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VEHICULAR TRAFFIC NOISE PREDICTION AND PROPAGATION MODELLING USING ARTIFICIAL NEURAL NETWORK

AHMED ABDULKAREEM AHMED

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VEHICULAR TRAFFIC NOISE PREDICTION AND PROPAGATION MODELLING USING ARTIFICIAL NEURAL NETWORK



AHMED ABDULKAREEM AHMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

January 2018

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

VEHICULAR TRAFFIC NOISE PREDICTION AND PROPAGATION MODELLING USING ARTIFICIAL NEURAL NETWORK

By

AHMED ABDULKAREEM AHMED

January 2018

Chairman : Professor Biswajeet Pradhan, PhD Faculty : Engineering

Noise is a sound of variable frequencies considered as one of the leading causes of environmental challenges faced in many cities due to high traffic volume and has a harmful effect on the population. Discomforting issues such as interference with communication, speech, effects on attention, people's health and well-being, psychological and cardiovascular alterations are some of the major disturbances caused to our environment. This thesis presents a Neural Network (NN) model developed to predict and simulate the propagation of vehicular traffic noise in a dense residential area at the New Klang Valley Expressway (NKVE) in Shah Alam Seksyen 13, Malaysia. The proposed model comprises of two main simulation steps: i) the prediction of the vehicular traffic noise using NN in order to obtain the final noise maps for weekends and weekdays; ii) The simulation of the propagation of the traffic noise emission in the study area using a mathematical model to define the propagation of the study area. By utilizing the Chi-square statistical analysis, the former model was developed with six selected noise predictors. These predictors include the number of motorbikes, the sum of vehicles, car ratio, large vehicles ratio (truck, lorry, and bus), highway density, and a LiDAR derived Digital Surface Model-DSM. The neural network and its hyperparameters were optimized through a systematic optimization procedure based on a grid search approach. In contrast, the noise propagation model was developed based on principle concepts of traffic noise. This model was based on road geometry, barriers, distance, the interaction of air particles, and weather parameters which are applied to Geographic Information System (GIS). The noise measurement was carried out continuously at 15-min intervals and the data were analyzed by taking the minimum, maximum, and averages of every data set recorded during the day. The measurement was carried out four times a day (morning, afternoon, evening, and midnight) all through two-days of the week (Sunday and Monday). The optimal radial basis function NN model was used which comprised of 17 hidden layers with a back-propagation algorithm. The

learning rate of 0.05 and a momentum of 0.9 were used in this experiment. The results showed that the proposed NN model achieves a validation accuracy of 78.4% and an error in noise prediction with less than 4.02 dB. The model also outperforms the Multilayer Perceptron (MLP) model by almost 5% of validation accuracy and 0.3 dB in noise level prediction. In addition, the three most influential parameters on traffic noise were car ratio, the sum of vehicle, and large vehicle ratio. Overall, the proposed models were found to be promising tools for traffic noise assessment in dense urban area of the study area.

Keywords: traffic noise; noise prediction; noise propagation, neural networks, mathematical models.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PREDIKSI BUNYI LALU LINTAS TRAFIK KENDERAAN DAN PEMODELAN MENGGUNAKAN NEURAL NETWORKS

Oleh

AHMED ABDULKAREEM AHMED

Januari 2018

Pengerusi : Profesor Biswajeet Pradhan, PhD Fakulti : Kejuruteraan

Hingar adalah pelbagai frekuensi bunyi dan merupakan satu daripada punca utama cabaran persekitaran yang dihadapi di bandar oleh kerana aliran trafik yang tinggi dan mempunyai kesan berbahaya terhadap populasi. Isu isu ketidakselesaan seperti gangguan komunikasi, pertuturan, efek tumpuan, masalah kesihatan dan kesejahteraan, psikologi dan perubahan kardiovaskular merupakan antara punca gangguan utama terhadap alam sekitar kita. Tesis ini memaparkan model Rangkaian Saraf (NN) yang dibangunkan untuk mejangkakan dan mensimulasikan penyebaran bunyi bising lalu lintas dari kenderaan dalam kawasan berpenduduk padat di Lebuhraya Baru Lembah Klang (NKVE), Malaysia. Model yang dicadangkan terdiri daripada dua langkah utama simulasi: i) ramalan bunyi bising lalu lintas dari kenderaan menggunakan NN untuk mendapatkan peta hingar akhir pada hujung minggu dan hari biasa; ii) Simulasi pelepasan penyebaran bunyi bising lalu lintas di kawasan kajian menggunakan model matematik untuk mentakrifkan penyebaran di kawasan kajian. Dengan menggunakan analisis statistik Chi-square, model sedia ada dibangunkan dengan enam pilihan peramal bunyi. Peramal-peramal ini termasuk bilangan motosikal, jumlah kenderaan, nisbah kereta, nisbah kenderaan berat (trak, lori dan bus), ketumpatan lebuhraya, dan Model Permukaan Digital-DSM Dapatan LiDAR. Rangkaian seni bina dan hiperparameternya dioptimumkan melalui prosedur optimasi bersistematik berdasarkan pendekatan carian grid. Sebaliknya, model penyebaran hingar dibangunkan berdasarkan konsep asas hingar lalu lintas. Model ini berlandaskan pada geometri jalan, halangan-halangan, jarak, interaksi zarah udara, dan parameter cuaca yang digunakan pada Sistem Informasi Geografik (GIS). Kiraan hingar telah dijalankan secara berterusan dengan selang 15 minit dan data telah dianalisa dengan mengambil kira minimum, maksimum dan purata setiap data yang direkodkan sepanjang hari. Kiraan telah dilakukan sebanyak empat kali sehari (pagi, tengah hari, petang, dan tengah malam) sepanjang dua hari dalam seminggu (Ahad dan Isnin). Model fungsi asas jejari optimal NN telah digunakan yang terdiri daripada 17 lapisan rahsia dengan algoritma back-propagation. Kadar pembelajaran



sebanyak 0.05 dan momentum sebanyak 0.9 telah digunakan dalam eksperimen ini. Hasil kajian menunjukkan bahawa model NN yang dicadangkan mencapai ketepatan pengesahan sebanyak 78.4% dan kesilapan ramalan hingar kurang daripada 4.02 dB. Model ini juga melepasi model Multilayer Perceptron (MLP) dengan melebihi 5% ketepatan pengesahan dan 0.3dB dalam tahap ramalan hingar. Tambahan pula, tiga parameter hingar lalu lintas paling berpengaruh ialah nisbah kereta, jumlah kenderaan, dan nisbah kenderaan berat. Secara keseluruhannya, model yang dicadangkan didapati dapat dijadikan alat yang meyakinkan untuk penilaian hingar lalu lintas di kawasan berpenduduk padat di kawasan kajian.



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v

I certify that a Thesis Examination Committee has met on 19 January 2018 to conduct the final examination of Ahmed Abdulkareem Ahmed on his thesis entitled "Vehicular Traffic Noise Prediction and Propagation Modelling using Artificial Neural Network" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Hussain bin Hamid, PhD

Associate Professor Faculty of Engineering Universiti Putra Malaysia (Chairman)

Helmi Zulhaidi bin Mohd Shafri, PhD Associate Professor Faculty of Engineering Universiti Putra Malaysia (Internal Examiner)

Abd Manan Samad, PhD Professor Sr. Universiti Teknologi MARA Malaysia (External Examiner)

NOR AINI AB. SHUKOR, PhD Professor and Deputy Dean School of Graduate Studies Universiti Putra Malaysia

Date: 27 February 2018

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Biswajeet Pradhan, PhD Professor Faculty of Engineering Universiti Putra Malaysia (Chairman)

Fauzan Bin Mohd Jakarni, PhD

Senior Lecturer Faculty of Engineering Universiti Putra Malaysia (Member)

> **ROBIAH BINTI YUNUS, PhD** Professor and Dean School of Graduate Studies Universiti Putra Malaysia

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Signature: Name of Chairman of Supervisory	
Committee:	Professor Dr. Biswajeet Pradhan
Signature:	
Name of Member of Supervisory	
Committee:	Dr. Fauzan Bin Mohd Jakarni

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LIST OF ABBREVIATIONS

	EIA	Environmental Impact Assessment
	NN	Neural Network
	GIS	Geographic Information System
	LiDAR	Light Detection And Ranging
	NKVE	New Klang Valley Expressway
	MLP	Multilayer Perceptron
	Leq	Equivalent Continuous Level
	GPS	Global Position System
	ANN	Artificial Neural Networks
	BP	Back-Propagation
	L–M	Levenberg–Marquardt
	UAE	United Arab Emirates
	ORNAMENT	Ontario Ministry of Transport Road Traffic Noise Model
	BSTN	Basic Statistical Traffic Noise Model
	LMA	Levenberg-Marquardt Algorithm
	dB	Decibel Level
	DSM	Digital Surface Model
	DEM	Digital Elevation Model
	IDW	Inverse Distance Weighted
	RPC	Rational Polynomial Coefficients
	GCPs	Field Measured
	WS	Wind Speed
	SoV	Sum of Vehicles
	CR	Car Ratio
	HD	Highway Density
	MR	Motorbike Ratio
	М	Number of Motorbikes
	С	Number of Cars
	HV	Heavy Vehicles
	HVR	Heavy Vehicles Ratio
	RBF	Radial Basis Function

BFGS	Broyden–Fletcher–Goldfarb–Shanno
RBFT	Radial Basis Function Training Algorithm
LAeq	Average Equivalent Noise
Е	Noise Emission of Vehicles
Crg	Road Geometry Coefficient
Cb	Barrier Coefficient
C_d	Distance Coefficient
Cair	Air Interaction Coefficient
Cw	Weather Coefficient
Т	Time
D	Day
Lw	Average Continuous Equivalent Noise For Weekdays And Weekends
Ls	Average Continuous Equivalent Noise For Weekends
Lm	Average Continuous Equivalent Noise For Weekdays
L morning	Average Continuous Equivalent Noise For Morning
Lafternoon	Average Continuous Equivalent Noise For Afternoon
Levening	Average Continuous Equivalent Noise For Evening
Lnight	Average Continuous Equivalent Noise For Night
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
WHO	World Health Organization standards
DOE	Department Of Environment
СРСВ	Central Pollution Control Board
IDW	Inverse Distance Weighting
JTG B03-2006	Specifications for Environmental Impact Assessment of Highways
HJ2.4-2009	Technical Guidelines for Noise Impact Assessment
WG-AEN	Working Group on Assessment of Exposure to Noise

CHAPTER 1

INTRODUCTION

1.1 Introduction

Highway networks play a major role in every country's economy and in providing accessibility services to the citizens. Making these infrastructures vital and efficient is a priority in every developing world. However, traffic noise is a major problem on highways contributing to the overall noise pollution. The primary causes of traffic noise are heavy (truck, lorry, and bus) and medium (two and four wheel) cars, motorbikes, and other traffic and road geometrical factors (slope, curves, and intersect). There are different physical and psychological effects for every inappropriate noise level (Morley et al., 2015).

High traffic noise affects the human health and comfort including hearing defects, high blood pressure, irregularity of heart rhythm, and ulcers (Harman et al., 2016; Lee and Fleming, 1996; Ozer et al., 2009; Steele, 2001). In addition, there are other effects such as disorders, sleeplessness and sleep late, irritability and stress. Also, effects on work performance such as reduction in productivity, has also been reported (Ozer et al., 2009). Besides, collecting noise measurements on high-speed highways can be expensive, time-consuming, and dangerous. Therefore, traffic noise models are highly significant and can go a long way in reducing the challenges aforementioned. Furthermore, at the design stage, traffic noise cannot be measured. Thus, it requires traffic noise models to provide data for efficient and comfortable traffic design for the living environment in industrial, commercial, and residential areas. The analysis and modeling of the traffic noise facilitate proper planning of environmentally friendly road networks.

Prediction models of vehicular traffic noise are effectively used as decision-support tools for traffic noise prediction and simulation on highways (Molina et al., 1998). There are many traffic noise prediction models (Steele, 2001), and the early method among them was based on constant speed experiments with zero acceleration and prediction based on the equivalent continuous level (L_{eq}) by considering multiple vehicles for traffic over a specific period (Garg and Maji, 2014; Steele, 2001). The recent methods are mostly based on regression analysis using statistical and soft computing algorithms (Ragettli et al., 2016a; Singh et al., 2016). However, these models are often developed based on experimental data. As such, each of the models is highly affected by the composition of uniqueness of the traffic flow and characteristics of the measurement locations. This main disadvantage of the traffic noise prediction models limits their use universally (Rahmani et al., 2011). The models fail to be generalized due to the local conditions such as vehicle type and weather conditions (Hamad et al., 2017).



Therefore, this study proposes efficient techniques and assessment tools to generate cost-effective traffic noise maps in GIS and evaluates the impacts of the measured/predicted noise on surrounding population and properties. Despite many models that used for predicting traffic noise emissions such as statistical, regression, GIS and GPS techniques in literature, these models varies substantially from one to another. In this approach, road geometry and surrounding environments will be modelled by very high-resolution LiDAR point clouds and satellite images. Major and necessary attribute information will be used together with the produced road geometric model to compute and visualize traffic noise distribution in the study area.

1.2 Problem Statement

Traffic noise is a nuisance generated from highway traffic which contributes to the overall noise pollution in residential and other communal areas around cities. The traffic noise resulted from heavy and medium cars, motorbikes, other traffic as well as road geometry factors lead to physical and psychological impacts to our body system (Ruiz-Padillo et al., 2014); however, these vehicles are necessary for our daily transportation. Thus, the necessity to develop a method to overcome these challenges at the early stages of the construction design of the highways is crucial. This is in line with Environmental Impact Assessment (EIA) requirement that it is compulsory to carry out a noise assessment before any pavement is constructed (Gruen et al., 1995).

Therefore, many models are proposed to predict and propagate noise level to be used for highway designs (Steele, 2001; Reed et al., 2012). Various parameters have been used in different models which affect the accuracy standards between the experimental and the proposed models. Although, these studies showed the feasibility of using Neural Network (NN) for predicting traffic noise in various geographic locations and under different situations. However, their black box nature is the major setback which is highly data-oriented. Thus, this thesis presents a traffic noise prediction model based on NN to improve the performance of such models through architecture and hyperparameter optimization in addition to model parameters selection via statistical analysis.

Various propagation models have been carried out by many researchers, and in every case, different parameter is considered. Many features affect the spatial patterns of noise propagation in the natural environment. Sound energy absorption in the atmosphere depends on certain features such as air temperature, elevation, humidity and types of traffic flow. The noise levels in the roadway model were modified by the sufficient ground along the propagation path. Thus, the necessity is to develop a noise propagation model to overcome these challenges at the specific study area, especially on high-speed highways which could be dangerous and expensive.

1.3 Objectives of the Study

The current research aims to model traffic noise coming from highways in Shah Alam Seksyen 13, Malaysia and produce noise maps in GIS using LiDAR techniques. The specific objectives are as following:

- 1. To identify traffic noise predictors and collect relevant data of traffic flow and noise measurements for the noise modeling and mapping.
- 2. To develop a prediction model for traffic noise estimation using Neural Network model.
- 3. To develop a mathematical model to measure and predict traffic noise propagation level in the study area from vehicle traffic flow.

1.4 Research Questions

This thesis comprehensively addresses the following research questions:

- 1. What is the method and instrument to collect, estimate, and prepare input data such as traffic volume, noise measurements?
- 2. What are the factors used for traffic noise prediction and which is the most efficient model to be employed?
- 3. What would traffic noise propagation equation be used to develop noise map?

1.5 Significance of the Study

Noise models provide quantitative relationships between traffic volumes and traffic noise, which are important to make predictions on noise levels of newly planned expressways. These methods will be beneficial to government establishments to assess the Environmental Impact Assessment (EIA) that include noise pollution. This is one of the mandatory requirements to be carried out for all new infrastructural projects (Gershon, 2015). Noise pollution assessment by consultancy agencies is costly due to the demands of experts and advanced noise modeling systems. However, GIS-based noise assessment tools are easy to use and inexpensive and can be used by governments, thus, reducing EIA projects budgets.

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In addition, noise models also give a general view of greenhouse gas emissions (Woodcock et al., 2009). Traffic noise standards are changing with the increasing of city development. This requires a periodic assessment of traffic noise and potential solutions to be rapidly and easily determined. Noise mapping is a handy tool for generating information about environmental impacts and enabling the visualization of noise pollution in the urban landscape. This could help to improve highway facilities provided for transportation systems in advanced nations such as Malaysia.

Several concerns about traffic noise from residents in urban areas have been reported in newspapers, magazines and other mediums especially for newly planned expressways such as Kinrara–Damansara Expressway (KIDEX). Noise maps generated by GIS with the aid of modeling and simulations can be published online so that residents can have access to them and could check the situations by themselves before and after the construction of such expressways.

1.6 Scope of the Study

This study is limited to evaluation of noise pollution around Tolls in Shah Alam Seksyen 13 for smart roads and efficient traffic noise control for future traffic design and planning. The proposed model is inexpensive and easy-to-use engineering methods for traffic noise impact assessment. Also, the noise maps generated by GIS can be available by which residents can check the situations before and after the construction of such expressways via modeling and simulations.

The research covers noise pollution around the residential, commercial, industrial, public, educational, religious, and other parts of the environment in Shah Alam Seksyen 13. (31 cm) panchromatic resolution and (1.24 m) multispectral resolution image satellite worldview-3 was used to build Geodatabase and cloud points (LiDAR data) to acquire valuable information for the proposed model.

Neural Network (NN) and Chi-square statistical analysis were utilized for the proposed predicted model and propagation model respectively. Parameters such as number of cars, number of heavy vehicles, number of motorbikes, sum of vehicles (Sov), car ratio (CR), heavy vehicle ratio (HVR), motorbike ratio (MR), highway density (HD), a Digital Surface Model (DSM), a Digital Elevation Model (DEM), and wind speed (WS) was employed in the NN model. Also, factors such as wind direction and speed, barriers such as tall buildings, and the interaction of air particles with the noise waves are employed in the propagation model.

1.7 Thesis Outline

This section presents the layout of thesis and the content of each chapter as follow:

Chapter one presents the background to the need for the environmental noise assessment of highway traffic on settlements Shah Alam Seksyen 13 and also the aim and objective of the study. The problem statement and scope of the research work are also presented.

Chapter two presents the literature review on some aspects concerning noise and its effects on inhabitants. Also, research works conducted on prediction and propagation models used in literature is reported in this chapter.

Chapter three present the research methodology employed in this experiments. The procedure used, equipment used, prediction and the propagation models used and the features considered in the experiment to obtain an accurate result is discussed in details.

Chapter four describes the result obtained from the experiments carried out on the prediction and the propagation of noise generated from vehicular traffic along the study area. Various analytical tools used were discussed and compared for optimum result.

Chapter five presents the conclusions and recommendations based on the data obtained and the result of the analysis carried out for further investigation or action.

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