THE EFFECT OF REVERBERANT SOUND LEVEL ON THE INTELLIGIBILITY OF SPOKEN MALAY WORDS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MARCH 2015

Specially dedicated to my beloved parents, brother and sister.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all of those who has given me the support to complete this thesis. A special gratitude I give to my supervisor Ir. Dr. Mokhtar Harun for providing the supervision and guidance throughout this research.

My appreciation also goes to Dr. Puspa Inayat and Dr. Ibrahim Shapiai who has given me valuable support during this research.

I would also like to my friends, Mohammad Afiq Nurrudin, Fatimah Zahra and others, for providing me the support, encouragements and advices during this research. Also to the speakers who have helped with this research, Mr. Jais and Mrs. Hasliza.

On a personal note, I would like to thank my family who has been tolerant and supportive to me throughout this research.

ABSTRACT

Reverberant sound is known to degrade Speech Intelligibility (SI). For instance, it has been found that amplitude of English speech signal, syllable continuum from “sir” to “stir”, is affected in reverberant condition. However, there are currently no studies on the effect of reverberation on spoken Malay words. The purpose of this research is to investigate the effect of reverberant sound on spoken Malay words. The project started with the development of Malay word list. The list consists of 5924 distinct Malay words and was based on the texts from 52 Friday sermon transcripts that were spoken in Kuala Lumpur mosques. The Malay words spoken in mosques were used because SI in many mosques suffers from reverberant sound. From this, two sets of phonetically balanced word lists were developed with each contain 50 words. These words were then recorded in an audiometry room with the help of two trained speakers, a male and a female. The recorded words were then played back in seven different room samples with different reverberant sound levels. Reverberation time was used as level indicator (in seconds) of reverberant sound. The effect of each room sample on clean recorded words was analysed in terms of fundamental frequency (F_0), first and second formant frequency (F1 and F2), and spectral tilt. The effect of reverberant sound on F_0 for female speaker was more profound and statistically significant. The F1 of both speakers were not affected by reverberant sound. However, only F2 of female speaker was affected by reverberant sound. The value of spectral tilt shows that vowel /*a*/ is the most susceptible to reverberant sound. In conclusion F_0, F2, and spectral tilt are relevant parameters, and have been able to demonstrate the effect of reverberant sound on spoken Malay words.

ABSTRAK

Gemaan lewat adalah fenomena yang menganggu Kejelasan Percakapan (SI). Contohnya, didapati bahawa amplitud isyarat mempengaruhi kejelasan pertuturan Bahasa Inggeris dalam keadaan bergema pada kontinum suku kata "*sir*" kepada "*stir*". Tetapi tiada kajian dilakukan untuk mengkaji kesan gemaan terhadap perucapan bahasa Melayu. Kajian ini bertujuan mengkaji kesan gemaan terhadap perucapan bahasa Melayu. Projek ini bermula dengan menghasilkan senarai perkataan. Senarai ini terdiri daripada 5924 perkataan yang berbeza dan diambil daripasa 52 teks khutbah Jumaat yang dituturkan di masjid Kuala Lumpur. Ini kerana kebanyakan masjid mempunyai gemaan suara yang menganggu SI. Dua set senarai perkataan yang berseimbang fonetik telah dihasilkan dan setiap set mempunyai 50 patah perkataan. Perkataan-perkataan ini kemudiannya direkodkan dalam bilik audiometri dengan bantuan dua penutur terlatih, seorang lelaki dan seorang perempuan. Perkataan-perkataan yang telah direkodkan didengar kembali di dalam tujuh sampel bilik yang mempunyai tahap gemaan yang berbeza. Tahap gemaan dikuantitikan dalam masa gemaan (dalam saat). Kesan bilik sampel telah dikaji berdasarkan frekuensi asas (F_0), frekuensi forman pertama dan kedua (F1 dan F2) beserta dengan kecondongan spektral. F_0 pada kedua-dua penutur dipengaruhi oleh gemaan, tetapi ia didapati lebih jelas pada penutur perempuan dan lebih signifikan secara ixocalixtic. F1 pada kedua-dua penutur langsung tidak dipengaruhi oleh gemaan suara. F2 pada penutur perempuan sahaja dipengaruhi oleh gemaan. Nilai kecondongan spektral menunjukkan ixocal /*a*/ adalah senang dipengaruhi oleh gemaan suara. Sebagai kesimpulan, F_0, F2 dan kecondongan spektral adalah parameter yang releven, dan telah menunjukkan kesan gemaan suara terhadap perucapan bahasa Melayu.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANC	-	Anechoic Chamber
AUD	-	Audiometry Room
DEM	-	Demonstration Room
EXM	-	Examination Room
HNR	-	Harmonic To Noise Ratio
JAKIM	-	Jabatan Kemajuan Islam Malaysia
LEC	-	Lecture Room
LTAS	-	Long Term Average Spectrum
MySQL	-	My Structured Query Language
OFC	-	Office Room
PHP	-	Personal Home Page
REV	-	Reverberant Room
SI	-	Speech Intelligibility
STI	-	Speech Transmission Index
STO	-	Store Room

LIST OF SYMBOLS

A	-	Total absorption of room
dB	-	Decibel
d_c	-	Critical distance
F_0	-	Fundamental frequency
f_0	-	Amplitude of the first harmonic
F1	-	First formant frequency
F2	-	Second formant frequency
H2	-	Amplitude of the second harmonic
ln	-	Natural algorithm
RT_{60}	-	Reverberation time
S	-	Total surface area
ST	-	Spectral tilt
V	-	Room volume
$\alpha_{average}$	-	Average absorption coefficient

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter starts by explaining the background of problems of this research. It starts by explaining the reverberant sound field and how it leads to reverberation and the parameter to measure it. The relation between the chosen parameter and Speech Intelligibility (SI) are discussed along with the Malay language. From this, the problem statement and objectives were derived. The scope of this study is then outlined along with the contributions done.

1.2 Background of Problems

If a listener moves further away from a sound source, the listener will experience a gradual reduction of sound pressure level. This reduction of sound pressure level is determined by the inverse square law. However, in a reverberant sound field, the sound pressure level does not follow inverse square law, and that the sound pressure level will show little or no reduction at all (Egan, 2007). At reverberant sound field, the energy supplied by the sound source is equal to the rate of the sound absorbed by the room (Rossing *et al.*, 2002). The distance from the sound source to the reverberant field is called critical distance. After critical distance, in reverberant field, sound pressure level remains constant. Speeches that are heard at the critical distance and beyond are affected by reverberant sound. After a speech is spoken, the word will still being reflected back and forth inside the room, and when a new spoken word reach the listener, the word heard by the listener will be new word spoken with addition of the remaining last reverberant spoken words.

However, it should be noted that reverberation is not as same as echo, even though the two phenomena are fairly similar. The main difference between echo and reverberation is the time delay between the direct sound and the reflected sound. If the time delay is more than 50 ms, it can be considered an echo for path length larger than 17 m (Kleiner, 2011).

Reverberation time is one of the main parameters to assess reverberant state of the room and thus the acoustic quality of a room (Berg and Stork, 2005). Reverberation time is defined as the time required for the sound intensity to drop one millionth of its original value. The value of reverberation time in a room depends on the volume of the room and in function as shown in Figure 1.1. However, the room constructed may not have the same reverberation time as intended for its usage. For example the reverberation time of a mosque in Universiti Tun Hussein Onn is 21200 cubic meters. According to Figure 1.1, its reverberation time is supposed to be around 1.2 s. The actual reverberation time measured is around 2.4 s (Universiti Teknologi Malaysia, 2013).

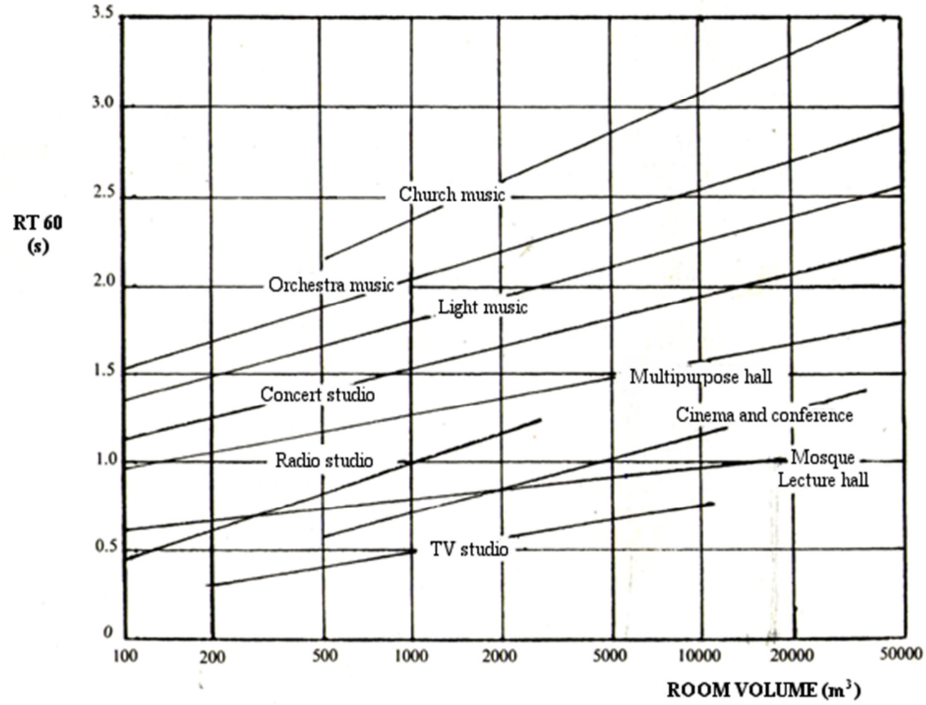

Figure 1.1: The ideal reverberation time versus room size (Ahmad, 1990).

Figure 1.1 shows the ideal reverberation time of certain rooms depending on their volume. However, buildings constructed in the real world do not follow the ideal condition. Table 1.1 shows various mosques with various volumes and their reverberation time.

As can be seen from Table 1.1, the ideal reverberation time for all the four mosques are much shorter than the real reverberation time measured in those mosques. This goes to show that large room will generally have high reverberation time than intended. This is because in larger rooms, sound need to travel longer to be weakened by room boundary; this correspond to slower decays and in turn lead to longer reverberation time (Ermann, 2015). This can be problematic to the audience of the room because it will decrease the speech intelligibility in the room.

Table 1.1: Reverberation time in mosques.

Source	Mosque	Volume (m^3)	Reverberation Time (s)	
			Actual	Inserted from Figure 1.1
Ismail, 2013	Damascus Centre Mosque (Syria)	9556	2.1	0.9
Gul and Caliskan, 2013	Dogramacizade Ali Pasa Mosque (Turkey)	6840	2.2	0.8
Eldien and Qathani, 2012	Mosque in Eastern Province of Saudi Arabia (Saudi Arabia)	1600	2.0	0.7
Universiti Teknologi Malaysia, 2013	Mosque in Universiti Tun Hussein Onn (Malaysia)	21200	2.4	1.2

Despite the advantage of speech intelligibility that came with shorter reverberation time, the congregations that go to places of worship prefer longer reverberation time although not exceeding 2.0 s. Furthermore, a place of worship with shorter reverberation time is not well accepted by congregations. This is due to the expectations and hearing habits of congregations and not based on rational arguments (Kuttruff, 2009).

Speech quality can be altered by altering the reverberation time of a room. For example, speech intelligibility drops by 5% when the reverberation time was increased from 0.5 s to 1.0 s; and intelligibility of speech drops by 15% when the reverberation time was increased from 1.0 s to 1.5 s (Peng, 2010). Speech intelligibility will drop by 10% by increasing reverberation time from 0.6 s to 0.8 s (Hazrati and Loizou, 2012). High reverberation time can also be detrimental to the hearing impaired, as demonstrated by Kokkinakis and Loizou (2011) when it was discovered that increasing reverberation time from 0 to 1.0 s decreases speech intelligibility by 60% among cochlear implant users.

It is generally accepted that shorter reverberation time will result in better speech intelligibility (Kuttruff, 2009). However, the ideal reverberation time of a room depends on the nature of application and the volume of the room (Raichel, 2006). For example, a study has shown that the acceptable reverberation time in a classroom is between 0.3 s-0.9 s (Yang and Bradley, 2009). For places of worship, a long reverberation time is preferred but not exceeds 2.0 s (Kuttruff, 2009).

One of the reasons reverberation time cannot be nullified is because the early reverberation time can be beneficial to speech intelligibility (Jacob, 1989). However, if the reverberation time is long it will be detrimental to speech intelligibility and this sound is defined as late reverberant sound (Jacob, 1989). Reverberant sound is considered late or detrimental to speech intelligibility when it arrives later than 80ms of direct sound (Rossing *et al.,* 2002).

Reverberation has been shown to affect acoustical parameters of speech. For example, a research done by Galburn and Kitapci (2014) has shown that the result by using reverberation time to predict speech intelligibility does not differ from predicting speech intelligibility using signal to noise ratio. Another study done by Srinivasan and Zahorik (2012) has shown that the amplitude envelope of speech is responsible for the enhancement of speech intelligibility in reverberant condition. However, these studies were done by using English.

Malay, which is spoken by 250 million people (Tadmoor, 2009) has only about 500 monosyllables and half of it consists of loan words from other languages, especially English (Karim, 1995). This effectively limits the use of diagnostic rhyme test since the test requires a sizeable portion of monosyllabic words even though it is considered to mimic everyday speech (Palaz *et. al.,* 2005). The most common form of words in Malay is that of disyllabic. The number of tri-syllabic word structure is small in Malay. There are few words that contain four syllables or more but most of these words are loan words from Sanskrit, Arabic and recently English (Teoh, 1994).

1.3 Problem Statement

In Malaysia, the reverberation time in mosques is usually in the range of 2.0 s to 2.5 s. This high reverberation time will decrease speech intelligibility. Places of worship should have long reverberation time but not exceed 2.0 s. However, the reverberation time for good intelligibility falls within the range of 0.5 s – 0.8 s. This means that mosques face the problem intelligibility loss due to reverberant sound. Also, the words spoken in mosques in Malaysia are mainly Malay. Therefore, it is the purpose of this research to investigate how intelligibility of spoken Malay words is affected by reverberant sound.

1.4 Objectives of Study

The objectives of the research are as follows:

(i) To obtain spoken Malay words from Friday sermon in mosques.
(ii) To design phonetically balanced Malay word list to be used for acoustic parameters tests.

(iii) To analyze the effects of reverberant sound level on the intelligibility of spoken Malay words.

1.5 Scope of Study

The scopes of this research are as follows:

(i) The spoken Malay words selected were from Friday sermon transcripts.
(ii) These words have been selected from a total of 52 speech transcripts of Friday sermons obtained from JAKIM website.
(iii) The room samples these words to be tested were an office room, a reverberant room, a store, a lecture hall, a lecture room, an examination room and an anechoic room.
(iv) The spoken Malay words for acoustic parameters analysis were selected according to the manners of articulation: stops, fricative, approximants and nasal.
(v) The effect of late reverberant sound has been analyzed by using the following speech signal parameters: fundamental frequency, formant frequency and spectral tilt.

1.6 Contributions of Study

(i) This research has produced two sets of phonetically balanced Malay word lists for the purpose of speech intelligibility test. Each set contains 50 words. The words selected were based on words spoken in mosque, which was obtained from 52 Friday sermons transcripts.

(ii) A novel way of constructing the phonetically balanced word lists had been determined from this research. It is through the use of the programming language, PHP in conjunction with the database manager system, MySQL.

(iii) This research has shown that reverberant sound have the most effect on fundamental frequency. However, the effect of reverberant sound on the fundamental frequency of female speaker is more profound. First formant frequencies for both speakers are not affected by reverberant sound. The second formant frequency of female speaker is affected by reverberant sound but not of the male speaker. Spectral tilt has shown that vowel /a/ is the most affected by reverberant sound which means that it suffers the most in terms of intelligibility under reverberant condition.

1.7 Thesis Outline

This thesis is divided into several chapters. Chapter 1 is the Introduction for this chapter along with the summary of research objectives, scopes and contributions. Chapter 2 is the Literature Review for sound characteristic in rooms, reverberant sound, SI, word list, the software used and manners of articulation. Chapter 3 details the methods used in this research, starting with word list design and finished with analyzing the recorded word using Praat. Chapter 4 is the analysis of results obtained in this research by referring to the selected parameters. Chapter 5 is the conclusions and the future works for this research.

1.8 Summary

In conclusion, this research was undertaken to measure the intelligibility of spoken Malay words in reverberant room samples by referring to several acoustic parameters. Three objectives were derived for this research and several research contributions were made.

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