CLASSIFICATION OF INTERIOR NOISE COMFORT LEVEL OF PROTON MODEL CARS USING ARTIFICIAL NEURAL NETWORK

by

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LIST OF ABBREVIATION

ISO	International Standard Organization
CNCI	Car Noise Comfort Index
GUI	Graphical User Interface
BP	Backpropagation
HCI	Human Computer Interface
NVH	Noise, Vibration and Harshness
etc	et cetera
e.g.	Exempli gratia (for example)
Hz	Hertz
dB	Decibel
N	Newton
m	Meter
rms	Root Mean Square
SPL	Sound Pressure Level
dB (A)	A-weighted Decibel
CRP	Composite Rate of Preference
HF	High Frequency
SIL	Sound Intensity
dB lin	Linear Decibel
dB (D)	D-weighed Decibel
dB (AD)	A,D-weighed Decibel
SB	Spectrum Balance
HFF	High Frequency Factor
L_{eq}	Equivalent Continuous Sound Pressure Level
DAT	Digital Audio Tape
ANOVA	Analysis of Variance
PCA	Principal Component Analysis
WT-NN	Wavelet Preprocessing Neural Network
SQM	Sound Quality Measurement
BEM	Boundary Element Method

B&K	Bruel and Kjaer
COP	Coherent Output Power
SVD	Singular Value Decomposition
3D	3-Dimension
MLP	Multi Layer Perceptron
IRI	International Roughness Index
RPM	Revolution per Minute
km/h	Kilometer per Hour
ANC	Active Noise Control
FFT	Fast Fourier Transform
kHz	Kilohertz
NR	Noise Rating
ANN	Artificial Neural Network
ms	Milliseconds
$L_{\rho A}$	A-weighted Sound Pressure Level
m/s	Meter per Second
mm	Milimeter
SC	Stationary Condition
MC	Moving Condition
SLM	Sound Level Meter
TP	Temporal Power
SC-TP	Stationary Condition Temporal Power Feature
MC-TP	Moving Condition Temporal Power Feature
TLEQ	Temporal Equivalent Continuous Sound Pressure Level
SC-TLEQ	Stationary Condition Temporal Equivalent Continuous Sound Pressure Level
MC-TLEQ	Moving Condition Temporal Equivalent Continuous Sound Pressure Level
TEE	Temporal Energy Entropy
SC-TEE	Stationary Condition Temporal Energy Entropy Feature
MC-TEE	Moving Condition Temporal Energy Entropy Feature
TL	Temporal Loudness
SC-TL	Stationary Condition Temporal Loudness Feature

MC-TL	Moving Condition Temporal Loudness Feature
DFT	Discrete Fourier Transform
DSP	Digital Signal Processing
SP	Spectral Power
SC-SP	Stationary Condition Spectral Power Feature
MC-SP	Moving Condition Spectral Power Feature
SLEQ	Spectral Equivalent Continuous Sound Pressure Level
SC-SLEQ	Stationary Condition Spectral Equivalent Continuous Sound Pressure Level
MC-SLEQ	Moving Condition Spectral Equivalent Continuous Sound Pressure Level
SEE	Spectral Energy Entropy
SC-SEE	Stationary Condition Spectral Energy Entropy Feature
MC-SEE	Moving Condition Spectral Energy Entropy Feature
SL	Spectral Loudness
SC-SL	Stationary Condition Spectral Loudness Feature
MC-SL	Moving Condition Spectral Loudness Feature
CF	Composite Feature
TCF	Temporal Composite Feature
SC-TCF	Stationary Condition Temporal Composite Feature
MC-TCF	Moving Condition Temporal Composite Feature
SCF	Spectral Composite Feature
SC-SCF	Stationary Condition Spectral Composite Feature
MC-SCF	Moving Condition Spectral Composite Feature
FFNN	Feedforward Neural Network
ENN	Elman Neural Network
PNN	Probabilistic Neural Network
.EXE	Executable file format

KLASIFIKASI TAHAP KESELESAAN BUNYI DALAMAN DALAM KERETA MODEL PROTON MENGGUNAKAN RANGKAIAN SARAF TIRUAN

ABSTRAK

Klasifikasi tahap keselesaan bunyi dalaman kenderaan adalah salah satu bidang sampingan yang paling menjanjikan dalam penyelidikan automotif. Penunjuk keselesaan bunyi dalaman kenderaan dibangunkan untuk membantu pemandu menjejaki tahap keselesaan bunyi bising di dalam kereta. Penentuan keselesaan kenderaan adalah penting kerana pendedahan berterusan kepada bunyi bising dan getaran membawa kepada masalah kesihatan untuk pemandu dan penumpang. Dalam penyelidikan ini, sistem klasifikasi tahap keselesaan bunyi dalaman kereta keluaran Proton telah dibangunkan untuk mengesan tahap keselesaan bunyi dalam kereta dengan menggunakan rangkaian saraf tiruan. Kajian ini memberikan tumpuan kepada pembangunan pangkalan data terdiri daripada sampel bunyi kereta yang diukur daripada kereta model Proton berlainan dalam keadaan pegun dan bergerak. Dalam keadaan pegun, tahap tekanan bunyi diukur pada 1300, 2000 dan 3000 putaran per minit manakala dalam keadaan bergerak, bunyi direkodkan apabila kereta bergerak pada kelajuan malar dari 30 km/j sehingga 110 km/j. dB Solo digunakan dalam penyelidikan ini sebagai alat pengukur bunyi dalam kereta. Ujian subjektif dijalankan untuk mencari penilaian juri untuk sampel bunyi. Data diproses terlebih dahulu dan ciri-ciri tertentu diekstrak daripada bingkai isyarat. Hubungan antara penilaian subjektif dan objektif juga diuji. Set ciri tersebut kemudiannya diberikan kepada model rangkaian saraf tiruan untuk mengklasifikasikan tahap keselesaan. Indeks masing-masing dipaparkan pada Pengantara Grafik Pengguna yang direka. Keputusan ujikaji menunjukkan bahawa penggunaan ciri-ciri komposit yang dicadangkan menghasilkan ketepatan klasifikasi yang lebih baik berbanding dengan kaedah pengekstrakan ciri konvensional. Ciri-ciri komposit spectra memberikan ketepatan klasifikasi tertinggi sebanyak 94.21%.

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ABSTRACT

Car interior noise comfort level classification is one of the most promising sub-fields in automotive research. Car interior noise comfort indicator is developed to help the drivers to keep track of the noise comfort level in the car. Determination of car comfort is important because continuous exposure to the noise and vibration leads to health problems for the driver and passengers. In this research, a proton model cars noise comfort level classification system has been developed to detect the noise comfort level in cars using artificial neural network. This research focuses on developing a database consisting of car sound samples measured from different proton make cars in stationary and moving state. In the stationary condition, the sound pressure level is measured at 1300 RPM, 2000 RPM and 3000 RPM while in moving condition, the sound is recorded while the car is moving at constant speed from 30 km/h up to 110 km/h. dB Solo equipment is used to measure the noise level inside the car. Subjective test is conducted to find the jury's evaluation for the specific sound sample. The data is preprocessed and features are extracted from the signal frames. The correlation between the subjective and the objective evaluation is also tested. The feature set is then feed to the neural network model to classify the comfort level. The respective index is displayed at the designed Graphical User Interface (GUI). Experimental results show that the use of proposed Composite Feature yields a better classification accuracy compared to the conventional feature extraction method. The Spectral Composite Feature gives the highest classification accuracy of 94.21%.

CHAPTER 1

INTRODUCTION

1.1 Overview

Riding comfort is the term that defines the comfortness of noise, vibration and motion inside a car, experienced by both driver as well as the passengers. ISO 2631 whole-body vibration certification testing covers the comfort, safety and health of the passengers subjected to it.

The assessment of ride comfort consists of four domains, namely, seat vibration, steering wheel vibration, interior noise and general handling in motion of the car. Steering wheel vibration is due to tire unbalance. Interior noise in the car deals with the averaged overall sound pressure level and sound metrics such as loudness, sharpness and roughness of the noise. General handling in motion of the car is due to braking force, where it will affect the comfort of the passenger and driver in terms of drivability comfort. Measuring and quantifying ride comfort can help meeting the necessary standards and regulations. It also helps to troubleshoot, understand and improve the noise and vibration comfort in the car. (Alan E. Duncan, Frank C. Su, & Walter L. Wolf, 1996; Allman-Ward, Williams, Dunne, & Jennings, 2004; Gamerio, 2002)

Out of all the four domains, only seat vibration, steering wheel vibration and general handling in motion of the car deal with physical effect on human. Another domain, the interior noise of the car deals with psychological effect on human. Since the effect is indirect and hidden, most of the car users tend to neglect how much the continuous exposure to the noise affect the driver’s and passenger’s health. The effect might be prolonged but if it is not controlled properly, it might end up in many health problems such as stress, body ache and migrane. (Genuit, 2004; Laux, 1999)

Car interior noise comfort recognition has drawn considerable attention from researchers in recent years. The aim of this research work is to develop a car interior noise comfort level recognition system using neural network model which can recognise the interior noise comfort level based on the background noise. The features extracted from the stationary and moving sound samples are used in developing the neural network model. The proposed model is trained and tested for its validation. It is designed in such a way that it can be used in local cars. The main motivation and objectives of this research work has been discussed in this chapter.

1.2 Problem Statement

Continuous exposure to the noise when travelling in a car will always leads to many health problems if it prolongs. Since the effect is indirect and hidden, most of the car users tend to neglect how much the exposure affect the driver's and passenger's health. The effect might be on long term but if it is protracted, it might end up in many health problems. To overcome this situation, many car interior noise comfort level recognition system were proposed by researchers and car manufacturers but still there is no any product available commercially. Most of the systems available only for internal usage and has been privatized. This research aims to develop a car interior noise comfort level recognition system for the local cars which will be easy to operate and more user-friendly for the car users. The proposed system will convert the background noise recorded in the car into equivalent index accurately and efficiently.

1.3 Significance of the Study

Regular car user experiences many health problems due to continuous exposure to noise and vibration when travelling in a car. Most of the users neglect the effect of the continuous exposure to the noise and vibration. If the effect is not controlled, it will lead to serious health problems such as headache, stress and high blood pressure complication. This research work will be helpful for the local Malaysian drivers in many ways. The primary advantage is to help the car users to follow up on the interior noise comfort level indication. Keeping track to the interior noise comfort is vital to prevent any extension to the harmful noise exposure. The proposed system is developed in such a way that it can be used in any local cars. The system indicate the interior car noise comfort level index based on feature extraction and neural network modelling, applied to the recorded sound samples. This helps the car users to use this system to detect the car interior noise comfort level and take the appropriate preventive measures to enhance their health condition if the comfort level is above the threshold of normal comfort level. Another advantage of the research would be for the evaluation of car physical condition. The used car buyers will always need the assistance of car mechanics or car experts to evaluate the car before buying. It would be troublesome to find a car expert since their availability will be always limited. The proposed system is developed to assist the used car buyers in evaluating car condition to evaluate the car using the proposed Car Noise Comfort Index (CNCI), even without any experience in assessing the car condition. CNCI can be related with the car condition rating since hearing the noise emanated from the car is the primary way the car experts evaluate a car condition.

1.4 Research Objectives

The purpose of this research is to develop a noise comfort level indication system for the local Malaysian cars using artificial neural network. The objectives of this research are as follows.

i. **To develop a dataset of interior noise level for local cars.**
Developing a dataset for interior noise level is a demanding task for local Malaysian cars. There is no standard dataset has been formulated before for the interior car noise level of the local cars. In this research, the first and foremost objective is to develop the car interior noise level dataset for local cars.

ii. **To develop a suitable preprocessing method.**
In signal processing, proper framing and signal filtration play a major role in reducing or increasing the processing time. In this research, it is proposed to develop a simple preprocessing method which will reduce the processing time and increase the accuracy of the system.

iii. **To develop feature extraction algorithms to extract valuable features from the sound samples.**
Feature extraction plays an important role in car interior noise comfort level recognition system. There are many types of feature extraction methods used in the previous work. In this research, it is proposed to develop temporal and spectral based feature extraction algorithms.

iv. **To develop an intelligent car interior noise level classification tool.**

Neural Network provides alternative form of computing that attempts to mimic the functionality of the brain. In this research, it is proposed to develop a car interior noise comfort level recognition system using neural network model.

v. **To develop a user-friendly Graphical User Interface (GUI) platform for car interior noise level classification.**

Development of PC based automatic recognition system for the car interior noise comfort level recognition is an important task of this research. It is proposed to develop a GUI for the car interior noise comfort level recognition system.

1.5 Thesis Organization

This thesis explores the topic of car interior noise comfort level recognition system using digital signal processing along with artificial intelligence techniques. The research works carried out are present in seven chapters in this thesis.

Chapter 1 (current chapter) provides the introduction of this research and an overview on how the dissertation is organized.

Chapter 2 provides the literature reviews on types of car noises, the passenger comfort related to car noise, the features and indices associated to the car noise comfort classification and the application car interior noise comfort classification. The previous works on car interior noise comfort level recognition are surveyed and discussed.

Chapter 3 describes the development of experimental protocols, modification on the standard ISO data collection protocol and the modified protocol validation.

Chapter 4 describes the signal processing and feature analysis techniques that are used in this research. The brief description of the feature extraction methods and the data reduction technique used is also explained in this chapter.

Chapter 5 presents the concepts of a feedforward neural network model trained by backpropagation (BP) Algorithm. The network architecture and the training methods used to develop the car interior noise comfort level classification are explained in detail. The classification with feedforward neural network trained with backpropagation and Elman backpropagation algorithm, and with the Probabilistic Neural Network is also discussed. This chapter also presents the results obtained for the developed neural network models and different feature extraction methods. Further, the development of GUI has also been discussed.

Chapter 6 describes how the project has achieved the goals set. Further, this chapter summarizes the contribution made in this research. The suggestions for future research works are also been discussed.