PREDICTING NOISE-INDUCED HEARING LOSS (NIHL) IN TNB WORKERS USING GDAM ALGORITHM

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ABSTRACT

Noise is a form of a pollutant that is terrorizing the occupational health experts for many decades due to its adverse side-effects on the workers in the industry. Noise-Induced Hearing Loss (NIHL) handicap is one out of many health hazards caused due to excessive exposure to high frequency noise emitted from the machines. A number of studies have been carried-out to find the significant factors involved in causing NIHL in industrial workers using Artificial Neural Networks (ANN). Despite providing useful information on hearing loss, these studies have neglected some important factors.

The traditional Back-propagation Neural Network (BPNN) is a supervised Artificial Neural Networks (ANN) algorithm. It is widely used in solving many real time problems in world. But BPNN possesses a problem of slow convergence and network stagnancy. Previously, several modifications were suggested to improve the convergence rate of Gradient Descent Back-propagation algorithm such as careful selection of initial weights and biases, learning rate, momentum, network topology, activation function and 'gain' value in the activation function.

This research proposed an algorithm for improving the current working performance of Back-propagation algorithm by adaptively changing the momentum value and at the same time keeping the 'gain' parameter fixed for all nodes in the neural network. The performance of the proposed method known as 'Gradient Descent Method with Adaptive Momentum (GDAM)' is compared with 'Gradient Descent Method with Adaptive Gain (GDM-AG)' (Nazri, 2007) and 'Gradient Descent with Simple Momentum (GDM)' by performing simulations on classification problems. The results show that GDAM is a better approach than previous methods with an accuracy ratio of 1.0 for classification problems like

Thyroid disease, Heart disease, Breast Cancer, Pima Indian Diabetes, Wine Quality, Australian Credit-card approval problem and Mushroom problem.

The efficiency of the proposed GDAM is further verified by means of simulations on Noise-Induced Hearing loss (NIHL) audiometric data obtained from Tenaga Nasional Berhad (TNB). The proposed GDAM shows improved prediction results on both ears and will be helpful in improving the declining health condition of industrial workers in Malaysia. At present, only few studies have emerged to predict NIHL using ANN but have failed to achieve high accuracy. The achievements made by GDAM has paved way for indicating NIHL in workers before it becomes severe and cripples him or her for life. GDAM is also helpful in educating the blue collared employees to avoid noisy environments and remedies against exposure to excessive noise can be taken in the future to prevent hearing damage.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANN	-	Artificial Neural Networks
BMI	-	Body-Mass-Index
BPNN	-	Back-Propagation Neural Network
BPAM	-	Back-Propagation with Adaptive Momentum
DOSH	-	Department of Occupational Safety and Health, Malaysia
GDAM	-	Gradient Descent with Adaptive Momentum
GDM	-	Gradient Descent with Momentum
GDM-AG	-	Gradient Descent with Momentum and Adaptive Gain
HDI	-	Hearing Deterioration Index
high	-	highest value in the interval [0,1]
Hz	-	Hertz
KHz	-	Kilo-Hertz
L	-	lower bound
low	-	lowest value in the interval [0,1]
LHL	-	Left Hearing Loss
MLP-ANN	-	Multilayer Perceptrons Artificial Neural Networks
NIHL	-	Noise-Induced Hearing Loss
NIOSH	-	National Institute of Occupational Safety and Health
PTS	-	Permanent Threshold Shift
rand	-	Random number generator built-in function of Matlab
RHL	-	Right Hearing Loss
RSI	-	Rothman Synergy Index
SPL	-	Sound Pressure Level
TNB	-	Tenaga Nasional Berhad
TTF	-	Time-To-Failure
TTS	-	Temporary Threshold shift
n	-	Number of nodes in the output layer

t_k	-	Desired output of the kth output unit
O_k	-	Network output of the kth output unit
α_k	-	Momentum coefficient
O_j	-	Output of the jth unit
O_i	-	Output of the ith unit
w_{ij}	-	Weight of the link from unit i to unit j
w_{jk}	-	Weight of the link from unit j to unit k
w_{net}	-	Total Network Weights
$a_{net,j}$	-	Net input activation function for the jth unit
θ_j	-	Bias for the jth unit
y_{new}	-	new value obtained
y_{old}	-	old value in the data
$y_{\max}$	-	maximum and minimum of the old data range
$y_{\min}$	-	minimum of the old data range
T_i	-	predicted data
A_i	-	actual data
n	-	total number of input patterns
N	-	Number of values or elements
X'	-	first score
x_i	-	number of input patterns
Y'	-	second score
y_i	-	predicted patterns
%	-	percentage sign
U	-	upper bound

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

In the last three decades, Malaysian Industry has progressed a lot and has not only benefited Malaysian citizens in many ways but it also has caused adverse health effects on the Malaysian industrial workers. One of the major occupational health problems that an Industrial worker faces today is Noise-Induced Hearing Loss (NIHL). Noise-Induced Hearing Loss (NIHL) usually occurs due to continuous exposure to the noise levels of 90 plus decibels emitting from the heavy machines.

Noise-Induced Hearing Loss (NIHL) is a common occupational health problem identified among the workers working in the textile plants, basic metal industry, chemical industry, beverages and non-metallic mineral product industry. It was revealed in 1990's Audiometric (hearing loss test) survey by Department of Occupational Safety and Health, Malaysia (DOSH) that about 26.9 percent of industrial workers had a hearing threshold of 3000 - 6000 Hz which was greater than normal and 21.9 percent of workers were already suffering from detectable hearing loss (Leong, 2003). In another Audiometric test conducted at Stesen Janakuasa Sultan Ismail, Terengganu by Rizal (2002), it was revealed that Gas Turbine Station had the most number of NIHL effectees than Steam Turbine, Boiler or Pump Station. The test exposed that out of the 37 workers selected; about 39.6 percent of workers were already suffering from hearing loss.

Human ear plays a vital role in the human body; it is not only a source of hearing in humans but it also helps human body in maintaining its balance. Any problem with the hearing ability damages the human's life by reducing the quality of communication (Zaheeruddin & Jain, 2004). Noise-Induced Hearing Loss (NIHL) can be categorised as temporary or permanent, depending on how much sensorineural loss has occurred in the patient. Usually Noise-Induced Hearing Loss (NIHL) progresses unnoticed until it began to interfere with the communication and thus decreases the quality of life.

Seeing Noise-Induced Hearing Loss (NIHL) as a growing problem in the Malaysian Industry, Factories and Machinery (Noise Exposure) Regulations, 1989 has been passed by Department of Occupational Safety and Health, Malaysia (DOSH) in order to control the level of noise to permissible limits. In line with this, employers are required to abide the following stated regulations;

I. *No Employee shall be exposed to noise level exceeding equivalent continuous sound level of 90 dB (A) or exceeding the limits specified in the first schedule or exceeding the daily dose of unity.*
II. *No employee shall be exposed to noise level exceeding 115dB (A) at any time.*
III. *No employee shall be exposed to impulsive noise exceeding a peak sound pressure level of 140 dB(A).*

Noise-Induced Hearing Loss (NIHL) is found to cause many harmful effects in humans, but the latest improvements in Artificial Neural Networks (ANN) has paved way for researchers to predict various harmful effects of noise on humans such as human work efficiency in noisy environment (Zaheeruddin & Garima, 2005), speech interference in noisy environment (Zaheeruddin & Jain, 2005), noise induced sleep disturbance (Zaheeruddin & Jain, 2006), and noise induced annoyance (Zaheeruddin, 2006). Artificial Neural Networks (ANN) are modelled on the human brain and consists of processing units known as artificial neurons that can be trained to perform complex calculations like human brain. Unlike traditional methods in which an output is based on the input it gets, an Artificial Neural Networks (ANN) can be trained to store, recognize and estimate patterns without having the information about the form of function (Zheng, Meng, & Gong, 1992, Kosko, 1994, Basheer & Hajmeer, 2000, Krasnopolsky & Chevallier, 2003, Coppin, 2004).

Artificial Neural Networks (ANN) techniques, particularly Back-Propagation Neural Network (BPNN) algorithm has been widely used as a tool for discovering a mapping function between a known set of input and output examples. Despite providing effective solutions, the training process for an Back-Propagation Neural Network (BPNN) entail the designer to arbitrarily select parameters such as network topology, initial weights and biases, learning rate value, the activation function, value for gain in activation function and momentum. An improper choice of any of these parameters can result in slow convergence or even network paralysis, where the training process comes to a standstill or get trapped at local minima. Therefore, this research focuses on using Back-Propagation Neural Network (BPNN) model with an improvement on the momentum value to predict Noise-Induced Hearing Loss (NIHL) in industrial workers. Results from the prediction will be used in determining the noise hazards which directly influence the worker's health.

1.2 Problem Statement

Back-Propagation Neural Network (BPNN) is a supervised learning Artificial Neural Network (ANN) algorithm. Due to its ability to learn by calculating the errors of the output layer to find the errors in the hidden layers, Back-Propagation Neural Network (BPNN) is highly suitable for problems in which no relationship is found between the outputs and inputs (Coppin, 2004). However, BPNN has got a problem of slow convergence and network stagnancy. Nazri (2007) proposed an improved algorithm known as GDM-AG which increased the accuracy in the convergence rate by making the gradient slope smoother with the introduction of adaptive gain value. It was discovered during this research that changing the momentum term adaptively also can affect the performance of the BP. Therefore, this study tries to investigate and further proposes a new algorithm that will use adaptive momentum to remove oscillations in the gradient path and at the same time will keep the gain value fixed for all trials (Rehman, Nazri, & Ghazali). This study will validate the accuracy of the proposed algorithm by comparing with the conventional BPNN algorithm and GDM-AG proposed by Nazri (2007), on selected classification problems. This study will prove the effectiveness of the proposed algorithm by predicting the Noise-Induced Hearing Loss (NIHL) in the workers of Tenaga National Berhad (TNB).

1.3 Objectives of the Study

This study encompasses the following three objectives:

i. To propose an improved algorithm which improves the accuracy in the existing GDM-AG (Nazri, 2007) algorithm by choosing the optimal values for momentum coefficient.

ii. To assess the performance accuracy of the proposed algorithm with the conventional BPNN and GDM-AG algorithms on selected benchmark classification problems.

iii. To validate the proposed algorithm in predicting NIHL in Malaysian Industrial workers by using TNB data sets.

1.4 Scope of the Study

This study will focus on the use of improved BPNN to predict the level of Noise-Induced Hearing Loss (NIHL) in human workers which will help regulatory bodies to take precautionary measures in-order to reduce excessive emitting noises from the machines in an industry, so that Noise-Induced Hearing Loss (NIHL) in human workers can be reduced and the smooth running of Industrial process can be ensured.

1.5 Significance of the Study

1) The ‘Gradient Descent Adaptive Momentum (GDAM)’ is proposed in this study. GDAM uses adaptive momentum to remove oscillations in the gradient path by making the path much smoother whereas GDM-AG uses ‘adaptive gain’ to add more slopes to the gradient path to avoid local minima problem (Rehman, Nazri, Ghazali, 2011).

2) In the first phase, this study investigates the accuracy of the proposed GDAM algorithm with the GDM-AG (Nazri, 2007) and the conventional BPNN algorithms. The performance of GDAM is verified by means of simulation on the eight classification problems. The final results show significant improvements in the convergence rate and thus pave way for GDAM to be used as an alternate approach to GDM-AG (Nazri, 2007).

3) In the second phase, this study predicts Noise-Induced Hearing Loss (NIHL) in Tenaga Nasional Berhad (TNB) workers in order to improve the deteriorating health condition of industrial workers in Malaysia. At present, BPNN is not widely utilized for predicting NIHL in industrial workers. So far, the studies (Yahya & Ghazali, 2006) used to predict NIHL have not achieved high accuracy in predicting NIHL.

4) The GDAM algorithm demonstrated very good results and achieved high accuracy in-terms of predicting NIHL in TNB workers. The Mean Square Error (MSE) calculated for Left Hearing Loss (LHL) and Right Hearing Loss (RHL) is found to be 0.00218 and 0.00230 respectively. While Yahya & Ghazali (2005) produced high MSE’s for LHL = 0.0052 and RHL = 0.0056 using Levenberg-Marquadt higher order neural network algorithm for the same TNB dataset (Rehman, Nazri, & Ghazali, 2011). The overall accuracy achieved for NIHL prediction in human workers is close to 99.37 and 99.01 percent for left and right ears respectively. The findings in this study are very helpful in educating the workers to avoid noisy environments and remedies against exposure to excessive noise can be taken in the future to prevent hearing damage in workers.

1.6 Thesis Outline

This thesis is subdivided into six chapters including the introduction and conclusion chapters. The following is the outline of each chapter.

Besides providing an outline of the thesis, Chapter 1 contains the overview on the background of the study, scope of the study, objectives and significance of the research undertaken.

Chapter 2 reviews the previous studies made on back-propagation neural network (BPNN), its applications and problems with training efficiency are discussed. The problem of slow convergence and the use of adaptive gain value by Nazri (2007) to speed-up convergence training of BPNN are also noted. Studies on noise and hazards related to noise especially Noise-Induced Hearing loss (NIHL) are acknowledged globally and locally. This chapter also reviews the previous contributions made by various researchers on predicting NIHL using neural networks. In the end, this chapter discusses the possibility of modifying the GDM-AG algorithm by introducing adaptive momentum in it to predict NIHL in humans with more accuracy.

On the foundations laid by Chapter 2, Chapter 3 present an improved and efficient gradient descent with adaptive momentum (GDAM) algorithm to increase the accuracy of the existing GDM-AG algorithm with gain introduced by Nazri (2007), by choosing the optimal values for momentum coefficient. Other sections elaborate on the data collection, data partitioning, pre-processing, post-processing, network architecture and performance comparison of the proposed GDAM algorithm with GDM-AG and conventional BPNN algorithms.

In Chapter 4, the proposed GDAM algorithm is programmed into Matlab programming language and it is tested for its accuracy on selected benchmark classification problems. Finally, the accuracy performance of the proposed GDAM is compared with GDM-AG and the conventional BPNN algorithms.

In Chapter 5, the proposed GDAM algorithm is further validated for its accuracy and efficiency on real dataset on NIHL obtained from TNB. The NIHL is predicted with high accuracy and hearing deterioration indexes (HDI) of the selected workers are calculated. Again the comparison of the results generated by GDAM is done with GDM-AG and conventional BPNN algorithms.

Finally in Chapter 6 research contributions are summarised and several recommendations for preventing Noise-Induced hearing loss (NIHL) in the industry are suggested. Future works are also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Noise-Induced Hearing Loss (NIHL) has become a major source of health problem in industrial workers due to continuous exposure to high frequency sounds emitting from the machines. In the past, several studies have been carried-out to identify NIHL industrial workers. Unfortunately, these studies neglected some important factors that directly affect hearing ability in human. Artificial Neural Networks (ANN) particularly Back-propagation neural network (BPNN) provides very effective way to predict hearing loss in humans (Rehman, Nazri, & Ghazali). However, the training process for a BPNN require the designers to arbitrarily select parameters such as network topology, initial weights and biases, learning rate value, the activation function, value for gain in activation function and momentum. An improper choice of any of these parameters can result in slow convergence or even network paralysis, where the training process comes to a standstill or get stuck at local minima (Nazri, 2007). Therefore, this chapter focuses on the previous literature work that suggested certain improvements on Back Propagation Neural Network (BPNN) model to predict the important factors that directly affect the hearing of industrial workers.

2.2 Sound

Sound may be defined in terms of either psychological or physical phenomena. In the psychological sense a sound is an auditory experience- the act of hearing something. In the physical sense sound is a series of disturbances of molecules within, and propagated through, an elastic medium such as air (Martin & Clark, 2012). When sound is propagated it carries useful information such as voice, music and so on. But, it also carries unwanted elements like noise which can be further divided into vexation and prosaic (Yahya & Ghazali, 2006). National Institute of Occupational Safety and Health (NIOSH) classifies sound on the basis of varying sound sensitivity among different animal species. These ranges are categorized as infrasonic (0-20 Hz), audible (20Hz-20KHz), and ultrasonic (greater than 20KHz) as shown in the figure 2.1.

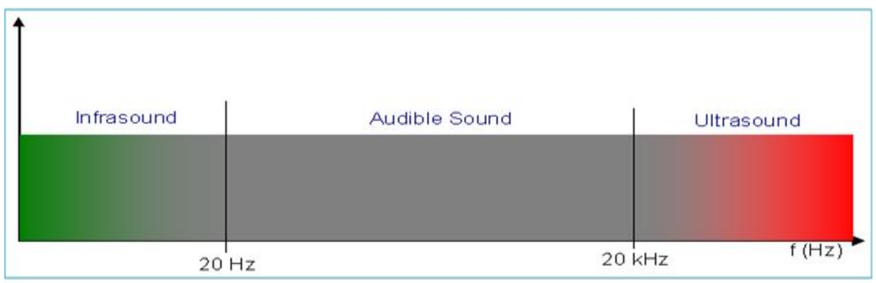

Figure 2.1: Perception of Sound in Mammals and other species

2.2.1 Measurement of Sound

Sound is a measurable quantity of physics. There are two expectations of sound measurements, which are shrill and piercing sounds. Shrill is determined from sound wave frequency and piercing is determined by sound intensity (Yahya & Ghazali, 2006). Audiologists and acousticians are more accustomed to making measurements of sound in pressure than in intensity terms (Martin & Clark, 2012). Sound Pressure is a pressure disturbance in the atmosphere whose intensity is directly influenced by the strength of the source, surroundings and the receiver's distance from the source.

Sound Pressure Level (SPL) is measured in decibels (dB) and expressed mathematically as:

$$SPL = 10\log_{10}\left(p^2 / {p_{re}}^2\right) dB \qquad (2.1)$$

where;

SPL : Sound Pressure Level (dB)

p_{re} : Reference sound pressure ($2\times10^{-5}\,Pa$)

p : Sound pressure of the source

2.2.2 Noise

The word "Noise" is derived from the Latin word "Nausea" meaning sea sickness. Noise is considered as an intense sound by people but strictly speaking noise is a non-harmonic and non-periodical sound without having any agreeable music quality. The sound called noise, can be thus additionally alternating, multi-frequency and impulsive in nature. In short, noise is a wrong sound, in the wrong place and at the wrong time (Singal, 2005).

We perceive different sounds in our daily lives such as the chirping of birds, a wooden creaking floor, car horn honking, phone bell ringing, music playing in the background etc. Sometimes, we are exposed to high pressure sounds without knowing the consequences of long-term exposure. When, we hear noises that are too loud or it becomes painful to hear then a health condition called Noise-Induced Hearing Loss (NIHL) can occur (Stephen, 2002) (Rehman, Nazri, & Ghazali, 2011).

2.3 Audiology and Noise-Induced Hearing Loss (NIHL)

Audiology is the study of hearing, balance and related disorders and the organ involved in hearing is the ear which works on the basic principles of mechanical energy. A human ear consists of three parts, the outer ear, the middle ear, and the inner ear. Sound pressure waves enter the outer ear and travel through the ear canal to the middle ear. The ear canal channels the waves to the eardrum, a thin, sensitive membrane stretched tightly over the entrance to your middle ear. The waves cause your eardrum to vibrate. It passes these vibrations on to three tiny bones in your ear causing them to vibrate and pass the mechanical signals into the inner ear. The cochlea, which is shaped like a shell contains hundreds of special cells (hair cells) attached to nerve fibers, which then transmit information of nerve impulses to the brain via the auditory nerves (Sataloff & Sataloff, 2006) (Martin & Clark, 2012). The anatomical structure of the ear is shown in the Figure 2.2.

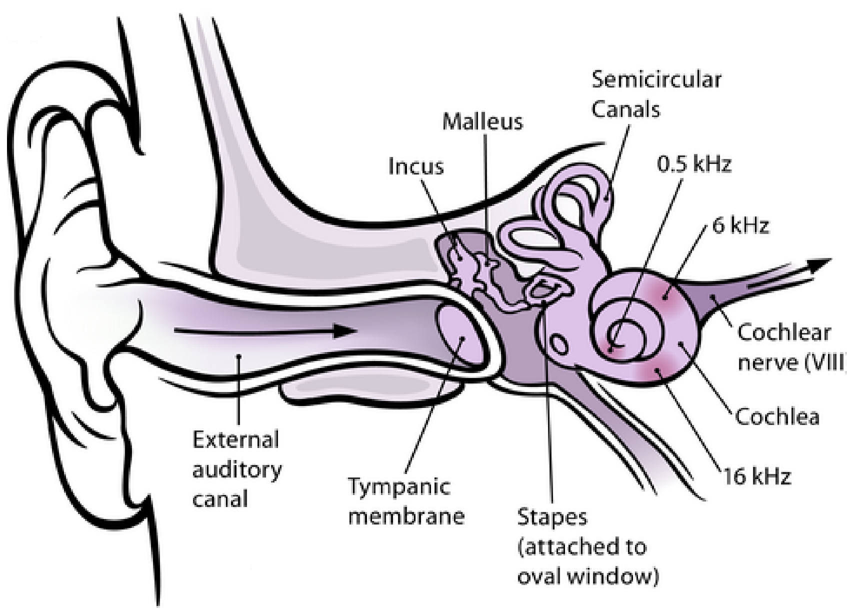

Figure 2.2: Anatomy of the Human Ear (Source: Chittka & Brockmann, 2005)

Noise-Induced Hearing Loss (NIHL) is considered as the second most common form of sensorineural hearing deficit after presbycusis (age related hearing loss) Shearing forces caused by any sound have an impact on the stereocilia of the hair cells of the basilar membrane of the cochlea in the inner ear; when excessive, these forces can cause cell death (Rabinowitz, 2000). Figure 2.3, shows the comparison of healthy hair cells in cochlea with the damaged ones.

Figure 2.3: Comparison of damaged and intact hair cells in Cochlea
(Source: Chittka & Brockmann, 2005)

Noise-Induced Hearing Loss (NIHL) is of two types, reversible and irreversible. Reversible NIHL is called temporary threshold shift (TTS) while permanent NIHL is called permanent threshold shift (PTS). When a person is exposed to excessive noise for longer duration of time, then temporary threshold shift (TTS) occurs. A person with temporary threshold shift (TTS) usually recovers over a period of 16-48 hours. But if the person is continuously exposed to high intensity noise, permanent injury such as breaks in rootlet structures, mixing of endolymph and perilymph, hair cell apoptosis and degeneration of cochlear nerve fibres may result. This causes a permanent threshold shift (PTS) (Mitchell & McCombe, 2009).

2.3.1 Hearing Impairment

Clinically, NIHL begins with a temporary threshold shift (TTS). The extent of the temporary threshold shift (TTS) is related to noise intensity, frequency and temporality (Mitchell & McCombe, 2009). Noise can cause permanent threshold shift (PTS) at chronic exposures equal to an average Sound Pressure Level (SPL) of 85 dB (A) or higher for an eight-hour period. Based on the logarithmic scale, a 3 dB increase in Sound Pressure Level (SPL) represents a doubling of the sound intensity.

Therefore, four hours of noise exposure at 88 dB(A) is considered to provide the same noise "dose" as eight hours at 85 dB(A), and a single gunshot, which is approximately 140 to 170 dB(A), has the same sound energy as 40 hours of 90-dB(A) noise (Rabinowitz, 2000). Table 2.1 describes the common sources of noise that we experience knowingly or unknowingly in our environment.

Table 2.1: Common sources of Noise in daily life (Source: Rabinowitz, 2000)

Sound Loudness	**Decibels (dB)**
Gunshot (peak level)	140 to 170
Jet takeoff	140
Rock concert, chain saw	110 to 120
Diesel locomotive, stereo headphones	100
Motorcycle, lawnmower	90
DOSH level for hearing conservation program	85*
Conversation	60
Quiet room	50
Whisper	30 to 40
** Measurement expressed as dB(A), a scale weighted toward sounds at higher frequencies. 8-hour time-weighted average.*	

Continuous exposure to noise of high frequency causes Noise-Induced hearing Loss (NIHL) at 4KHz. As the noise exposure continues, the 4KHz notch deepens and damages other higher frequencies (Morioka, Miyashita, & Takeda, 1997)(Rabinowitz, 2000) (Mitchell & McCombe, 2009).

Figure 2.4 shows the different threshold shift levels referring to temporary threshold shift (TTS) and permanent threshold shift (PTS). Threshold shift is the minimum Sound Pressure Level (SPL) at which a person can hear a sound at a given frequency (Yahya & Ghazali, 2006). Line (A), shows the classic early dip at 4KHz. Line (B), shows the stage at which the frequencies just above and below 4KHz become involved. And the Line (C) is point at which Noise-Induced Hearing Loss (NIHL) become prominent.

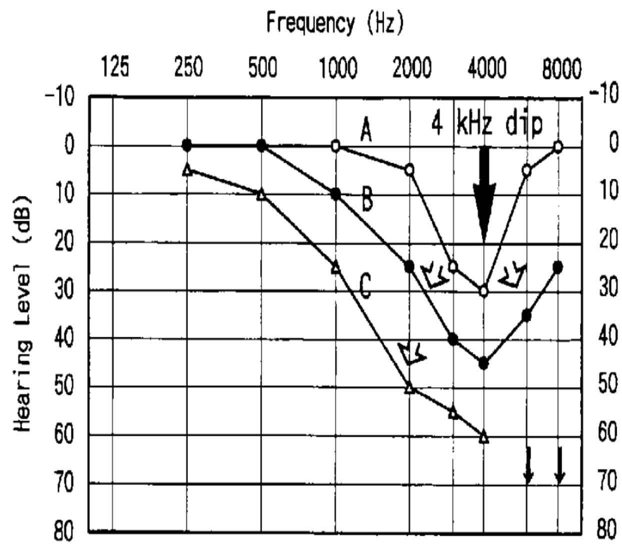

Figure 2.4: Hearing threshold shift (Audiometry)

(Source: Morioka, Miyashita, & Takeda, 1997)

2.4 How to Determine the Hearing Loss

Hearing loss can happen to anyone belonging to any age group. Whether an infant or an adult, if exposed to high frequency noise for a long duration of time then Noise-Induced Hearing Loss (NIHL) deficit can be experienced by anyone. Hearing Impairment can be found on both ears or on one, a person experiencing hearing loss may find it difficult to interpret words at low or high frequencies and ultimately quality of life will be affected due to ill-perception of sounds (Patel & Ingle, 2008) (Yahya & Ghazali, 2006).

There are two ways of finding hearing deterioration, one is a questionnaire made to be duly filled by the patient, and other is the pure tone audiometric test done using specialized equipment by an audiologist. The first test is to find out the problems and may vary from person to person but the audiometric test gives more accurate results as it is based on measuring the hearing ability in decibels (dB). Audiometric test can completely identify the hearing impairment in a person by using the arithmetic average of the individual experiencing hearing loss with a threshold shift of 25dB at a range of octave band frequencies (500, 1000, 2000, 4000, 6000, 8000 Hz) (Factories and Machinery (Noise Exposure) Regulations, 1989). From this data an audiogram of hearing loss at various frequencies is produced. Figure 2.5 illustrates the Audiogram of an employee in Tenaga National Berhad (TNB) facilities in Paka, Terengganu. The audiogram shows hearing impairment of an employee in the years 1995 and 2000. In 1995, the employee had a threshold shift of 26.25dB and 23.75 on right and left ears respectively. While in the year 2000, hearing impairment had reached critical thresholds of 33.75dB and 27.50dB on right and left ears respectively. This hearing loss observation asks for the extensive implementation of workers health protection program in the facilities.

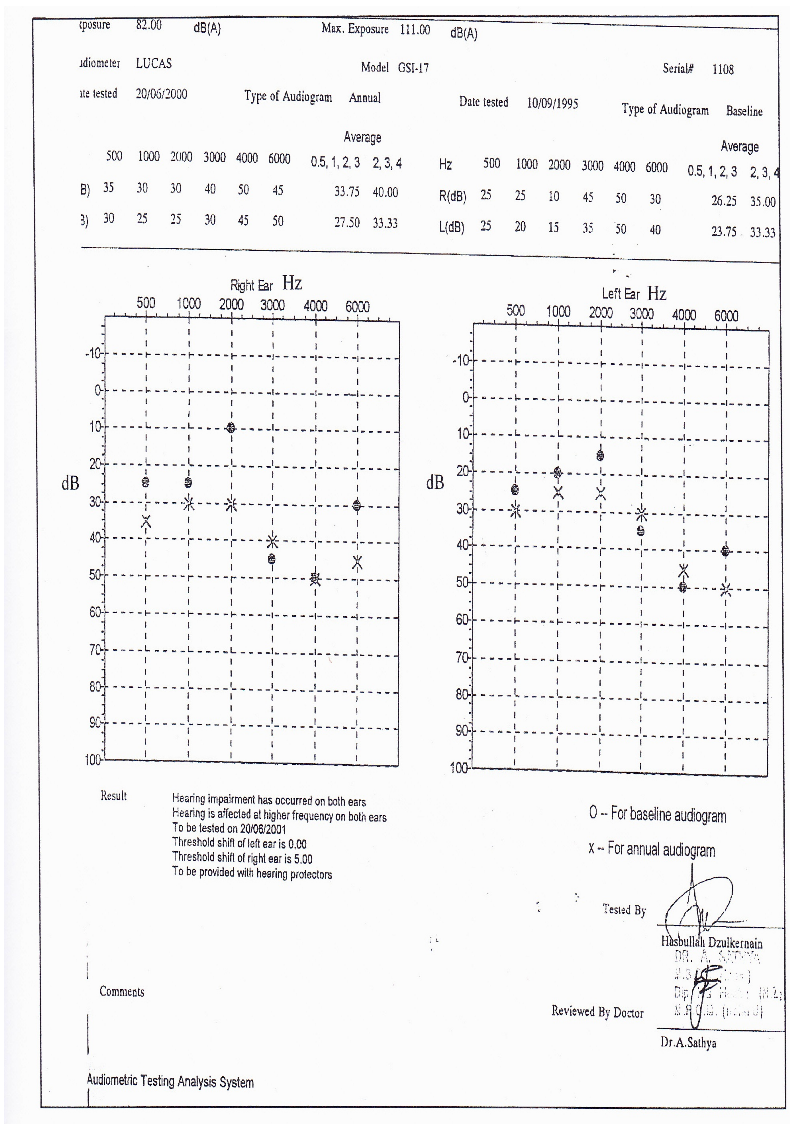

Figure 2.5: An Audiogram of a TNB Worker in the year 1995 and 2000
(Source: Yahya & Ghazali, 2006)

2.4.1 Hearing Loss Observation using HDI

There are scientific correlations between the noise levels, exposure, and hearing damage risk. Extensive work undertaken in Dresden, Germany (Kraak, 1981) shows the percentage risk of developing a hearing handicap and the median loss incurred with exposure as (Leong, 2003)(Bies & Hansen, 2003):

a) a function of mean sound pressure level in the workplace (dBA) and exposure (years).

b) a function of hearing deterioration index, HDI. The formula is shown below:

$$HDI = 10 \log_{10} \left[\int_0^t 10^{L/20} \, dt \right] \tag{2.2}$$

where;
HDI stands for hearing deterioration index,
L is the mean exposure level (dBA),
and *t* is the time exposure.

It is evident that hearing deteriorates very rapidly during the first 10 years and progressively more so as the exposure level rises above 80 dBA. This implies that to avoid hearing impairment in 80 percent of the population, the strategy that should be implemented is to avoid acquiring a HDI greater than 59 during a lifetime. This index is consistent with a noise level of 85 dBA exposure over a lifetime. At 90 dBA, there is a 20 percent risk of developing a hearing impairment after 30 years exposure as shown in the Figure 2.6.

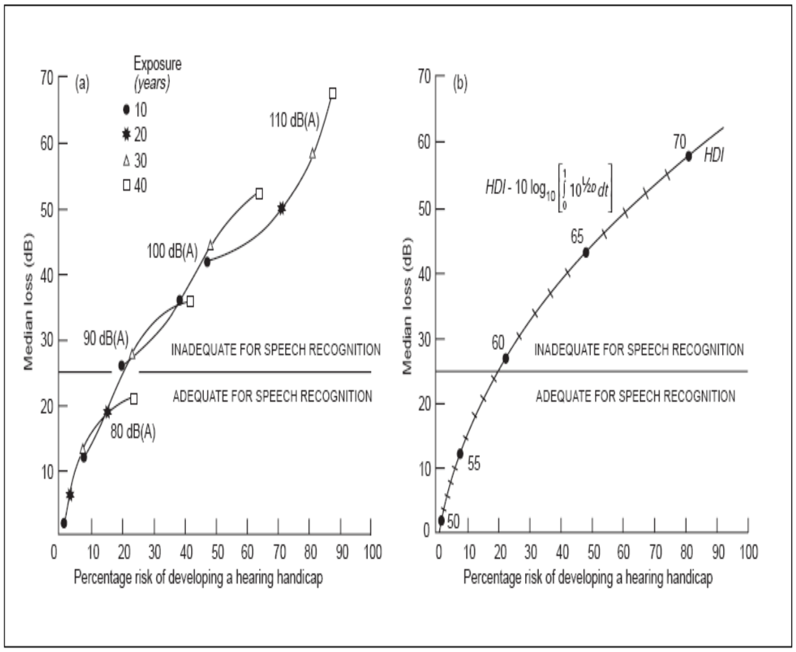

Figure 2.6: Hearing damage as a function of exposure

(Source: Bies & Hansen, 2003)

2.4.2 Hearing Loss due to Noise Pollution Worldwide

Noise-Induced Hearing Loss (NIHL) is rated among the top-10 work related and most prevalent occupational health hazard (Borchgrevink, 2003) caused due to excessive exposure to high frequency noise emitting from the machines in the industry (Rehman, Nazri and Ghazali, 2011). Due to the severe nature of hearing handicap experienced by Noise-Induced Hearing Loss (NIHL) patients, it is extensively studied throughout the world since the late 18th century using different analytical methods and techniques. In the recent years, developed countries have been able to control Noise-Induced Hearing Loss (NIHL) to an extent in the working environment. But Noise-Induced Hearing Loss (NIHL) still exists as a living menace to a worker’s health in an industry.

In contrast to the developed nations, the developing countries where the industrial revolution started in the late 19th century, Noise-Induced Hearing Loss

(NIHL) is often not considered as a major health problem and often neglected (Debray, Mishra, & Ghosh, 2002). Either the machines used are very old and not well-maintained or the working environment is very poor in the industry (Patel & Ingle, 2008). Currently, the labour inside the steel rolling mills, bottling factories, mining industry, power plants, forging and the weaving units are highly affected by Noise-Induced Hearing Loss (NIHL). This situation demands for the emergency implementation of the laws and regulations by the enforcement officers inside the industry. Also, this situation stresses on the review of practices and methods used by the occupational health experts to identify Noise-Induced Hearing Loss (NIHL) in an industry more accurately, as the variables involved now are far greater as they were a century before.

Since the industrial revolution in the developed countries like America, Noise-Induced Hearing Loss (NIHL) is acknowledged as the second most common occupation disease after presbycusis (age related hearing loss). An estimated 28 million case of partial hearing impairment are reported until the end of the 20^{th} century. While 10 million people have hearing loss caused due to excessive noise caused in the workplace or in the recreational activities. Besides Noise-Induced Hearing Loss (NIHL), the economic costs of occupational hearing loss are estimated to be in billions of dollars (Rabinowitz, 2000).

Palmer *et al.* (2002) discovered severe hearing deficit in the 153,000 male and 26,000 female workers in Great Britian. The problem was again associated with the lack of noise control both at the receiver and the source. In France Riviere *et al.* (2008), carried-out an audiometric test on 511 subjects working in a nitrogen fertilizer industry. The test was conducted after an explosion the took place on September 21, 2001. All the factors such as age, gender, past occupational noise exposure, medical history or ear problems, distance from the explosion and functional symtoms following the explosion were considered. The audiograms of the test subject showed that 49 percent of worker hearing was more deteriorated than was reported before with hearing shifts at 2000Hz and 4000Hz multiple frequencies.

Prevalence of Noise-Induced Hearing Loss (NIHL) was found quite significant among the workers in the lime-stone mining industry located in the eastern part of Turkey. Work experience, noise levels and miners age were considered as the variables involved in causing Noise-Induced Hearing Loss (NIHL). Out of 23 employees who were running different operations and working on different sites, crushing workers and lorry drivers were the ones expreiencing high hearing loss on both ears. Although, lorry drivers were exposed to a daily noise dose of 70-79 dB(A) but middle-aged drivers were the ones experiencing hearing loss. Also, stone crushing plant workers, exposed to a daily noise dose of 90-99 dB(A) with a work experience of 4-11 years were among the ones experiencing Noise-Induced Hearing Loss (NIHL) (Onder, Onder, & Mutlu, 2011).

Noise-Induced Hearing Loss (NIHL) is considered as a major threat to the health of the workers in the continent of Africa. Audiometric experts from the valley of Nile have greatly contributed to the field of occupational hearing loss. In Cairo, Egypt, the major sources of noise are the industrial complexes located at the northern and southern parts of the city. Multiple studies were done in 1984, 1988 and 1991 to measure Noise levels in Cairo and Amman.The studies were conducted in the commercial areas for 10-hour periods. The noise levels reached a peak of 92dB(A), varying to 76dB(A) from noon to 3 p.m. In 1984, workers in a forge-hammering plant also showed significant hearing threshold-shift in the 2-4 KHz range. While in Amman, Jordan, noise levels reached a peak of 81dB(A) from 8a.m. to 12noon which is quite low if compared with Egypt (World Health Organization (WHO): Prevention of Noise-Induced Hearing Loss, 1997).

Amedofu (2002) carried out a study on 252 test-subjects working in a surface gold mining company in Ghana. All the workers were aged between 20-50 years and variables such as age, duration of exposure and premployment history with noise exposure was considered. Pit, processing, analysis laboratory, bore hold and mess areas were surveyed for hazardous noise. The results showed that all areas except mess area had noise levels of more than 85 dB(A). 59 workers were showing significant threshold shifts at 4KHz while 41 workers who had a pre-employment history with noise were showing significant hearing loss. This showed that any factor not under the control of the company may affect the employee as well. Ologe, Akande, & Olajide (2006), studied Noise-Induced Hearing Loss (NIHL) on 150 subjects in a steel rolling mill in Nigeria. During the noise mapping of the workplace the minimum noise level was 49 dB(A) while maximum noise level was found to be at 93 dB(A). About 28.2 percent worker were reported with mild to moderate hearing loss in the better ear while 56.8 percent had mild to moderate hearing loss in their worse ears. All the workers showed considerable hearing threshold shifts at 4KHz due to increasing noise exposure.

In Asia, countries like Pakistan, Iran, India, Taiwan, and Thailand are trying their best to avoid work related injuries in the factories. Despite every effort the prevalence of Noise-Induced Hearing Loss (NIHL) is still growing and a lot of blue collared employees are identified with severe hearing losses. And thus the quality of life is deteriorating instead of becoming better for the middle class people in these countries. In Pakistan, Industrial Noise is greatest in steel mills, large textile industries and in bottling factories. Ashraf *et al.* (2009) found the non-permissible noise levels of 88.4- 104dB (A) in the weaving units of five textile industries in Karachi Pakistan. This cross-sectional audiometric study included 248 worker exposed to noise for some time period. It was observed that hearing loss was greatly increasing due to overtime and long duration of work such as prolong period of 10 years. Attarchi, Labbafinejad, and Mohammadi (2010) indicated smoking as a new variable in accelerating hearing loss during a NIHL study on 478 employees working in an automobile company in Iran.

In India, Patel & Ingle (2008) detected high prevalence rate of hearing loss among pulse-processing workers in Dana Bazaar in Maharashtra state. The Noise-Induced Hearing loss (NIHL) blame was given to the poor environment and the machines being used without maintenance in the mills. Hole & Pande (2009) also tried to find the factors involved in affecting workers productivity in a thermal power plant. They identified noise of 90 dB(A) as the biggest threat to workers after hot environment.

Chou, Lai, & Kuo (2009) found the occurrence of Noise-Induced Hearing Loss (NIHL) among the workers of a large semi-conductor factory in Taiwan. The 218 workers exposed to fluctuating noise levels of 80-90 dB(A) showed significant notches at 4KHz frequency. Besides high noise other factors such as chemicals and gases like Toulene, carbon monoxide and carbon disulphide were found to have an added effect on hearing loss.

Since the last two decades, Thailand started becoming a semi-industrialized country. In Bangkok the noise become a problem due to traffic, construction and industry. The National Environmental Board of Thailand has recommended levels of 85 dB(A) for 8 hours shift. But the noise problem is not solved because of the lack of public awareness of the effect of noise on hearing and the difficulties in controlling noise. A recent study for the National Committee on Noise Pollution Control measured noise exposure and hearing impairment in various occupational groups and found 21.1 to 37.7 % with Noise-Induced Hearing Loss (NIHL) (World Health Organization (WHO): Prevention of Noise-Induced Hearing Loss, 1997).

2.4.3 Hearing Loss due to Noise Pollution in Malaysia

In the past 30 years, Malaysian Industry has progressed a lot and emerged as a key player in maintaining the economical stability. Despite providing efficient solutions for Malaysian economical progress most of the major industries face a nemesis in the form of Noise. The high frequency noise emitted from the machines is causing adverse side-effects to the health of the blue-collared employees. One of the most common health injury caused due to exposure to high frequency noise is known as Noise-Induced Hearing Loss (NIHL).

Wagiman (2001) studied the risk of noise in oil palm factories in Malaysia. He divided his analysis in six different parts which were noise contouring, noise identification, noise dose measurement, frequency analysis, location surveyor, and suggestions for noise control. During the analysis, he found that 6 stations were producing excessive noise of 95 dB(A) during the eight our shift while the other 6 stations were producing the noise within permissible limit and according to the Factories and Machinery Act 1967(Noise Exposure 1989). The noise producing stations were Engine room, nut braking room, kernel plant, Winding, external, and internal boilers. Also the questionnaire given to 32 workers indicated that 19 percent of workers were having Tinnitus (continuous ringing in the ears) while other 13 percent workers were having Noise-Induced Hearing Loss (NIHL) on one or both ears. In the results, he suggested strict use of ear-muffs by all the workers in the facility to reduce strain to ears due to exposure to high noise levels.

In another study on Power Plant Noise Analysis at Stesen Janakuasa Sultan Ismail, Paka, Terengganu, Rizal (2002) indicated that steam turbine, gas turbine, boiler, and pump stations produced noise levels of more than 90 decibels. The highest Sound Pressure Level (SPL) was recorded at Gas Turbine Station which was between 94.4-101.9 dB(A). Also, the audiometric results showed that 39.6 percent workers out of a selected 37 workers had developed Noise-Induced Hearing Loss (NIHL). He also suggested removing noise both at the source and at the receiver.

In a similar cross-sectional study, Mohd. *et al.* (2004) tried to find hearing impairment in 261 workers due to noise exposure at Power Stations in Sarawak. The purpose of this study was to determine the prevalence of hearing impairment among these workers and factors associated with it. Age, duration of employment and types of electricity generators used in the power stations were factors found to be significantly associated with hearing impairment. The water-turbine generator produced less noise and had resulted in lower prevalence of hearing impairment (39.4%) when compared with that of the gas-turbine type (58.3%) which was producing more noise. Logistic regression analysis shows that duration of employment variable has significantly contributed to the hearing impairment. This study raises high concerns on the prevalence of hearing loss among workers. And also asks for the aggressive implementation of hearing conservation programs.

Mokhtar *et al.* (2007) tried to study the effects of noise on 120 workers in a new way. The effects of physiological and psychological effects of noise and the auditory, hearing loss and sleep disturbance was observed among the workers working in rubber product manufacturing, metal stamping, publication and printing industries. A questionnaire consisting of all the negative aspects of noise on humans was distributed among the workers and the responses were collected for analysis. In the results, Chi-Square test indicated that the physiological, hearing loss, auditory and sleep disturbance effects of noise were statistically significant while the psychological effects were found to be insignificant.

Rus *et al.* (2008) in a most recent study tried to unearth the knowledge, attitude, and practice of sawmill workers towards Noise-Induced Hearing Loss (NIHL). For the purpose of study, a total of 83 workers were selected in Kota Bharu, Kelantan. Age, sex, duration of working years, smoker, non-smoker, salary per month and level of education were some of the factors considered during the study. The results showed that the workers knowledge, attitude and practice related to Noise-Induced Hearing Loss (NIHL) was quite low which was quite discouraging. Therefore to educate the workers and change their attitude towards the Noise-Induced Hearing Loss (NIHL), it is required to start a workers awareness program. In recent years, analytical techniques have been successfully applied in conjunction with Artificial Neural Networks (ANN) to better predict the cause of NIHL problem. The next sections will describe ANN and the previous studies on NIHL prediction using ANN.

2.5 Artificial Neural Networks (ANN)

Artificial Neural Networks (ANN) is analytical techniques modelled on the learning processes of human cognitive system and the neurological functions of the brain. Artificial Neural Networks (ANN) works by processing information like biological neurons in the brain and consists of small processing units known as Artificial Neurons, which can be trained to perform complex calculations (Deng, Chen, & Pei, 2008).

An Artificial Neuron can be trained to store, recognize, estimate and adapt to new patterns without having the prior information of the function it receives. This ability of learning and adaption has made ANN superior to the conventional methods used in the past. Due to its ability to solve complex time critical problems, it has been widely used in the engineering fields such as biological modelling, financial forecasting, weather forecasting, decision modelling, control systems, manufacturing, health and medicine, ocean and space exploration etc. (Zheng, Meng, & Gong, 1992, Kosko, 1994, Basheer & Hajmeer, 2000, Krasnopolsky & Chevallier, 2003, Coppin, 2004, Lee, 2008).

2.6 Multilayer Perceptrons Artificial Neural Networks (MLP-ANN)

The first "Single Layer Perceptron-Artificial Neural Network" model was developed by Frank Rosenblatt (1958). Rosenblatt (1958) model used a single layer and threshold step-function which made it impossible to train a perceptron network on complex non-linear problems like XOR. Minsky and Papert (1969) published a detailed critical analysis of perceptron network in which they explained a number of critical weaknesses of perceptrons, such as problem of stagnancy in training non-linear problems and the use of step function. Further research on ANN remained stagnant until Rumelhart, Hinton & Williams (1986) proposed a Multilayer Perceptrons Artificial Neural Networks (MLP-ANN) with non-linear and differentiable transfer functions instead of a step-function. MLP-ANN is similar to perceptron networks but it varies in number of layers. An MLP-ANN consists of an input layer, one or more hidden layers and an output layer of neurons. In MLP-ANN, every node in a layer is connected to every other node in the adjacent layer. MLP-ANN are usually classified into several categories on the basis of supervised and unsupervised learning methods and feed-forward and feed-backward architectures (Deng, Chen, & Pei, 2008). Figure 2.7 shows the schematic diagram of MLP-ANN with two-hidden layers.

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