CLASSIFICATION OF MATERIALS USING ARTIFICIAL INTELLIGENCE TECHNIQUES BASED ON MODAL PROPERTIES GENERATED BY VIBRATION

MOHD HILMAN BIN MOHD AKIL TAN

UNIVERSITI MALAYSIA PERLIS

2013

Classification of Materials Using Artificial Intelligence Techniques Based on Modal Properties Generated by Vibration

By

Mohd Hilman Bin Mohd Akil Tan
(1030610481)

A thesis submitted in fulfillment of the requirements for the degree of Master of Science (Mechatronic Engineering)

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2013

ACKNOWLEDGEMENTS

All praise to Allah S.W.T the almighty, the most gracious, the most merciful and the ever forgiving, for his blessing and guidance have enabled me to finally complete this research. I hope that this humble work would have some good effect to the world. This project could have not been realized if not for the combined effort and dedication of many people along the way, and it is in my utmost delight to personally thank them here.

My deepest gratitude goes out to my supervisors, Mrs. Nur Liyana binti Tajul Lile, Prof. Dr. Sazali bin Yaacob and Dr. Mohd Shukry bin Abdul Majid for their time and efforts in guiding me to finish the work. I apologize for any trouble or difficulties that might had occurred during the overall period of supervision.

I am very thankful to the Ministry of Science, Technology and Innovation Malaysia (MOSTI) for funding the research through the Fundamental Research Grant Scheme (FRGS) headed by the lovely Mrs. Fauziah binti Mat.

I would also like to thank all the members, students and staffs of Intelligent Signal Processing (ISP) Cluster and School of Mechatronics for creating such a pleasant and encouraging environment to work with. Special thanks to Mr. Muhammad Naufal Mansor and Mr. Muhamad Aliff bin Mad Yussof for their relentless supports and aids in completing the research.

Last but certainly not least, a bundle of appreciation I owed to my parents, family, my beautiful wife, Nur Hikmah binti Ahmad and friends for their never-ending love, prayers and words of encouragement in my time of need.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Al	Aluminium
ANN	Artificial Neural Network
DR	Damping Ratio
FRF	Frequency Response Function
k-NN	K-Nearest Neighbour
LDA	Linear Discriminant Analysis
NF	Natural Frequency
SS	Stainless Steel

LIST OF SYMBOLS

a	Length
b	Width
t	Thickness
k	Stiffness
m	Mass
E	Young's modulus
v	Poisson's ratio
f	Frequency
λ	Frequency factor
γ^2	Coherence function
G_{FX}	Cross Power Spectrum between the excitation and response signal
G_{XX}	Power Spectrum of the excitation signal
G_{FF}	Power Spectrum of the response signal
H_0	Null Hypothesis

Klasifikasi Bahan Menggunakan Teknik Kecerdasan Buatan Berdasarkan Sifat Modal Yang Terhasil Daripada Getaran

ABSTRAK

Motivasi projek ini adalah untuk mengintegrasikan teknologi pemprosesan isyarat dan pencirian bahan ke arah membangunkan sistem ujian tanpa musnah dalam pengenalpastian bahan. Tujuan kajian ini adalah untuk mendapatkan parameter modal daripada keluli tahan karat SS304, aluminium 1100 dan kaca, mengesahkan parameter dengan mencari dan membandingkan pemalar elastik bahan berbanding nilai daripada teori dan ujian konvensional, dan mengklasifikasikan parameter menggunakan analisis diskriminan linear (LDA) , *k*-jiran terdekat (*k*-NN), dan rangkaian neural buatan (ANN) mengikut jenis bahan masing-masing. Parameter modal diperolehi dengan kaedah analisis modal, satu teknik yang menggunakan getaran pengujaan bahan dengan penggunaan tukul impak dan analisis fungsi sambutan frekuensi (FRF) yang terhasil daripada pengujaan, melalui kaedah memilih puncak pada rajah penstabilan. Nilai untuk parameter modal disahkan oleh LMS Modal Sintesis, program dalam perisian analisis modal, ujian kenormalan oleh Minitab 17, sejenis perisian statistik, dan dengan membandingkan pemalar kenyal bahan di antara nilai yang diperoleh daripada mengeksploitasi parameter modal, ujian konvensional dan teori. LMS Modal Sintesis membandingkan peratusan korelasi dan kesilapan dua isyarat FRF; satu sebagai isyarat daripada nilai eksperimen yang tepat dan satu lagi dari isyarat sintesis yang dihasilkan oleh perisian itu sendiri. Ujian kenormalan menganalisa sejauh mana parameter modal akan mengikuti taburan normal berdasarkan ujian Anderson-Darling. Penentuan pemalar elastik menilai ketepatan dan kredibiliti nilai-nilai parameter modal berdasarkan korelasi pemalar elastik daripada eksploitasi parameter modal dengan nilai-nilai eksperimen dan teori. Parameter modal yang telah disahkan digunakan sebagai input bagi pengklasifikasian tiga pengelas berbeza. LDA memberikan keputusan yang terbaik untuk kajian ini. Pengaturan ini kemudian digunakan untuk pengelasan parameter modal dengan tambahan gangguan untuk terus menguji kebolehpercayaan sistem klasifikasi. Semua keputusan dan analisis dibentangkan dan dibincangkan dengan teliti di dalam tesis.

Classification of Materials Using Artificial Intelligence Techniques Based on Modal Properties Generated by Vibration

ABSTRACT

The motivation of this project is to integrate the technology of signal processing and materials characterization into developing a system of non-destructive test of material identification. The purpose of this research is to obtain the modal parameters of stainless steel SS 304, aluminium 1100 and glass, validating the parameters by finding and comparing the elastic constants of the materials to theoretical and conventional testing values, and classifying the parameters using linear discriminant analysis (LDA), *k*-nearest neighbor (*k*-NN), and artificial neural network (ANN) according to their respective material types. The modal parameters were obtained by modal analysis method, a vibration technique that employs impulse excitation of the materials by using impact hammer and analysis of the frequency response function (FRF) resulted from the excitation through peak-picking on the stabilization diagram. The values for modal parameters were validated by LMS Modal Synthesis, a program in the modal analysis software, normality test by MiniTab 17, a statistical software, and by comparing elastic constants of materials between the ones obtained from exploiting the modal parameters, conventional testing and theoretical values. LMS Modal Synthesis compares the percentages of the correlation and error of two FRF signals; one being the signal from the exact experimental values and another from the synthesize signal generated by the software itself. Normality test analyses on how closely the modal parameters will follow the normal distribution based upon the Anderson-Darling test. Elastic constant determination shows how credible and precise the values of modal parameters based upon the correlation of the elastic constants from the exploitation of modal parameters with the experimental and theoretical values. The validated modal parameters are the used as the features for classification by three different classifiers. LDA gave the best performance for this research. The architectures are then used for classification of modal parameters with the addition of noise to further test the reliability of the classification system. All the results and analysis are presented and discussed thoroughly in the thesis.

CHAPTER 1

INTRODUCTION

1.1 Background

In an industrial context, having the right material for the right structural purpose is vital in order to ensure the safety and reliability of the structure constructed. In order to have the rightly suited material for a specific purpose, the material needs to be tested to acknowledge its attributes. This practice is known as material characterization.

The study of material characterization helps to understand more about the behaviour of the materials so that the utilization of the materials could be varied and used to the utmost potential. In order to characterize the properties of materials, the materials need to be probed by certain tests and the responses of the materials from such probing and testing would be used as the parameters in order to determine the properties of the materials such as elasticity and strength.

Knowledge of materials characterization is widely applied in the area of failure analysis to prevent engineering breakdown especially the very much undesirable catastrophic and cascading ones. In the area where safety, reliability and quality control are highly regarded, the continuous development of analysis technique and measurement technology for materials characterization becomes inevitable.

There are generally two types of test to characterize the materials; destructive or non-destructive testing. A destructive test would leave the specimens tested no longer usable for further testing and often require specific shape and size of the specimens.

Non-destructive testing on the other hand is a test which could be done repetitively on the same specimen as it does not alter the subjected specimens being tested. Most of the testing could be done on specimens in varied forms of shape and measurement. Thus it is not odd to find that non-destructive testing received favourable attention due to the advantages over destructive testing.

One example of non-destructive test is the experimental modal analysis. Modal analysis is the study of dynamic characteristic of structures induced by vibrational excitation. The responses from the excitation are referred as modal parameters. There are three types of modal parameters; natural frequency, mode shape and damping ratio. The values and changes in these parameters signify the values and changes in the physical properties of materials. Therefore, these parameters play imperative roles in classifying the materials accordingly to their properties (Dukkipati, 2004)

1.2 Problem statements

Destructive test requires the specimen to bet cut in specific shape and dimension. This approach is not effective because it does not represent the actual form of the application of the material. It is crucial to have the appropriate mechanism that able to test any kind of material without being cut or secluded from in its nature of application. This could be achieved by extensively researching on possible ways to contribute to the development of non destructive testing

Although non-destructive testing is very much desirable and perceived to be the better form of testing for materials structure compared to destructive testing, there are still various concerns related to non-destructive method that is worth looking deeper into such as the insufficiency of database available for modal parameters of materials especially values of natural frequencies of materials according to their shapes and sizes, lack of proper guidelines of suitable supporting structures for experimental modal analysis outlining the acceptable standard for it and deficiency of the use of blackbox classification method in characterization of materials.

1.3 Objectives

This research attempts to get to the bottom of the issues impeding the development of non-destructive testing in materials characterization as stated before. The objectives of this research are outlined as below.

- To acquire the modal parameters of different materials having the same dimension
- To determine the elastic constants of the materials from the acquired modal parameters
- To classify material modal parameters using classification algorithm

1.4 Scope of work

The scope of this research is basically to implement modal analysis of plate structures as hypothetically, different plate structures from different materials would generate different natural frequencies intrinsic to the types of the materials. The specimens used are three metal plates having the same dimension. The metals chose are notably distinctive in order to guarantee classifiability of the materials. The specimens are tested by the method of experimental modal analysis to obtain the modal parameters of the plates. The acquired modal parameters are validated before being utilized as the features for classification. The features are then classified by three different classification algorithm that is *k*-Nearest Neighbour, Linear Discriminant Analysis and Artificial Neural Network where the classification rate of all the classifiers are discovered.

1.5 Thesis outline

Chapter 1 is the introduction chapter of the research. It gave the general idea of the whole work done and the flow of the general process of the research. This chapter explains the research background, problems or issues associated with the research of interest, research objectives, scopes of work and the outline of every chapter of the thesis.

Chapter 2 reviews and discusses all the previous work done relating to the research topic. This includes the field of mechanical vibration, material properties, non dimensional analysis, signal processing and classification. Various techniques were used by researchers from all around the world throughout times. These techniques were compared in term of performance, feasibility of carrying out the experiment and reliability of the results. This research employed some of the techniques proven to be highly accurate and also some relatively new concepts which deemed to be practical and potentially worth to be further explored.

Chapter 3 explains the methods and procedures involved in conducting the investigation. The research procedures and the fundamental background of the process were outlined. This chapter also explains the method of data acquisition, right from the preparation of specimens to the classification of features. The methods include the procedure of conducting impact hammer testing and subsequently modal analysis of the frequency response function (FRF) signal to obtain the desired modal parameters. Validation of the data set is important in order to have reliable features before classifying them using various classification algorithm, thus implemented

Chapter 4 outlines the results for all the experiments conducted and the results were analysed to provide deeper understanding of such behaviour. All of the results were tabulated and outstanding results were singled out and discussed for such behaviour based on the fundamental understanding of the research ground of the method and the subsequent results.

Chapter 5 is the conclusion for the research done, highlighting all the findings of the research and provide ideas or foundation for future works of how this area of research could be further developed

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Throughout history, various methods and techniques have been done in order to achieve the intended hypotheses. Some were meticulously documented while others were not as detailed as they should have been. It is important to collect, reviewed and analysed the earlier works as many as possible regarding the field of interest of where a research is intended to dig deep into to gain much more holistic understanding of the area of interest so that any possible shortcomings or even possible results could be accurately anticipated.

This chapter gives the insight of where this research is inspired and rooted from by explaining briefly about other literatures that have been conducted regarding the subject of interest such as methods of parameters excitation, where various forms of excitation of the mechanical vibration could be identified, ways to determine elastic constant, ranging from conventional destructive testing to various non-destructive techniques and classification of materials, to gain further understanding of how various classifying algorithm work.

These techniques were compared in terms of performance, feasibility of carrying out the experiment and reliability of the results. This research employed some of the techniques already proven to be highly accurate and also some relatively new concept which deemed to be practical and potentially worth to be explored more and possible optimization for better performances.

2.2 Methods of materials parameters excitation

There have been great numbers of experimental procedures set up in order to excite and extract the desired corresponding values of natural frequencies of materials. This is due to the fact that natural frequencies hold the key understanding in mechanical vibration behaviour. As pointed out by the National Physics Laboratory (NPL, 2010) of United Kingdom, frequency measurement is the most accurate unit of measurement, thus it was not atypical for the augmenting favour of finding natural frequencies of materials for the last couples of decades since first recognized by Galileo Galilei in 1602 (Rao, 2005).

Ernst Chladni the “Father of Acoustics” as he often referred is famous for pioneering the observation of nodal patterns in vibrating plates by technique of bowing beginning in 1787 (Ullmann, 2007). In order to excite the frequencies of the plate, he used the bow and drew it at the edge of the plate to induce the vibration (McVeigh, 2000). Bow has been long used as the main instrument in exciting the violin strings, where in comparison to plucking, the use of bow allows the energy to be perpetually exerted and maintaining the note thus the rich harmonic spectrum could be sustained (Wolfe, 2005).

The bowing technique continue to be used as part of the research procedures carried out by Waller (1939). She then proposed another method of frequency excitation by means of solid carbon dioxide. A solid carbon dioxide block was introduced into contact with materials where the large temperature difference caused the heat dissipation from the metal to the solid carbon dioxide. Due to the sublimation of the solid carbon dioxide, significant amount of gas pressure was produced thus generating vibration with loud notes. The frequencies of the vibrations were measured by the calibrated valve oscillator. The same technique also been used in her other subsequent research (Waller, 1939, 1940, 1949).

The last couple of decades saw the extensive change in ways of frequency being excited from the way it was first recognized. Nowadays the method for frequency excitation is done by either employing the wave propagation method or modal vibration method.

The wave propagation method involves the use of acoustical excitation. Past research methods include the work done by Roy et al (1995) of which they used ultrasonic back wall echoes from copper and aluminium plates. On the other hand Mfoumou et al (2006) used the acoustical excitation of sheet materials like paperboard (PPR) and Low Density Polyethylene (LDPE) and the same technique in assessing the frequency shift measurement in damage detection (Mfoumou et al, 2008). The combination of ionizing radiation of Co^{60} and resonance ultrasound spectroscopy has been used by Abdukadyrova (2009) to record the resultant spectra of bending vibrations together with the main characteristics such as the amplitude of vibrations and resonance frequencies.

The modal vibration method has been used in many research laboratories and industries due to its ease of use and inexpensive testing equipments. Modal testing could be classified into two types that is dynamic shaker and impact hammer testing (Schwarz & Richardson, 1999). However, much of the research regarding the excitation of frequencies of materials involved more use of the latter. Deobald & Gibson (1988) used the impact hammer testing to determine the natural frequencies of aluminium and graphite/epoxy plates. The same specification have also been used by Hwang & Chang (2000) and Alfano & Pagnotta (2006) albeit different types of plates. Other notable works which used the same technique of impact hammer testing includes