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NEURAL NETWORKS FOR NOISE PREDICTION: AN AUTOMOTIVE CASE STUDY

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ABSTRACT
In the most complex cases, conventional analytical techniques for noise prediction are often unable to produce sufficiently accurate results to be of practical benefit. One such case is the prediction of automotive pass-by noise, early in the development of a new vehicle. However, this paper describes how this noise prediction problem can be posed in a manner suitable for solution by neural networks. This has been achieved by dividing it into two simpler problems, first the prediction of vehicle performance, then the prediction of pass-by noise using performance as one of the inputs. Preliminary results for both neural networks are presented and the achievable accuracy is discussed.

1 - INTRODUCTION
In the most complex cases, conventional analytical techniques for noise level prediction are often unable to produce sufficiently accurate results to be of practical benefit. One such case is the prediction of automotive pass-by noise, early in the development of a new vehicle.
All new European vehicles must complete a pass-by noise test [1]. The current EU test limit for category M1 vehicles is 74 dB(A). The limit has been lowered a number of times since its introduction, and will probably be reduced again before the test is replaced.
The pass-by noise test result depends on both the vehicle and the test procedure. The test however, aims to assess the pass-by noise of a vehicle type, so the procedure tries to minimize the effects of the test environment, the driver, the test equipment and variations in production. What remains should be solely a function of the vehicle design, which has four main noise sources. These are the powertrain, exhaust and intake which are coherent sources and the tire/road interaction which produces incoherent noise. At present, these four sources each make roughly the same contribution to the total pass-by noise. For the designer it is therefore not obvious where most effort should be made to reduce the overall vehicle noise. If a predictive model were available, designers could perform "what-if" experiments on their design. These could indicate whether the vehicle would be likely to pass the test and if not, which noise sources need the most attention. They could then be used to work out the relative cost/benefit of potential design changes. Waiting until a physical prototype is built can cause delays and require costly remedial work. Designing contingencies can lead to wasted effort.
Presently there are no 'whole vehicle' analytical models which can predict the pass-by noise given a number of vehicle parameters. However there is a large body of data describing existing vehicles and their pass-by noise test results. Neural networks were therefore identified as a technology potentially able to build a predictive model of pass-by noise from this data.

2 - NEURAL NETWORKS
Artificial neural networks can build predictive models from example data and are constructed from simple processing units called artificial neurons which are connected together to form a network [2]. They learn to solve a particular problem under the supervision of a training algorithm such as back-propagation. A set of example inputs and outputs are assembled which represent the particular problem domain. The training algorithm presents each example in turn to the network, which then produces an output value.

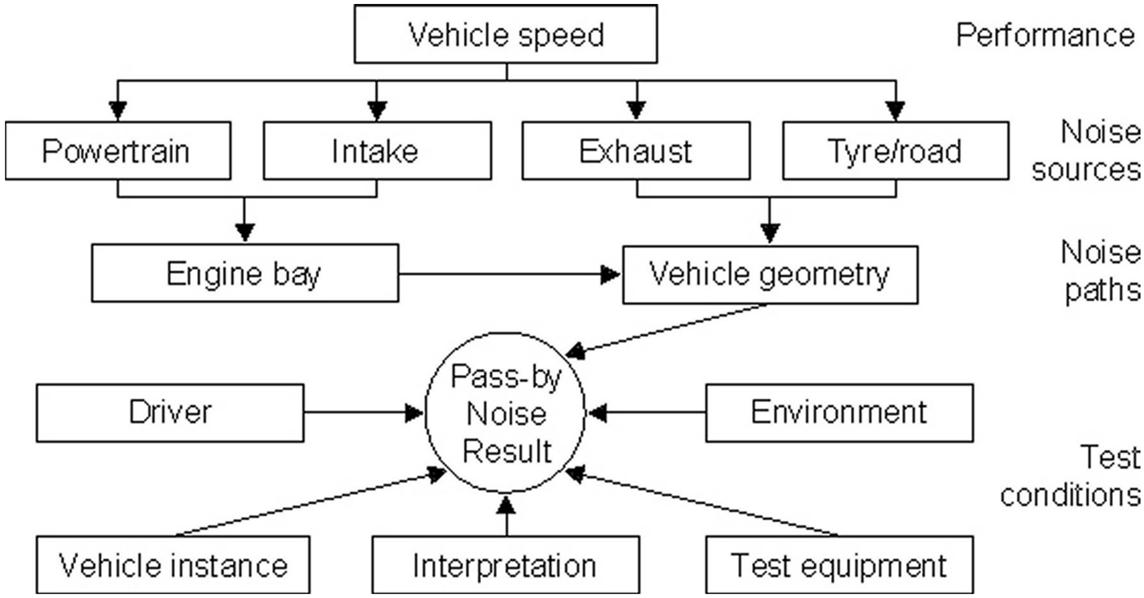

Figure 1: Contributions to pass-by noise test result.

Back-propagation uses the error between network output and the desired output to adjust the weights and biases of the network in order to minimize the error over the whole set of examples.
Once trained, a neural network works as a function approximator. A neural network with an appropriate architecture can approximate any general function to arbitrary accuracy. Neural networks generalize well, that is they produce sensible outputs when presented with previously unseen inputs. Traditional computing requires a deep understanding of the problem, and the methods and data required to solve it. With neural computing, by contrast, the problem is not solved explicitly. Rather, the solution is represented by the set of examples (the data), and "discovered" by training. This is a very useful property, since it is not possible to predict pass-by noise analytically.

3 - INPUT SELECTION AND DATA COLLECTION

The neural networks approach to pass-by noise prediction requires a database of pass-by noise test results, where both inputs and output are recorded. Before this could be compiled, it was necessary to select which inputs to use. These needed to be parameters which are believed to causally affect the noise of the vehicle and which are available at design time.
A number of NVH experts brainstormed a very large list of candidate inputs. The list was filtered to remove those which were impractical to measure, or not primary causes. The remaining were scored according to perceived importance and ease of collection. This gave a ranked list of inputs.
The problem then required a representative database being compiled of all pass-by noise tests. However initial estimates of the amount of data required, for the number of potential inputs, appeared to be greater than that available. Extra tests were therefore planned to enable the required data to be collected. In addition to collecting extra data from the normal program of pass-by noise tests, special tests were carried out to collect data for this project. The extra tests provided data from non-standard vehicles, where, for example, the exhaust had been muffled, or the undertray or engine bay lining had been removed. Such data extended the range of many input variables, and also increased their variation.
However, at the same time, the problem was broken down into two sub-problems, with lower data requirements, to enable results to be generated in a shorter time. This was achieved by splitting the problem into two stages, separating out vehicle performance which itself is a very suitable input to the pass-by noise network since it affects all four noise sources. The inputs required for this sub-problem were better known, and some analytical models already existed which could help (analytical models of vehicle performance are available, however they do not work well for diesel or turbocharged engines)

4 - RESULTS

The final version of the pass-by noise database contains a spreadsheet of 3596 rows by 163 columns, over half a million cells, representing 38 distinct vehicles. The vehicles are quite diverse and include: petrol and diesel engines; direct and indirect injection engines; front, rear and four-wheel drive vehicles;

four, five, six and eight cylinder engines; in-line and V engines; turbocharged and non-turbocharged engines; longitudinal and transverse engines; various engine bay treatments and some vehicles with muffled exhaust or intake systems.
The vehicle performance neural network, though an unplanned outcome of this research project, is proving very useful in its own right. It predicts engine exit speed to an accuracy of ±4.8%. This is not quite as accurate as the best existing analytical model. However the neural network's big advantage over the model is that it works for both diesel and turbocharged vehicles, unlike the analytical model.
The pass-by noise neural network predicts pass-by noise to ±1.4%. At the current pass-by noise limit of 74 dB(A), this is equivalent to an error of about ±1.1 dB(A). There are no whole-vehicle analytical models that can predict pass-by noise better than an engineer can guess − ±3 dB(A). The successful use of analytical or finite element models for noise studies has been limited to individual components, rather than the whole vehicle. The development of a pass-by noise neural network will therefore be of considerable use to vehicle designers. The developed methods and procedures would also be applicable within other automotive companies and also to other manufacturers faced with similar problems.
As a result of this research, vehicle designers are now using the neural networks. Initially, the networks will be used to predict performance and pass-by noise, but they will also be used to analyze the effect of changing design parameters. This will become more accurate when the networks learn mapping functions that more accurately resemble the physics of the problems. Consequently data collection and neural network development will continue. It may become possible to build more accurate and realistic neural networks with more varied, modern data and newer neural network techniques.
Since vehicle technology changes over time, the neural networks will slowly become out of date. They embody the statistical relationship between the vehicle design parameters and the performance and pass-by noise of the vehicles they were trained on. The advantage of continued data collection is therefore twofold. Periodic retraining on data from new vehicles will keep the networks current. Also, the data from older vehicles can be replaced. Furthermore, a rich supply of varied data may allow better neural networks to be trained.

5 - CONCLUSION

The use of neural networks as a technique for solving complex noise prediction problems has been established. This has been achieved through the development of a tool for predicting pass-by noise early in the development of a new vehicle. This tool consists of two neural networks. The first predicts vehicle performance, its output then being used as an input for the second which predicts pass-by noise level.
The current neural networks achieve an accuracy of ±1.4%. At the current pass-by noise limit of 74 dB(A), this equates to an error of about ±1.1 dB(A) which is considerably less than the ±3 dB(A) uncertainty currently achieved by analytical models or by engineers' best guesses.

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