A Comparative Study on Interior Acoustical Comfort towards Perodua's Compact Car Model through Monte Carlo Simulation Method

By

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LIST OF ABBREVIATIONS

BSS	Blind Sources Separation
VDV	Vibration Dose Value
CPX	Close Proximity Method
VACI	Vehicle Acoustical Comfort Index
KNN	K-Nearest Neighbour
MVN	Multivariate Normal
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
NI	National Instrument
GUI	Graphical User Interface
RPM	Revolution Per Minute
VACF	Vehicle Acoustical Comforts Factor
ANOVA	Analysis of Variance
CC	Cubic Centimetre

LIST OF SYMBOL

Q_{ij}	*j*th metric for sound quality for the *i*th condition
P_i	Vehicle acoustical comfort factor for the *i*th condition
c_j	Coefficient for the *j*th metric of sound quality
c_L	Coefficient for loudness sound quality metrics
c_S	Coefficient for sharpness sound quality metrics
c_{SP}	Coefficient for sound pressure sound quality metrics
μ	Average variable
Σ	Summation
Π	pi
E(x)	Expected of *x*
∈	Set of membership/element of group of data

Kajian Perbandingan Keselesaan Akustik Dalaman terhadap Model Kereta Kompak Perodua melalui Kaedah Simulasi Monte Carlo

ABSTRAK

Masyarakat kini banyak menggunakan masa mereka dengan kenderaan terutamanya kereta, untuk bergerak ke sesuatu tempat. Oleh itu keselesaan yang mampu disediakan oleh sebuah kenderaan amat penting untuk memberi suasana keselesaan kepada pengguna kereta tersebut. Keselesaan akustik kenderaan merupakan salah satu faktor yang penting dalam isu untuk memberikan keselesaan kepada pengguna kenderaan ketika menggunakan kenderaan tersebut. Secara logiknya bunyi hingar yang kuat semasa berada di dalam kereta mampu membuatkan pengguna kereta tersebut berasa kurang selesa. Secara psikologinya, suasana yang kurang selesa ketika menggunakan kereta mampu memberi kesan terhadap pengguna kereta seperti mengganggu konsentrasi pemandu. Sekiranya hal ini berlaku maka daya tumpu pemandu tersebut juga turut terjejas dan ini mampu mengundang perkara yang tidak diingini. Kajian ini adalah bertujuan untuk mengkaji tahap keselesaan bunyi hingar di dalam kabin kereta. Kereta yang digunakan dalam kajian ini adalah kereta kompak keluaran Perodua, iaitu Axia, Myvi, dan Viva. Objektif kajian ini adalah untuk mengkaji bunyi hingar di dalam kabin kereta tersebut dan mencari tahap keselesaan bunyi hingar di antara ketiga-tiga kereta ini. Kemudian, tahap keselesaan bunyi hingar antara ketiga-tiga kereta ini dibandingkan untuk mencari kereta apakah yang mempunyai tahap keselesaan bunyi hingar yang terbaik antara kereta-kereta tersebut. Dalam kajian ini, tahap hingar di dalam kabin ketiga-tiga kereta ini diukur mengikut kelajuan enjin kereta masing-masing. Bunyi hingar dalam kabin kereta-kereta ini diambil ketika kereta tersebut berada dalam dua keadaan iaitu ketika dalam keadaan pegun dan tidak pegun. Ketika dalam keadaan tidak pegun bunyi hingar dalam kereta tersebut diambil semasa dipandu melalui tiga jenis jalan, iaitu lebuh raya, jalan bandar, dan jalan kaki lima. Satu sistem pengaturcaraan dibangunkan untuk merakam bunyi-bunyi hingar dalam kabin kereta tersebut. Bunyi-bunyi hingar ini dinilai secara objektif dan subjektif. Dalam penilaian secara objektif, metrik kualiti bunyi hingar yang telah dirakam tersebut di ekstrak menggunakan perisian "B&K Sound Quality". Metrik kualiti bunyi tersebut kemudian dikaji melalui kaedah analisis regresi. Satu persamaan diterbitkan melalui analisis tersebut. Penilaian secara subjektif pula menilai bunyi-bunyi hingar yang dirakam itu terhadap penilaian individu. Lima individu terlibat dalam menilai bunyi-bunyi hingar tersebut. Kemudian, pendekatan data lombong diguna pakai dalam kajian ini untuk mengilustrasikan data bunyi hingar ini. Data bunyi hingar ini dikumpulkan menjadi lima gugusan melalui kaedah gugusan berhierarki. Untuk mengkaji ketepatan pengelasan gugusan data yang telah dibuat itu, kaedah Jiran Terdekat-*k* digunakan dan keputusan yang diperoleh menujukan peratus ketepatan pengelasan data-data tersebut adalah tinggi. Kemudian, bunyi hingar untuk ketiga-tiga kereta dalam kajian ini yang telah dianalisis, dibandingkan menggunakan pendekatan analisis variasi (ANOVA) untuk membanding bunyi-bunyi hingar kereta-kereta tersebut antara keadaan-keadaan yang terlibat sewaktu rakaman/pengukuran bunyi hingar dilakukan. Keputusan yang diperoleh melalui kaedah Simulasi Monte Carlo, menunjukan bahawa tahap keselesaan bunyi hingar untuk model Axia ada menyenangkan manakala tahap keselesaan hingar untuk model Myvi dan Viva pula di kategorikan sebagai marginal ataupun sedikit.

A Comparative Study on Interior Acoustical Comfort towards Perodua's Compact Car Model through Monte Carlo Simulation Method

ABSTRACT

Societies nowadays spend most of their time travelling with vehicles, especially cars, and move from one place to another place. Therefore the comforts of a vehicle could provide is very important to give the feeling of pleasantness to the users of the car. Vehicle acoustic comfort is one of the important factor in order to provide driving comforts to the user when the vehicle is in use. Logically annoying noise inside the cabin car will to make the car's user to feel less comfortable. Psychologically, an uncomfortable environment during driving session with the car will affect the user's car especially to the driver where it can be a kind of distraction during driving. If this happen, then the drivers concentration will also be affected and this could led to an unwanted incidents. This study was proposed to investigate the comfort level of noise in the car cabin. The cars used in this study are the compact cars from Perodua, the Axia, Myvi and Viva models. The objective of this study was to investigate the noise in the cabin of the car and to find the comfort noise levels between the three cars. Then, the level of acoustical comfort between the three cars were compared to find which car have the best noise comfort level between those cars. The hypothesis of this study are more the higher the cars' engine speed, the higher the level of noise generated in the cabin of the car and the rougher the road surface, the higher the noise will be transferred into the car's cabin. Therefore, in this study, the level of noise in the car cabin for all of the three cars are measured according to the engine speed, respectively. The noise in the cabin of the cars was recorded when the car is in two circumstances, namely when in stationary and non-stationary. In stationary state, the noise in the car were recorded while being driven through three types of roads, which are the highway, urban streets, and pavement. A coding system using LabVIEW were developed to create a system to record the sounds of the noise in the cabin of the car. The recorded noise will then be used for evaluation. The noise were assessed in to approach, objectively and subjectively. In objective evaluation, the sound quality parameter of the recorded noise were extracted by using the "B&K Sound Quality" software. These sound quality parameter will be the data and was assessed by means of regression analysis. Then an equation was published through the analysis. In subjective assessment the recorded noise were evaluated based on jury assessment. Five individuals were involved in assessing the noise. Then, data mining approach were implemented in this study to illustrate this noise data. The collected data noise were divided into five clusters class through hierarchical cluster method. To assess the accuracy of the classification group of the data that has been made, the method of k-Nearest Neighbors were implemented and the results obtained were in percentage, which shows that the classification accuracy of such data is very accurate with percentage of above 95%. Then, the noise of the three cars used in this study were analyzed and compared between the states of the cars during the recording/measurement session by using analysis of variation (ANOVA). Results from the Monte Carlo Simulation approach shows that the level of acoustical comforts for Axia were determined as 'pleasant' while Myvi and Viva were determined as 'marginal'.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Nowadays, cars have become one of the requirements in today life style, especially for those who have a family. One of the reason why a family needs a car because it is an ideal vehicle for them to move from one place to another. As it has become a necessity of life in the present day, this has led it to received high demand in the market. Automotive industry is the one who won't miss this opportunity and this has contribute to intense competition between those involved in this industry to produce a car that will able to satisfy and meet the needs of customers.

One the factors that attract car users to own a car is the comfort features of the car can offered while in used, for example in terms of the characteristics of the interior noise of the car which can affect the user's comforts while driving the car as the annoyance from the noise could reduce the user's driving comforts. Most of the time, loud noises inside a car could led to an unpleasant feeling towards the user, especially when the car is in used, and this unpleasant feeling will annoyed the user especially the driver. These annoying experience could distract the driver, hence it could reduce the driver's focus and awareness during the driving session, and this could led to an undesired situation.

Therefore, the interior acoustical comforts are one of an important factors in driving comforts and has led researchers and engineers in automotive field to actively and consecutively conduct many experiments and researches regarding car's comforts, particularly about the car interior noise, in order to produce a car that can offer comforts to the users. This research is to study the interior acoustical comforts towards Perodua's compact cars which are the Axia, Myvi and Viva models to obtain the interior acoustical noise index, which can be used by other the engineers or researchers to use these index in order to improve the interior acoustical comforts of the cars.

1.2 Problem Statement

Researcher and engineers are consistently exploring and researching in effort to improve the interior acoustical noise of a vehicle so that it can provide a comfortable feeling to the vehicle user. In term of improving the interior noise of a vehicle, a measurement of the interior noise should be done first. To measure the noise level in the interior vehicle cabin, sound power and a-weighted noise level are the common technique usually used to take the measurement of the noise, but this kind of techniques are not adequate. The most frequently approach to measure the quality of interior car acoustical sound is by defining the annoyance or specific index. This approach involves both objective and subjective assessment. Obtaining the acoustical noise index of the vehicle will allow researchers from various field in automotive acoustics research to use the index and thus will save the investigation time by skipping the jury test process which consume lots of time (Nor, Arifin, Fouladi, 2008).

1.3 Research Objective

The objectives in this study are explained as follows:

i. To produce an acoustical comfort index for each three (3) Perodua's compact cars
ii. To measure the level of noise in the cabin by employing the data mining approach
iii. To compare the interior noises for each three (3) Perodua's compact cars between each state/condition.

1.4 Research Scope

The scopes of study are described as follows:

i. The measuring of noise is conducted only on three (3) Perodua's compact cars which are Myvi, Viva, and Axia models.
ii. All the measured cars are only in automatic transmission.
iii. The age of the vehicle are as follows; Axia (1 year), Myvi (6 years), Viva (8 years).
iv. The cubic centimetre (cc) of the cars are as follows; Axia (1000cc), Myvi (1300cc), and Viva (1000cc).
v. The measuring of noises for each three (3) cars only involves in the interior car's cabin only and the exterior measurements only act as reference.
vi. The measurement only conducted in stationary and non-stationary state.

vii. The measurement for non-stationary state is only conducted on three types of road which are pavement, urban, and highway road.

1.5 Research Hypotheses

The hypotheses in this study are roughly based on two assumptions:

i. The higher the engine speed (rpm), the louder or more audible the noise in the interior car's cabin.
ii. The rougher the road condition/type the higher the noise generated inside the car's cabin.

1.6 Research Outcome

The outcome of producing the vehicle acoustical comfort index in this research, it will allow or help other automotive researchers to use the comfort index to continue furthering the research or even in a new research that related with vehicle comfort index. The index will not only useable in vehicle noise study or investigation, but it will also help in research related to the vibration of vehicle. Thus, this research can also be the guideline for other automotive researchers of how to investigate in vehicle acoustical comfort.

1.7 Thesis Outline

The first chapter of this thesis is Introduction, here the general information regarding this research is written. The problem statement of the research is described in this section. Others like the objectives, scopes, research hypothesis, and the outcome of this research, are also presented in this chapter.

Chapter 2 of this thesis is dedicated to the literature review of past research or study that are related to the noise and vibration of interior vehicle cabin. The method and the analysis discussion of previous or related research are described in this chapter. Also the outcome of the previous research are also stated in this section.

Chapter 3 is about the methodology involved in this research, explanation about the process or procedure done in this research like how the research is conducted, what tools are used in the research, where the test is being conducted and many more are presented in this section.

Chapter 4 will present the result of the research. The collected data in the research will be presented in this section. Plus, the process or the analysis of the obtained raw data will also be presented in this section.

Chapter 5 is the conclusion. The conclusion of this research from the result of this research will be concluded in this chapter. The summary of the research and the recommendation for future research or study is presented in this section.

1.8 Thesis Flowchart

The overall process involved in this study are briefly explained through the Figure 1.1 below.

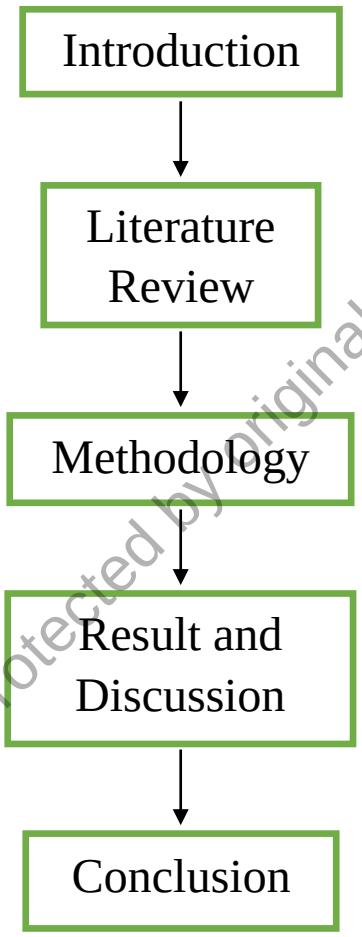

Figure 1.1: Thesis flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The investigation or study that have conducted by other previous researchers which related to vehicle noise, vehicle acoustical comforts, or data mining approach are presented.

2.2 Car Interior Noise

One of the vital aspects that effect in driving comfort is the interior acoustic of the vehicle. The automotive industries have regarded this issue as a serious matter to solve the interior noise problem to satisfy the customer need. Researchers and engineers have conducted a lot of studies and experiment about vehicle interior noise (Zuo and Yan, 2006).

Nowadays people spend a significant amount of their time traveling by their vehicle and lead to a major role that support the increase of comfort level in either private or public transportation. Therefore, driving comfort is become an important criteria for buyers and passengers when buying a vehicle (Nopiah, Junoh, & Arifin, 2013). This lead to extensive efforts done by car manufacturers to improve the car's interior noise comfort (Paulraj, Andrew, & Yaacob, 2013).

One of the reasons that lead to the improvements of driving comfort can be due to safety issue since psychologically, comforts can result a pleasant atmosphere. A pleasant environment can increase the awareness or focus while driving or riding, hence it improve the performance of the driver and passenger. While in commercial field, driving comfort plays crucial criteria in the market since this will affect the impression of the consumer toward the vehicle manufacturer. The driving comfort have no specific conclusion since most of evaluation depends on subjective assessment, hence this will lead to variation of response even conducted in the same environment because different people have different opinions and point of view, they evaluate differently even in the same situation.

Paulraj, Andrew, and Yaacob, state that, driving comfort can be categories into several aspect, the vibration, acoustical comfort noise, and motion occur inside a vehicle, all of this are the element which experienced by both driver and passengers. The evaluation of ride comfort can be divided into four domains, which are, interior noise, steering wheel vibration, seat vibration and common control in motion of the vehicle (Paulraj et al., 2013).

According to Genuit (2009), in automotive industry, investigation on interior noise has been an important task for acoustical engineers to determine the quality of a vehicle in the case of designing a comfortable vehicle. The assessment of interior acoustical comfort of a vehicle cannot be done by only considering the airborne noise outside of the vehicle, but it should also taking account the noise generated from the passenger(s) inside the vehicle. The author proposed variable test settings such as noise and vibration imitation in a driving simulation, actual drive test, and noise playback in

listening room. The outcomes of the interaction between sound and vibration are acquired from the test (Genuit, 2009).

Fig.2.1: Adaptability of human hearing (Genuit, 2009)

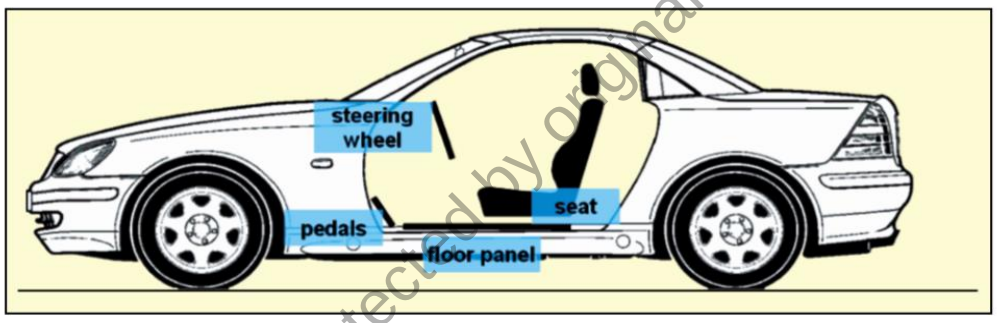

Fig.2.2: Vehicle driver's main contact point (Genuit, 2009)

In a research by Nopiah, Junoh, and Arifin, on the relation between sound quality and vibration generated by the transmission at the engine and the tire contact with the road, the authors performed data analysis of both the sound and vibration and resulting the trend's significance levels. Through the research, the author realizes that the generation of noise and the exposed vibration are related and influenced by the intensity of acoustical comfort in car's cabin. The authors have proposed an assessment method model on the acquired sound sample and the obtained vibration data by implementing the clustering and classification method (Nopiah, Junoh, & Arifin, 2015d).

2.3 Noise

In Noise and Vibration Control book (Munjal, 2013), sound can be labelled as drifting disturbance and is a longitudinal wave in air. Air is one of the medium for wave to travel from the source to the receiver cause by the mass and elasticity characteristic of air. Wave can be classified into two state variable, particle velocity and pressure. It can be represented as disturbance of the static ambient pressure and the wind‘s mean flow velocity correspondingly. However the disturbance depends on time, space or distance. Noise usually defined as unwanted or undesirable sounds depend on situation because of its loudness or frequency characteristics. Excessively exposed to noise could lead to several physiological effects such as headache, annoyance, less concentration, rising of blood pressure, decrease of working efficiency or worst, accident at the workspace.

Normally the generated noise in the internal vehicle cabin due to the vibration of the vehicle structure will affect the driver’s performance and hence it will reduce the driver’s focus. It can be defined that noise is a cause of annoyance towards humans where it may bother the conversation or other activities while driving. Hence it will affect the driver concentration.

There are two major sources of generation of noise, the structural noise and airborne noise which depending on certain situation. The airborne noise is produced when a car is moving and the collision between the car frame and the surrounding air volume and the combustion engine system. While the impacts of a car transmission and