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Automated classification of urban locations for environmental noise impact assessment on the basis of road-traffic content

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ABSTRACT

Urban and road planners must take right decisions related to urban traffic management and controlling noise pollution. Their assessments and resolutions have important consequences on the annoyance of population exposed to road-traffic-noise and controlling other environmental pollutants (e.g. NOx or ultrafine particles emitted by heavy vehicles). One of the key decisions is the selection of which noise control actions should be taken in sensitive areas (residential or hospital areas, school areas etc), that could include costly measures such as reducing the overall traffic, banning or reducing traffic of heavy vehicles, inspection of motorbikes sound emission, etc. For an efficient decision-making in noise control actions, it is critical to classify a given location in a sensitive area according to the different prevailing traffic conditions.

This paper outlines an expert system aimed to help urban planners to classify urban locations based on their traffic composition. To induce knowledge into the system, several machine learning algorithms are used, based on multi-layer Perceptron and support vector machines with sequential minimal optimization. As input variables for these algorithms, a combination of environment variables was used. For the development of the classification models, four feature selection techniques, i.e., two subset evaluation (correlation-based feature-subset selection and consistency-based subset evaluation) and two attribute evaluation (ReliefF and minimum redundancy maximum relevance) were implemented to reduce the models' complexity. The overall procedure was tested on a full database collected in the city of Granada (Spain), which includes urban locations with road-traffic as dominant noise source. Among all the possibilities tested, support vector machines based models achieves the better results in classifying the considered urban locations into the 4 categories observed, with values of average weighted *F*-measure and Kappa statistics (used as indicators) up to 0.9 and 0.8. Regarding the feature selection techniques, attribute evaluation algorithms (ReliefF and mRMR) achieve better classification results than subset evaluation algorithms in reducing the model complexity, and so relevant environmental variables are chosen for the proposed procedure. Results show that these tools can be used for addressing a prompt assessment of potential road-traffic-noise related problems, as well as for gathering information in order to take more well-founded actions against urban road-traffic noise.

1. Introduction

1.1. Urban road-traffic and noise

Road-traffic is known to be one of the main sources of pollution in urban environments (Nedic, Despotovic, Cvetanovic, Despotovic, & Babic, 2014). In many European urban areas, the road-traffic has been found as the predominant source of noise and most airborne pollutants (Can et al., 2011b). Both noise and air pollution are major environmental stressors that may lead to important psychological or physiological effects (Foraster et al., 2011). In terms of environmental noise, the influence of road-traffic-noise on human health has been analyzed by several studies (Babisch, 2006; Babisch et al., 2013; Brink, 2011; Caciari et al., 2013; Fyhri & Klaboe, 2009; Ising & Krupa, 2004; Muzet, 2007; Pirrera, De Valck, & Cluydts, 2010), which pointed out the road-traffic-noise not only as the most annoying noise source in urban environments (Calixto, Diniz, & Zannin, 2003), but also as a concern for public

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health and environmental welfare (Kassomenos, Vogiatzis, & Bento Coelho, 2014). Furthermore, road-traffic-noise influences property prices in urban areas (Blanco & Flindell, 2011).

An important aspect to be considered is the composition of the road-traffic. The appearance of heavy vehicles and powered two wheelers (motorbikes and mopeds) in traffic lead to higher noise levels and reported annoyance (Braun, Walsh, Homer, & Chuter, 2013; Paviotti & Vogiatzis, 2012). Moreover, these road vehicles have been found as the most prevalent noticed-sound-events (NSE) in urban environments (Torija, Ruiz, Alba-Fernandez, & Ramos-Ridao, 2012). Under the assumption that sound has to be noticeable in order for it to contribute to an overall impression of annoyance, the NSE is a crucial factor to be considered for the evaluation of road-traffic-noise annoyance (De Coensel et al., 2009). Therefore, a tool for the identification of NSE might be used for the elaboration of action plans against environmental noise in urban environments.

Due to the good correlations found between noise levels and traffic intensity, some authors have approached the estimation of traffic parameters from recorded sound levels (Can et al., 2011a; Torija & Ruiz, 2012). Thus, for instance, Torija and Ruiz (2012) developed a series of classifiers to detect the urban scenarios where the percentage of heavy vehicles or motorcycles/mopeds is greater than a given threshold.

1.2. Applications of machine learning in environmental noise modeling

Machine learning algorithms have been widely applied to real-world environmental applications. As two of the most applied machine learning methods, artificial neural network (ANN) and support vector machine (SVM) are powerful algorithms for classification and regression problems. Thus, ANN- and SVM-based models have been developed in research fields such as, air pollution (Hájek & Olej, 2012), geology (Anifowose, Labadin, & Abdulraheem, 2015; Feng, Zhang, Zhang, & Wen, 2015), hydrology (Cho et al., 2014; Lafdani, Nia, & Ahmadi, 2013; Tan, Yan, Gao, & Yang, 2012; Xu & Liu, 2013), meteorology (Mercer, Dyer, & Zhang, 2013; Wu, Long, & Liu, 2015), renewable energy (Ekici, 2014; Gnana Sheela & Deepa, 2013; Mena, Rodríguez, Castilla & Arahal, 2014; Yadav & Chandel, 2014; Yadav, Malik, & Chandel, 2014; Yaïci & Entchev, 2014; Zeng & Qiao, 2013), or transportation (Jiang, Zhang, & Chen, 2014; Li et al., 2014; Ma, Tao, Wang, Yu, & Wang, 2015; Zhu, Cao, & Zhu, 2014).

Regarding noise related applications, several authors have used ANN algorithms to develop prediction models. Thus, Givargis and Karimi (2010) presented a multi-layer Perceptron (MLP) model which uses 5 input variables (hourly traffic flow, percentage of heavy vehicles, hourly mean traffic speed, gradient and angle of view) for the estimation of hourly A-weighted sound pressure level ($L_{Aeq,\ 1\ h}$) in roads in Tehran at distances under 4 m from the near-side carriageway edge. In this work no significant difference was detected between the performance of the developed neural network and a calibrated version of the CORTN model (UK Calculation of Road Traffic Noise). Kumar, Nigam, and Kumar (2014) applied a multi-layer feed forward back propagation (BP) neural network, trained by Levenberg–Marquardt (L–M) algorithm, to develop an ANN model for predicting highway traffic noise. This model accurately estimated the 10 percentile exceeded sound level (L_{A10}) and the L_{Aeq} descriptor by accounting the input parameters found as more relevant to Indian highway traffic conditions (traffic volume, heavy vehicle percentage and average vehicle speed). Nedic et al. (2014) used 5 input variables (number of light motor vehicles, number of medium trucks, number of heavy trucks, number of buses and the average traffic flow speed) for the development of an ANN model for L_{Aeq} prediction in Serbian roads, which outperformed some classical noise prediction models. In order to assess road-traffic-noise in urban environments, Cammarata, Cavalieri, and Fichera (1995), using data collected with typical features of commercial, residential and industrial area, and with number of cars, number of motorcycles, number of trucks, average height of the buildings and width of the road as input variables, proposed a two cascading level neural architecture, where at the first level a learning vector quantification (LVQ) network filters the data discarding all the wrong measurements, while at the second level the BP algorithm predicts the sound pressure level (L_{Aeq}) in urban environments. Genaro et al. (2010) included 25 input variables, which were found as the whole variable set used by all the traditional noise prediction models evaluated. In this work, a MLP model was implemented to predict L_{Aeq} descriptor using data samples from the city of Granada (Spain). Also, a principal component analysis (PCA) was used to simplify the model (up to 11 input variables). This model outperformed the traditional noise prediction models. Torija, Ruiz, and Ramos-Ridao (2012), using a set of variables for the characterization of sound emission and propagation (20 input variables) and 821 samples collected in urban environments (Granada, Spain), developed an ANN model (trained by Levenberg–Marquardt variant with Bayesian regulation back-propagation algorithm) for the estimation of the L_{Aeq} descriptor, but also the estimation of parameters related to the temporal structure and spectral composition of urban sound environments ($L_{31.5-125\ Hz}$, $L_{160-1600\ Hz}$, $L_{2-10\ kHz}$, TSLV and CF). Moreover, a reduction of the input variables (up to 14) based on the analysis of the correlation coefficients and the distribution of the test residuals were performed.

Other applications of ANN in the acoustics field have been related to classification issues. Sánchez-Pérez, Sánchez-Fernández, Suárez-Guerra, and Carbajal-Hernández (2013) developed a model for aircraft classification with an identification performance above 85%. This model was based on the take-off noise signal segmentation (four segments) in time. Once extracted the different aircraft noise patterns, by using Linear Predictive Coding (LPC), the classification was addressed with the implementation of four parallel MLP (one for each segment). Moreover, a wrapper feature selection method was used for reducing the computational cost. Márquez-Molina, Sánchez-Fernández, Suárez-Guerra, and Sánchez-Pérez (2014) developed an aircraft take-off noises classification model. For the obtaining of the input variables, a feature extraction process of aircraft take-off signals was conducted through a 1/24 octave analysis and Mel frequency cepstral coefficients (MFCC), and the classification model was made by using two parallel feed forward neural networks (FFNN), achieving a total effectiveness of 83%. Torija and Ruiz (2012) performed an analysis to identify the 1/3-octave bands most influential on road-traffic intensity. Based on the gathered information, a series of MLP-based model were developed for the estimation of the overall road-traffic intensity and for the detection of conditions with percentage of heavy vehicles or motorbikes/mopeds larger than the usual values.

Although SVM algorithms have not been as extensively used in noise-related issues as ANN, some interesting applications could be highlighted. Barkana and Uzkent (2011) presented two stages classification method for the automatic recognition of environmental noises, where first, a feature extraction based on the pitch range was conducted, and second, SVM and k-means algorithms as classification techniques were trained on the extracted features. SVM classifier outperformed k-means by about 7%. Based on a previous study (Torija, Ruiz, & Ramos-Ridao, 2013) on the differentiation of urban soundscapes as a function of 14 acoustical descriptors and 15 semantic differential scales, Torija, Ruiz, and Ramos-Ridao (2014) implemented two techniques, SVM and SVM trained using sequential minimal optimization algorithm (SMO), for the development of a model for the classification of urban soundscapes (using the same 14 acoustical descriptors as input variables). According to