UNIVERSITI PUTRA MALAYSIA

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By

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SIGNIFICANCE OF HARMONIC CONTENTS WITH RESPECT TO THE TIMBRE OF THE VIOLONCELLO

By

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September 2002

Chairman: **Dr. Minni Ang Kim Huai**

Faculty: **Human Ecology**

Harmonic contents (harmonic or inharmonic partials) is an important waveform characteristic that influences the timbre of musical tones. The first part of this research is aimed at finding out (through waveform analysis) the harmonic and inharmonic partials of four sampled violoncello (or cello) C#3 tones, each played using a different technique. The four different techniques studied are 'arco', 'spiccato', 'pizzzicato' and 'tremolando'. From the results of the waveform analysis, the difference in timbre between the four different playing techniques of the cello could be understood by comparing the harmonic contents of the four cello tones. The results of the waveform analysis generally showed that the four different playing techniques have different number of harmonic and inharmonic partials in their spectra. Both the 'spiccato' and 'tremolando' techniques produced more inharmonic compared to harmonic partials while the 'arco' technique produced more harmonic

compared to inharmonic partials. The 'pizzicato' technique produced only harmonic partials. The results of the waveform analysis is then used in the second part of this research that is aimed at finding out the significance of various groups of harmonic or inharmonic partials in contributing to the timbre of the cello through a listening test. For this test, the results of the waveform analysis are used to modify the harmonic contents of the four cello tones. The timbres of the modified cello tones are then compared with the original cello tones by using short music sequences. Comparisons are then made between the four different techniques by using tables and graphs. Results indicate that different groups of harmonic or inharmonic partials affect the timbre of the cello in different ways. In other words, some groups of harmonic or inharmonic partials are more significant to the timbre of the cello compared to other groups. Besides, the timbres of the four different playing techniques are influenced by the harmonic contents modifications differently. The results generally showed the 'spiccato' technique as the technique that is influenced most significantly and the 'pizzicato' technique as the technique that is influenced least significantly in timbre by the harmonic contents modifications executed. The timbres of both the 'arco' and 'tremolando' techniques are influenced moderately by the harmonic contents modifications. However, the timbre of the cello 'arco' technique is influenced more significantly by the harmonic contents modifications compared to the 'tremolando' technique.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESIGNIFIKANAN KANDUNGAN HARMONIK KEPADA KUALITI BUNYI VIOLONCELLO

Oleh

LIU LI YOON

September 2002

Pengerusi: **Dr. Minni Ang Kim Huai**

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Kandungan harmonik (separa harmonik atau inharmonik) merupakan ciri gelombang yang penting dalam mempengaruhi kualiti bunyi nada-nada muzikal. Bahagian pertama kajian ini adalah bertujuan mendapatkan separa harmonik dan inharmonik (melalui analisis gelombang) untuk empat nada C#3 violoncello (atau cello), masing-masing dimainkan dengan menggunakan teknik yang berlainan. Teknik-teknik yang dikaji adalah 'arco', 'spiccato', 'pizzicato' and 'tremolando'. Daripada keputusan analisis gelombang, perbezaan dalam kualiti bunyi antara empat teknik permainan cello yang berlainan tersebut dapat difahami dengan membuat perbandingan di antara kandungan harmonik bagi empat nada cello tersebut. Keputusan analisis gelombang secara keseluruhannya menunjukkan bahawa empat teknik permainan tersebut mempunyai bilangan separa harmonik dan inharmonik yang berbeza di dalam spektra mereka. Kedua-dua teknik 'spiccato' dan 'tremolando'

menghasilkan lebih separa inharmonik berbanding dengan separa harmonik manakala teknik 'arco' menghasilkan lebih separa harmonik berbanding dengan separa inharmonik. Teknik 'pizzicato' menghasilkan hanya separa harmonik sahaja. Keputusan analisis gelombang yang diperolehi akan digunakan di dalam bahagian kedua kajian ini yang bertujuan untuk mengetahui kesignifikanan beberapa kumpulan separa harmonik atau inharmonik dalam mempengaruhi kualiti bunyi cello melalui suatu ujian pendengaran. Untuk ujian ini, keputusan analisis gelombang digunakan untuk mengubah kandungan harmonik keempat-empat nada cello tersebut. Kualiti bunyi nada-nada cello yang telah diubah kandungannya akan dibandingkan dengan nada-nada cello asal dengan menggunakan beberapa sekuens muzik yang pendek. Perbandingan kemudian dibuat diantara kempat-empat teknik tersebut dengan menggunakan jadual dan graf. Keputusan ujian menunjukkan bahawa kumpulan separa harmonik atau inharmonik yang berbeza mempengaruhi kualiti bunyi cello dengan cara berbeza. Dengan kata lain, sesetengah kumpulan separa harmonik atau inharmonik adalah lebih signifikan kepada kualiti bunyi cello berbanding dengan kumpulan yang lain. Selain dari itu, kualiti bunyi teknik permainan yang berlainan dipengaruhi oleh perubahan-perubahan kandungan harmonik tersebut dengan cara berlainan. Secara kesuluruhannya, keputusan yang diperolehi menunjukkan bahawa teknik 'spiccato' adalah teknik yang dipengaruhi paling banyak dan teknik 'pizzicato' adalah teknik yang dipengaruhi paling sedikit dalam kualiti bunyi oleh perubahan-perubahan kandungan harmonik tersebut. Kualiti bunyi kedua-dua teknik 'arco' and 'tremolando' dipengaruhi secara sederhana oleh perubahan-perubahan kandungan harmonik tersebut. Bagaimanapun, kualiti bunyi teknik 'arco' dipengaruhi lebih banyak oleh perubahan-perubahan kandungan harmonik tersebut berbanding dengan teknik 'tremolando'.

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I certify that an Examination Committee met on 20th September 2002 to conduct the final examination of Liu Li Yoon on her Master of Science thesis entitled "Significance of Harmonic Contents with Respect to the Timbre of the Violoncello" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommended that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations that have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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LIU LI YOON

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CHAPTER ONE

INTRODUCTION

Musical timbre or tone quality is defined as the way in which musical sounds differ once they have been equated for pitch, loudness and duration (Krumhansl, 1989). Thus, timbre enables us to recognize two different instrument sounds with the same pitch, loudness and duration. Music researchers like Helmholtz (1877), Risset and Mathews (1969), Houtsma (1989), Handel (1995), and Wessel (1999) have all defined timbre in their own views or perspectives. According to Brown (1999), studies on how human beings perceive timbre have been performed over the past four decades with the indefinable goal of correlating the results of perceptual experiments with a small number of acoustical properties of the sounds studied. Many of these studies were performed by first modifying acoustic signals and then experiments were done to determine whether listeners could distinguish or perceive the difference of timbre between the altered signals and the original signals.

Helmholtz carried out the first significant studies on timbre in the 19^{th} century (Hourdin, Charbonneau and Moussa, 1997). The various investigations performed by Helmholtz proved that the timbre of a sound is influenced by its harmonic contents (hamonic or inharmonic partials). [Harmonics are defined as the several different frequencies present in a sound, in addition to the frequency that corresponds to the note being played which is the fundamental harmonic. These harmonics above the fundamental, also known as partials or overtones are integer multiples of the fundamental harmonic (Huber and Runstein, 1995). Harmonics are integer multiples of the fundamental harmonic while partials could be either integer or non-integer

multiples of the fundamental harmonic. Partials that are integer multiples of the fundamental harmonic could also be referred as harmonic partials while partials that are non-integer multiples of the fundamental harmonic are known as inharmonic partials]. For example, an extremely nasal timbre stresses on different harmonics as compared with a mellow timbre. The timbre of the tuning fork and of the stopped diapason organ is clear and pure because the sound they produce is almost without overtones (Encyclopedia Britannica, 2000). Thus, timbre is the result of the unique harmonic content that each sound produces (Rubin, 1995). In other words, timbre is the combination of fundamental frequency, harmonics, and overtones that gives each voice, musical instrument, and sound effect its unique colouring and character (Mott, 2001).

Different types of timbres are associated with different harmonic contents. For example, 'bright' timbres are likely to contain high-level upper harmonics; 'bell-like' sounds are rich in inharmonic contents; many 'percussive' timbres have high noise (Cary, 1992) as well as inharmonic contents (Runas, 1998); open, warm and filled-out timbres have spectra that emphasize on even-numbered (second, fourth and sixth) harmonics and closed, harsh and stopped-down sounds emphasize on odd-numbered (third and fifth) harmonics (Alten, 1996). The second harmonic, an octave above the fundamental, adds fullness to sound, the third harmonic softens sound while harmonics above the seventh harmonic give sound edge, bite and definition (Alten, 1996). Some sounds are made up of only harmonic partials while others are made up of a combination of both harmonic and inharmonic partials.

Two notes of the same pitch, loudness and duration would also sound different if the shape of their amplitude or ADSR envelope (refer to **Figure 1**) is different. This means that different instruments would produce different ADSR or amplitude envelopes with different ADSR parameters that lead to the difference in their tone qualities or timbres.

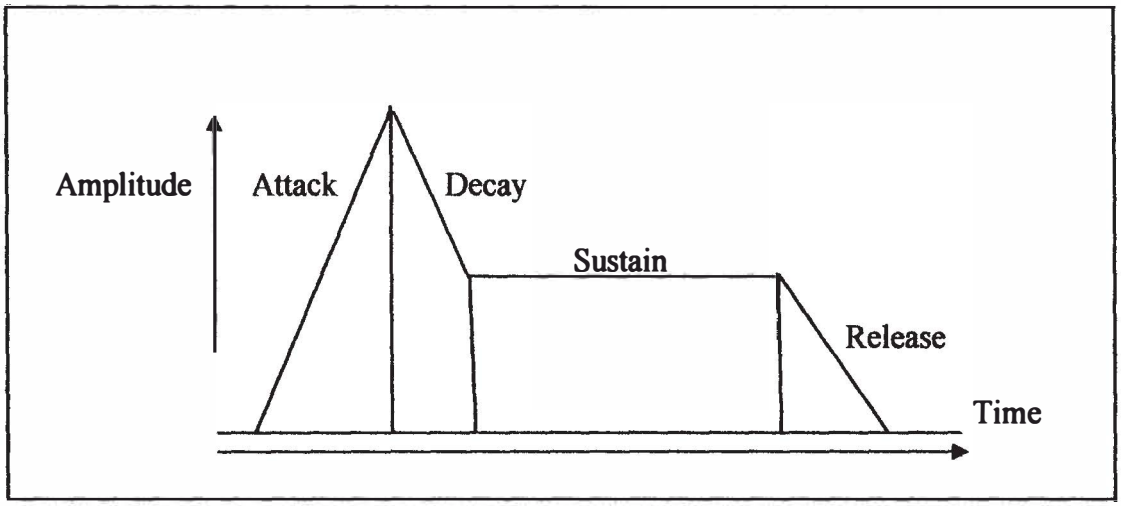

Figure 1: A Typical ADSR Envelope

Different techniques of playing also affect the timbre of an instrument. For example, a similar note would sound different if it is played on a violin using different techniques like bowing, plucking, tremolo etc even though it is played with equal loudness. This is because the shape of the amplitude envelope would be different when different techniques of playing are used.

Of the two important factors that contribute to the timbre of musical tones mentioned, only the significance or importance of harmonic contents would be studied in this research. Besides contributing to the timbre of musical instruments, these two factors are the most common waveform characteristics that allow one

waveform to be distinguished from another. Other waveform characteristics include velocity, wavelength and phase (refer to **Appendix A**).

Many research projects on instrumental timbre have been performed by music researchers worldwide. Some of these researchers include Charbonneau (1981), Wolfe (1998), Conklin (1999) and recently Mellody and Wakefield (2000).

The aim of this study is to find out the influence and significance of various groups of partials (harmonic or inharmonic) to the timbre of the violoncello which is more commonly known as the cello, an instrument from the strings family played using four different techniques that are 'arco', 'spiccato', 'pizzicato' and 'tremolando'. A listening test would be carried out to compare the timbres of the original sampled tones and their modified versions (modified in terms of harmonic contents). A similar note, C#3 (middle C#3), is analyzed for all the four different techniques. Studies on other types of instruments have also been performed widely by researchers in the past. Some of the instruments studied include piano and harpsichord (Weyer, 1976), plucked-strings (Karplus and Strong, 1983), double bass (Abbas, 1989), winds (Keefe, 1992) and violins (Miller, 1993; Mellody and Wakefield, 2000).

Statement of the Problem

Tone color or timbre is the subjective quality of a sound that allows us to tell the difference between musical instruments (Phenomena Cross Reference, 1995). When a similar instrument is played using different techniques, different timbres are produced. Thus, waveform analysis is required to find out the harmonic contents (hamonic or inharmonic partials) that represent the four different playing techniques ('arco', 'spiccato', 'pizzicato' and 'tremolando') of the cello. The significance of the contribution of specific harmonic or inharmonic partials to the timbre of the cello has yet to be documented. The difference in timbre between the 'arco', 'spiccato', 'pizzicato' and 'tremolando' playing techniques, not fully explained as yet, may be better understood and explained with this information.

In theory, every sound has its own harmonic contents (harmonic or inharmonic partials) that distinguishes it from any other sound. By modifying the harmonic contents (harmonic or inharmonic partials) of a musical waveform, the timbre of the sound also changes. The significance of harmonic contents (harmonic or inharmonic partials) in contributing to the timbre of the cello played using different techniques needs to be determined through the listening test, whereby the timbres of the original cello tones may be compared with their modified versions (various groups of harmonic or inharmonic partials filtered out).

Objective of the Study

There are three objectives of this study that are to:

1) obtain and compare the harmonic contents (harmonic or inharmonic partials) of the cello played using different techniques,

2) find out the difference between the significance of various groups of partials (both harmonic or inharmonic) to the timbre of the cello in dependence on the playing technique employed and

3) find out whether the timbres of certain playing techniques of the cello are influenced more (or less) significantly by harmonic contents (harmonic or inharmonic partials) compared to other techniques.

Significance of the Study

By finding out the harmonic contents (harmonic or inharmonic partials) of the sampled tones that represent the cello through waveform analysis and knowing the contribution of this waveform characteristic to the timbre of the cello (through the listening test) in dependence on the playing technique employed and also by understanding how the various playing techniques are affected or influenced by the various groups of harmonic or inharmonic partials, we would have a better understanding of the waveform features and acoustics of the cello. This enables us to synthesize more natural and high quality sounding cello tones with different timbres in correspondence with the various playing techniques by using the results of the harmonic analysis.

The results of the waveform analysis could also be utilised via filters designed to produce many different types of creative and original sounds like the various sound effects used in films and electroacoustic compositions and sounds that are not in the repertoire of natural instruments.

Design of the Study

This study is divided into three parts. The first part is made up of two smaller sections that are a) selecting the various cello samples for analysis and b) copying or importing the samples into the waveform or spectrum analysis software for the harmonic analysis.

The second part focuses on the modification of the harmonic contents (harmonic or inharmonic partials) of the four cello waveforms (the results of the harmonic analysis from the first part are used) using a digital audio editing software. Modifications are executed by filtering out various groups of harmonic or inharmonic partials from the four cello spectra, each played using a different technique ('arco', 'spiccato', 'pizzicato', 'tremolando'). Similar modifications are executed on the four different cello spectra so that the significance of the various groups of harmonic or inharmonic partials to the timbres of the four different techniques of the cello could be compared.

The third part focuses on the listening test where both the original and modified cello waveforms are loaded as soundfonts. A different MIDI sequence is

played using the original and the modified soundfonts for each different technique of the cello. In this way, the timbres of the original soundfonts were compared with the modified soundfonts for each different technique. From the comparison, the significance of the various groups of partials in influencing the timbre of the cello in dependence on the playing technique employed is deduced. The playing technique that is influenced most to least significantly in timbre by each of the various groups of partials is also deduced.

Organization of the Thesis

In Chapter Two, the literature review is undertaken. This focuses on topics like how harmonic contents and waveform envelope influence the timbre of musical instruments; a brief history and definition of the waveform analysis method that is used; the significance of waveform analysis and also past and current research on spectrum and waveform envelope analysis and timbre of musical tones.

In Chapter Three, the methodology is discussed. The steps for executing the harmonic analysis are explained. Besides that, the steps taken to modify the cello waveforms for the listening test are explained. The procedures of the listening test are also explained.

Chapter Four is focused on the results and discussion of the harmonic analysis as well as the listening test. Graphs and tables are used in the discussion of the results obtained.

The last chapter presents the conclusions of the study. This chapter ends with suggestions for further study. The literature review is now considered further.

CHAPTER TWO

LITERATURE REVIEW

This chapter focuses on how the two most common factors: harmonic contents and waveform envelope affect the timbre of musical instruments; a brief history and definition of the waveform analysis method that is used and also the significance of waveform (spectrum) analysis. Besides, past and current research on spectrum and waveform envelope analysis and timbre of musical tones are documented.

How Harmonic Contents and Waveform Envelope Influence the Timbre of Musical Instruments

Musical sounds have been traditionally viewed as a series of sinusoidal components, each having an amplitude and frequency (McAdams, Beauchamp and Meneguzzi, 1999). Each instrument sound has its' own unique waveform (spectral) structure/envelope (approximated by using a continuous line to connect graphs of amplitude versus frequency) and harmonic contents or spectrum components (harmonic or inharmonic partials) that distinguishes it from all other sounds. These two differences between sounds explain the difference in timbre or tone quality between different instruments.

(Note: When the propagation of a sound wave is described by a graph of amplitude versus time (time domain), it is known as waveform and when it is described by a graph of amplitude versus frequency (frequency domain), it is known as spectrum).