PREDICTING TREE BELT NOISE SHIELDING WITH NEURAL NETWORKS

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ABSTRACT

Tree belts along roads, when well designed, are useful noise abatement measures and come with many additional ecological and human-health related advantages. Before, a methodology was developed based on simulating sound propagation with full wave models in two orthogonal planes (the so-called “split-plane” approach), showing high resemblance with full 3D simulations. But even with such a pronounced model complexity reduction, computing times stay large and need specific modeling expertise. General parameters like above ground biomass density are only first order predictors; the fine structure of the design (like e.g. the planting scheme) will make a (non-deep) tree belt a viable noise abatement solution or not. Given this high complexity of the sound propagation problem, advanced techniques like artificial neural networks were explored to predict the noise shielding performance of tree belts based on a large dataset of explicitly simulated setups. This opens possibilities for ultrafast evaluations in engineering methods for sound propagation outdoors, and at the same time, overcoming the current inaccuracies one gets when the effect of vegetation is to be predicted.

1. INTRODUCTION

A noise map has become an important policy instrument nowadays. It is not only used to assess the impact of environmental noise on the population, but also to visualize the spatially dependent decibel reduction that is to be expected by putting an abatement scenario into practice.

The accuracy of noise maps should be seen in relation to the complexity incorporated in mainly the noise propagation module used. Sound propagation outdoors faces many challenging features [1] like the occurrence of different types of grounds, terrain undulations and meteorological effects. In an urban environment, complex diffraction patterns appear and there are many reflections in between (non-flat) facades. In order to keep calculation times realistically, the propagation models rely on ray tracing and various simplifications are made. Especially in micro-environments where complex sound propagation is involved (e.g. sound propagation towards an enclosed courtyard from a diffusely reflecting street canyon), sound pressure level predictions might be far off [2]. As a result, a noise map is often considered to only give an impression of the sound field by a set of spatially distributed sources in a particular environment. In this view, using noise maps for designing a noise abatement solution might be inappropriate.

Nevertheless, given its popularity and ease of use in communication to authorities and laymen, many times noise abatement solutions are designed by such approximate propagation models, even for cases where computing times are not of main concern given e.g. the limited extent of the area considered. This inevitably leads to non-optimal design of the measures taken, or to a simple neglect of abatement types not captured in noise mapping software like e.g. a dense tree belts placed along a road [3] or a natural or shape-optimized berm [4-5].

In this work, focus is on modeling the effect of tree belts along roads. This noise abatement is not captured in most noise mapping propagation modules, and if it appears, the accuracy is typically poor. Such cases were analyzed in detail by means of full-wave numerical simulations before [3]. Specific scenarios related to the planting scheme, diameter of the trunks, spacing in between the trees and the degree of randomness involved can be accurately predicted and do impact its acoustic performance [3]. Calculation times, however, are many orders of magnitude too high for use in noise mapping calculations. In this work, it is studied to what extent the results of such predictions can be used to come to ultrafast assessments by means of (shallow) artificial neural networks (ANN).

2. TREE BELT PERFORMANCE DATASET

The dataset for the development of the ANN is based on the work initiated in Ref. [1] and was extended with additional parameter combinations here. The case of a 4-lane road, with an equal distribution of the traffic over the lanes, containing 15 % heavy vehicles, all driving at 70 km/h, was considered, which could be appropriate for suburban road traffic.

Although the attenuation during propagation could have been considered separately from the source power modeling, the fitting in the current work was done on total A-weighted road traffic noise insertion loss of the tree belt, relative to sound propagation to a reference case. The latter is a similar case with only grassland between the border of the road and the receiver. The ground not covered by the road and the tree belt was considered as grassland as well in the tree belt scenarios.
The numerical modeling uses the “split-plane” approach [3] (see Fig. 1), where sound propagation is considered in a vertical plane to capture the interaction between sound waves and the various ground types (including impedance discontinuities between rigid ground, forest floor and grassland) with a Parabolic Equation (PE) method [6]. In the second plane, parallel to the ground and normal to the first plane, the multiple scattering by the tree trunks is modeled with the finite-difference time-domain (FDTD) method adapted for use in outdoor sound propagation applications [7]. It is then assumed that the height of the trunks are of minor importance only, and interactions between sound propagation in the horizontal and vertical plane are fully absent. Both assumptions are backed up by comparison with full 3D calculations at scatterer densities larger than the ones to be found in realistic tree belts, and by in-situ measurements [8-9]. For a more detailed description of the modeling process, the reader is referred to Ref. [3].

The road surface is modeled as a rigid plane. The forest floor and grassland are approached as rigid-porous media with appropriate parameters deduced from short-range in-situ measurements [10].

The bark of trees is able to absorb sound to a limited extent. Detailed measurements have been performed [11] showing some differences in between species. In the dataset, frequency independent absorption coefficients ranging from 0 to 7.5% (upon normal incident) were considered. Differences in this very low absorption range were shown to impact the tree belt noise shielding.

### 3. PARAMETER SELECTION FOR THE FITTING

In order to develop an ANN, a set of input parameters must be defined based on the numerical simulations. Although some parameter choices are rather straightforward (like depth of the tree belt - here defined normal to the road, distance of the receiver relative to the border of the road, diameter of the trunks, and the “filling fraction” of the tree belt), other parameters might be less trivial to define.

Simulations showed that a rectangular tree planting scheme might be efficient [3]. Also for other schemes (like a triangular setting, or “facade-centered cubic” arrangement), the distinction between spacing normal to the road and parallel to the road is followed. There, a virtual rectangular arrangement is considered, but with missing elements. Nevertheless, these missing elements will emerge in the lower filling fractions relative to a fully populated rectangular scheme with similar spacing in between the trees. This means that the shortest distance between neighboring scatterers is not used as this would not allow defining rectangular planting schemes.

Various scenarios were analyzed including missing trees in the belt, randomness in position of the trunks and in its diameter. For these, the percentage omitted trees and the percentage randomness (relative to either the spacing between the trees, or relative to its diameter) were used as independent predictors.

For comparison, the same dataset was used to feed a standard multiple linear regression approach to predict the road traffic noise insertion loss.

### 4. ANN DESCRIPTION AND PERFORMANCE METRICS

Matlab’s ANN functions for fitting were used, implementing a two-layer feed-forward network, with sigmoid activation functions in the hidden layer. The number of hidden neurons was set to 10.

The number of identified inputs is 14. The single output is the simulated road traffic noise insertion loss as predicted with the full-wave numerical method which is considered here as the “ground truth”, thus assuming supervised learning. The number of cases is 245, involving various parameter combinations that have been
explicitly simulated with the full wave model described in Section 2.

The default 70/15/15 percentages for training, testing and validation of the ANN were taken. The training was performed with the Levenberg-Marquardt algorithm. The root mean-squared errors (RMSE) on the insertion losses for the training and validation subsets were 0.04 and 0.2 dBA, respectively.

5. MULTIPLE LINEAR REGRESSION (MLR) MODELING

As a result of stepwise parameter selection and consequently removing (independent) parameters whose coefficients do not differ statistically significantly from 0 at the 5% significance level, the following MLR model was obtained and reads, using Wilkinson’s notation:

\[ IL_{dBA} = d1 + d2 + \text{depth} + r + \text{abs} + ff \]  \( (1) \)

where \( d1 \) is the spacing in between the trees along the road length axis, \( d2 \) is the spacing normal to it, \( \text{depth} \) is the depth of the tree belt, \( r \) is the diameter of the trunks, \( \text{abs} \) is the absorption coefficient of the trunks, and \( ff \) is the filling fraction.

Only fixed effects were modeled and a normal distribution of the outcomes was assumed. Interactions between the parameters were not considered in the MLR analysis.

6. INSERTION LOSS FITTING ACCURACY

The scatter plots Figs. 2 and 3 show the full-wave simulated insertion losses versus the insertion losses obtained by the two fitting approaches, for the MLR and ANN, respectively.

The MLR fitting proves to be a valid model, with a RMSE of 0.6 dBA. Nevertheless, for most targeted insertion losses, the variations in the predictions are still quite large, amounting to roughly 3 dBA. Relatively spoken, this is a significant error in the prediction of the tree belt efficiency, which is typically below 5-6 dBA for the 15-m deep belts that were most prominent in the dataset.

Especially the specific combinations of tree belt parameters that give larger insertion losses than the “average” response are of main interest. These will make a tree belt a noise abatement solution worth to be considered or not.

7. CONCLUSIONS AND OUTLOOK

With the use of an ANN, accurate evaluations are possible for a complex sound propagation problem like transmission through a tree belt. Features beyond scatterer density (or filling fraction of the tree trunks) can be captured.

This opens possibilities for superfast evaluations in noise mapping propagation modules, avoiding the neglect of noise abatement measures simply because they cannot be (accurately) predicted or represented.
Although the current study focuses on tree belt road traffic noise shielding efficiency, other sound propagation configurations that are time consuming to evaluate could be considered as well. Full-wave modeling in outdoor sound propagation applications has become mature, partly due to the continuously increasing access to computing infrastructure, and thus provides accurate predictions on which models like ANN can be trained.

In the current evaluations, only interpolation is considered. Extrapolation beyond the parameter ranges, but also parameter combination ranges, appearing in the full-wave simulations might be more challenging. Note, however, that the use of a training, validation and test subset in the neural network procedure already prevents the potential problem of overfitting on the current dataset. Nevertheless, more work is needed to check whether interdependencies and interactions between the different parameters are truly captured.

8. REFERENCES


