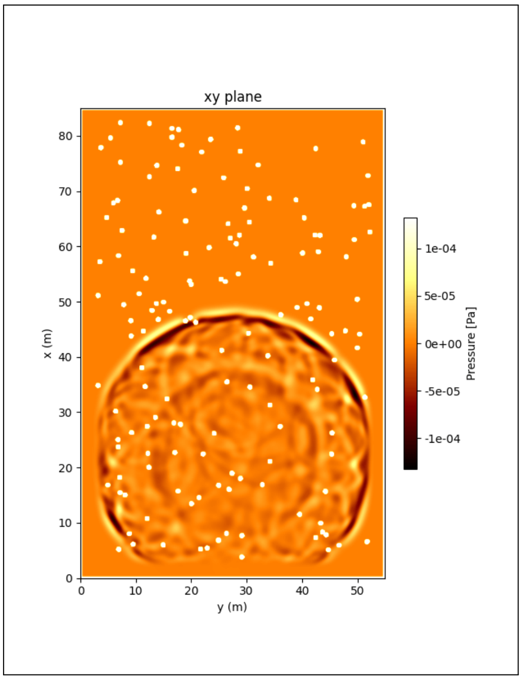

Figure 3. Pressure [Pa] field at time step 35.

3.5 Discussion

Additional results will be presented at the conference that will compare the sound levels obtained numerically with in situ measurements given in [1]. When validated, the TLM model could be used to generate impulse responses for forest environments, contributing to the development of natural environment auralization techniques. Furthermore, this model can be used for the evaluation of forests as noise-reducing barriers for the noise pollution. Additionally, TLM simulations can be applied to a wide range of scenarios for sound propagation in complex outdoor environments.

4. CONCLUSION

This paper has presented a methodology to validate the Transmission Line Matrix (TLM) method for modelling sound propagation in forests. The process involves several steps, starting with the generation of a forest geometry from the coordinates and diameters of trees listed in a CSV file. This geometry is then converted into a Cartesian mesh using the FreeCAD API, choosing appropriate impedance parameters to perform simulations. Qualitative results of wavefront propagation are given in the paper

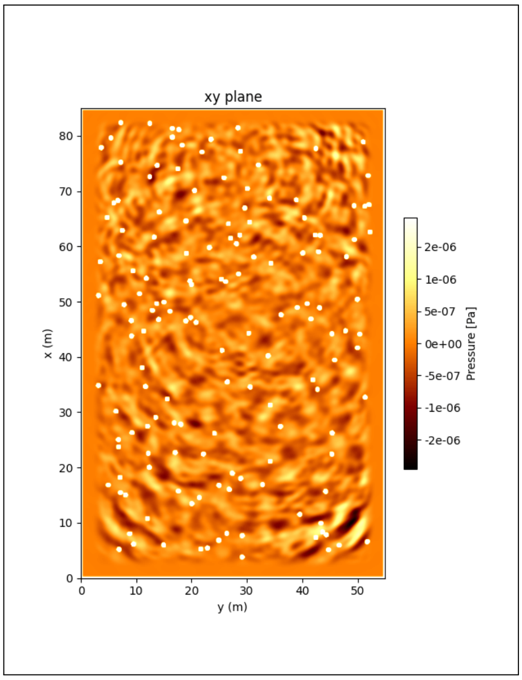

Figure 4. Pressure [Pa] field at time step 106.

that will be completed at the conference by comparisons with in situ measurements.

Future work could involve further validation of the TLM method in different forest types and under different weather conditions, as well as investigating the impact of different forest management practices on sound propagation. Additionally, the TLM method could be used to explore the effects of noise pollution on wildlife, as well as for the development of acoustic monitoring systems for forest conservation.

Overall, the results of this study show the potential of the TLM method for improving our understanding of sound propagation in forests and for facilitating the development of more effective environmental acoustics strategies.

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