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**A Comparative Study on Whole Body Vibration  
(WBV) Comfort towards Perodua's Compact Car  
Model Using Monte Carlo Simulation**

by

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## LIST OF ABBREVIATIONS

BS 6841	British Standard 6841
IOS 2631	International Standard 2631
RMS	Root Mean Square
VDV	Vibration Dose Value
VACI	Vehicle Acoustical Comfort Index
KNN	K-Nearest Neighbour
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
NI	National Instrument
GUI	Graphical User Interface
RPM	Revolution per Minute
ANOVA	Analysis of Variance
LDA	Linear Discriminant Analysis
MVN	Multivariate Normal
WBV	Whole Body Vibration

## LIST OF SYMBOL

$n_{i,k}$	Sample class $k$ till $i$
$S_b$	Distribution matrixes between classes
$S_w$	Distribution matrixes in class
$\Sigma_k$	Covariance matrix class $k$
$T$	Total period in seconds during which the vibration occurs
$\alpha$	Coefficient for RPM value
$\beta$	Constant variable
$\mu_k$	Mean vector class $k$
$e(x)$	Mean for all vector
$K$	Number of class
$N_k$	Number of sample in class $k$
$\lambda_k$	Constant variable
$\mu$	Group mean
$n$	Number of groups

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## **Kajian Perbandingan Keselesaan Getaran Seluruh Badan Bahagian Dalam Model Kereta Kompak Perodua Menggunakan Kaedah Monte Carlo**

### **ABSTRAK**

Pada masa kini, penduduk Malaysia banyak menghabiskan sejumlah besar masa perjalanan dengan kenderaan untuk bergerak dari satu lokasi ke lokasi lain dan ini boleh menjadi sebab utama untuk mengurangkan getaran yang minimum bagi tahap keselesaan kenderaan. Dalam tahun-tahun kebelakangan, penyelidik dan jurutera daripada industri automotif telah menjalankan banyak kajian dan percubaan untuk penilaian getaran dalaman kereta. Getaran yang terhasil semasa pemanduan boleh mempengaruhi tekanan dan menghilangkan fokus pemandu dan penumpang, dan ini adalah salah satu punca utama yang boleh menyebabkan kemalangan di jalan raya. Walau bagaimanapun, imej-imej visual yang kabur dihasilkan melalui prestasi visual pemacu kerana terdedah kepada getaran dalam kabin dalaman kereta. Imej-imej kabur disebabkan oleh pergerakan maya antara retina mata dan objek yang dilihat oleh pemandu dan boleh menjadi punca utama yang membawa untuk kemalangan. Penghantaran enjin; ekzos keluar, dan bunyi bising yang disebabkan oleh kenalan geseran antara jalan dan tayar adalah punca utama yang menghasilkan getaran. Biasanya, getaran di dalam kabin kereta dalaman dihasilkan akibat secara langsung daripada peningkatan kelajuan enjin kerana kelajuan enjin dan getaran halaju akan mengikut perkadaran terus, oleh itu, semakin meningkat kelajuan enjin (rpm) semakin tinggi getaran yang dijanakan. Walau bagaimanapun, jenis jalan dan geseran antara tayar dan permukaan jalan boleh menjadi faktor utama serta penyumbang kepada getaran yang dihasilkan. Kereta yang digunakan dalam kajian ini adalah kereta kompak keluaran Perodua, iaitu Axia, Myvi dan Viva. Objektif kajian ini adalah untuk mengkaji getaran yang terhasil di dalam kabin kereta tersebut dan mencari tahap keselesaan getaran di antara ketiga-tiga kereta untuk membandingkan kereta manakah yang mempunyai tahap keselesaan getaran 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. Getaran yang terhasil ketika ujikaji di dalam kabin kereta-kereta ini direkodkan dan disimpan dalam bentuk data ketika kereta tersebut berada dalam dua keadaan iaitu ketika dalam keadaan pegun dan tidak pegun. Ketika dalam keadaan tidak pegun getaran yang terhasil dalam kereta tersebut diambil semasa dipandu melalui tiga jenis jalan, iaitu lebuhraya, jalan bandar, dan jalan kampung. Satu sistem pengaturcaraan dibangunkan untuk merekodkan getaran yang terhasil dalam kabin kereta tersebut. Data yang diperolehi akan dikaji melalui penilaian getaran seterusnya kaedah analisis regresi. Satu persamaan diterbitkan melalui analisis tersebut dan daripada persamaan itu, data yang signifikan akan digunakan dalam proses algoritma pengugusan min-k. Data vibration yang signifikan akan dibahagikan menjadi lima gugusan. Untuk mengkaji ketepatan pengelasan gugusan data yang telah dibuat itu, kaedah Jiran Terdekat- $k$  dan Analisis Diskriminasi Linear digunakan bagi menunjukkan peratusan ketepatan pengelasan data-data yang telah diguguskan. Kemudian, bunyi hingar untuk ketiga-tiga kereta dalam kajian ini yang telah dianalisis, dibandingkan menggunakan pendekatan analisis variasi (ANOVA).

## **A Comparative Study on Whole Body Vibration (WBV) Comfort towards Perodua's Compact Car Model Using Monte Carlo Method**

### **ABSTRACT**

Nowadays people of Malaysian spend a significant amount of time traveling by the vehicle to travel from one location to another location and this could be a main reason to decrease minimal vibration for the comfort level in transportation. In the recent years, the researchers and engineers from automotive industry have conducted lot of study and experiment for assessment and evaluation of the interior car cabin vibration. Meanwhile, consumer fulfillment, has become an important issue for the automotive industry as a significance of competition between companies and attenuation others profit restrictions. The vibration that generated while driving can influence pressure and eliminate the focus to the driver and passenger, and this is one of the main causes that can lead accidents on the roads. Nevertheless, blurred visual images are produced through the visual performance of the drivers because of the direct exposure to vibration in interior cabin car. These blurred images are caused by the virtual movement between retina of the eye and the object seen by the driver and can be a main cause lead for an accident. The engine transmission; exhaust exit, and the noise caused by the tier-road contact are the main sources that generated vibration velocities. Normally, vibration in the interior car cabin correspond generated due to directly to the increasing of engine speed because of engine speed and vibration velocity are in direct proportion, thus, higher engine speed (rpm) the vibration generate more as well. However, type of road and the friction between the tire and the road surface could be the main factors as well that contribute to the generated vibration. Cars that has been used in this study is a compact car by Perodua, namely Axia, Myvi, and Viva. The objective of this research is to study the vibration which generate in the cabin of the car and seek for the vibration comfort level between all three cars to compare car which has a finest level of comfort between this three cars. In this study, the level of vibration in the cabin of the three car engine speed as measured by car respectively. Vibration generated during experiments in the cabin cars is recoded and stored in the form's data and the test in two circumstances, namely, state of stationary and is not stationary. When in a situation not stationary vibration resulting in the car taken during guided through three types of road namely highway, pavement and urban. A programming system developed to record the generation of vibration in the cabin of the car. Data collected that have been collected will be go through some process start with methods evaluation vibration and regression analysis. An equation will be approach through the analysis to find the significant data that can be used in the process which is K-Means algorithm. Based on the trends of the experienced and exposed vibration, the model is able to differentiate the level of comfort between the clusters by grouping the level of sound vibration into five categories which are most pleasant, medium pleasant, marginal, medium annoying and most annoying. To review the accuracy of classification data cluster, the K-Nearest Neighbor method and Linear Discriminant Analysis is used for shows the percentage accuracy of classification data have been cluster. Later, the vibration for the three cars in this study which has analyzed, compared using the approach of analysis of variance (ANOVA).

# CHAPTER 1

## INTRODUCTION

### 1.1 Background Study

Transportation is an important requirement for people to go from one location to another location. One of the most widely used transports in the world is the car. The number of vehicles registered in Malaysia has reached to 14.8 million at the end of 2016 compared to just 7.6 million ten years ago, (2006). It shows how the use of car is a major requirement for the people of this country thus received a high demand for its production. Minimal whole body vibration in the car's cabin through driving is an important aspect in determining the choice of the best car. As a result, the vibration that generated while driving can influence pressure and eliminate the focus to the driver and passenger, and this is one of the main causes that can lead to accidents on the roads (Paulraj, Yaacob, Andrew, & Marhainis, 2011).

Among other causes due of direct exposure to the vibration towards the body of the driver is can cause the driver with visual deficiency to generate blurred visual images (Junoh, Nopiah, & Fouladi, 2012). The blurred image production resulted from simulated movement between the retina of the eye and the object seen by the driver. This will cause further disruption to the driver which can cause accident. Among the main causes of vibration is the friction between the tire and the road surface, the

vibrations resulting from the engine and exhaust (Nopiah, Junoh, & Ariffin, 2013). Additionally, the engine speed and vibration interrelating with each other, therefore, when the engine speed progressively increase the vibration velocity is increased as well and this also led to the production of vibration.

Nowadays, with the increasing development of sophisticated technology, travel comforts in driving cars were in high demand from the customers. This lead to competition between the automotive industry to produce cars that are more comfortable and to meet the to customers' requirements and at the same time reduce the cost and time of manufacturing for every new model. In recent years, many studies and experiments have been carried out by researchers and engineers to find solutions to the comfort while driving, especially in reducing whole body vibration (Nopiah, Junoh, & Arifin, 2012).

Normally, jury test is used by the automotive industry to assess whole body vibration in the vehicle cabin (Nopiah, Junoh, & Arifin, 2013), but the results of the jury test data are not accurate and more towards biases. Therefore, the main objective of this study is to improve the results of previous experiment by using the jury test based on the experiment and replace it with an objective test. The method used in this study is data analysis for investigating the main factors of the production of vibration in the car's cabin.

## **1.2 Problem statement**

The specific research problems are described as follows:

- i. The design of interior cabin that generates vibration which can potentially affect driver to lose focus and stressful. Therefore, data analysis is needed to improve the design of car cabin based on measured data.
- ii. The exposure of whole body vibration can lead to affect driver's emotion and concentration by causing comparative movements between driver's retina and the object seen by the driver which can lead to the road accidents.
- iii. The jury test used by automotive industry to evaluate vibration in car cabin is recognized for its biasness and not too accurate.

## **1.3 Objectives**

The objectives that are addressed in this study are as follows:

- i. To evaluate the impact of the sources (tire-road interaction and engine transmission) that contributes for vibration that generated in the vehicle cabin.
- ii. To measure the level of vibration in the cabin based on experimental analysis through the clustering and classification methods.
- iii. To compare the whole body vibration towards Perodua compact car's model for type of road through the data mining approach.

#### **1.4 Scope of Study**

The scope of study that are addressed in this study are 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. 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 centimeter (cc) of the cars are as follows; Axia (1000cc), Myvi (1300cc), and Viva (1000cc).
- v. The evaluation of vibration for each three cars only involved in the interior car's cabin only.
- vi. The measurement is only conducted in stationary and non-stationary state. The non-stationary state is conducted on pavement, urban and highway road.

#### **1.5 Research Hypothesis**

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

- i. The higher the engine speed (rpm), the more generation of vibration in the interior car's cabin.
- ii. The rougher the road condition/type the higher the generation of vibration transferred into the car's cabin.

## 1.6 Thesis Outlines

The first chapter of this thesis is Introduction, here the general information regarding this research is written. Chapter 1 also presents the research objective, research problem of the statement, research scope, research questions, research hypothesis and the thesis structure.

Chapter 2 of this thesis presents the literature review of the impact factors that generate vibration in the interior cabin of a vehicle. Apart from that, it discusses the analysis and a method that have been used by previous researchers to employ in this research. 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 concept designs as well as the execution of methods applied in this study.

Chapter 4 will present the result of the research. The collected data in the research will be presented in this section. The overall results and findings each with detailed discussion and analysis.

Chapter 5 is the conclusion. The conclusion of this research from the result of this research will be concluded in this chapter. This chapter presents the summary and recommendation. This chapter also gives a suggestion or idea for future research.

## 1.7 Thesis Flowchart

The overall process involved in this study are briefly explained based on figure 1.1

below:

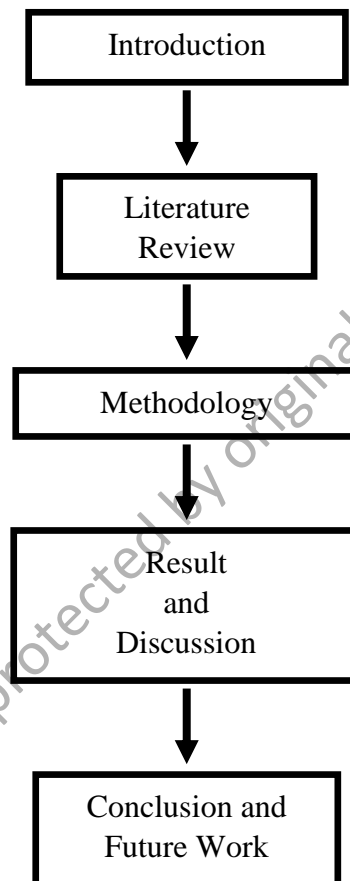


Figure 1.1: Thesis flowchart

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Minimal whole body vibration comfort is an important criterion for buyers in determining the quality or ratings in the purchase of a car. Nowadays people spend a significant amount of time travelling by the vehicle from one location to another location and this could be the main reason to decrease minimal vibration for the comfort level in transportation. In the recent years, the researchers and engineers from automotive industry have conducted a lot of study and experiment for assessment and evaluation of the interior car cabin vibration (Junoh, Nopiah, Muhamad, & Nor, 2011). The essential condition is concomitant with customer contentment driving and minimal vibration comfort. Meanwhile, consumer fulfillment, has become an important issue for the automotive industry as a significance of competition between companies and attenuation others profit restrictions ( Paulraj, Yaacob, & Marhainis, 2011).

However, the effects of vibration in a car will produce noise that causes focus or concentration of driver distracted and can lead to accident. As a result of this situation, the generated vibration causes tense for the driver and passengers while driving the vehicle. Nevertheless, blurred visual images are produced through the visual performance of the drivers because of the direct exposure to vibration in interior cabin