Acoustic Signature Recognition of Moving Vehicles Using Elman Neural Network

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ABSTRACT

Hearing impaired people cannot distinguish the sound of moving vehicles approaching them from behind. Since, it is difficult for hearing impaired to hear and judge sound information of vehicles, they often encounter risky situations while they are outdoors. In this paper, a simple algorithm is proposed to classify the type and distance of the moving vehicles based on the sound signature. A simple experimental protocol is designed to record the vehicle sound under different environment conditions and also for different speed of the vehicles. The noise emanated from the moving vehicles along the roadside is recorded along with the type and distance of the vehicle. Autoregressive modeling algorithm is used to extract features from the recorded sound signal. Elman neural network models are developed and trained using backpropagation algorithm to classify the vehicle type and its distance. The effectiveness of the network is validated through simulation.

Keywords: Hearing impaired, Sound signature, Autoregressive model, Elman neural network.

I. INTRODUCTION

People with hearing impairment are exposed to many environmental hazards, one such danger is when they walk on roads and are unaware of the vehicles approaching them from behind. Acoustic sensors could provide rehabilitation to such individuals to tackle such situation. Statistics compiled by the Social Welfare Department of Malaysia (SWDM), shows that the number of registered deaf people in Malaysia as of the year 2006 is 29,522 the actual numbers can be possibly higher [1]. According to the 2005 estimates of World Health Organization (WHO), 278 million people have disability of hearing in both the ears [2].

Several research studies have developed devices to provide acoustic information through senses of touch or vision for hearing impaired. In 1973, Frank Saunders, proposed an electro tactile sound detector using two microphones and converted the sound into electrical pulses. The source of sound is localized based on the difference in the intensity of the pulses [3]. Saunders et.al developed a tactile aid for the profoundly hearing impaired children to help understand speech [4]. In 1986, A. Boothroyd et.al, have developed a wearable tactile sensory aid which presents a vibratory signal representative of voice pitch and intonation patterns to the skin [5].

Acoustic noise signature emanated from moving vehicle is mainly influenced by the engine vibration and the friction between the tires and the road. Vehicles of similar types are known to generate similar noise signature [6]. Nooralahiyan et.al, proposed a vehicle classification

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method based on acoustic signature analysis using linear predictive coding [7]. Eigen method to recognize the vehicle sound signature based on the frequency vector principal component analysis has been proposed by Wu et.al [8]. A review on the state of the art vehicle classification analysis was done by Xiao et al [9]. Okada, et.al have computed the direction of the vehicle by comparing the amplitude of the sound signals captured by two microphones [10].

In recent years wavelets have been used to identifying and classifying the vehicle type. Lopez et al proposed a wavelet-based feature extraction for target identification [11]. Averbuch et.al, have also used wavelet packet algorithm for classification of vehicles and detection of moving vehicles [12, 13]. Using noise signature to identify moving vehicles has been investigated by Maciejewski et. al.[14].

Literature reveals that most of the studies on vehicle noise signature have been restricted to identification of vehicles only. However the distance of the vehicle also plays an important role in designing devices for the hearing impaired. In this study the type of vehicle as well as the distance of the vehicle is taken into consideration.

II METHODS

Data Collection

According to the Doppler principle the pitch and the original frequency of sound changes when a vehicle passes from the source to the observer. The pitch and the frequency increases when the sound emitting source approaches the observer and decreases when it moves away from the observer [15]. Based on this an experiment is developed to capture the sound emanated from the moving vehicle. For this work, a particular section of the road is considered and the various sound affecting parameters such as road condition, speed limit, background noise, and weather condition and wind direction are also studied. The road selected is a two way lane with a speed limit of 60 km per hour. The sound signal from the vehicles moving from X to Y is measured separately. Two locations A and B with a distance of separation 100 meters are chosen along the road as shown in Figure 1. A sound recorder ICD-SX700 is placed at the location B. which is used to record the noise from the vehicles. The sound is recorded between A and B. The corresponding time taken by the vehicle to travel from A to B is also observed. The number of samples collected along with the type of vehicle is shown in Table 1.

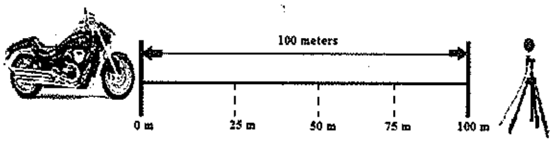

Fig. 1 Experimental Recording Setup

TABLE. I Type and number of vehicles

Vehicle type	Number of Vehicles
Car	35
Bike	35
Lorry	35
Truck	35
Total	140

Preprocessing and Feature Extraction

The sound signal is recorded at a sampling frequency of 44100 Hz. The normal human auditory system responds to the frequency ranges from 20 Hz to 20 kHz [16]. The signal is down sampled to 22050 Hz for further processing. The time taken by the vehicle to travel the distance of 100 meters is also calculated. The distance between A and B is divided into four equal distance zones, namely zone 1, zone 2, zone 3 and zone 4 such that each zone distance is fixed as 25 meters. The four zone representation is shown in Figure 2. The signal corresponding to each zone is further segmented into frames of size 1024. The number of frames corresponding to a particular zone varies as the speed of the vehicles is not same. The number of frames in each zone ranges between 10 to 50.

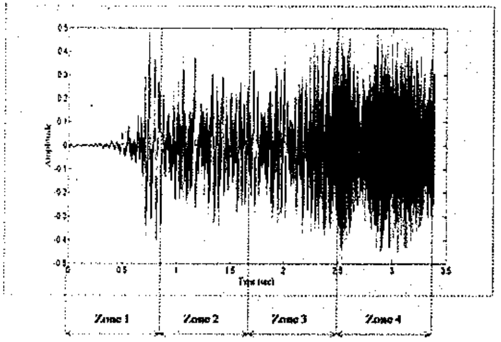

Fig. 2 Typical representation of zone segmentation of a signal

Autoregressive model is used to extract the data from the sound signal. A p^{th}order AR model shown in equation (1) is used to derive the AR coeffecients [17].

$$x_n = \sum_{i=1}^{p} a_i x_{n-i} + \varepsilon_n \qquad (1)$$

where the x_n is the n_{th} value which can be predicted by its previous p successive values:

$$x_n - 1, x_n - 2, \ldots, x_n - p.\ a_i$$

($i = 1,2,3, \ldots, p.$ ε_n is the fitting error for x_n)

The goal of an AR model is to estimate the AR coefficients that can fit the original data as much as possible through an optimization process.

In order to determine the optimal number of consecutive frames that will produce high classification accuracy, a simple analysis proposed using the AR features extracted from the consecutive frames. In order to determine the type and the position of vehicle, AR coefficients are extracted as features from the segmented frame signals. The AR features extracted from the frames are then associated to the vehicle type and zone position and a database is created. Further, the features from two consecutive two frames are combined together and associated to the vehicle type and associated to the zone position and the second database is created. In a similar manner the AR features obtained from 3, 4, 5, 6 and 7 consecutive frames are combined together and five more databases are created. Thus seven different feature databases are created by combining consecutive frame features.

Classification Results

A dynamic Elman neural network is trained using a back propagation (BP) training algorithm [18]. The BP training algorithm involves three stages, the feed forward of the input training pattern, the calculation and back propagation of the associated weight error and the weight adjustments. Using the seven data bases, seven network models are developed to classify the vehicle type. The features data are normalized using binary normalization method so as to rescale the values into a definite range (0.1 – 0.9). The normalized data are further randomized and for each data set three different sets of training samples namely 60 %, 70 % and 80 % of the total samples are selected. Using the guideline proposed in Master [19], the numbers of hidden neurons are chosen, for all the network models, the number of output neurons is fixed as three. The maximum epoch is fixed as 5000. The training tolerance was set to 0.05. Hyperbolic tangent sigmoidal activation function was used as an activation function for the hidden layer activation and logistic sigmoidal activation function was used for the output layer neurons.

The network is tested using the testing data samples and its performance is validated by measuring the classification accuracy. The network model is trained for 25 times and considered as one trail. Five such trails are carried out and the average classification accuracy, for all the network models is shown in Table. II. From Table. II it is observed that the features obtained from the four consecutive frames has the highest mean classification accuracies of 89.48%, 92.01% and 93.52% respectively for the 60%, 70% and 80% training data sets.

Seven Elman neural network models are developed to classify the vehicle position. The network models are trained using gradient descent backpropagation algorithm. For all the network models, the numbers of output neurons are fixed as three. The maximum iteration number was fixed as 5000. The training tolerance was set to 0.05. Hyperbolic tangent sigmoidal activation function was used as an activation function for the hidden layer activation and logistic sigmoidal activation function was used for the output layer neurons. The network was tested using the testing data samples and its performance is validated by measuring the classification accuracy. The network model is trained for 25 times and considered as one trail. Five such trails are carried out and the average classification accuracy, for all the network models is shown in Table. III, from Table. III it can be observed that the features obtained four frames has the highest mean classification accuracy of 87.34%, 89.955% and 92.871% respectively for the 60%, 70% and 80% training data sets.

TABLE. II Neural Network training results for the classification of the type of vehicle

Frame No.	Classification accuracy								
	Elman Network								
	60%			70%			80%		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
1	83.4	87.6	86.5	86.4	87.8	87.1	86.2	89.1	87.6
2	83.9	87.9	86.9	85	89.1	88.5	87.8	89.9	88.8
3	84.3	90.4	87.9	87.9	90.1	90.9	89.4	93.9	91.7
4	87.8	91.2	89.4	89.9	93.8	92	91.7	95.4	93.5
5	83.3	89.3	88.3	87.2	90.5	90.9	89.3	92.7	91.5
6	85.7	89.4	88.9	86.1	91.1	90.6	90.6	92.9	92.2
7	87.0	90.7	89	86.7	90.9	91.3	90.3	93.5	92.4

TABLE. III Neural Network training results for the classification of vehicle position

Frame No	Classification accuracy								
	Elman Network								
	60%			70%			80%		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
1	81	83.8	82.4	83	87.4	85.2	85.7	88.9	87.2
2	81.7	83.6	82.7	83.2	88.6	85.9	86.1	89.9	88
3	84.8	86.4	85.3	86.9	89.9	88.4	89.8	92.5	91.2
4	86	88.6	87.3	89.9	92.9	89.9	91.9	94.8	92.8
5	84.5	86.6	85	86.8	90.6	88.2	90.6	92.5	91.6
6	83.1	85.3	84.2	85.5	89.2	87.4	90.4	93.7	91
7	83.4	85.6	84.5	86.4	89.9	88.1	91.8	93.9	92.4

III. CONCLUSION

This paper presents an experimental procedure to capture the sound signals emanated from the moving vehicle. Autoregressive model features are extracted from the recorded signal. Simple neural network models are developed and trained using backpropagation algorithm to classify the type of vehicle and its distance from the subject. The training results show that the use of autoregressive modeling features differs from the frames contributes towards a better classification of the vehicle type and its distance from the subject.

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