AGE ESTIMATION BASED ON LENGTH OF LEFT-HAND BONE IN AFRICAN AMERICAN CHILDREN BELOW 18 YEARS OLD USING ARTIFICIAL NEURAL NETWORK

NOR ANIS NABILA BINTI SAARI

Bachelor of Computer Science (Graphics & Multimedia Technology) with Honours

UNIVERSITI MALAYSIA PAHANG

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ABSTRAK

Pengiraan umur telah digunakan dalam bidang kajian antropologi forensik untuk membantu identifikasi identiti individu. Anggaran umur menggunakan kaedah tradisional adalah unik dan hanya boleh digunakan untuk populasi tertentu. Tumpuan pada kajian ini adalah pengukuran tulang kiri untuk menganggarkan usia menggunakan kaedah matematik iaitu “Multiple Linear Regression” dan juga model komputasi lembut “Artificial Neural Network” (ANN) yang dapat menyumbang kepada alternatif model yang lain berbanding menggunakan model tradisional iaitu model Greulich dan Pyle (GP) dan model Tanner dan Whitehouse (TW) yang hanya berdasarkan pemerhatian oleh antropologi berpengalaman yang boleh menyebabkan pelbagai hasil anggaran umur. Model regresi dilakukan pada gambar X-ray tangan kiri dalam dataset Afrika Amerika dari awal kelahiran hingga berumur 18 tahun. Semua sembilan belas tulang tangan diukur secara manual menggunakan Photo Pos, Power of Software Company Ltd yang merupakan foto editor percuma yang akan menghasilkan garis pada setiap tulang kiri. Bagi ANN model, untuk menghasilkan keputusan yang lebih baik dalam ramalan usia, rangkaian neuron tersembunyi di ANN dimanipulasi seperti yang dicadangakan oleh Zain et al. dengan menggunakan alat Encog Workbench versi 3.3.0. Nilai R-square dan MSE bagi model yang dicadangkan telah dikira sebagai ukuran prestasi untuk membandingkan dengan penanda aras. Berdasarkan hasil anggaran umur yang dihasilkan oleh model-model ini, MSE yang dihasilkan oleh model ANN ialah 1.775 dan 2.487 bagi lelaki dan perempuan. Untuk membuat kesimpulan, ANN boleh digunakan untuk menganggarkan umur menggunakan panjang tangan kiri.

ABSTRACT

Age estimation is used in the field of forensic anthropology's studies to assists in the identification of individual's identity. The age estimation using traditional method was unique and applicable for a certain population only. The focus on this study is the measurement of left hand bone to estimate age using mathematical method of Multiple Linear Regression and also the soft computing models of Artificial Neural Network (ANN) that can contribute to another alternative models instead of using the traditional model of Greulich and Pyle (GP) model and Tanner and Whitehouse (TW) model that is based on the expert of anthropology' s experience which may lead to various of result of age estimation. The regression models were carried out on X-ray images of the left hand in African American dataset from new-born to 18 years old. All the nineteen bones of the left hand were measured manually using Photo Pos, Power of Software Company Ltd which is the free photo editor that will creating a line on the each of left-hand bones. For Artificial Neural Network to produce a better result in prediction of age, hidden neuron network in ANN is manipulated as suggested by Zain et al. using Encog Workbench tools version 3.3.0. The value of R-square and mean square error (MSE) of proposed model been calculated as performance measurement for compare with benchmark of age. Based on result produced by these models, mean square error produced by ANN model are 1.775 and 2.487 for both male and female, respectively. To conclude, ANN is reliable to estimate the age based on length of the left hand.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
GP	Greulich and Pyle
TW	Tanner and Whitehouse

CHAPTER 1

INTRODUCTION

1.1 Background

Age estimation is the most crucial part to be concern where it recently shows increasing number of adolescents and children with unknown identity to proof their actual age especially those who are engaging in criminal activities. The United Stated Department of Justice (DOJ) stated that at 2009, more than 60 percent of children were exposed to violence either directly or indirectly such as abuse drugs and alcohol and involved in criminal behavior. Therefore, the forensic anthropology plays a role to get the legal evidence and significance prove to defend themselves. The main objective using this method is as assisting in identification of living individual at aged new born until 18 years old. In term of legislation, age estimation can avoid an individual from suffering unfair punishment and illegal procedures that is not relevant to an individual's age.

There are several common parts of age estimation in human body such as dental, where it has provided an estimation of juvenile skeletal that has been utilized the methods of Moorress, Faning and Hunt (1963) and Demirjian, Goldstein and Tanner (1973) for many years but it produced various of results in determining of age estimation (Phillips & Van Wyk Kotze, 2009). The study by (Jooste, L'Abbé, Pretorius, & Steyn, 2016) shows that the sternal ends of ribs can be used in age estimation of unknown adults where the method is reviewed and make comparison with other age markers of human skeleton. This method resulting was not very accurate to make a prediction of age in this population but there are three investigators from South African still applied this method even they found the repeatability among them when using this method. An advanced statistical method which is transition analysis has ability to make age estimation into a systematically and statistically where this method is developed by Boldsen and his colleagues on 2002 by using 36 features which are from cranial sutures, pubic symphysis and auricular surface for calculating their maximum likelihood point and contains 95%

confidence intervals with assisted by computer software named ADBOU (Jooste et al., 2016). The result of age estimation by using this method was inaccuracy and imprecision where influenced with the geographically and contextually distinct in this population.

Currently, hand bone is the most common indicator used in the age estimation. The traditional model of estimation age is Greulich and Pyle (GP) model and Tanner and Whitehouse (TW) model where these models are based on an observation. The limitation using this model is it really depend the expertise of forensic anthropology to estimate the age where it is means, the level experience of expert might produce difference result in age estimation. Furthermore, this model development is based on specific population only where there is no guarantee this model can be used to other population. There are several case studies used the area of hand as input in the development estimation model. One of the popular study by (Cameriere, Ferrante, Ermenc, Mirtella, & Štrus, 2008) where the method of multiple linear regression model can avoid from depending on expert in determining the estimation of age and the result obtained is more accurate.

The soft computing is widely used as the method in prediction. The most common used is Artificial Intelligence (AI) method that can obtain the better result instead of the traditional method. One of AI model that can be used for estimation model is Artificial Neural Network (ANN) which is one of AI method that has the capability to use the bone length as age indicator. Commonly, the different methods have their own different database. Therefore, the aim of this research is to develop age estimation model using soft computing model for African American’s population where the quantitative age indicator is left hand. The bone length is chosen as age indicator because measurement is more accurate and easier to collect data compared the common models that need the observation from expert of bone morphology only.

1.2 Problem Statement

The traditional models of age estimation which are GP and TW models are based on the observation of bone morphology from a radiograph of left hand by forensic anthropologist. Both have similar disadvantages which the result is based on the experts of anthropologies to estimate the age. Usually, the different experts with different experience may contribute to different prediction age estimation based on their expertise.

There are several studies used the quantitative data of bone measurement as input for age estimation such as using dental, sternal ends of ribs and also transition analysis but all these have their own limitation (Jooste et al., 2016; Oettlé & Steyn, 2000; Phillips & Van Wyk Kotze, 2009). The multiple linear regression which is using bone measurement as a new quantitative age indicator need to be more explored so the dependency to expert for determining the age can be reduced. The new quantitative indicator age can be used to as alternative age estimation in the parts of human body. To prove the significant of the quantitative indicator which is left hand the same multiple linear regressions used by the previous case studies and the result of the model is comparison with the benchmark of this study.

Therefore, based on the recent research, there is still needed a new efficient and reliable method to be replaced the traditional model which is based on the observation of bone morphology only It is really depending to the expert to make prediction of the age. Thus, the use of soft computing model such as ANN model is one of the suitable and intelligent approach that have powerful pattern recognition, patent classification and prediction capabilities (Casson, 2014) that can overcome accuracy in determining the age estimation for this population studies.

1.3 Research Question

Based on the problem statement above, there are several research questions that need to be addressed in this study:

I. How to analyse the dataset for age estimation in African American population?

II. Does the length of bones in left hand can be used as indicator for age estimation?

III. Does ANN soft computing models can produce accurate age estimation in this population of study?

1.4 Objectives

Based on research questions above, the following are the objectives of this study:

I. To collect dataset for age estimation for African American population.

II. To develop multiple linear regression for age estimation for African American population.

III. To implement Artificial Neural Network (ANN) age estimation model of African American population.

1.5 Significance of Research

The significance of this research study is stated as below:

I. The focus on this study is based on bone measurement to estimate age using soft computing models that can contribute to alternative models beside the traditional model.

II. The length of left-hand bone used as new indicator and as alternative inputs for age estimation. In case there is no other parts of subject's body are available it can use the left-hand bone to get the estimation of age.

III. Developed this model in identifying the age will be beneficial to the field of Forensic Anthropology especially for African American's children.

1.6 Scope

The scopes of this study of research are stated as below:

I. A total of 353 X-ray images of African American left-hand bones from 181 male and 172 females are used in this study where the measured data used is length of left-hand bones from new-born to 18 years old.

II. The measurements of each bone in the left hand were obtained manually on each image using Photo Pos, Power of Software Company Ltd which is free photo editor.

III. The images are obtained online from website http://ipilabmysql.usc.edu/newindex.php that allowed for education and open research only.

IV. IBM SPSS Statistics Version 22.0 is used to calculate and analysis the result of the model of multiple linear regression.

V. The Artificial Intelligence (AI) techniques that used in this research is Artificial Neural Network (ANN) as the age estimation for African American population.

VI. The Encog Workbench version 3.3.0 is used to calculate the age estimation of the ANN model.

1.7 Thesis Organisation

This thesis is organized into 7 Chapters. In Chapter 1 presents the introduction of the study, problem statement, scope, objectives and the importance of the study. Chapter 2 presents the literature review about the general development of models used for age estimation. Chapter 3 presents the methodology of the study and together with the development. In Chapter 4 to 6 is the implementation of the proposed model methods used in this research which is multiple linear regressions and ANN model. The result of the proposed model is discussed in detail on each chapter. Lastly, Chapter 7 is discussing the limitation and weakness throughout running this research including the future work about the research studies field in future for better improvement of the obtained result.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Forensic anthropology is the branch of human biology which is the study of human anatomical and variability of physiological such as post-mortem of living individuals for medico-legal purpose. In real world, age estimation is a crucial aspect to construct an accurate biological profile for assisting the forensic victim identification. The study by (Bacci, Nchabeleng, & Billings, 2018) stated that in adults, age estimation is focused on the changes of degenerative skeleton where a large number of skeletal elements such as pubic symphysis, sternal rib ends, auricular surface, dentition and cranial sutures have been used in age estimation. Currently, the research trend is focusing the identification of living individuals using by age approximation with criminal records. Therefore, forensic identification needs specific and sensitive of estimation model.

The morphological technique is applied to living individual below 18 years old were mostly from the system of skeletal and dental. Others age-dependent features such as development and growth of hand and wrist bone, and the third molars at the end of skeletal are in small number used for estimation age. Using morphological models is causing a gradual decline in precision as the age increase. For adulthood which is above than 18 years old shows the result precision by these techniques are below average.

Some of constraint in estimating age on certain method is easily influenced by different criteria, such as ethnicity, socio-economic citation, nutritional and geographical location. It has shown that results obtained from a certain study might be not applicable to others population and different sample or dataset might not applicable to other population.

2.2 Importance of Age Estimation

In the context of criminal procedure that involving living individuals, the reconciliation of skeletal and chronological age is crucial for criminal justice system. In the same time, it is an important to appreciate the skeletal and chronological ages where the measurement since birth is not same and depending on analytical approaches. Therefore, the work of forensic scientists and allied professionals is wide reaching which public giving them their trust for play the role in the medico-legal system very well. There are legal requirements for age estimation in the living such as refugee and asylum seekers, human trafficking, criminal responsibility, child pornography and falsification of age (Franklin, Flavel, Noble, Swift, & Karkhanis, 2015).

I. Refugee and asylum seekers

According to United Nations High Commissioner for Refugees (UNHCR), victims of war, internal conflict or natural disasters are almost half of them are children where they are having to forcibly displaced from their homes which can cause the risk of abuse, neglect, violence, exploitation, trafficking or forced military recruitment that need to protect.

In Convention on the Right of Child (1990) that involving 193 of the 195 United Nation (UN) stipulates that States Parties need to consider about the discrimination where must to ensure and respect the rights of every child within their jurisdiction, defined as individuals under the age of 18 years old. However, there is no legitimate identity documentation as a proved or evidence for individuals claiming to be children.

II. Human Trafficking

Definition human trafficking is exploitation of a person for individual benefits using threat or by forcing. A victim of trafficking is increasing especially that involving child particularly in Africa and Middle East.

The motivation for people trafficking is for sexual exploitation, forced labour, adoption forced military recruitment, begging and organ harvesting. Usually, the victims involve are from less developed country such as South and East Asia, Central Europe, sub-Saharan Africa, and South America but not to forget that this also occurs in developing country including North America and in Western and Central Europe, and the Middle East.

Children who are from low socioeconomic background are vulnerable to trafficking where the demand for cheap labour, young brides, prostitution and pornography, and clandestine adoption. These can lead the children to engage in criminal activities where can involve them in local punitive system and making fake identity documents.

III. Criminal responsibility

In most developed countries such as Australia and New Zealand the age of criminal responsibility is 10 years old meanwhile India, Jordan and Indonesia the children under 7 to 8 years old cannot be arrested or charged with crime. United State (UN) published guidelines where there is illegal of criminal responsibility charge for the children.

A young people between 17 to 21 years old are responsible for their action but still cannot have the criminal liability same with an adult where on this stage of age, they are preferred to rehabilitation compared to punishment. Offenders who are not classify as children must enter according the adult justice system. The implementation for the criminal justice system is to clearly define the age of majority and minority of individuals within their respective judicial system.

IV. Child pornography

The visual of still or video images of individual under the age is referring to child pornography. The age of consent is the minimum age for an individual as legally permitted to involve in sexual activity. In Chile, Mexico and Paraguay their age of consent is from 12 to 18 years old while Egypt, Guatemela and Haiti starting from 18 years old and most frequently is at age 16 years old. However, the age of consent is irrelevant which involving individuals who are at least 18 years old in the context of pornography

The identification of pornography which involving subjects at age less than 18 years old must perform accurately because the individuals in question may not available for an actual physical assessment where age assessment is usually based solely on visual inspection of secondary sexual characteristics. Therefore, it is crucial to make sure that children are not mistakenly identified as adults.

V. Falsification of age

Age estimation of living required involving individuals who deliberate falsify their birth year to increase or lower their age. This happened because the individuals want to legally marry, achieve the required age threshold for employment in industry.

Another common practice is falsification of age in professional sports where particularly by individuals' representative of global regions facing economic hardship. Usually, in such circumstance the risk of false negatives and false positives as the assessment of skeletal development for caters the youths and misrepresentation of chronological.

2.3 Previous Case Study on Estimation of Age

Basically, the common traditional model used in estimation age is multiple linear regression where the ability to determine the relative influence of the variables and it has the capability to identify any outliers or anomalies. Table 1.1 below shows the previous studies conducted by several case studies in estimating of age.

Table 1.1 Previous Case Study of Estimation Age

Authors	Sample	Methods	Measurement	Results
1.Roberto Cameriere , 2007	150 Italian children & adolescentAged at 5 to 15 years old Tooth & wrist	Regression model	Variance Median IQR Standard error (SE)	There is a correlation coefficient between age and morphological variables
2.N. Jooste, 2016	149 black individuals (Pretoria Bone Collection) 36 features from the cranial sutures, pubic symphysis and auricular surface in South Africa	Advanced statistical method	Repeatability, accuracy and precision	Lack of satisfactory precision

	using ADBOU computer software			
3.M.F Darmawan, 2014	333 images of left hand from Asian dataset X-ray images under 19 years old of the left hand from Asian Measured image using free image software and statistical analysis by SPSS	Multiple linear regression models S-curve regression	Single bone (S-curve regression) and all bones (highest R-square) method	11 regression models were applied on the length for each bone of the left-hand bone A regression models were applied to all left-hand bones
4.Martin Urschler, 2016	Hand bone age 17-18 year Analysed the correlation between hand MRIs and radiographs	Greulich–Pyle (GP) and Tanner–Whitehouse (TW2) Linear regression and inter-observer agreement	Correlation between age estimates from MRI and radiographs was high for both GP	7 & 17 years old radiograph and the MRI scan of the hand were performed
5.Harold Matthews, 2018	Adolescent from 3D photographs	Cross-sectional sample Longitudinal validation sample Image acquisition Image standardization Defining prototype	Accuracy Mean absolute error	Correctly predicted about 75% of the head overall and 85% of the face
6.Ksenija Zelic, 2015	Adulthood of Serbian population 598 panoramic radiographs (290	Third molar development	Maturity index Accuracy	Result produced high sensitivity for both female and male

	males and 299 females)			
7.Laure Spake, 2017	Autopsies of 1256 individuals in Australia, New Zealand and U.S Aged birth to 18 years old at death	Z-scores and independent sample t-tests	Length of cadaver	Different results in Australian and New Zealand as opposed to U.S due to socioeconomic inequality
8. Roberto Cameriere , 2007	158 of Slovenian children and adolescents aged at 6 to 16 years old Carpals as age indicator	Regression models	Ratio of total area of carpal bones and epiphyses of ulna & radius Total of variance Median of absolute values Quartile deviation Standard error	This model explained 86% of the total variance
9.Ivan Galic, 2017	Sample of orthopantomography's (OPTs) of 2223 Italian children (4 and 15 years old) A single mandibular tooth as input	Cameriere's normalized measurement (CNM)	Accuracy	Mandibular teeth of development at up 13 years old
10.Amal A. El-Bakary, 2014	57 Egyptian children and adolescents (142 boys and 115 girls) Aged 4-18 years old	Regression Model (refer Italian sample)	Ratio between total area of carpal bones and epiphyses of ulna and radius	Median of the absolute values of residuals was 1.67 years, with a standard error of estimate of 1.85 years Cameriere's method is not fully suitable for the Egyptian sample and a new modified formula was proposed

2.4 Common Models Based on Hand Bone in Estimation Age

I. Greulich–Pyle (GP)

The estimation of skeletal age is a means of assessing development and the process of skeletal maturation in children and adolescents for clinical or forensic purposes. These assessments involve comparing the skeletal age of a test population against established standards. The most commonly used standards are those published in the Radiographic atlas of skeletal development of the hand and wrist by GP.

The differences in growth rate and maturation have been attributed to secular trends and differences in genetic origin, health status and economic status. These factors influence growth and skeletal development, causing varying effects on different populations. The study by (Schmeling *et al*., 2006) stated that GP atlas often used as assessment of skeletal maturity, but it is may not be relevant for the current generation of children due to economic growth and the variety of regions and races which are also influenced the development of the children.

II. Tanner and Whitehouse Model (TW)

The TW method is used for assessing the skeletal maturity that have been used for more than three decades. TW method can assign a numeric score to each stage of hand and wrist bone maturation where this sum of scores produced the measurement of skeletal maturity score (SMS). By calculating the relationship between SMS and chorological age can produce the population-specific that already produced in Belgium, Italy, Argentina and United State as well in other countries (Büken et al., 2008).

The problems using TW method is poor in positioning of the hand when radiograph is taken where it makes changes the appearance of the epiphysis. This will lead to misinterpret the result. The lack of consistency needs more good observers to reduce the intra and inter observe error.

III. Multiple linear regression models

A study was conducted by (Cameriere, Ferrante, Mirtella, & Cingolani, 2006) which same case study where used carpals area and epiphyses of ulna and radius as input in estimating age that are based on regression models. This model stated that the regression model is much easier than the traditional models and the accuracy also almost closer to actual age. Therefore, in this study used length of each bone in the left hand as a new variable in age estimation where the length is use as the alternative variables for age estimation proses.

In this study also will develop mathematical modelling and soft computing models where these models able to make prediction age directly compared to traditional models which are have variety of intra and inter-observer that lead to different result so the use of soft computing techniques in this study as another method to the traditional models and common mathematical models to enhance the age estimation's result.

The regression model consists of various type regressions which are linear regression, multiple linear regression, single quadratic regression (SQR) and support vector regression (SVR) that can be used as the age estimation method. All the regression models produce R-square value and have its own equation which is the combination of the parameters and constant values. The best result is when R-square is fit of the model.

In Asian data set for age estimation analysis, for single bone eleven regressions is applied on the length of each bones while for all bones of the left hand one regression is applied. Multiple linear regressions are the best method that applied to all bones where according to MSE value is 1.654 years for male and 3.006 years for female. The equation of multiple linear regressions is the best method for age estimation that has complete left-hand bones.

2.5 Details of Multiple Linear Regression Model

The multiple linear regression is study of the relationship between independent and dependent variable. It is a statistical model which uses several explanatory variables to estimate the result of a response variable. It includes a group of random variables and equation of mathematics. This model has ability to form straight linear lines that approximate all the individuals' data points. The general equation of multiple linear regression models is shown as Equation 1.1 below:

$$\hat{Y} = b_0 + b_1 X_1 + b_2 X_2 + \cdots + b_p X_p$$

Equation 2.1 Multiple linear regression formula where Y is the predicted value of the dependent variable, X_1 through X_p are p distinct independent or predictor variables, b_0 is the value of Y when all the independent variables (X_1 through X_p) are equal to zero, and b_1 through b_p are the estimated regression coefficients. The multiple linear regression model is based on four assumptions. One of them is there is a linear relationship among their dependent and independent variables. The independent variables are not highly related to each other. Basically, the observation is chosen from independently and randomly population which the residuals must be normally distributed with a mean and variance.

2.6 Artificial Neural Network (ANN)

An artificial neural network (ANN) is a computational model based on the structure and functions of biological neural networks. It is also considered nonlinear statistical data modelling tools where it can model and patterns the complex relationship between the input and output.

ANN is one of the most recognized where it can learn from observing data sets and used as a random function approximation tool. These types of tools can help for estimating the most cost-effective and idea methods. Besides, ANNs have three layers that are connected where the first layer consists of input neurons, the second neurons send data on to the second layer and will be sending the output neurons to the third layer. Figure 1 shows the illustration of the biological ANN.

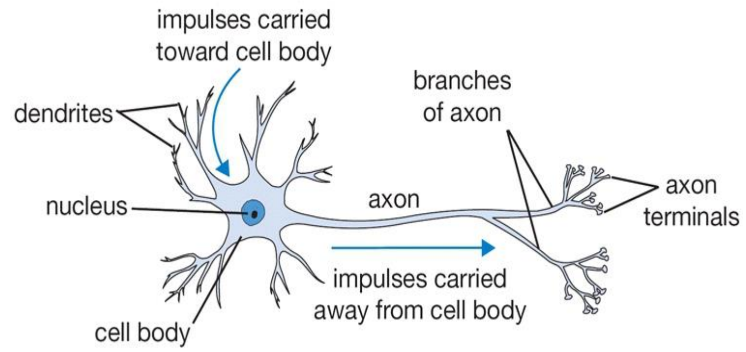


Figure 2.1 Labelling of neurons

Collections of processing elements are constituted by ANN model in constructing the network structure is known as *perceptron.* This *perceptron* is placed in the network's layers which each of the *perceptron* contribute to release output and managing input. The input can be an original data or other *perceptron's* output while the output may be the result or may be an input to others *perceptron.* At least one input layer and one output layer are needed to develop a network structure.

Generally, in development of ANN model the visible and hidden unit relates to one or more other input *perceptron* using weight in other layers. For the network model with two or more layers, the first order information will be processed, and the output will be consecutively acquired same with multiple linear regression.

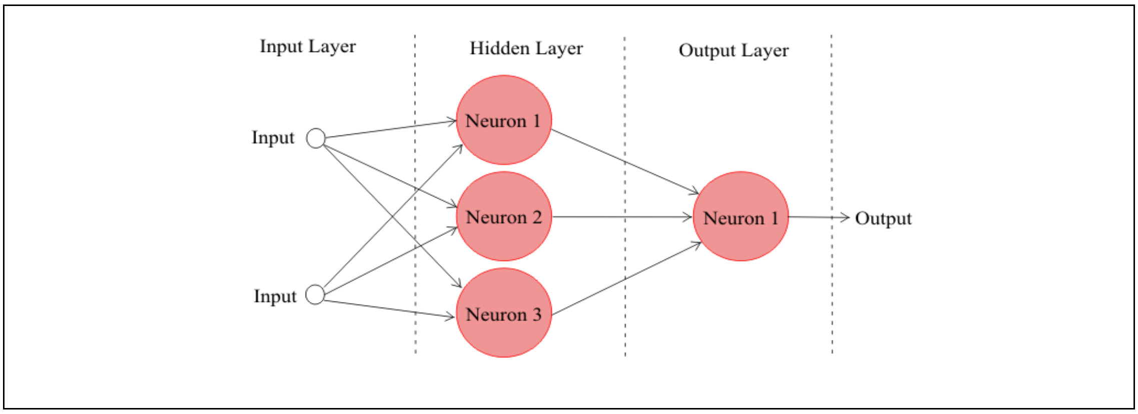


Figure 2.2 The layer of neurons

Figure 2.2 shows the neural network architecture which is containing many 'hidden neurons". In the hidden layer, it must modify using nonlinear function such as a sigmoid that will give the input for the next layer. The purposed is to reduce the effect of huge or outlier input. In prediction there is an element of randomness of starting point that need the network to try at least for thrice to produce some average results.

2.7 Factors Influencing of ANN Model

Principally, the process of trial and error with some factors are considered (Zain et al., 2010) for obtaining the optimal of ANN model. The application of the ANN model for the modelling purpose in various areas including forensic area is used extensively by researchers but there have been no specific rules that could serve as a basis to be followed by this study in constructing the perfect model. Therefore, the efficiency of this model is fully dependent on the process of trial-and-error. Thus, eight factors which may influence the efficacy of ANN model is considered in this study which are:

i. Structure of the Network

ii. Normalization of data

iii. Ratio of training and testing data

iv. Network algorithm

v. Transfer function

vi. Performance function

vii. Training function

viii. Learning function

These eight factors will determine the best ANN model using process of trial and error in developing the ANN model for age and sex estimation. ANN or other soft computing model for age estimation which based on measurement of bone is not fully done research yet. Thus, the used of the ANN model need to explore more to see the significant of this model in estimation of age. Lastly, proved that the ANN model can highly handling the quantitative data that can produce a better result of prediction making.

2.8 Summary

The traditional model for estimating age is based on the observation of bone morphology from the radiograph of the left hand by forensic anthropologist. The raising issue is the model were very depending on the expert of forensic anthropologist to estimate the age which the difference levels of experience of the forensic anthropologist might produce a higher variation intra-observer of the error between the actual age and predicted age.

The second problem is the model for age estimation has a specific population where the model used for a population may not be generalised for others population. The third problem is soft computing model which is very limited used in age estimation studies field. Based on these problems stated above, the purpose of this study is to develop age estimation model for African American population and to test with different measurement where does the bone length of left hand can be used as an alternative to the traditional models. The bone length in estimating age has not yet conducted as the new measurement for age estimation.

A study was conducted by (Cameriere et al., 2006) which same case study where used carpals area and epiphyses of ulna and radius as input in estimating age that are based on regression models. This model stated that the regression model is much easier than the traditional models and the accuracy also almost closer to actual age. Therefore, in this study used length of each bone in the left hand as a new variable in age estimation where the length is use as the alternative variables for age estimation proses.

In this study also will develop mathematical modelling and soft computing models where these models able to make prediction age directly compared to traditional models which are have variety of intra and inter-observer that lead to different result so the use of soft computing techniques in this study as another method to the traditional models and common mathematical models to enhance the age estimation's result.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed the methodology used in data collection of left-hand bone which is used as the indicator for age estimation. The process of development of multiple linear regressions and ANN also described. Validation and evaluation process discussed in detail to see the reliability and it will compare with the best model of the proposed model in estimating the age. The system requirement for the development of each models are also discussed.

3.2 Research Flow

In this research flow for this study, involves five phases which are:

I. Problem statement
II. Data collection and definition
III. Development of multiple linear regressions
IV. Implementation of ANN model
V. Validation and evaluation of results

The details of framework are shown in Figure 3.1 as below:

Phase 1: Problem Statement:

Define the problem and its solution of age estimation based on hand bone

⇩

Phase 2: Data Collection and Definition:

- Define how data collection is collected and what parameters are used

- Define how the data measured into useful inputs
- Data Normalization for Original Dataset

↓

Phase 3: Development of Multiple Linear Regressions using Normalized Original Dataset

- Produce equation, R-square value, MSE value and graphs which actual age against predicted age for male and female
- Compare with ANN model for evaluation purpose.

↓

Phase 4: Implementation of ANN Model using Normalized Original Dataset

ANN Model:

- Define network structure and its algorithm
- Produce MSE value and graphs which actual age against predicted age for male and female
- Select the best network hidden layer network based on the performance measurement by using RMSE

↓

Phase 5: Validation and Evaluation Results:

- Validate each proposed model based on benchmark of this study by using performed the measurement used
- Evaluate each of proposed models between each other's model to select the best model for age estimation

Figure 3.1 Framework flow of research

3.3 Problem Definition

The definition term of problem is a precise and concise statement of the issue. The first phase in this study is clearly stated the problem definition for this research study is to investigate the goal of finding the solution. In Section 1.2 been described the problem definition.

3.4 Data Collection and Definition

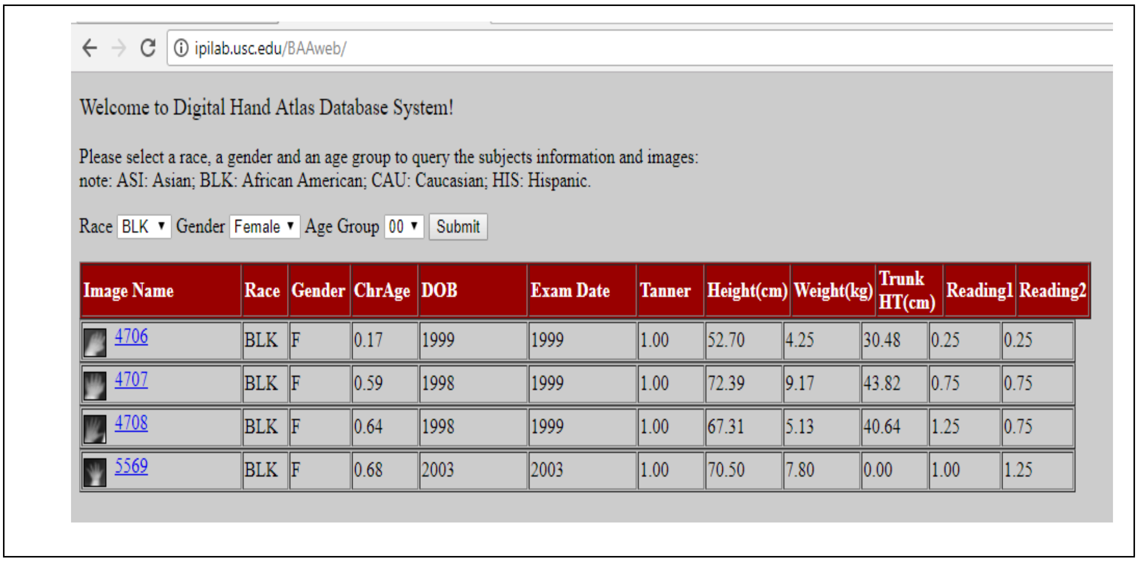
There are two type of datasets were used in this research study for age estimation which are original dataset and normalized original dataset. The details for each dataset are described as below:

3.4.1 Original Dataset of Left-Hand Bones

The original dataset is taken from http://ipilab.usc.edu/BAAweb/ which is online dataset that consist of four races which are Caucasian, African American, Hispanic and Asian. In this study, it focuses on African American population as subjects used in age estimation as mentioned in the problem statement.

A total of 344 X-ray images of African American's left-hand bones where there are 179 males and 165 females respectively are used in this estimation of age. The dataset used are ranged from new-born which is 1 to 18 years old without any record of bone problems such as bone cancer, fractures, and other genetic bone problems. The quality of bone of each subject are very important to avoid affecting the measurement of their left-hand bones. These radiographs were taken from Image Processing and Informatics Lab of the University of Southern California, funded by the National Institute of Health which strictly open for research and education proposed only. Each radiograph was including with patients' demographic data and reading from radiologist.

Each of subjects consist of image name, race, gender, chronological age, date of birth (DOB), exam date, height (cm), weight (kg), trunk (cm), reading 1 and reading 2 were documented for reference. The reading 1 and reading 2 were predicted by the expert and experience radiologist using GP model. In determining the validation purpose, the GP model is used as the benchmark for the study. The sample of this online dataset is shown in Figure 3.2.



ipilab.usc.edu/BAAweb/

Welcome to Digital Hand Atlas Database System!

Please select a race, a gender and an age group to query the subjects information and images:
note: ASI: Asian; BLK: African American; CAU: Caucasian; HIS: Hispanic.

Race BLK Gender Female Age Group 00 Submit

Image Name	Race	Gender	ChrAge	DOB	Exam Date	Tanner	Height(cm)	Weight(kg)	Trunk HT(cm)	Reading1	Reading2
4706	BLK	F	0.17	1999	1999	1.00	52.70	4.25	30.48	0.25	0.25
4707	BLK	F	0.59	1998	1999	1.00	72.39	9.17	43.82	0.75	0.75
4708	BLK	F	0.64	1998	1999	1.00	67.31	5.13	40.64	1.25	0.75
5569	BLK	F	0.68	2003	2003	1.00	70.50	7.80	0.00	1.00	1.25

Figure 3.2 Sample dataset of African American

The radiographs were collected from Image Processing and Informatics Lab of University of Southern which is located at California. Funded by the National Institute of Health and restricted for open research and education purposed only. Candidates were scrutinized and approved by the institutional review board for clinical investigators.

There were four groups of hand bones which are distal phalanx, middle phalanx, proximal phalanx and metacarpal. The middle phalanx group have four bones while the others three groups have five bones respectively. The total of nineteen bones is accounted for the hand. The part of epiphyses and diaphysis in childhood are the main portions of long bone. Epiphyses is the end of a long bone that is separated from the main bone by a layer of cartilage but during adulthood stage is joint the main bone through ossification. Diaphysis is central shaft of a long bone which is consisting mainly of compact bones surrounding a cavity. In childhood and adolescence stage, there are six major phases: 1) Infancy (new-born to 14 months for males, new-born to 10 months for female), 2) Toddlers (14 months to 3 years of age for males, 10 months to 2 years of age for females), 3) Pre-puberty (3 years to 9 years of age for males, 2 years to 7 years of age for females), 4) Early and Mid-puberty (9 years to 14 years of age for males, 7 years to 13 years of age for females), 5) Late Puberty (14 years to 16 years of age for males, 13 years to 15 years of age for females) and, 6) Post-puberty (16 years to 19 years of age for males, 15 years to 17 years of age for females).

The input use in this study is the length of each bone in left hand. To measure the nineteen bones length in each x-ray image is using a free photo editor (Photo Pos Pro, Power of Software Company Ltd) that will create a line in each bone. It will be beginning from the base-middle point to the end-middle point of the bone on each X-ray images and it will automatically produce the length of line in centimeter (cm). For infancy phase, the line was created by ignoring the epiphyseal in the bone while for other phases, the lines were created by including the epiphyseal even if just small epiphyseal appeared in the images. Figure 3.2 shows an example of measuring the bone length of each phase from X-ray image.

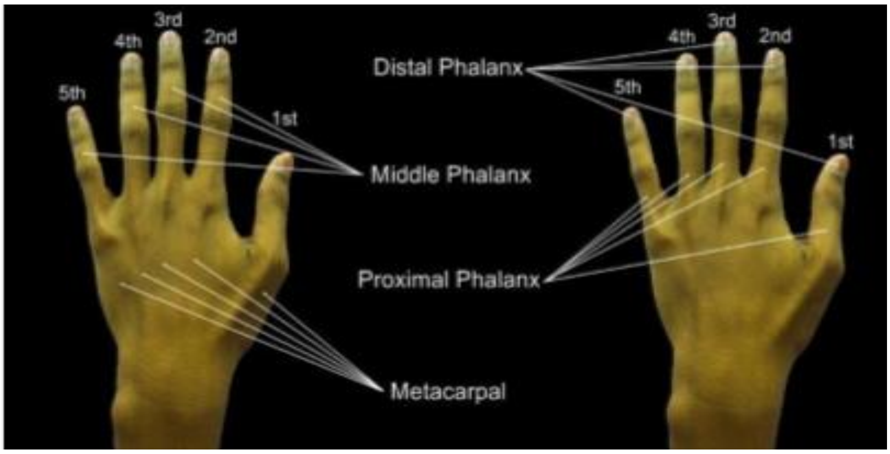


Figure 3.3 Left hand bones

3.4.2 Normalized Original Dataset

The next step after the data collection is data normalization. All the data should be normalized before implementing on neural network in order to make all the inputs data equally in approximate range. In this research, Max-Min normalization techniques is used to change the data set value in in a range of [0,1]. This technique can acquire a linear transformation based on the original data. The standard formula for normalization is shows in Equation 3.1.

$$\mathbf{y} = \frac{\mathbf{x} - \mathbf{min}}{\mathbf{max} - \mathbf{min}}$$

Equation 3.1 Normalization Formula

The interval value for [0,1] will be used for the sigmoid activation function. The normalized original dataset of length of nineteen bones in the left hand of each subject used. This dataset is used in developing the multiple linear regressions and the ANN model. Before developing the proposed models, this dataset will be categorized into two dataset which are training dataset (80%) and testing dataset (20%). The training dataset is used to develop the models while testing dataset is used to validate the models.

3.5 Proposed Model for Age Estimation

This section discusses about the development of multiple linear regression and ANN model for age estimation. The details methodology of each model is discussed respectively in their section. The dataset used is the normalized original dataset for the both multiple linear regression and ANN model.

3.5.1 Development of Multiple Linear Regression

In this study, the multiple linear regressions have selected as one of the proposed models where previously studies stated that this model is can use on hand bone measurement for age estimation. The multiple linear regressions also used as benchmark for the ANN model. From the previous result case study also shown that multiple linear regressions are one of the best used in estimation.

The development of the multiple linear regressions is based on the normalized dataset. This model used all the length of bones which contains nineteen bones as input in developing the model. Multiple linear regressions are developed an equation for both male and female in estimating the age which is based on the training dataset. The testing dataset can make prediction age for age subject in this dataset where this dataset will be included to the equation. The framework of development multiple linear regression as shown in Figure 3.4.

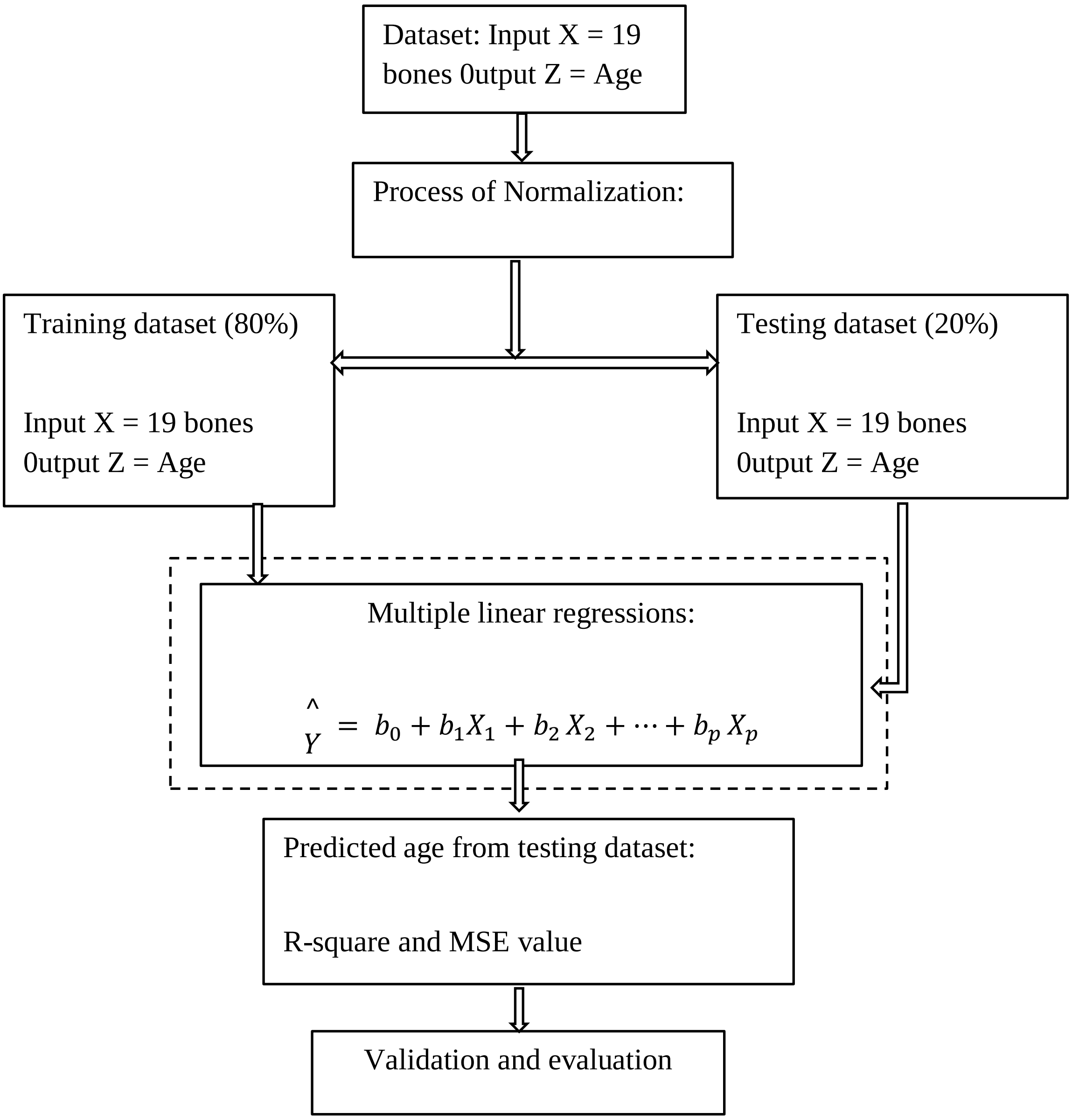


Figure 3.4 Framework of multiple linear regression for age estimation

3.5.2 Implementation of ANN model

Based on the literatures, ANN model is chosen based on the use can be implemented to variety of task with different fields such as business, industry and science. The traditional models in age estimation make prediction of age based on qualitative data only which is observation of bone morphology from forensic anthropologist that might be produced different result due to expert and experience in that field. To overcome this problem, the new quantitative age subject which the bone length is use and ANN is shown from recent research activities that have powerful pattern classification, pattern recognition and prediction capabilities. Thus, in age estimation, used of the bone length as a new age indicator is very reliable to ANN model.

The development of multi-layered ANN model was influenced by three factors which were the network, problem complexity and learning complexity. All these factors will affect the performance of result. The study by (El-Bakary et al., 2014) stated that for evaluating the accuracy of age estimation must evaluated the mean difference between the real age and estimated age. To get the real age it needs to subtract the value from the estimated age. A positive result indicated an overestimation while a negative one is an underestimation.

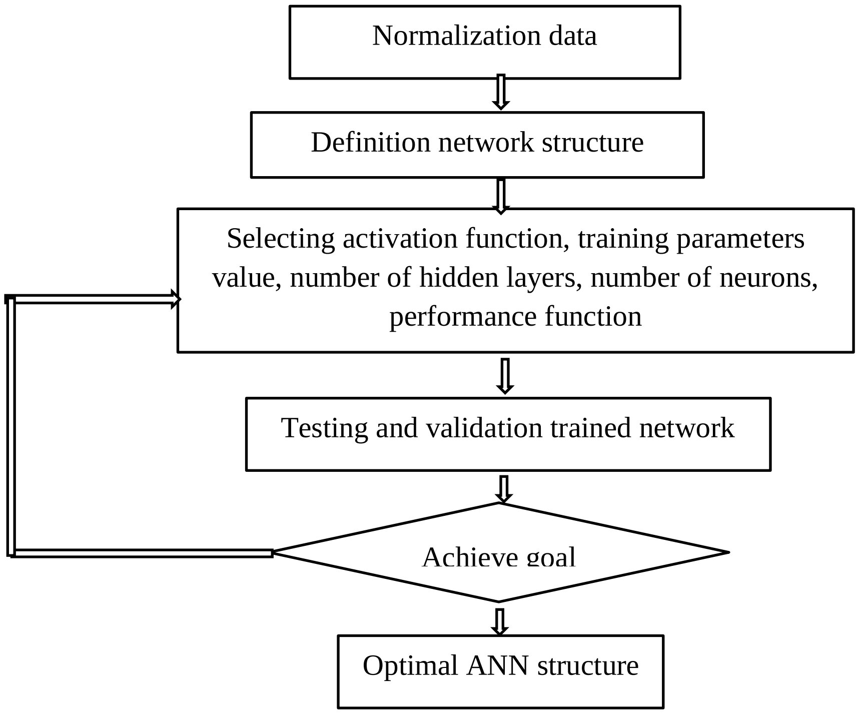


Figure 3.5 Framework of ANN

I. Design of the Neural Network

Artificial neural network (ANN) is a machine learning modelling inspired from biological neural networks that transmit and process information from one neuron to another. The architecture design or the model of the neural network consists of three layers which are the input layer, the hidden layer and the output layer. The weight which applied in the hidden and output nodes is to determine the activation of the neural network. In the input layer, it consists of passive nodes where the number of nodes is representing the number of attributes. As mentioned earlier, the value on each attribute is set in range [0,1] for the use of sigmoid activation function as shown in Figure 3.3 which is to train the data between 0 and 1.

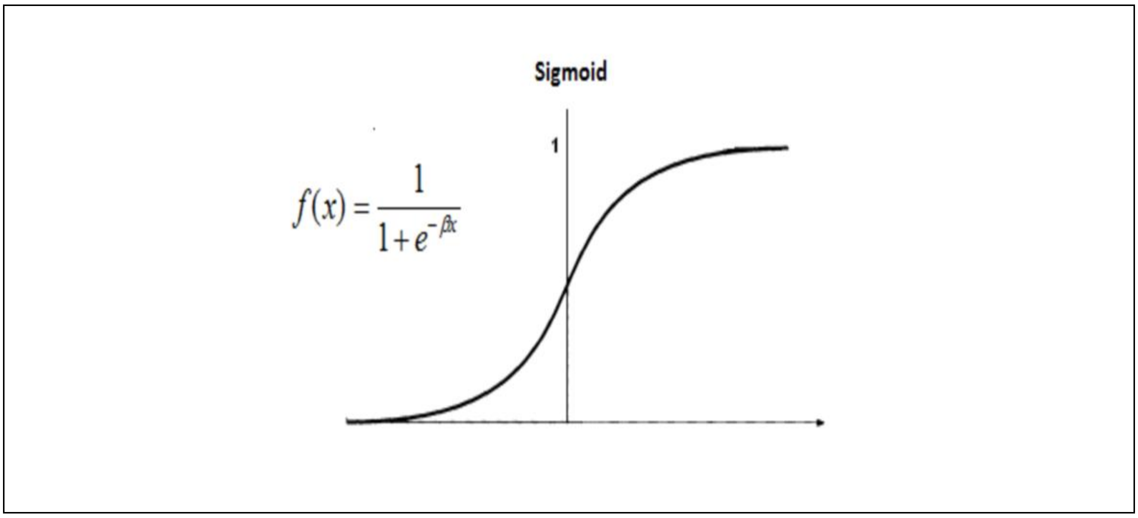


Figure 3.6 Sigmoid graph function

The sigmoid function is typically used in multilayer neural network, during the back propagation and it is the functions are usually applied on the hidden and output layers. In figure 3.4, it illustrates the activation flow while figure 3.5 shows the formula for sigmoid function.

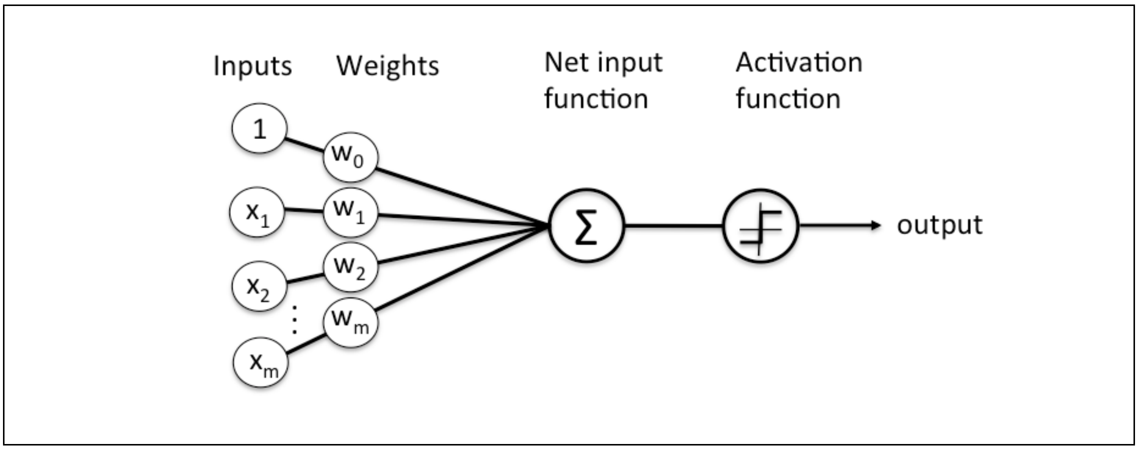


Figure 3.7 Activation function flow

To train the data, a design of a neural network is created by decided on how many neurons are needing to be used and how the neurons are connected in order to form a network model. Thus, four design is constructed as shown in figure below, which consist three or four layers but different number of hidden nodes. The input nodes are corresponding with the number of attributes.

$$y = \frac{1}{1 + e^{-2}}$$

Equation 3.2 Sigmoid function formula

II. Data Training using Back-Propagation Algorithm

During the training process, 70% of the dataset is being used. This is to make the neural network learn the pattern based on the dataset. The training process start by applying a random weight on each connection weight in the network. Next, the backpropagation algorithm is used to adjust all the weight until the neural network able to output the required value.

Back-propagation algorithm is one of a rule standard learning technique to train an ANN model. It is a process to calculate the gradient of a loss function together with all the weights that applied within the network. It starts with forward propagation where the input data is feed to the input layers of the network. Zhang et al. (1998) and Zain et al. (2010) recommend a formula in determining the number of nodes in the hidden layer which is "$2n$ + 1", "$2n$", "$1n$", and "n/2", where the n is the number of input nodes. Along the process, it involves the activations functions to transmit from input layer until the output is generated from the output layer. The output will then be observed and if it is contrast from the expected output, the error will be calculated, and the output layer propagated backward into the network. Thus, the weight will be adjusted in hidden and output layers in order to reduce error.

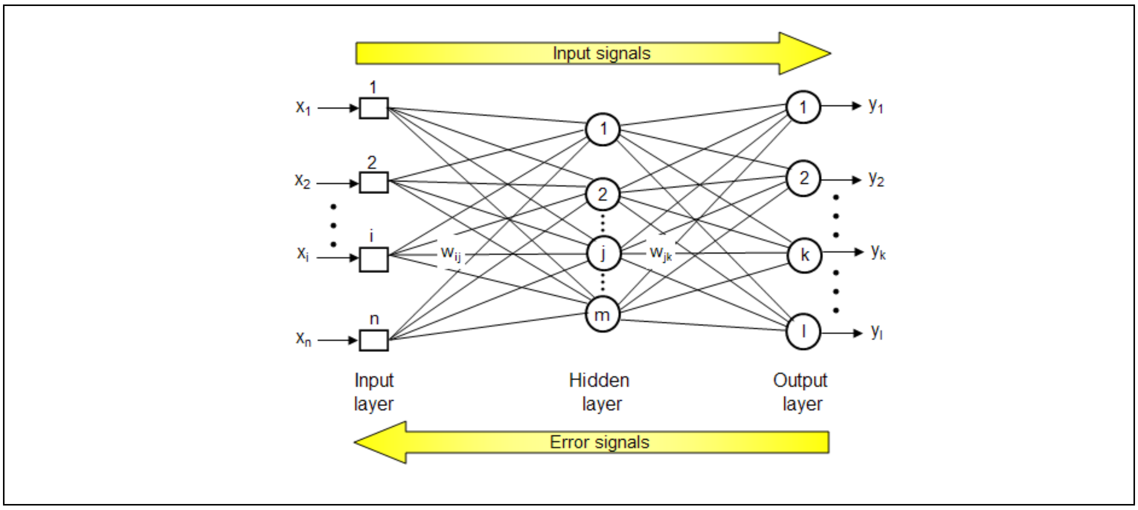


Figure 3.8 Feed forward with back propagation

3.6 Hardware and Software

This research need assist a tool in form of hardware and software to execute the program smoothly. The hardware and software used in this study must have highly effective and efficient specification to carry out in this developing and implementation process more precisely. For the development process used the latest version of Windows which is Microsoft Windows 10 with the specification of Intel i3 CPU, 2.33 GHz and 4.00 GB of RAM.

The software used for measuring the length of left bones is using Photo Pos Pro, Power of Software Company Ltd which is free photo editor for open research and education purposed used only. The data collection used software of Microsoft Excel while in documentation used Microsoft Office. To develop the multiple linear regression models used IBM SPSS Statistic 22.0 for generating the equation. The main software that used in this study is Encog Workbench tools version 3.3.0 which is used for developing the ANN model.

3.7 Validation and Evaluation of Results

The validation and evaluation are an important step to prove the result obtain are can be measured accurately. In this section described the method used for each model in validation and evaluation process which use the results of the proposed models based on normalized reduced dataset. The details process of validation and evaluation are described below:

I. Validation process for age estimation

In this study, validation process is measuring the proposed model's result does it can produce outperform the benchmark dataset or vice versa, significant used the test and to see their reliability of the proposed models. A comparison between the proposed models and benchmark is performed which are based on MSE value and value. From the predicted age, R-square value and MSE value is used to calculate the measurement of the traditional model which is the benchmark for the comparison purposed. To prove the model is reliable to be used for age estimation, the results obtained, and proposed models must significant and outperform the benchmark.

II. Evaluation process for age estimation

For evaluation process, MSE value proposed by the multiple linear regression and ANN model have compared each other to select or the best model used in age estimation.

3.8 Summary

In this chapter discussed about the methodology used in developing the multiple linear regressions and ANN model in estimating the age for African American's children using their left-hand bone. The flows for each steps of the development were also discussed. The method used for each model to validate and evaluate the result were also mention in this chapter.

CHAPTER 4

AGE ESTIMATION USING MATHEMATICAL MODELLING

4.1 Introduction

This chapter explains the proposed model in estimating the age for male and female of African American's children population using mathematical modelling which is multiple linear regression. This chapter will discuss includes the development of model, analysis results obtained and discussions of the results. Based on the analysis and discussion of the results, there is soft computing method of Artificial Intelligence (AI) is selected for obtained more accurate age estimation based on Chapter 2.4 which are Artificial Neural Network that will be discussed in Chapter 5.

4.2 Pre-processing of Data Collection

The normalized original data of length in left hand that consists of nineteen bones in African American's children population. The formula used for normalization as shown in Equation 3.1 in Chapter 3 where x, the original data while maximum and minimum value of dataset were counted to obtain the normalized data. The normalized data of all the subjects are shown in Appendix A. The details of this dataset are explained in Section 3.4.2. In Table 4.1 and Table 4.2 are the descriptive analysis on the original dataset is shown for male and female respectively. From the Table 4.1 and Table 4.2, the mean age was 10.856 and 10.877 for male and female respectively. It shows that the different of age gender was not statistically significant. These tables also show the mean length of all bones of female is longer than the mean length of all bones of male. The small value of standard deviation of each bone in both tables also explained the length of each bone is closer to the mean length. The normalized original dataset is divided into two parts which is the training dataset and testing dataset. The divided dataset is also shown in Appendix B. The ratio of the training dataset is 80% while for the testing dataset is 20%. These ratio values are common for many previous case studies. The training dataset is used on developing the models while the training dataset is used to validation purposed of the model. The total of training and testing dataset for both male and female will used by the multiple linear regressions is shown in Table 4.3.

Table 4.1 Descriptive analysis for male

	Bone	N	Mean	Std. Error	Std. Deviation	Variance
Age	-	181	10.856	0.021	4.767	0.656
First Finger	Metacarpal	181	3.218	0.064	0.856	0.733
	Proximal Phalanx	181	2.220	0.042	0.568	0.323
	Distal Phalanx	181	1.701	0.032	0.427	0.183
Second Finger	Metacarpal	181	4.849	0.089	1.193	1.424
	Proximal Phalanx	181	2.879	0.049	0.659	0.434
	Middle Phalanx	181	1.678	0.030	0.398	0.158
	Distal Phalanx	181	1.208	0.024	0.318	0.101
Third Finger	Metacarpal	181	4.726	0.088	1.189	1.413
	Proximal Phalanx	181	3.284	0.056	0.754	0.568
	Middle Phalanx	181	2.064	0.035	0.476	0.227
	Distal Phalanx	181	1.324	0.024	0.322	0.104
Fourth Finger	Metacarpal	181	4.166	0.077	1.035	1.072
	Proximal Phalanx	181	3.083	0.051	0.684	0.468
	Middle Phalanx	181	1.985	0.033	0.445	0.198
	Distal Phalanx	181	1.356	0.025	0.337	0.114
Fifth Finger	Metacarpal	181	3.808	0.073	0.988	0.976
	Proximal Phalanx	181	2.408	0.021	0.565	0.319
	Middle Phalanx	181	1.404	0.064	0.355	0.126
	Distal Phalanx	181	1.160	0.042	0.305	0.093

Table 4.2 Descriptive Analysis for Female

	Bone	N	Mean	Std. Error	Std. Deviation	Variance
Age	-	172	10.877	0.049	4.912	1.588
First Finger	Metacarpal	172	3.182	0.060	0.782	0.611
	Proximal Phalanx	172	2.190	0.040	0.521	0.271
	Distal Phalanx	172	1.634	0.028	0.361	0.131
Second Finger	Metacarpal	172	4.727	0.082	1.073	1.151
	Proximal Phalanx	172	2.908	0.048	0.634	0.402
	Middle Phalanx	172	1.654	0.028	0.365	0.133
	Distal Phalanx	172	1.182	0.021	0.273	0.075
Third Finger	Metacarpal	172	4.630	0.081	1.065	1.135
	Proximal Phalanx	172	3.285	0.055	0.715	0.511
	Middle Phalanx	172	2.054	0.035	0.456	0.208
	Distal Phalanx	172	1.284	0.022	0.293	0.086
Fourth Finger	Metacarpal	172	4.096	0.073	0.963	0.927
	Proximal Phalanx	172	3.063	0.051	0.670	0.449
	Middle Phalanx	172	1.960	0.032	0.417	0.173
	Distal Phalanx	172	1.301	0.022	0.286	0.082
Fifth Finger	Metacarpal	172	3.725	0.069	0.910	0.828
	Proximal Phalanx	172	2.379	0.040	0.522	0.272
	Middle Phalanx	172	1.375	0.024	0.317	0.100
	Distal Phalanx	172	1.182	0.086	0.265	0.070

Table 4.3 Total of training and testing dataset for female and male

Gender	Total subjects	Dataset	Ratio per dataset	Total
Male	181	Training dataset	80	145
		Testing dataset	20	36
Female	172	Training dataset	80	138
		Testing dataset	20	34

4.3 Development of Multiple Linear Regression

In this study, the development of multiple linear regressions is using IBM SPSS software statistical tool. The aim of this model is to estimate the age of left-hand that consist of nineteen bones of children in African American population. The basic formula for multiple linear regression is shown in Equation 4.1.

$$y = a + b_1x_1 + b_2x_2 + \cdots + b_ix_i \tag{4.1}$$

where,

y : dependent variable which is the predicted age,

x : independent variables which are the length of bone,

i : total of variables which is the nineteen bones,

a : value of Y when all the length of bones (x_1 through x_i) are equal to zero, b_1 through b_i : estimated regression coefficients of each bone.

In developing process of the model is to explore the relationship borders between each of bone and the age. The common model to this purpose is by calculating the coefficient of determination (r) and sigma (α) value. The r value is used to measures the strength and direction of a linear relationship between each of bones and the age which value of r is always between +1 and –1. R value of 1.0 indicates that the bones have strong relationship with the age while α value is used to see the significant of the correlation between the bones and the age.

The formula to calculate r value is shown in Equation 4.2 where n is the total subjects, and the other parameters remain the same with Equation 4.1 By using Equation 4.1 is for calculating the r value while the SPSS tools for calculating the α value where the value of each r and α value regarding to their bones is shown in Table 4.4. The table shows high correlation between each of bone and the age regarding to the r value, for both male and female. The highest correlation for male is metacarpal from fifth finger which is 0.942 and metacarpal from second finger which is 0.881 for female. From this result, all of bones are considered have high relationship with the age, thus, will be used as input in estimating age using multiple linear regression.

$$r = \frac{n\sum_{i=1}^{n} xy - (\sum_{i=1}^{n} x)(\sum_{i=1}^{n} y)}{\sqrt{(n\sum_{i=1}^{n} x^2) - (\sum_{i=1}^{n} x)^2}\sqrt{(n\sum_{i=1}^{n} y^2) - (\sum_{i=1}^{n} y)^2}} \tag{4.2}$$

Table 4.4 The value of parameter r between all the bones and the age, for male and female

Finger	Bone	Male		Female	
		R value	Sigma (α)	R value	Sigma (α)
First Finger	Metacarpal	0.937	0.000	0.863	0.000
	Proximal Phalanx	0.928	0.000	0.871	0.000
	Distal Phalanx	0.909	0.000	0.829	0.000
Second Finger	Metacarpal	0.940	0.000	0.881	0.000
	Proximal Phalanx	0.905	0.000	0.859	0.000
	Middle Phalanx	0.891	0.000	0.852	0.000
	Distal Phalanx	0.916	0.000	0.861	0.000
Third Finger	Metacarpal	0.938	0.000	0.878	0.000
	Proximal Phalanx	0.933	0.000	0.869	0.000
	Middle Phalanx	0.923	0.000	0.819	0.000
	Distal Phalanx	0.926	0.000	0.842	0.000
Fourth Finger	Metacarpal	0.933	0.000	0.871	0.000
	Proximal Phalanx	0.920	0.000	0.867	0.000
	Middle Phalanx	0.902	0.000	0.862	0.000
	Distal Phalanx	0.912	0.000	0.859	0.000
Fifth Finger	Metacarpal	0.942	0.000	0.867	0.000
	Proximal Phalanx	0.924	0.000	0.872	0.000
	Middle Phalanx	0.890	0.000	0.868	0.000
	Distal Phalanx	0.890	0.000	0.804	0.000

4.3.1 Developing in Multiple Linear Regression Equation

The equation produced by the multiple linear regressions is used to estimate the age and measuring the performance measurement of this model. Therefore, the parted dataset which is the training dataset and the testing dataset are used to develop the equation and validate the results, respectively. To develop the equation, the Equation 4.1 will be used and the parameters a and b_1 to b_i need to be calculated. Parameter b is calculated using Equation 4.3 and parameter a is calculated using Equation 4.4. Parameter a can be calculated when each of parameter b is calculated.

$$b_i = \left(\frac{r_{y,x_i} - \prod_{m=1}^{l} r_{y,x_{m\ldots\ l}} * r_{x_i,x_{m\ldots\ l}}}{1 - \left(\prod_{m=1}^{l} r_{x_i,x_{m\ldots\ l}}\right)^2}\right)\left(\frac{SD_y}{SD_{x_i}}\right), m \neq i \tag{4.3}$$

i : total of variables which is the nineteen bones,

l : 19,

r_{y,x_i}: correlation value (r) between the age i^th bone,

$r_{y,x_{m\ldots\ l}}$: correlation value between the age and the m^th bone, until the age and the l^th bone, except the correlation of the age and the i^th bone,

$r_{x_i,x_{m\ldots\ l}}$correlation value between the i^th bone and the m^th bone, until the i^th bone and l^th bone, except the correlation value between the same i^th bone,

SD : standard deviation.

$$a = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - \ldots - b_i\bar{x}_i \tag{4.4}$$

$\bar{y}$: mean of the age,

$\bar{x}i$: mean of each bone length

To calculate parameters b for each bone in Equation 4.3, the correlation value between the age and each bone, and the correlation between the bones need to be determined. By using SPSS tools, the correlation matrix of the age and each bone, and between the bones, is developed and shown in Table 4.6 and Table 4.7, for both male and female, respectively. By inserting the correlation values from these tables, and the remaining parameters value (SD_y and SD_{x_i}) to the Equation 4.3 regarding to their gender, each of the parameters b for both male and female is calculated and shown in Table 4.8.

Table 4.5 The value of parameters $y¯$ and $x¯\_i$ for male and female

	Variables	Male	Female
	Age (y¯_1)	0.571	0.576
First Finger	Metacarpal (x¯_1)	0.667	0.705
	Proximal Phalanx (x¯_2)	0.598	0.612
	Distal Phalanx (x¯_3)	0.655	0.577
Second Finger	Metacarpal (x¯_4)	0.643	0.664
	Proximal Phalanx (x¯_5)	0.606	0.688
	Middle Phalanx (x¯_6)	0.625	0.609
	Distal Phalanx (x¯_7)	0.649	0.633
Third Finger	Metacarpal (x¯_8)	0.714	0.685
	Proximal Phalanx (x¯_9)	0.626	0.668
	Middle Phalanx (x¯_10)	0.574	0.510
	Distal Phalanx (x¯_11)	0.620	0.605
Fourth Finger	Metacarpal (x¯_12)	0.619	0.687
	Proximal Phalanx (x¯_13)	0.641	0.669
	Middle Phalanx (x¯_14)	0.584	0.613
	Distal Phalanx (x¯_15)	0.606	0.640
Fifth Finger	Metacarpal (x¯_16)	0.601	0.654
	Proximal Phalanx (x¯_17)	0.623	0.645
	Middle Phalanx (x¯_18)	0.586	0.591
	Distal Phalanx (x¯_19)	0.508	0.584

Table 4.6: Correlations matrix between all variables, for male

	Variables	Age	First Finger (cm)			Second Finger				Third Finger				Fourth Finger				Fifth Finger			
			Metacarpal	Proximal	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal
	Age	1	0.937	0.928	0.909	0.94	0.905	0.891	0.916	0.938	0.933	0.923	0.926	0.933	0.92	0.902	0.912	0.942	0.924	0.89	0.89
First Finger	**Metacarpal**	0.937	1	0.973	0.947	0.977	0.954	0.934	0.928	0.975	0.971	0.952	0.937	0.974	0.962	0.919	0.939	0.972	0.965	0.915	0.912
	Proximal	0.928	0.973	1	0.944	0.966	0.957	0.947	0.92	0.962	0.976	0.961	0.93	0.965	0.968	0.939	0.936	0.965	0.977	0.938	0.906
	Distal	0.909	0.947	0.944	1	0.951	0.928	0.922	0.953	0.955	0.951	0.942	0.96	0.957	0.946	0.914	0.955	0.953	0.948	0.911	0.936
Second Finger	**Metacarpal**	0.94	0.977	0.966	0.951	1	0.958	0.937	0.928	0.992	0.978	0.961	0.943	0.989	0.97	0.932	0.944	0.985	0.973	0.922	0.914
	Proximal	0.905	0.954	0.957	0.928	0.958	1	0.94	0.903	0.95	0.966	0.945	0.923	0.951	0.955	0.919	0.927	0.954	0.965	0.922	0.893
	Middle	0.891	0.934	0.947	0.922	0.937	0.94	1	0.911	0.932	0.948	0.956	0.917	0.937	0.942	0.929	0.923	0.936	0.949	0.935	0.892
	Distal	0.916	0.928	0.92	0.953	0.928	0.903	0.911	1	0.934	0.93	0.934	0.974	0.934	0.92	0.897	0.96	0.931	0.931	0.906	0.967
Third Finger	**Metacarpal**	0.938	0.975	0.962	0.955	0.992	0.95	0.932	0.934	1	0.975	0.96	0.944	0.994	0.968	0.932	0.947	0.987	0.968	0.919	0.921
	Proximal	0.933	0.971	0.976	0.951	0.978	0.966	0.948	0.93	0.975	1	0.98	0.947	0.976	0.989	0.954	0.954	0.973	0.986	0.945	0.915
	Middle	0.923	0.952	0.961	0.942	0.961	0.945	0.956	0.934	0.96	0.98	1	0.947	0.961	0.975	0.964	0.951	0.96	0.976	0.958	0.913
	Distal	0.926	0.937	0.93	0.96	0.943	0.923	0.917	0.974	0.944	0.947	0.947	1	0.943	0.94	0.922	0.978	0.942	0.949	0.915	0.955
Fourth Finger	**Metacarpal**	0.933	0.974	0.965	0.957	0.989	0.951	0.937	0.934	0.994	0.976	0.961	0.943	1	0.97	0.936	0.947	0.989	0.97	0.925	0.914
	Proximal	0.92	0.962	0.968	0.946	0.97	0.955	0.942	0.92	0.968	0.989	0.975	0.94	0.97	1	0.952	0.947	0.965	0.98	0.933	0.897
	Middle	0.902	0.919	0.939	0.914	0.932	0.919	0.929	0.897	0.932	0.954	0.964	0.922	0.936	0.952	1	0.929	0.936	0.958	0.953	0.891
	Distal	0.912	0.939	0.936	0.955	0.944	0.927	0.923	0.96	0.947	0.954	0.951	0.978	0.947	0.947	0.929	1	0.946	0.953	0.917	0.951
Fifth Finger	**Metacarpal**	0.942	0.972	0.965	0.953	0.985	0.954	0.936	0.931	0.987	0.973	0.96	0.942	0.989	0.965	0.936	0.946	1	0.973	0.926	0.913
	Proximal	0.924	0.965	0.977	0.948	0.973	0.965	0.949	0.931	0.968	0.986	0.976	0.949	0.97	0.98	0.958	0.953	0.973	1	0.959	0.924
	Middle	0.89	0.915	0.938	0.911	0.922	0.922	0.935	0.906	0.919	0.945	0.958	0.915	0.925	0.933	0.953	0.917	0.926	0.959	1	0.902
	Distal	0.89	0.912	0.906	0.936	0.914	0.893	0.892	0.967	0.921	0.915	0.913	0.955	0.914	0.897	0.891	0.951	0.913	0.924	0.902	1

Table 4.7 Correlations matrix between all variables, for male

	Variables	Age	First Finger (cm)			Second Finger				Third Finger				Fourth Finger				Fifth Finger			
			Metacarpal	Proximal	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal	Metacarpal	Proximal	Middle	Distal
	Age	1	0.863	0.871	0.829	0.881	0.859	0.852	0.861	0.878	0.869	0.819	0.842	0.871	0.867	0.862	0.859	0.867	0.872	0.868	0.804
First Finger	Metacarpal	0.863	1	0.829	0.881	0.972	0.961	0.940	0.933	0.974	0.963	0.920	0.924	0.970	0.973	0.948	0.926	0.983	0.946	0.934	0.879
	Proximal	0.871	0.952	1	0.859	0.963	0.972	0.959	0.933	0.960	0.970	0.935	0.932	0.955	0.962	0.961	0.934	0.963	0.958	0.948	0.878
	Distal	0.829	0.915	0.939	1	0.918	0.926	0.939	0.929	0.926	0.932	0.924	0.937	0.922	0.920	0.942	0.941	0.926	0.923	0.938	0.885
Second Finger	Metacarpal	0.881	0.972	0.963	0.918	1	0.974	0.949	0.937	0.989	0.974	0.925	0.924	0.982	0.964	0.949	0.930	0.979	0.949	0.940	0.878
	Proximal	0.859	0.961	0.972	0.926	0.974	1	0.966	0.929	0.974	0.990	0.949	0.932	0.965	0.979	0.969	0.932	0.972	0.969	0.949	0.871
	Middle	0.852	0.940	0.959	0.939	0.949	0.966	1	0.934	0.950	0.962	0.959	0.940	0.940	0.947	0.966	0.939	0.948	0.941	0.960	0.873
	Distal	0.861	0.933	0.933	0.929	0.937	0.929	0.934	1	0.942	0.941	0.914	0.965	0.939	0.924	0.936	0.963	0.933	0.926	0.937	0.942
Third Finger	Metacarpal	0.878	0.974	0.960	0.926	0.989	0.974	0.950	0.942	1	0.979	0.936	0.938	0.993	0.968	0.960	0.941	0.987	0.954	0.942	0.890
	Proximal	0.869	0.963	0.970	0.932	0.974	0.990	0.962	0.941	0.979	1	0.951	0.940	0.973	0.985	0.978	0.942	0.975	0.971	0.956	0.882
	Middle	0.819	0.920	0.935	0.924	0.925	0.949	0.959	0.914	0.936	0.951	1	0.940	0.927	0.934	0.964	0.933	0.933	0.924	0.928	0.878
	Distal	0.842	0.924	0.932	0.937	0.924	0.932	0.940	0.965	0.938	0.940	0.940	1	0.934	0.926	0.941	0.983	0.931	0.926	0.927	0.926
Fourth Finger	Metacarpal	0.871	0.970	0.955	0.922	0.982	0.965	0.940	0.939	0.993	0.973	0.927	0.934	1	0.961	0.953	0.938	0.985	0.950	0.934	0.884
	Proximal	0.867	0.973	0.962	0.920	0.964	0.979	0.947	0.924	0.968	0.985	0.934	0.926	0.961	1	0.970	0.928	0.978	0.965	0.947	0.875
	Middle	0.862	0.948	0.961	0.942	0.949	0.969	0.966	0.936	0.960	0.978	0.964	0.941	0.953	0.970	1	0.945	0.959	0.959	0.965	0.890
	Distal	0.859	0.926	0.934	0.941	0.930	0.932	0.939	0.963	0.941	0.942	0.933	0.983	0.938	0.928	0.945	1	0.931	0.922	0.933	0.919
Fifth Finger	Metacarpal	0.867	0.983	0.963	0.926	0.979	0.972	0.948	0.933	0.987	0.975	0.933	0.931	0.985	0.978	0.959	0.931	1	0.956	0.941	0.877
	Proximal	0.872	0.946	0.958	0.923	0.949	0.969	0.941	0.926	0.954	0.971	0.924	0.926	0.950	0.965	0.959	0.922	0.956	1	0.957	0.878
	Middle	0.868	0.934	0.948	0.938	0.940	0.949	0.960	0.937	0.942	0.956	0.928	0.927	0.934	0.947	0.965	0.933	0.941	0.957	1	0.886
	Distal	0.804	0.879	0.878	0.885	0.878	0.871	0.873	0.942	0.890	0.882	0.878	0.926	0.884	0.875	0.890	0.919	0.877	0.878	0.886	1

Table 4.8 The value of parameters b of the nineteen bones for male and female

Bones		Male	Female
First Finger	Metacarpal	0.217	-0.244
	Proximal Phalanx	0.29	0.403
	Distal Phalanx	-0.224	-0.268
Second Finger	Metacarpal	0.381	0.641
	Proximal Phalanx	-0.133	-0.795
	Middle Phalanx	-0.083	0.148
	Distal Phalanx	0.32	0.324
Third Finger	Metacarpal	0.432	0.796
	Proximal Phalanx	0.422	-0.574
	Middle Phalanx	-0.081	-0.202
	Distal Phalanx	0.518	-0.355
Fourth Finger	Metacarpal	-0.946	-0.144
	Proximal Phalanx	-0.134	0.655
	Middle Phalanx	0.213	0.134
	Distal Phalanx	-0.276	0.56
Fifth Finger	Metacarpal	0.801	-0.478
	Proximal Phalanx	-0.562	0.601
	Middle Phalanx	0.078	0.169
	Distal Phalanx	-0.149	-0.17

To calculate parameter a in the Equation 4.1 for both male and female, the value of parameters y^{-} and x^{-}_i from Table 4.5, and the parameters b from Table 4.8, will be inserted to the Equation 4.4 regarding to their gender. The calculation of parameter a for both male and female are shown below.

$$a = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - \ldots - b_i\bar{x}_i \quad (4.4$$

$$\begin{aligned}\boldsymbol{a\ (for\ male)} \quad = \quad & 0.571 - (0.217)(0.667) - (0.29)(0.598) - \\ & (-0.224)(0.655) - (0.381)(0.643) - (-0.133)(0.606) - \\ & (-0.083)(0.625) - (0.32)(0.649) - (0.432)(0.714) - \\ & (-0.422)(0.626) - (-0.081)(0.574) - (0.518)(0.620) - \\ & (-0.946)(0.619) - (-0.134)(0.641) - (0.213)(0.584) - \\ & (-0.276)(0.606) - (0.801)(0.601) - (-0.562)(0.623) - \\ & (0.078)(0.586) - (-0.149)(0.508)\end{aligned}$$

$$= \mathbf{-0.155}$$

$$\boldsymbol{a\,(for\ female)} = 0.576 - (-0.244)(0.705) - (0.403)(0.612) - (-0.268)(0.577) - (0.641)(0.664) - (-0.795)(0.688) - (0.148)(0.609) - (0.324)(0.633) - (0.796)(0.685) - (-0.574)(0.668) - (-0.202)(0.51) - (-0.355)(0.605) - (-0.144)(0.687) - (0.655)(0.669) - (0.134)(0.613) - (0.56)(0.64) - (-0.478)(0.654) - (0.601)(0.625) - (0.169)(0.591) - (-0.17)(0.584)$$

$$= -0.217$$

The calculated parameter a and parameter b (taken from Table 4.8) are then inserted into the Equation 4.1 to complete the equation of multiple linear regression for age estimation, for both male and female, as shown in Equation 4.5 and Equation 4.6, respectively.

$$\boldsymbol{The\ predicted\ age\ for\ male} = -0.155 + (0.217)(x\_1) + (0.29)(x\_2) + (-0.224)(x\_3) + (0.381)(x\_4) + (-0.133)(x\_5) + (-0.083)(x\_6) + (0.32)(x\_7) + (0.432)(x\_8) + (0.422)(x\_9) + (-0.081)(x\_10) + (0.518)(x\_11) + (-0.946)(x\_12) + (-0.134)(x\_13) + (0.213)(x\_14) + (-0.276)(x\_15) + (0.801)(x\_16) + (-0.562)(x\_17) + (0.078)(x\_18) + (-0.149)(x\_19) \quad (4.5)$$

$$\boldsymbol{The\ predicted\ age\ for\ female} = -0.217 + (-0.244)(x\_1) + (0.403)(x\_2) + (-0.268)(x\_3) + (0.641)(x\_4) + (-0.795)(x\_5) + (0.148)(x\_6) + (0.324)(x\_7) + (0.796)(x\_8) + (-0.574)(x\_9) + (-0.202)(x\_10) + \quad (4.6)$$

$(-0.355)(x\_11) + (-0.144)(x\_12) +$
$(0.655)(x\_13) + (0.134)(x\_14) +$
$(0.56)(x\_15) + (-0.478)(x\_16) +$
$(0.601)(x\_17) + (0.169)(x\_18) +$
$(-0.17)(x\_19)$

The next step is to predict age of the subjects for both male and female using the testing dataset as described in the previous section. The testing dataset can be seen in the Appendix A. Two equations above, which are the Equation 4.5 and Equation 4.6 will be used to predict age for male and female, respectively. All the length of nineteen bones of each subject from the testing data will be inserted into the equation regarding to their gender. The calculated age produced by both equations regarding to male and female are then shown in Table 4.9. This calculated age is then denormalized to get the predicted age in normal form and shown in the same table. By using the denormalized predicted age, the MSE value for this model is calculated and shown in the same table for both male and female. Graph of the actual age and the predicted age of denormalized testing dataset for both male and female is shown in Figure 4.1.

Table 4.**9** The predicted age produced by multiple linear regressions, the actual age and the MSE value of testing data, for both male and female.

Num	**Male**				**Female**			
	Normalization data		**Denormalization Data**		**Normalization Data**		**Denormalization Data**	
	Actual age	**Predicted age**	**Actual age**	**Predicte d age**	**Actual age**	**Predicte d age**	**Actual age**	**Predicte d age**
1	0.000	0.000	0.950	0.000	0.000	0.000	0.170	0.000
2	0.030	0.000	0.890	0.000	0.020	0.000	0.590	0.000
3	0.050	0.000	1.280	0.000	0.060	0.008	1.260	0.309
4	0.060	0.006	1.380	1.060	0.060	0.000	1.300	0.000
5	0.100	0.100	2.150	2.666	0.120	0.044	2.330	0.975
6	0.100	0.461	2.100	8.861	0.120	0.103	2.390	2.050
7	0.150	0.248	3.130	5.199	0.190	0.207	3.760	3.954
8	0.170	0.148	3.360	3.487	0.160	0.221	3.230	4.217
9	0.230	0.199	4.600	4.365	0.230	0.241	4.420	4.584
10	0.250	0.270	4.840	5.581	0.240	0.275	4.590	5.209
11	0.290	0.361	5.660	7.150	0.260	0.329	5.060	6.189
12	0.290	0.347	5.680	6.903	0.310	0.247	5.850	4.691
13	0.360	0.294	6.940	5.990	0.320	0.342	6.090	6.429

14	0.340	0.466	6.600	8.955	0.330	0.373	6.310	7.007
15	0.380	0.396	7.350	7.748	0.420	0.492	7.930	9.171
16	0.400	0.463	7.660	8.896	0.410	0.481	7.770	8.968
17	0.420	0.512	8.030	9.744	0.460	0.472	8.710	8.820
18	0.460	0.486	8.830	9.286	0.470	0.408	8.930	7.645
19	0.480	0.561	9.160	10.574	0.480	0.550	9.030	10.245
20	0.480	0.595	9.220	11.167	0.480	0.547	9.000	10.190
21	0.540	0.502	10.230	9.562	0.560	0.610	10.650	11.340
22	0.550	0.460	10.430	8.852	0.530	0.574	10.000	10.679
23	0.590	0.621	11.230	11.600	0.590	0.557	11.040	10.365
24	0.590	0.521	11.300	9.887	0.600	0.666	11.260	12.366
25	0.640	0.664	12.050	12.351	0.650	0.635	12.260	11.802
26	0.640	0.517	12.120	9.817	0.660	0.556	12.380	10.350
27	0.690	0.658	13.120	12.250	0.690	0.708	13.030	13.135
28	0.700	0.831	13.200	15.206	0.700	0.639	13.140	11.861
29	0.750	0.758	14.090	13.962	0.760	0.708	14.380	13.140
30	0.750	0.787	14.230	14.454	0.800	0.754	15.100	13.971
Mean ($\bar{y}$)			**10.856**	**9.052**	Mean ($\bar{y}$)		**10.877**	**7.98**
Standard variation (s)			**4.767**	**4.782**	Standard variation (s)		**4.912**	**4.572**
R-square value			**0.858**		R-square value		**0.918**	
MSE value			**2.939**		MSE value		**3.996**	
RMSE value			**1.714**		RMSE value		**1.999**	

4.4 Analysis of Results

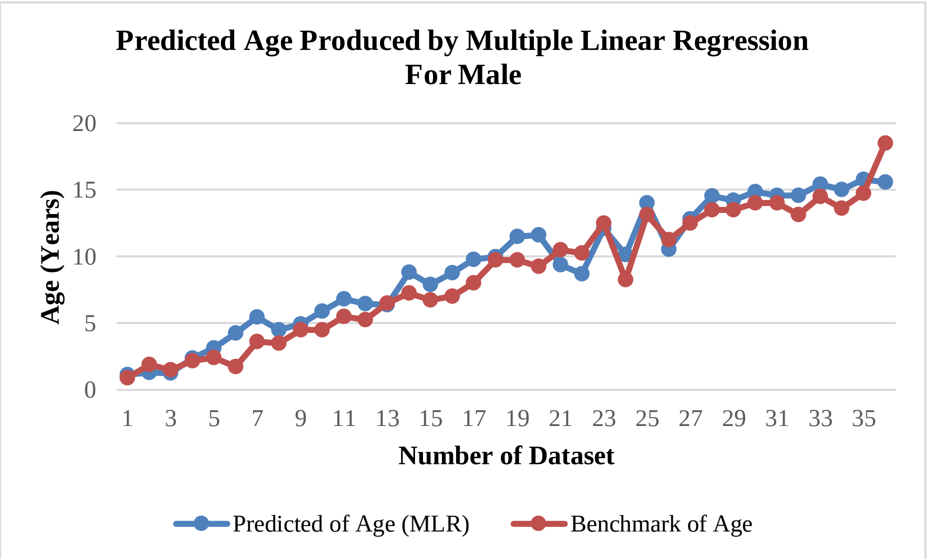


Figure 4.1 Predicted Age for Male using Multiple Linear Regression

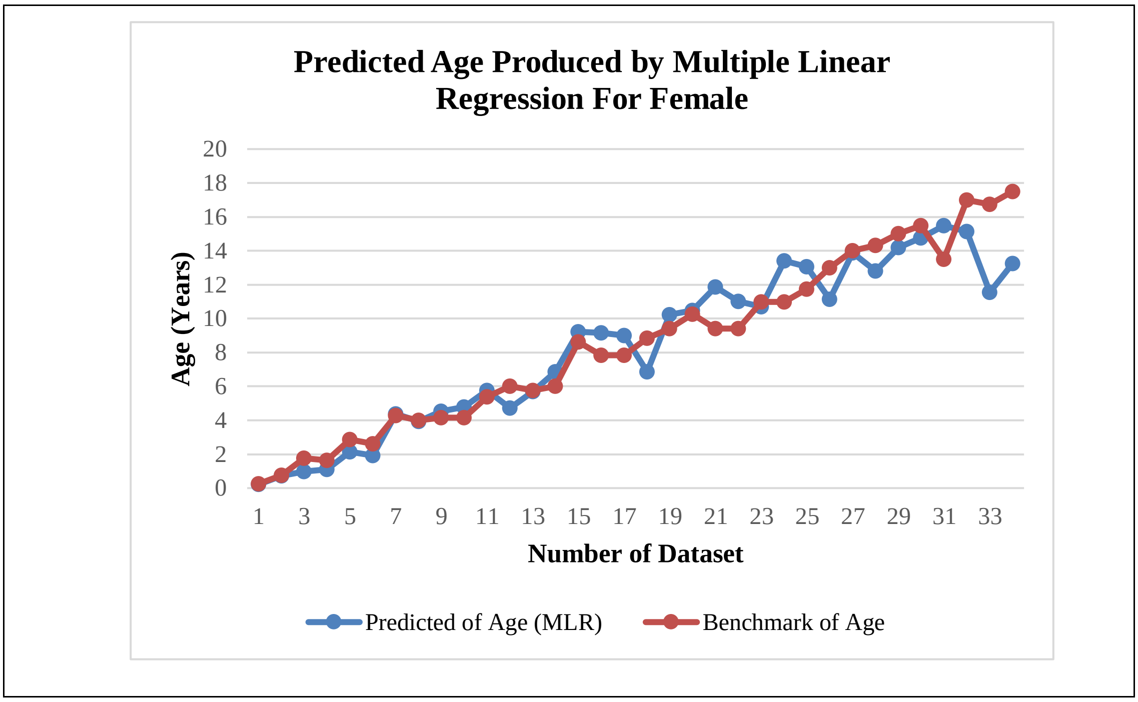


Figure 4.2 Predicted Age for Female using Multiple Linear Regression

From the above result, it can conclude that the result of age estimation by using the traditional method which is multiple linear regression is obtained slightly different range with the actual age. For male, at the age of 16 years old and for female at the age of 15 years old there are no big difference the length of hand bones growth. This will difficult to recognize the difference of length left hand bone for each gender.

For validation purpose in the end of this study, the predicted age produced by these radiologists using the GP model will be used as benchmark for the study for age estimation. It shows the result by GP model is better compared by method of MLR. However, weakness by using GP model is the estimation of age is based on qualitative data which is based on the observation of bone morphology from a radiograph of input by the forensic anthropology. The result of age estimation is different because it based on the experience and expertise of the forensic anthropology for an observation on the bone morphology.

4.5 Summary

In this study of age estimation, the multiple linear regression is a model that based on quantitative data of hand bone. From on the literature review in Chapter 3, the case studies that used the method of multiple linear regression shown that the measurement of bone is significant to be used for estimating age. However, the analysis of graphs in the previous section shows that the use of this method is inappropriate result because the data used more to non-linear data pattern. In recent research in field of ANN proved more powerful in prediction capabilities especially involving the non-linear data pattern. Therefore, the ANN is chosen as proposed model that will overcome the nonlinear data pattern problem. Using ANN also can measure the reliability and capability in obtaining the accurate estimating age result.

Based on the analysis of result obtained by multiple linear regression, it shows that large error on the MSE value and the line pattern of the age estimation graph for both gender models seemed to deviate with the actual age. The results produced is supported by several previous studies which is conclude that the accuracy of age estimation based on bone as the input have the limitation of estimation. The estimation by using hand bone can be apply for subject below about 16 years old for male and below about 15 years old for female. The vary result produced for age that above from 16 years and 15 years for male and female respectively due to the length of bone is not varies anymore so difficult to measure the differences of the length bone.

CHAPTER 5

AGE ESTIMATION USING ARTIFICIAL NEURAL NETWORK

5.1 Introduction

In this chapter, it will discuss more details about the implementation of Artificial Neural Network (ANN) methodology based on the design of algorithm. The target of this chapter is to achieve of the objective of this research. The backpropagation is used to train the data during the implementation. Lastly, testing is conducted for validating and verifying the output of the method and the algorithm that have been proposed in Chapter 3.7. The output of training and testing that obtained based on the method of ANN will be discuss on this chapter in details to support the objective of this research.

5.2 Implementation

The methodology for the implementation is stated as bellow:

I. Data normalization of left-hand bone
II. Design of the neural network model
III. Data training using back propagation algorithm

5.2.1 Left Hand Bones of Data Normalization

This dataset of length of left-hand bone is normalized by using the formula as stated in Chapter 3. Each value of dataset is normalized in the range between 0 to 1 as it is for the sigmoid activation function. All the nineteen left hand bone is measured and normalized by using Microsoft Excel Office 365.

5.2.2 Design of Hidden Neural Network Layer

Before starting the training process, a multilayer feedforward network needs to be created. In this research study there are 4 models of neural network are designed which are 19-39-1, 19-38-1, 19-18-1, 19-9.5-1 for male and female respectively. The number of nodes in hidden layer is chosen as recommended by Zhang et al. (1998) and Zain et al. (2010) as stated in Chapter 3. Based on the design model, the first layer is for the input nodes while for the second layer is for the hidden nodes and last is for the output. The output layer is to calculate the error and back propagate into the network in order to adjust the weight.

5.2.3 Data Training Using Back-Propagation Algorithm

The ANN model is trained suing 70% from the normalized dataset. The Java Encog Workbench 3.3.0 is used to train the neural network model to get the best weight for each model. Before starting the training process, the network learning rate and momentum is adjusted for each model where the model is set up with 0.01 learning rate and 0.1 momentum. Setting up the adjustment is to make sure the process is working faster and can obtain the output of estimation result in a short time for each model.

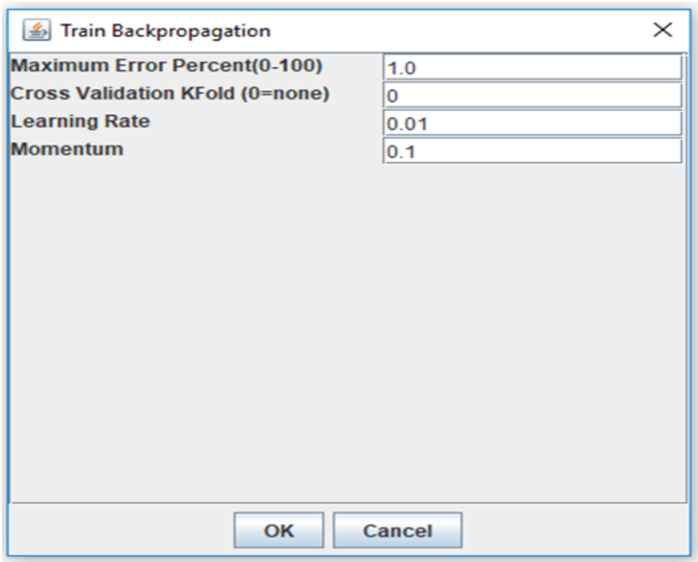


Figure 5.1 Adjusting Learning Rate and Momentum

For the iteration process, the maximum error percentage is set to 1.0 where the training will stop the iteration when the error is less 1 percent as shown in Figure 5.2.

This same training process is implemented on 16 different models that consist of different number of hidden layers. During the training process, the number of the neurons in hidden layer, the momentum and the learning rate is adjusting in order to obtain an accurate result.

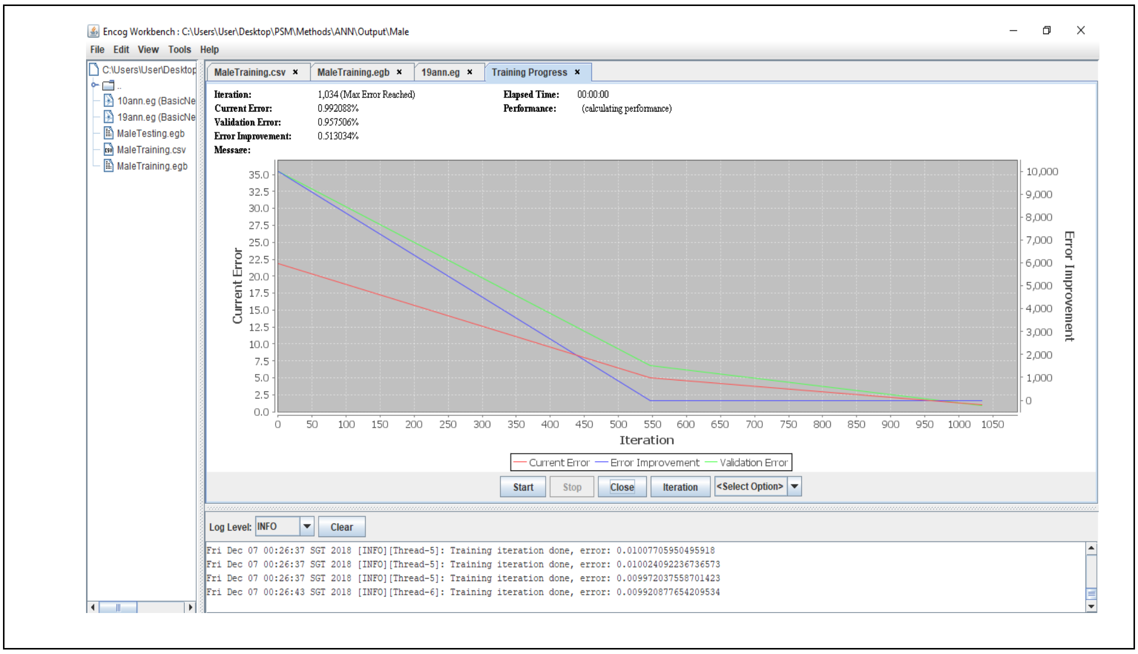


Figure 5.2 Iteration Process (Stopped when the current error is less 1%)

5.3 Testing and Verification

The testing and verification of the neural network need to be done to validate the model in order to determine the accuracy and efficiency of each modelling. In this research area for validation is by using Mean Square Error (MSE) and Root Mean Square (RMSE). Thus, 30% of the normalized left-hand bones dataset is used for testing.

The mean square error is used to calculate the mean and average for the error square while the network is being trained. It can determine the difference between the actual data that produced during the training and the expected data that has been set. The differences between the outputs are caused by the randomness of the back-propagation modelling and training. It is also to measure the fitness of the data. The smaller the MSE, the closer to find the line of best fit.

In this research, the MSE of each NN model will be shown in graph based on the network model that have been tested. The calculation of MSE for training process includes the total error of every error in 172 and 181 sample dataset and divided by their data sets for male and female respectively. For the testing process, it includes the total of every error sample dataset which are 36 and 34 sample dataset and divided by their data set for male and female respectively. The square error is produced by subtracting the actual output (ŷi) and the target output value (yi). Then, SSE is calculated where it will sum up the square error values.

Equation 5.1 shows the formula of MSE for the error in each training process of the neural network dataset process.

$$MSE\ = \frac{1}{n}\sum_{i=1}^{n}(\hat{y}i -\ yi))\ ^2$$

Equation 5.1 MSE for training dataset

Equation 5.2 show the formula of MSE for the error in each of testing process in Neural Network dataset process.

$$MSE\ = \frac{1}{n}\sum_{k=1}^{n}(\hat{y}i -\ yi))\ ^2$$

Equation 5.2 MSE for testing dataset

After calculating the value of MSE, the error is validate using the RMSE which is square root of men error that calculate the difference sample and population value. RMSE is used due to better measure of goodness of fit for accuracy instead of correlation coefficient. All the calculation of the MSE and RMSE of each Neural Network model is calculated by using Microsoft Excel 365. The formula for MSE is shown in Equation 5.3.

$$RMSE = \sqrt{MSE}$$

Equation 5.3 RMSE formula

5.4 Result Discussion

As for the result, the design of each the model will be calculated the result by performed measurement the MSE. Each of model is consist of variety number of hidden layer network as mention in earlier. The lowest value of MSE will be chosen as the best result produced by ANN for this population. Besides, the best of result estimation of ANN is compared with the benchmark of age and multiple linear regression models. Thus, it shows the better techniques to be used in future for estimating of age.

5.4.1 MSE and RMSE Value for Testing and Training Dataset

As mentioned earlier, 80% of the dataset of length of left-hand bones is used for training while 20% of the dataset is used for testing purpose of validation. Therefore, by using back propagation algorithm on 19-39-1, 19-38-1, 19-18-1, 19-9.5-1 for male and female respectively the value of MSE and RMSE is obtained.

I. MSE Value for 19-39-1 Model

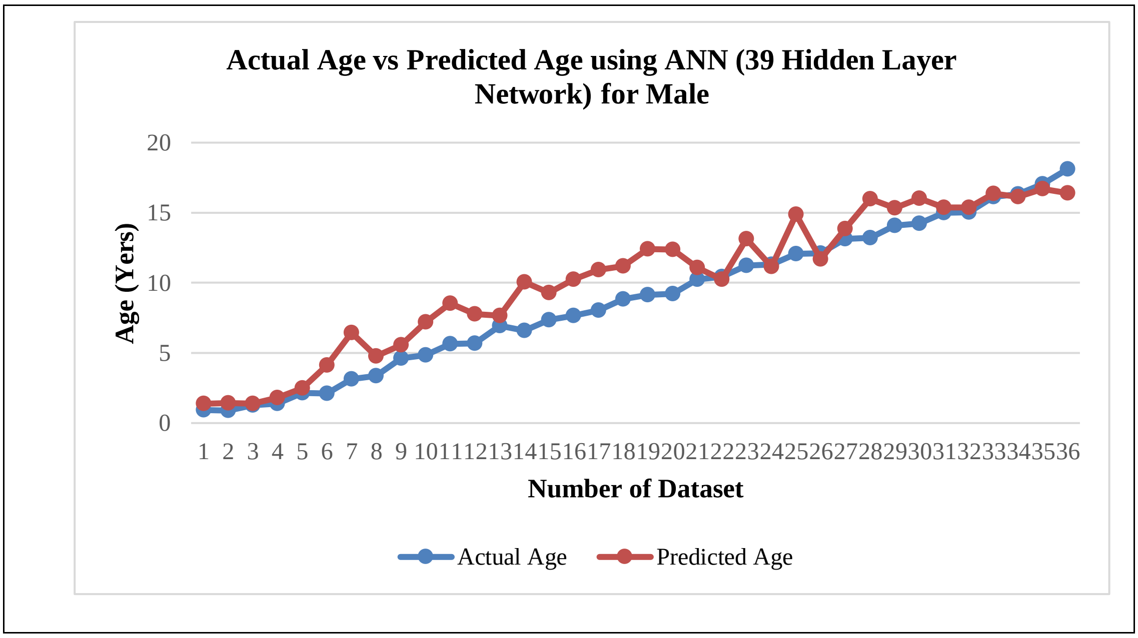


Figure 5.3 Predicted age using Artificial Neural Network for male

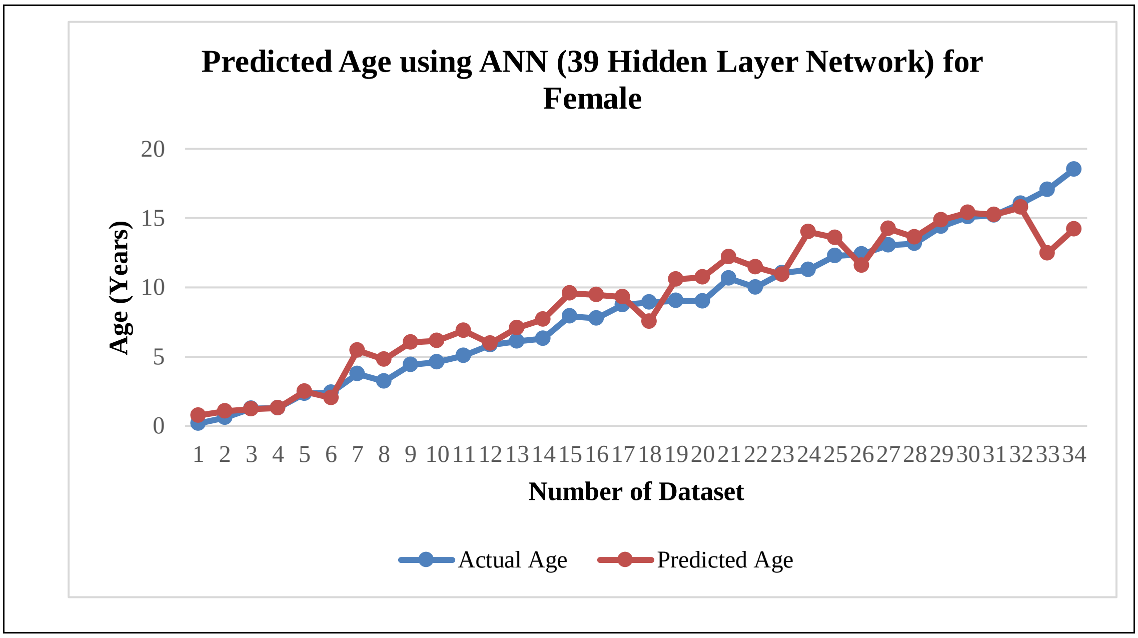


Figure 5.4 Predicted age using Artificial Neural Network for female

II. MSE Value for 19-38-1 Model

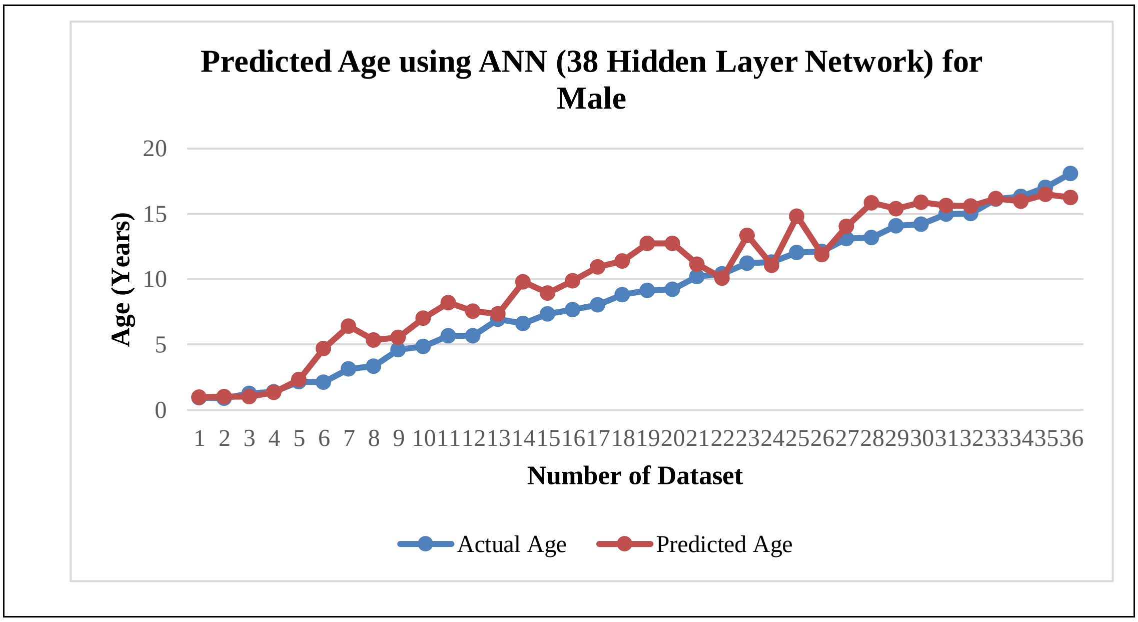


Figure 5.5 Predicted age using Artificial Neural Network for male

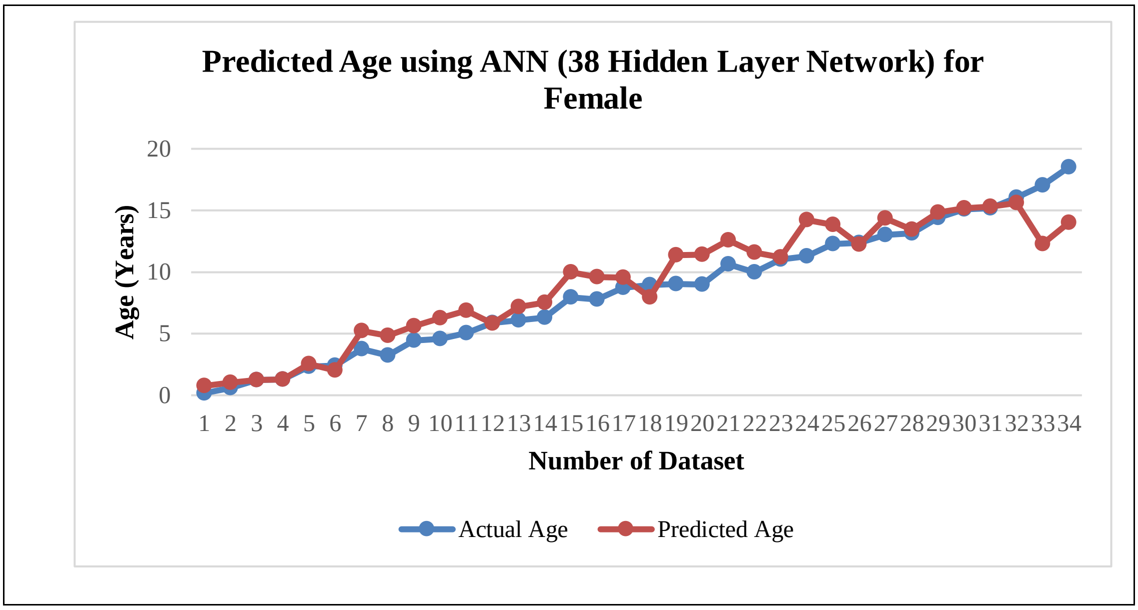


Figure 5.6 Predicted age using Artificial Neural Network for female

III. MSE Value for 19-19-1 Model

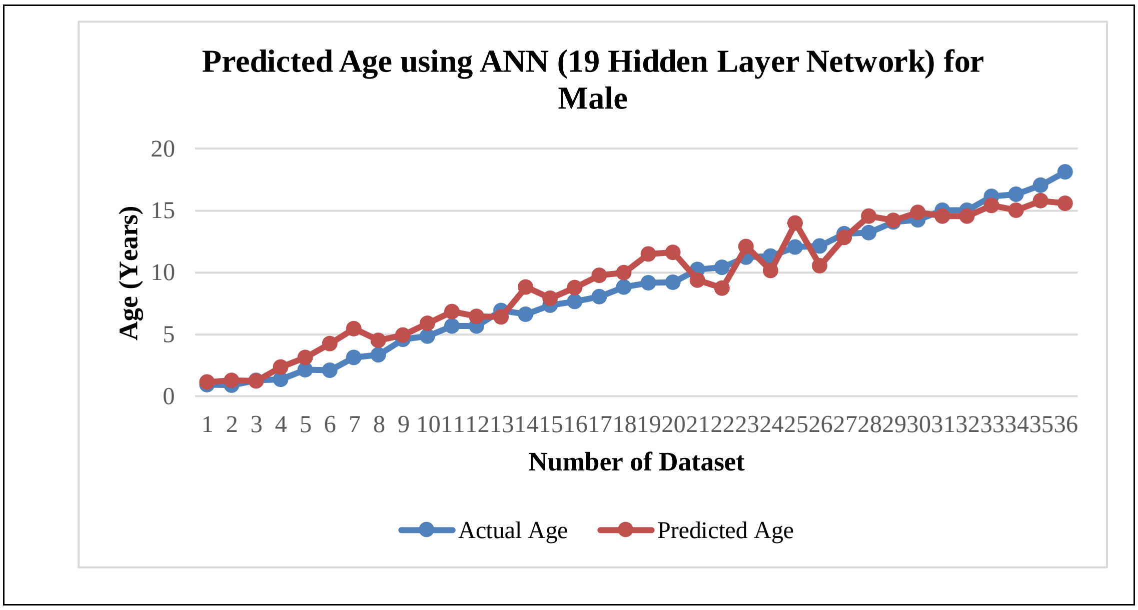


Figure 5.7 Predicted age using Artificial Neural Network for male

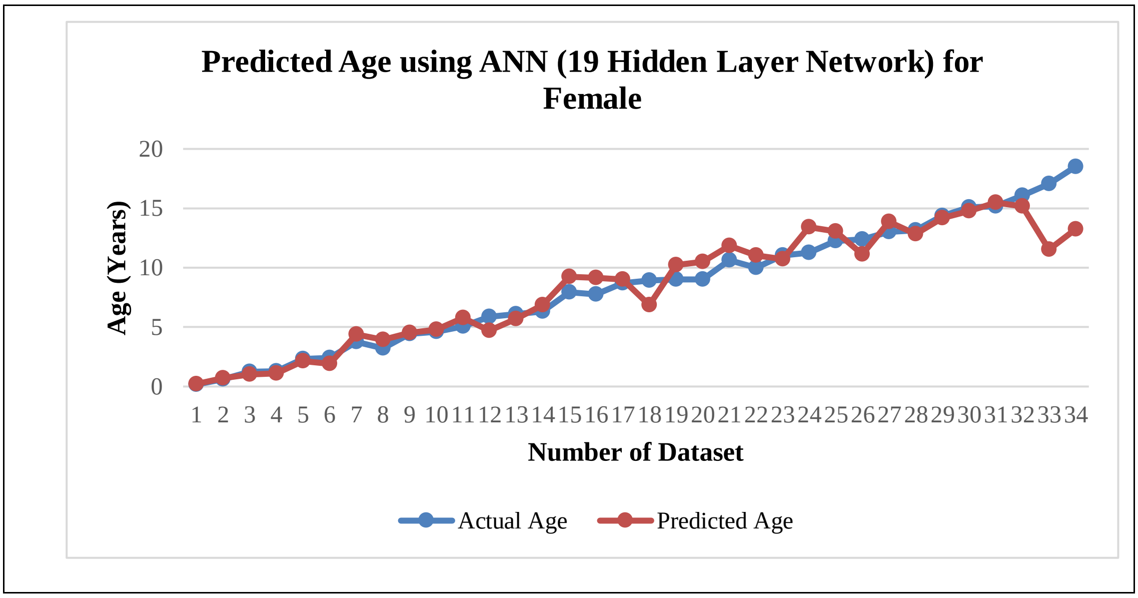


Figure 5.8 Predicted age using Artificial Neural Network for female

IV. MSE Value for 19-10-1 Model

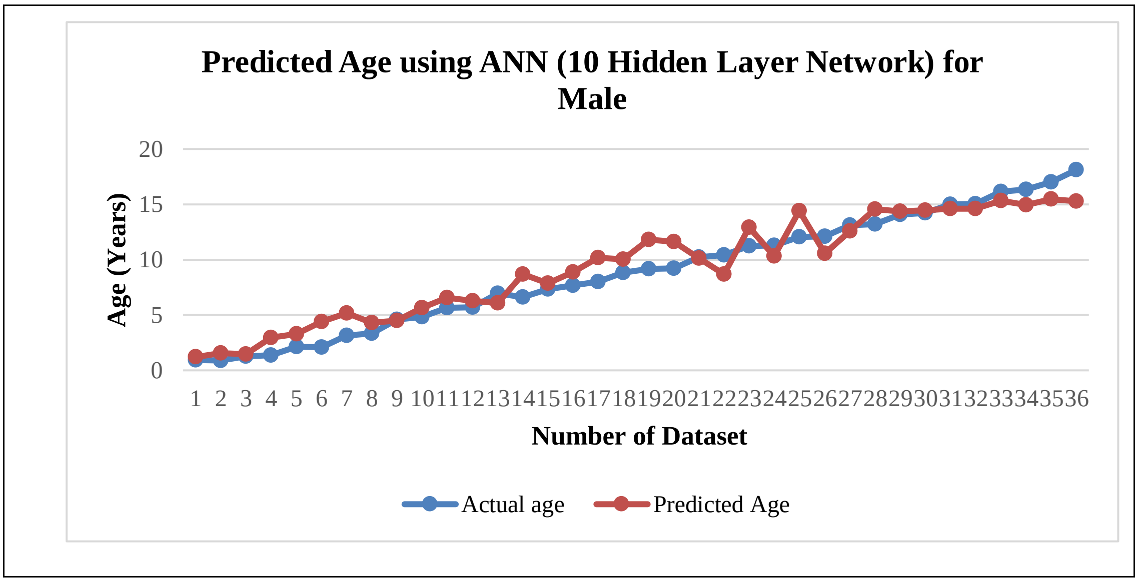


Figure 5.9 Predicted age using Artificial Neural Network for male

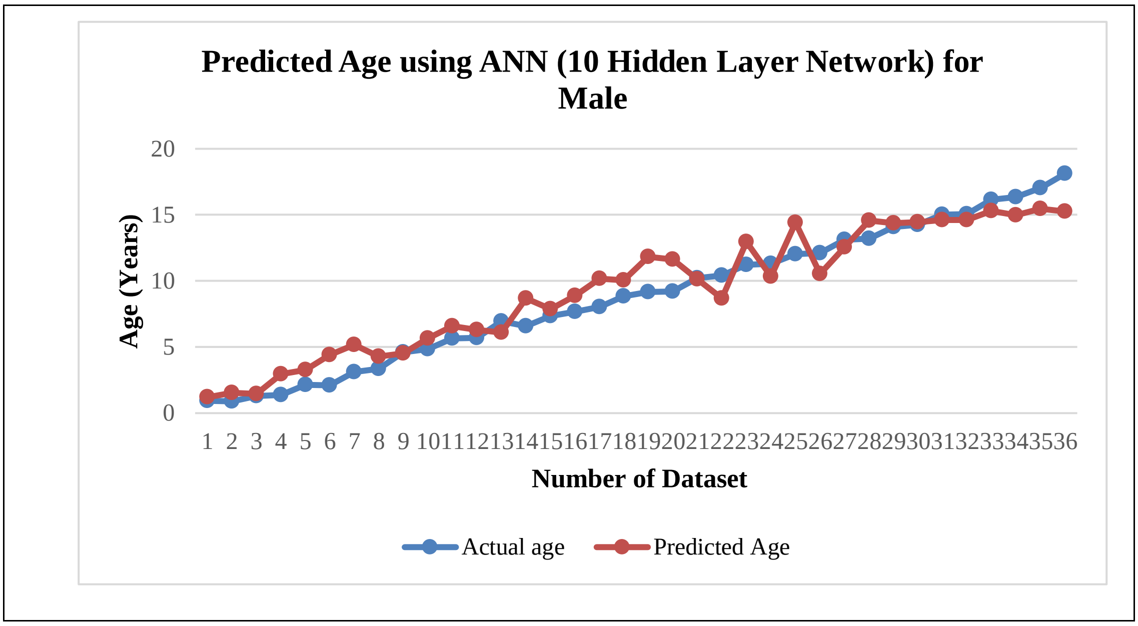


Figure 5.10 Predicted age using Artificial Neural Network for female

Table 5.1 MSE and RMSE of ANN model for male and female

Models	MSE		RMSE	
	Male	Female	Male	Female
19-39-1	3.428	2.548	1.851	1.596
19-38-1	3.485	2.916	1.867	1.708
19-19-1	1.775	2.487	1.332	1.577
19-10-1	2.033	2.779	1.426	1.667

Based on the result obtained above, it can be concluded that different models produced different value of MSE and RMSE. The best model of ANN is 19-19-1 model which is consist of 19 hidden layers for this population. Both for male and female show the smaller value of MSE which are 1.775 and 2.487 while RMSE are 1.332 and 1.577 respectively for male and female. The smaller values for MSE and RMSE indicate closer agreement between predicted and observed results, and an MSE of 0.0 indicates perfect agreement.

Instead of the other models, for male and female the number of the MSE and RMSE shows a big number. Thus, 19-19-1 model is chosen as the best of ANN model for estimating the age in this population.

5.4.2 Result of Age Estimation by ANN model

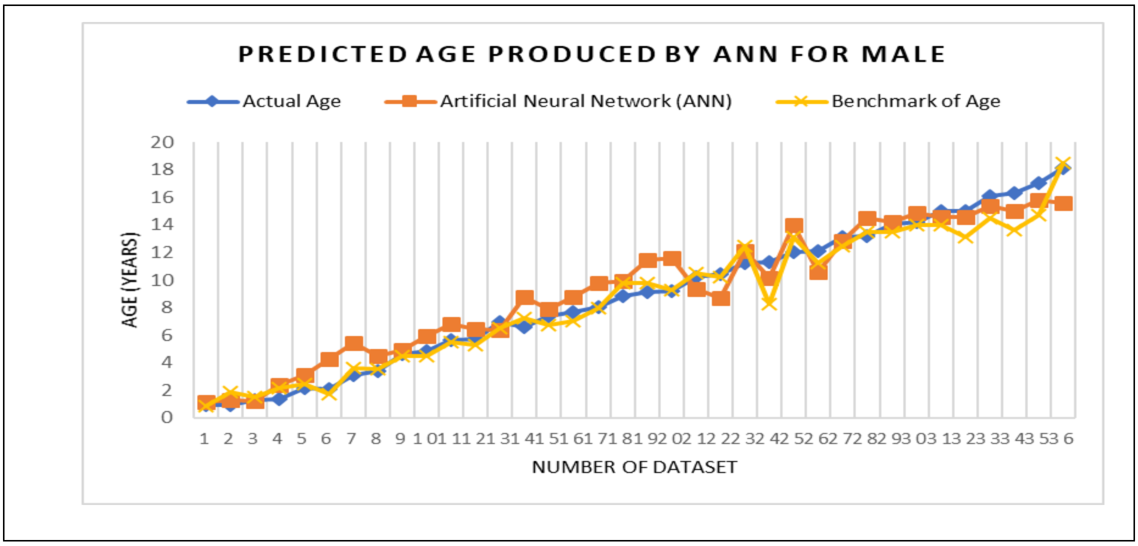


Figure 5.11 Predicted age produced by ANN model for male

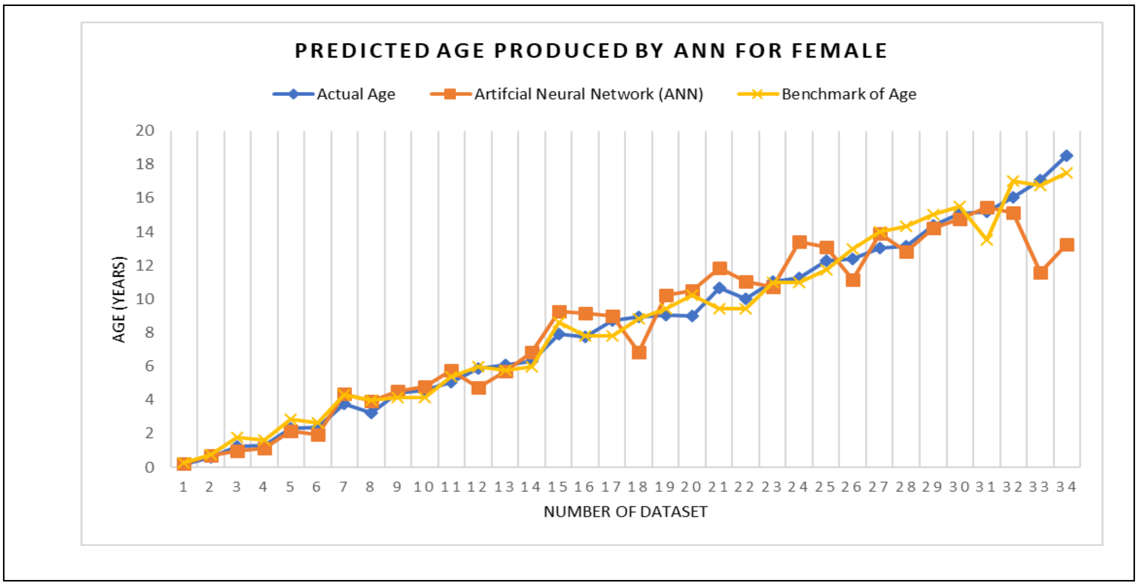


Figure 5.12 Predicted age produced by ANN model for female

Based on the result obtained above, benchmark of age produced better result instead of ANN model where the result of benchmark of age is closer to actual age compared ANN model. From the result above for each model, it clearly shows that the age above 15 years old and 16 years old for male and female respectively have obtained vary result from the actual age. During adulthood which is above 18 years old the precision of most morphological techniques is below par. This can affect to the accuracy of ANN model for age estimation.

5.5 Summary

As a summary the Chapter 6, it can be concluded that the accuracy of dataset is vary when the age is reaching 16 years old for male and 15 years old for female. It is due to no more rapid growth of left-hand bone that can produced the affect the accuracy of results. Thus, the model of 19-19-1 is chosen as the best model based on the performance of measurement the MSE and RMSE that shows a small value result. In the next chapter will discussed about the validation and evaluation of all the method that have been used in this research study in detail.

CHAPTER 6

VALIDATION AND EVALUATION

6.1 Introduction

In this chapter will explained with details all the techniques used in estimating of age such as using multiple linear regression and artificial neural network (ANN). All the result produced for male and female will be comparing to see the closer result with the benchmark and actual of age.

6.2 Result Analysis

As the analysis of result, accuracy of age can be measured using the MSE and RMSE value. The MSE is most common used by many researchers as stated in Table 1.1 in Chapter 2. Besides, RMSE is good measuring for fitness and produced better accuracy rather than coefficient correlation.

6.2.1 Validation of Age Estimation Results

For the validation purposed of estimation age is including the results obtained from the benchmark model, the artificial neural network (ANN) and the multiple linear regression for both male and female.

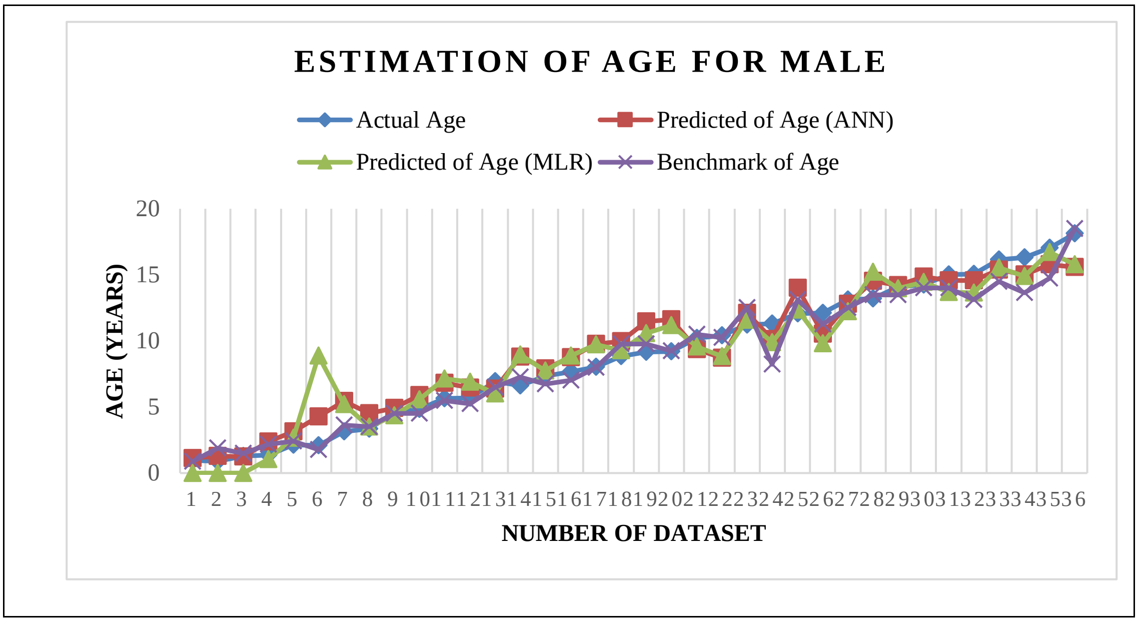


Figure 6.1 The estimation of age for male

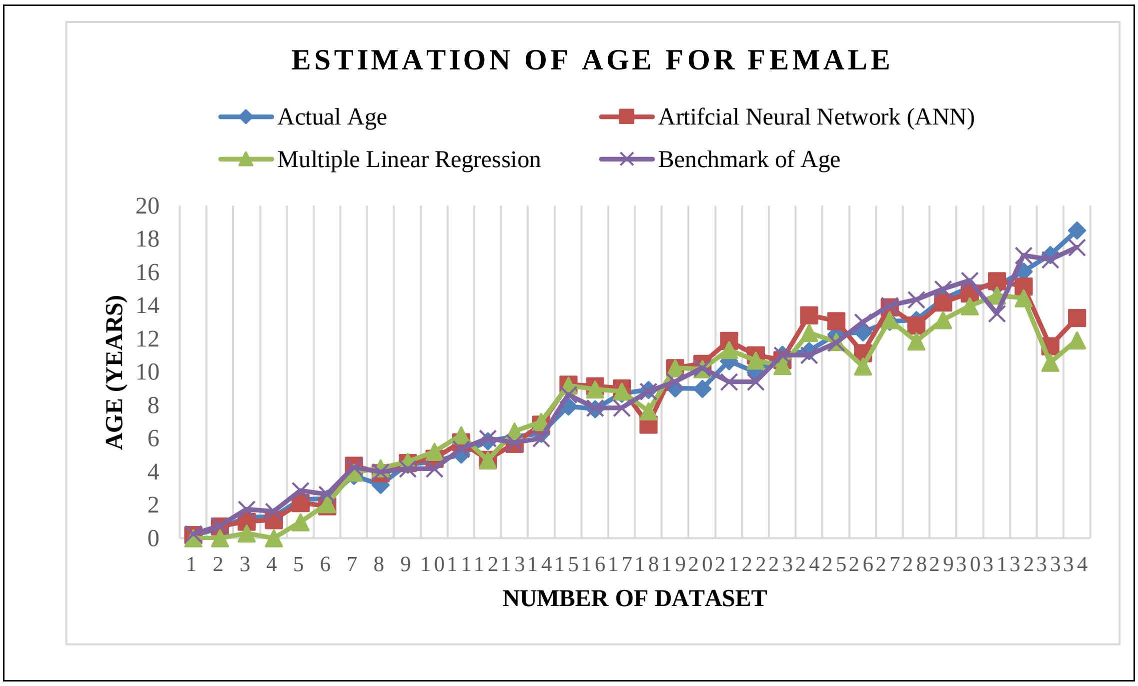


Figure 6.2 The estimation of age for female

Below is the value of MSE and RMSE of the models for male and female:

Table 6.1: MSE and RMSE value

	MSE		RMSE	
	Male	Female	Male	Female
Benchmark of Age	1.080	0.456	1.039	0.675
Multiple linear regression	2.939	3.996	1.714	1.999
Artificial Neural Network	1.775	2.487	1.332	1.577

For the validation, the age estimation method is validating to identify the best approach of estimation that the result is the closer to actual age and to better from the benchmark of age that using the GP model.

As the result obtained, the age estimation of ANN model is the suitable used for age estimation for this population instead of multiple linear regression where it can produce more accurate result. As can see in the graph above in Figure 6.1 and Figure 6.2 the ANN model result is closer to the actual and the benchmark's result.

Based the above graph, it can conclude that the data shows a far result from actual when the age is reaching 16 and 15 years old and above for male and female respectively. There is no rapidly growth of length have bone when reaching the age.

6.2.2 Evaluation of Age Estimation Results

For the evaluation purposed of estimation age is including the results obtained from the artificial neural network (ANN) and the multiple linear regression for both male and female.

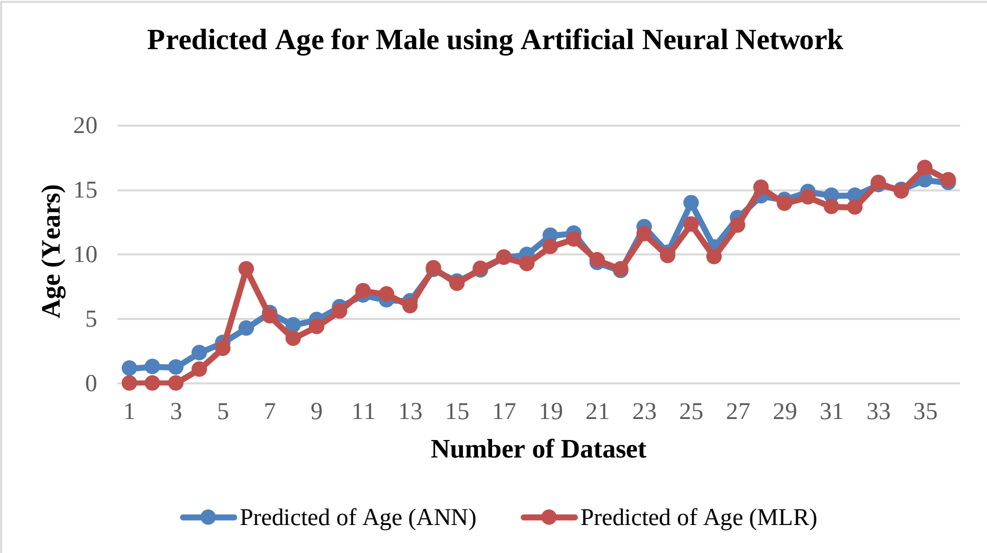


Figure 6.3 Age estimation using ANN and multiple linear regression for male

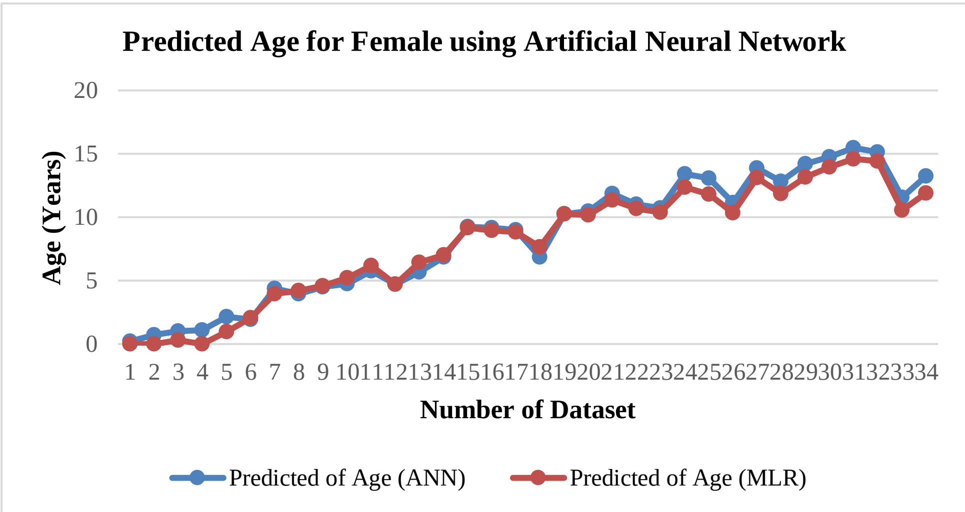


Figure 6.4 Age estimation using ANN and multiple linear regression for female

Based on the result in Table 6.1, ANN model has shown the smaller value of MSE and RMSE for male and female. In Figure 6.3, multiple linear regression model shows an extreme result at the age of 9 years old while ANN model is produced the optimum result for both genders. The smaller the value of MSE and RMSE indicates the result produced is better and close to the approximate actual age result.

The result obtained in Figure 6.3 and Figure 6.4 shows the ANN model produced better result compared to multiple linear regression model. The value of MSE and RMSE in ANN model is small value instead of multiple linear regression's result. ANN results are close to benchmark and actual age. As stated previously in literature review, multiple linear regression is based on the observation of expertise in the field of anthropology forensic which are from different background of experience in estimation. It will be produced different result based on their expertise in observing the bones. Thus, ANN model is helpful so that the dependency of the expert in estimating the age can be reduced or avoided.

6.3 Summary

In this chapter is stress on the method of validation and evaluation for the models. The validation of result shows that the benchmark age has better result of age estimation instead of ANN model. One of the reasons is, the limitation of input which is left hand bond that limit to the age above 15 and 16 years old for male and female respectively where the growth of hand bone is limited. This will affect the accuracy result of ANN model.

The evaluation for the model is involved the results obtained from ANN model and multiple linear regression. The evaluation is based on the performance measurement of MSE and RMSE value on each of model. The small the value produced more accurate results.

CHAPTER 7

CONCLUSION

7.1 Introduction

The purpose of this chapter is to summarize all the content of the research and including the constraint together with the future work of this research

There are many of artificial intelligence techniques that can be used for estimating age such as fuzzy logic, genetic algorithm and artificial neural network. for this research, artificial neural network is used for estimating the age of African American's children. The goal for this research is to study on the application of the neural network and multiple linear regression model in estimating age and to choose the most effective and accurate results from the design of neural network that have been proposed in previous chapter.

In the literature review, it has been discussed more details about the concept of ANN. There also stated several comparisons based on the type used of approach in estimating age.

The difference techniques have been discussed based on the output of execution in predicting the age. Overall, NN techniques is chosen in this area of research and the reason for chosen this technique already justified in Chapter 3. For this research, the implementation starts by designed the structure of the ANN where consist of four models which are 19-39-1, 19-38-1, 19-19-1, 19-10-1 for male and female respectively. Each of models are trained and tested by using the dataset provided.

As a conclusion, this research has achieved the entire objective of this research for solving the problems in estimating of age. Using ANN can help the anthropology getting better result of estimating. Onwards, there is no need to make prediction based on their observation that has many weaknesses. Therefore, ANN it is used to help in improvement of estimation age in this population.

7.2 Research Constrain

The constraint while conducting this research project are:

I. Manually measuring the input datasets may cause error to obtain the accurate result of prediction age.

II. The limitation of age above 16 years old and 15 years old for male and female respectively affect the accuracy of prediction age.

7.3 Future Work

In future work, the dataset for training and testing must be clear to get more accuracy the length of each of left-hand bone. Especially, each length of end bones is difficult to identify and measure their length. Besides, each of population is unique so the hidden layer is not same for each population. In this field of studies shows that 19 hidden network layers is the best used for this case. For getting the better result, the number of age measurement must be reduced where for male start from new born to 16 years old while for female start with newborn until 15 years old only. It is because above the number of age mention previously do not showing rapid growth of length hand bone anymore. Thus, the method of estimation for neural network can be enhanced by reducing the age for both genders to avoid from disturbing the accuracy of results as supported in literature review in Chapter 3.

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APPENDIX A
NORMALIZED DATA

Table 7.1 The sample of normalized data for female

Actual Age	Age	Metacarpal	Proximal Phala	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phalan
0.64	0.03	0.198	0.151	0.038	0.089	0.113	0.095	0.062	0.074	0.107	0.062	0.057	0.093	0.174	0.103	0.065	0.116	0.296	0.097	0.108
0.68	0.03	0.226	0.160	0.195	0.148	0.183	0.177	0.167	0.146	0.158	0.096	0.147	0.146	0.207	0.150	0.158	0.153	0.157	0.148	0.102
1.37	0.06	0.278	0.238	0.238	0.204	0.259	0.264	0.179	0.200	0.288	0.230	0.136	0.222	0.321	0.293	0.165	0.206	0.229	0.209	0.193
1.60	0.08	0.000	0.141	0.174	0.171	0.205	0.151	0.179	0.203	0.211	0.141	0.147	0.220	0.000	0.194	0.206	0.000	0.208	0.137	0.136
1.14	0.05	0.242	0.169	0.191	0.153	0.243	0.216	0.179	0.156	0.216	0.203	0.192	0.148	0.282	0.286	0.206	0.168	0.217	0.230	0.228
2.50	0.13	0.384	0.235	0.209	0.255	0.275	0.199	0.247	0.276	0.251	0.189	0.204	0.285	0.298	0.227	0.212	0.284	0.255	0.214	0.256
2.69	0.14	0.358	0.251	0.251	0.284	0.302	0.286	0.284	0.287	0.292	0.227	0.305	0.279	0.321	0.264	0.329	0.304	0.252	0.214	0.318
2.63	0.13	0.310	0.213	0.289	0.275	0.309	0.221	0.198	0.274	0.306	0.215	0.277	0.296	0.353	0.271	0.300	0.287	0.327	0.199	0.256
3.79	0.19	0.372	0.273	0.255	0.329	0.304	0.256	0.290	0.349	0.306	0.209	0.266	0.338	0.323	0.253	0.324	0.319	0.255	0.194	0.341
3.99	0.21	0.274	0.307	0.251	0.209	0.296	0.272	0.235	0.192	0.271	0.221	0.232	0.170	0.328	0.275	0.300	0.194	0.277	0.271	0.267
3.70	0.19	0.452	0.329	0.307	0.363	0.399	0.337	0.370	0.377	0.388	0.282	0.333	0.398	0.434	0.352	0.346	0.403	0.403	0.373	0.307
4.77	0.25	0.532	0.423	0.434	0.479	0.523	0.459	0.432	0.506	0.522	0.372	0.390	0.503	0.523	0.469	0.518	0.481	0.242	0.424	0.420
4.02	0.21	0.500	0.379	0.340	0.406	0.434	0.407	0.389	0.445	0.418	0.336	0.385	0.416	0.473	0.414	0.388	0.420	0.399	0.418	0.415
4.38	0.23	0.380	0.285	0.319	0.332	0.350	0.316	0.370	0.352	0.337	0.286	0.362	0.336	0.378	0.326	0.423	0.332	0.315	0.240	0.296
5.98	0.31	0.482	0.361	0.383	0.398	0.426	0.394	0.377	0.421	0.406	0.354	0.367	0.403	0.439	0.432	0.418	0.400	0.377	0.373	0.353
5.17	0.27	0.506	0.342	0.383	0.414	0.436	0.355	0.450	0.441	0.422	0.321	0.390	0.432	0.461	0.417	0.465	0.405	0.405	0.367	0.489
5.99	0.31	0.560	0.433	0.391	0.487	0.534	0.476	0.457	0.512	0.501	0.386	0.401	0.543	0.521	0.447	0.447	0.503	0.478	0.398	0.381
5.32	0.28	0.528	0.382	0.374	0.460	0.488	0.355	0.364	0.482	0.446	0.304	0.333	0.470	0.484	0.370	0.353	0.461	0.453	0.393	0.375
5.33	0.28	0.538	0.395	0.391	0.431	0.415	0.368	0.395	0.475	0.418	0.295	0.367	0.490	0.461	0.359	0.370	0.442	0.384	0.255	0.404
5.01	0.26	0.460	0.329	0.272	0.401	0.429	0.372	0.358	0.411	0.413	0.277	0.305	0.429	0.441	0.330	0.318	0.398	0.396	0.306	0.358
5.47	0.29	0.480	0.329	0.307	0.426	0.442	0.377	0.370	0.446	0.413	0.330	0.379	0.438	0.425	0.381	0.412	0.379	0.374	0.214	0.369
6.42	0.34	0.600	0.467	0.476	0.524	0.512	0.472	0.457	0.551	0.513	0.378	0.418	0.564	0.532	0.458	0.477	0.532	0.465	0.408	0.392
6.58	0.34	0.524	0.417	0.374	0.460	0.485	0.355	0.420	0.490	0.469	0.312	0.407	0.499	0.493	0.414	0.412	0.481	0.459	0.398	0.443
6.96	0.37	0.552	0.414	0.442	0.470	0.485	0.459	0.445	0.485	0.455	0.351	0.396	0.497	0.491	0.425	0.406	0.461	0.462	0.433	0.461
6.14	0.32	0.566	0.455	0.459	0.505	0.566	0.546	0.438	0.516	0.548	0.457	0.441	0.512	0.539	0.487	0.429	0.512	0.494	0.459	0.381
6.98	0.37	0.592	0.454	0.430	0.490	0.504	0.459	0.537	0.523	0.511	0.407	0.491	0.530	0.530	0.494	0.541	0.525	0.491	0.500	0.455
6.67	0.35	0.484	0.404	0.349	0.422	0.436	0.368	0.352	0.454	0.420	0.304	0.350	0.438	0.457	0.355	0.395	0.409	0.393	0.311	0.302
7.82	0.41	0.622	0.486	0.481	0.537	0.539	0.449	0.488	0.610	0.543	0.460	0.486	0.593	0.595	0.535	0.582	0.584	0.494	0.454	0.512
7.23	0.38	0.534	0.404	0.498	0.462	0.477	0.481	0.543	0.479	0.452	0.348	0.458	0.479	0.489	0.443	0.547	0.446	0.434	0.424	0.478

Table 7.2 The sample of normalized data for male

Actual Age	Age	Metacarpal	Proximal Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala
0.28	0.00	0.000	0.000	0.038	0.000	0.000	0.035	0.136	0.126	0.000	0.008	0.042	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.060
0.64	0.02	0.070	0.018	0.000	0.050	0.044	0.025	0.095	0.161	0.013	0.000	0.006	0.052	0.041	0.033	0.041	0.042	0.056	0.017	0.000
0.81	0.03	0.065	0.014	0.043	0.080	0.078	0.005	0.107	0.170	0.073	0.034	0.055	0.045	0.082	0.069	0.041	0.017	0.043	0.022	0.044
1.71	0.08	0.132	0.145	0.153	0.134	0.150	0.143	0.136	0.231	0.119	0.088	0.109	0.125	0.139	0.089	0.047	0.131	0.146	0.125	0.022
1.54	0.07	0.122	0.096	0.096	0.129	0.117	0.045	0.000	0.228	0.106	0.027	0.055	0.127	0.145	0.522	0.000	0.125	0.130	0.103	0.000
1.07	0.04	0.084	0.053	0.129	0.086	0.075	0.000	0.089	0.201	0.076	0.027	0.061	0.074	0.153	0.049	0.052	0.073	0.106	0.065	0.060
2.74	0.13	0.168	0.131	0.240	0.227	0.197	0.138	0.136	0.314	0.218	0.142	0.189	0.181	0.232	0.170	0.163	0.187	0.226	0.131	0.103
2.79	0.14	0.156	0.187	0.225	0.190	0.195	0.158	0.278	0.266	0.185	0.142	0.225	0.140	0.210	0.130	0.203	0.146	0.226	0.202	0.157
2.96	0.14	0.185	0.134	0.115	0.196	0.234	0.197	0.172	0.276	0.240	0.165	0.153	0.156	0.262	0.198	0.163	0.136	0.203	0.125	0.038
3.4	0.17	0.278	0.226	0.320	0.295	0.295	0.330	0.326	0.375	0.296	0.291	0.262	0.235	0.306	0.267	0.245	0.231	0.303	0.277	0.233
3.6	0.18	0.338	0.255	0.306	0.286	0.278	0.271	0.349	0.392	0.291	0.245	0.281	0.273	0.306	0.283	0.297	0.263	0.317	0.299	0.293
3.22	0.16	0.285	0.216	0.287	0.270	0.265	0.696	0.308	0.370	0.271	0.249	0.287	0.250	0.287	0.263	0.233	0.236	0.270	0.245	0.217
4.93	0.25	0.391	0.262	0.383	0.396	0.293	0.276	0.420	0.494	0.342	0.253	0.353	0.384	0.374	0.292	0.303	0.369	0.373	0.288	0.299
4.99	0.25	0.329	0.276	0.306	0.289	0.295	0.271	0.391	0.401	0.311	0.284	0.317	0.286	0.314	0.267	0.302	0.248	0.303	0.234	0.277
4.07	0.20	0.230	0.156	0.192	0.276	0.281	0.266	0.219	0.375	0.276	0.238	0.207	0.243	0.300	0.251	0.313	0.207	0.280	0.234	0.163
5.77	0.30	0.516	0.488	0.517	0.493	0.529	0.591	0.497	0.589	0.560	0.510	0.408	0.504	0.557	0.534	0.419	0.486	0.530	0.603	0.352
5.94	0.31	0.460	0.424	0.483	0.483	0.451	0.449	0.503	0.550	0.430	0.364	0.475	0.475	0.478	0.393	0.413	0.456	0.476	0.429	0.401
5.99	0.31	0.463	0.421	0.464	0.498	0.443	0.468	0.532	0.580	0.461	0.391	0.360	0.484	0.500	0.401	0.413	0.458	0.503	0.462	0.391
5.68	0.29	0.391	0.325	0.479	0.426	0.409	0.419	0.426	0.491	0.403	0.360	0.402	0.377	0.426	0.377	0.372	0.325	0.403	0.386	0.347
5.53	0.28	0.391	0.336	0.364	0.384	0.384	0.409	0.397	0.464	0.387	0.376	0.348	0.359	0.404	0.377	0.320	0.369	0.393	0.359	0.331
5.06	0.26	0.439	0.364	0.402	0.400	0.407	0.458	0.420	0.530	0.403	0.399	0.348	0.418	0.418	0.389	0.407	0.417	0.363	0.343	0.347
5.39	0.28	0.357	0.346	0.440	0.375	0.365	0.399	0.474	0.470	0.395	0.368	0.445	0.384	0.402	0.372	0.453	0.365	0.400	0.397	0.374
6.61	0.34	0.492	0.414	0.388	0.496	0.457	0.473	0.462	0.581	0.491	0.467	0.323	0.475	0.508	0.449	0.401	0.473	0.493	0.370	0.331
6.66	0.34	0.549	0.428	0.426	0.509	0.465	0.385	0.432	0.598	0.471	0.383	0.415	0.473	0.489	0.352	0.366	0.460	0.456	0.250	0.282
6.82	0.35	0.556	0.438	0.473	0.480	0.471	0.443	0.491	0.581	0.473	0.371	0.402	0.464	0.486	0.360	0.401	0.428	0.480	0.365	0.369
6.49	0.34	0.516	0.488	0.512	0.514	0.513	0.517	0.532	0.578	0.468	0.456	0.457	0.484	0.497	0.478	0.424	0.450	0.513	0.500	0.391
6.9	0.36	0.480	0.421	0.450	0.477	0.474	0.424	0.432	0.572	0.443	0.425	0.415	0.467	0.489	0.389	0.396	0.438	0.470	0.413	0.341
7.2	0.37	0.600	0.505	0.627	0.539	0.521	0.527	0.597	0.622	0.580	0.510	0.567	0.516	0.587	0.494	0.506	0.303	0.517	0.533	0.429
7.35	0.38	0.513	0.460	0.464	0.482	0.451	0.399	0.574	0.583	0.481	0.383	0.475	0.471	0.481	0.409	0.488	0.446	0.463	0.397	0.445

APPENDIX B
TESTING AND TRAINING DATA

Table 7.3 The sample of testing data for female

Actual Age	Age	Metacarpa	Proximal I	Distal Pha	Metacarpa	Proximal I	Middle Ph	Distal Pha	Metacarpa	Proximal I	Middle Ph	Distal Pha	Metacarpa	Proximal I	Middle Ph	Distal Pha	Metacarpa	Proximal I	Middle Ph	Distal Pha
0.17	0.00	0.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.000	0.000	0.046	0.000	0.000	0.000
0.59	0.02	0.200	0.094	0.093	0.107	0.140	0.126	0.105	0.121	0.135	0.113	0.073	0.109	0.184	0.147	0.112	0.122	0.148	0.153	0.125
1.26	0.06	0.222	0.191	0.123	0.150	0.175	0.191	0.093	0.151	0.181	0.145	0.090	0.133	0.241	0.179	0.117	0.155	0.173	0.122	0.085
1.3	0.06	0.220	0.144	0.162	0.139	0.199	0.195	0.099	0.126	0.188	0.156	0.121	0.157	0.255	0.216	0.153	0.160	0.227	0.168	0.120
2.33	0.12	0.332	0.235	0.276	0.244	0.253	0.225	0.290	0.252	0.232	0.218	0.333	0.233	0.291	0.238	0.306	0.236	0.179	0.118	0.244
2.39	0.12	0.314	0.188	0.209	0.265	0.275	0.177	0.198	0.270	0.262	0.147	0.192	0.250	0.321	0.198	0.218	0.241	0.248	0.189	0.120
3.76	0.19	0.530	0.408	0.366	0.411	0.461	0.321	0.241	0.454	0.452	0.262	0.380	0.484	0.475	0.362	0.400	0.455	0.440	0.342	0.404
3.23	0.16	0.444	0.345	0.293	0.358	0.410	0.312	0.284	0.397	0.371	0.265	0.300	0.383	0.414	0.319	0.324	0.359	0.384	0.347	0.335
4.42	0.23	0.484	0.304	0.353	0.374	0.396	0.333	0.420	0.397	0.388	0.292	0.390	0.392	0.425	0.366	0.423	0.361	0.371	0.362	0.455
4.59	0.24	0.448	0.370	0.404	0.361	0.423	0.450	0.395	0.371	0.408	0.357	0.390	0.296	0.418	0.454	0.435	0.357	0.399	0.464	0.369
5.06	0.26	0.504	0.423	0.511	0.433	0.517	0.581	0.488	0.454	0.494	0.416	0.447	0.456	0.503	0.465	0.511	0.443	0.453	0.505	0.404
5.85	0.31	0.510	0.382	0.395	0.428	0.447	0.398	0.377	0.439	0.429	0.324	0.362	0.447	0.448	0.388	0.394	0.427	0.396	0.367	0.392
6.09	0.32	0.532	0.442	0.447	0.441	0.536	0.442	0.482	0.466	0.504	0.336	0.401	0.470	0.541	0.436	0.465	0.464	0.509	0.388	0.438
6.31	0.33	0.600	0.502	0.455	0.502	0.558	0.485	0.500	0.510	0.531	0.398	0.481	0.518	0.534	0.520	0.553	0.518	0.481	0.500	0.506
7.93	0.42	0.710	0.586	0.476	0.634	0.631	0.502	0.550	0.631	0.585	0.392	0.463	0.634	0.593	0.487	0.518	0.606	0.569	0.480	0.546
7.77	0.41	0.662	0.545	0.562	0.621	0.649	0.528	0.537	0.634	0.622	0.489	0.548	0.627	0.627	0.577	0.582	0.635	0.610	0.556	0.466
8.71	0.46	0.618	0.508	0.442	0.549	0.566	0.502	0.537	0.577	0.548	0.416	0.481	0.590	0.589	0.498	0.547	0.582	0.531	0.526	0.529
8.93	0.47	0.644	0.545	0.464	0.558	0.612	0.524	0.482	0.569	0.578	0.380	0.452	0.572	0.587	0.469	0.482	0.536	0.550	0.393	0.455
9.03	0.48	0.698	0.627	0.545	0.594	0.639	0.602	0.660	0.608	0.599	0.469	0.582	0.386	0.598	0.557	0.635	0.602	0.572	0.474	0.506
9	0.48	0.694	0.589	0.515	0.615	0.633	0.576	0.550	0.626	0.626	0.451	0.481	0.590	0.627	0.564	0.535	0.593	0.638	0.565	0.551
10.65	0.56	0.712	0.621	0.630	0.653	0.704	0.632	0.691	0.692	0.668	0.540	0.633	0.669	0.695	0.651	0.671	0.628	0.645	0.612	0.608
10	0.53	0.672	0.627	0.591	0.629	0.706	0.649	0.710	0.669	0.638	0.540	0.616	0.658	0.639	0.641	0.665	0.648	0.626	0.633	0.597
11.04	0.59	0.672	0.621	0.600	0.620	0.666	0.579	0.679	0.658	0.631	0.487	0.593	0.671	0.643	0.593	0.630	0.654	0.629	0.571	0.569
11.26	0.60	0.780	0.671	0.655	0.736	0.736	0.675	0.735	0.762	0.731	0.590	0.639	0.741	0.727	0.685	0.659	0.672	0.673	0.648	0.648
12.26	0.65	0.752	0.649	0.609	0.703	0.712	0.602	0.698	0.710	0.691	0.498	0.639	0.723	0.714	0.586	0.753	0.705	0.645	0.586	0.688
12.38	0.66	0.754	0.671	0.638	0.648	0.677	0.688	0.703	0.644	0.650	0.543	0.587	0.580	0.618	0.648	0.612	0.591	0.576	0.648	0.557
13.03	0.69	0.744	0.592	0.566	0.685	0.663	0.576	0.630	0.759	0.666	0.504	0.565	0.693	0.691	0.619	0.623	0.665	0.701	0.602	0.535
13.14	0.70	0.764	0.618	0.549	0.748	0.717	0.667	0.655	0.767	0.710	0.522	0.628	0.791	0.700	0.612	0.647	0.740	0.695	0.577	0.620
14.38	0.76	0.772	0.658	0.642	0.714	0.747	0.662	0.747	0.752	0.724	0.581	0.656	0.732	0.720	0.685	0.759	0.689	0.720	0.689	0.699

Table 7.4 The sample of testing data for male

Actual Age	Age	Metacarpa	Proximal	Distal Pha	Metacarpa	Proximal	Middle Ph	Distal Pha	Metacarpa	Proximal	Middle Ph	Distal Pha	Metacarpa	Proximal	Middle Ph	Distal Pha	Metacarpa	Proximal	Middle Ph	Distal Pha
0.950	0.00	0.012	0.014	0.043	0.045	0.050	0.069	0.077	0.177	0.043	0.054	0.000	0.034	0.071	0.069	0.023	0.023	0.073	0.076	0.005
0.890	0.03	0.043	0.032	0.072	0.072	0.056	0.035	0.119	0.171	0.083	0.027	0.037	0.067	0.085	0.029	0.047	0.057	0.080	0.028	0.065
1.280	0.05	0.070	0.039	0.062	0.083	0.086	0.035	0.148	0.000	0.089	0.038	0.042	0.031	0.112	0.053	0.070	0.027	0.067	0.028	0.048
1.380	0.06	0.080	0.071	0.105	0.105	0.114	0.138	0.166	0.201	0.094	0.107	0.122	0.067	0.128	0.118	0.122	0.075	0.120	0.142	0.103
2.150	0.10	0.144	0.124	0.144	0.133	0.150	0.183	0.184	0.240	0.144	0.153	0.183	0.114	0.167	0.340	0.104	0.109	0.163	0.092	0.119
2.100	0.10	0.139	0.145	0.129	0.214	0.187	0.173	0.189	0.308	0.200	0.176	0.866	0.167	0.213	0.207	0.110	0.132	0.200	0.185	0.114
3.130	0.15	0.372	0.315	0.335	0.384	0.334	0.296	0.355	0.458	0.342	0.291	0.281	0.362	0.369	0.300	0.291	0.334	0.353	0.332	0.244
3.360	0.17	0.221	0.230	0.292	0.308	0.330	0.168	0.302	0.395	0.319	0.195	0.244	0.270	0.358	0.227	0.238	0.256	0.337	0.272	0.233
4.600	0.23	0.297	0.258	0.287	0.343	0.278	0.271	0.314	0.449	0.283	0.206	0.232	0.348	0.306	0.259	0.221	0.302	0.313	0.398	0.206
4.840	0.25	0.360	0.357	0.389	0.407	0.396	0.345	0.391	0.494	0.420	0.360	0.341	0.370	0.448	0.385	0.372	0.321	0.393	0.381	0.282
5.660	0.29	0.451	0.336	0.483	0.475	0.398	0.399	0.432	0.571	0.428	0.406	0.439	0.460	0.443	0.385	0.396	0.423	0.393	0.359	0.336
5.680	0.29	0.410	0.357	0.378	0.439	0.409	0.394	0.426	0.497	0.410	0.383	0.402	0.397	0.445	0.380	0.407	0.396	0.390	0.348	0.309
6.940	0.36	0.396	0.322	0.349	0.447	0.401	0.379	0.355	0.530	0.390	0.376	0.372	0.437	0.440	0.348	0.384	0.388	0.380	0.418	0.222
6.600	0.34	0.523	0.498	0.493	0.531	0.479	0.557	0.544	0.641	0.491	0.452	0.506	0.533	0.516	0.478	0.453	0.481	0.483	0.528	0.407
7.350	0.38	0.446	0.456	0.493	0.494	0.451	0.498	0.497	0.592	0.491	0.478	0.482	0.486	0.494	0.433	0.453	0.425	0.443	0.489	0.391
7.660	0.40	0.556	0.498	0.459	0.542	0.465	0.513	0.539	0.629	0.504	0.467	0.475	0.523	0.530	0.506	0.500	0.490	0.506	0.587	0.466
8.030	0.42	0.600	0.537	0.502	0.560	0.560	0.586	0.597	0.638	0.544	0.556	0.512	0.545	0.574	0.554	0.547	0.565	0.556	0.560	0.477
8.830	0.46	0.640	0.541	0.574	0.601	0.549	0.537	0.586	0.686	0.562	0.486	0.536	0.583	0.568	0.469	0.547	0.517	0.543	0.528	0.461
9.160	0.48	0.669	0.657	0.627	0.636	0.602	0.660	0.628	0.731	0.618	0.579	0.543	0.641	0.631	0.615	0.587	0.637	0.637	0.663	0.543
9.220	0.48	0.676	0.576	0.598	0.651	0.613	0.626	0.597	0.748	0.643	0.552	0.573	0.672	0.626	0.567	0.564	0.658	0.620	0.598	0.352
10.230	0.54	0.611	0.534	0.675	0.545	0.515	0.527	0.574	0.637	0.532	0.537	0.585	0.522	0.589	0.526	0.523	0.544	0.576	0.603	0.482
10.430	0.55	0.547	0.470	0.507	0.528	0.457	0.473	0.556	0.628	0.491	0.490	0.524	0.507	0.546	0.518	0.552	0.494	0.510	0.489	0.455
11.230	0.59	0.710	0.661	0.746	0.632	0.705	0.739	0.574	0.748	0.734	0.705	0.640	0.663	0.716	0.652	0.570	0.679	0.656	0.636	0.423
11.300	0.59	0.647	0.513	0.541	0.625	0.540	0.611	0.491	0.674	0.574	0.540	0.567	0.567	0.615	0.498	0.465	0.529	0.553	0.424	0.358
12.050	0.64	0.801	0.802	0.780	0.762	0.735	0.798	0.674	0.806	0.802	0.789	0.658	0.730	0.787	0.745	0.639	0.738	0.817	0.788	0.656
12.120	0.64	0.652	0.488	0.555	0.627	0.532	0.537	0.628	0.702	0.554	0.490	0.610	0.611	0.601	0.482	0.611	0.556	0.563	0.565	0.493
13.120	0.69	0.715	0.626	0.698	0.751	0.616	0.606	0.681	0.802	0.646	0.609	0.683	0.690	0.689	0.599	0.694	0.692	0.653	0.587	0.580
13.200	0.70	0.944	0.831	0.851	0.826	0.791	0.754	0.787	0.896	0.810	0.709	0.749	0.792	0.822	0.666	0.785	0.779	0.670	0.603	0.591
14.090	0.75	0.868	0.823	0.828	0.777	0.763	0.768	0.805	0.823	0.737	0.682	0.726	0.750	0.768	0.708	0.686	0.742	0.753	0.755	0.559

Table 7.5 The sample of training data for female

Actual Age	Age	Metacarpal	Proximal Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phalar
0.64	0.03	0.198	0.151	0.038	0.089	0.113	0.095	0.062	0.074	0.107	0.062	0.057	0.093	0.174	0.103	0.065	0.116	0.296	0.097	0.108
0.68	0.03	0.226	0.160	0.195	0.148	0.183	0.177	0.167	0.146	0.158	0.096	0.147	0.146	0.207	0.150	0.158	0.153	0.157	0.148	0.102
1.37	0.06	0.278	0.238	0.238	0.204	0.259	0.264	0.179	0.200	0.288	0.230	0.136	0.222	0.321	0.293	0.165	0.206	0.229	0.209	0.193
1.60	0.08	0.000	0.141	0.174	0.171	0.205	0.151	0.179	0.203	0.211	0.141	0.147	0.220	0.000	0.194	0.206	0.000	0.208	0.137	0.136
1.14	0.05	0.242	0.169	0.191	0.153	0.243	0.216	0.179	0.156	0.216	0.203	0.192	0.148	0.282	0.286	0.206	0.168	0.217	0.230	0.228
2.50	0.13	0.384	0.235	0.209	0.255	0.275	0.199	0.247	0.276	0.251	0.189	0.204	0.285	0.298	0.227	0.212	0.284	0.255	0.214	0.256
2.69	0.14	0.358	0.251	0.251	0.284	0.302	0.286	0.284	0.287	0.292	0.227	0.305	0.279	0.321	0.264	0.329	0.304	0.252	0.214	0.318
2.63	0.13	0.310	0.213	0.289	0.275	0.309	0.221	0.198	0.274	0.306	0.215	0.277	0.296	0.353	0.271	0.300	0.287	0.327	0.199	0.256
3.79	0.19	0.372	0.273	0.255	0.329	0.304	0.256	0.290	0.349	0.306	0.209	0.266	0.338	0.323	0.253	0.324	0.319	0.255	0.194	0.341
3.99	0.21	0.274	0.307	0.251	0.209	0.296	0.272	0.235	0.192	0.271	0.221	0.232	0.170	0.328	0.275	0.300	0.194	0.277	0.271	0.267
3.70	0.19	0.452	0.329	0.307	0.363	0.399	0.337	0.370	0.377	0.388	0.282	0.333	0.398	0.434	0.352	0.346	0.403	0.403	0.373	0.307
4.77	0.25	0.532	0.423	0.434	0.479	0.523	0.459	0.432	0.506	0.522	0.372	0.390	0.503	0.523	0.469	0.518	0.481	0.242	0.424	0.420
4.02	0.21	0.500	0.379	0.340	0.406	0.434	0.407	0.389	0.445	0.418	0.336	0.385	0.416	0.473	0.414	0.388	0.420	0.399	0.418	0.415
4.38	0.23	0.380	0.285	0.319	0.332	0.350	0.316	0.370	0.352	0.337	0.286	0.362	0.336	0.378	0.326	0.423	0.332	0.315	0.240	0.296
5.98	0.31	0.482	0.361	0.383	0.398	0.426	0.394	0.377	0.421	0.406	0.354	0.367	0.403	0.439	0.432	0.418	0.400	0.377	0.373	0.353
5.17	0.27	0.506	0.342	0.383	0.414	0.436	0.355	0.450	0.441	0.422	0.321	0.390	0.432	0.461	0.417	0.465	0.405	0.405	0.367	0.489
5.99	0.31	0.560	0.433	0.391	0.487	0.534	0.476	0.457	0.512	0.501	0.386	0.401	0.543	0.521	0.447	0.447	0.503	0.478	0.398	0.381
5.32	0.28	0.528	0.382	0.374	0.460	0.488	0.355	0.364	0.482	0.446	0.304	0.333	0.470	0.484	0.370	0.353	0.461	0.453	0.393	0.375
5.33	0.28	0.538	0.395	0.391	0.431	0.415	0.368	0.395	0.475	0.418	0.295	0.367	0.490	0.461	0.359	0.370	0.442	0.384	0.255	0.404
5.01	0.26	0.460	0.329	0.272	0.401	0.429	0.372	0.358	0.411	0.413	0.277	0.305	0.429	0.441	0.330	0.318	0.398	0.396	0.306	0.358
5.47	0.29	0.480	0.329	0.307	0.426	0.442	0.377	0.370	0.446	0.413	0.330	0.379	0.438	0.425	0.381	0.412	0.379	0.374	0.214	0.369
6.42	0.34	0.600	0.467	0.476	0.524	0.512	0.472	0.457	0.551	0.513	0.378	0.418	0.564	0.532	0.458	0.477	0.532	0.465	0.408	0.392
6.58	0.34	0.524	0.417	0.374	0.460	0.485	0.355	0.420	0.490	0.469	0.312	0.407	0.499	0.493	0.414	0.412	0.481	0.459	0.398	0.443
6.96	0.37	0.552	0.414	0.442	0.470	0.485	0.459	0.445	0.485	0.455	0.351	0.396	0.497	0.491	0.425	0.406	0.461	0.462	0.433	0.461
6.14	0.32	0.566	0.455	0.459	0.505	0.566	0.546	0.438	0.516	0.548	0.457	0.441	0.512	0.539	0.487	0.429	0.512	0.494	0.459	0.381
6.98	0.37	0.592	0.454	0.430	0.490	0.504	0.459	0.537	0.523	0.511	0.407	0.491	0.530	0.530	0.494	0.541	0.525	0.491	0.500	0.455
6.67	0.35	0.484	0.404	0.349	0.422	0.436	0.368	0.352	0.454	0.420	0.304	0.350	0.438	0.457	0.355	0.395	0.409	0.393	0.311	0.302
7.82	0.41	0.622	0.486	0.481	0.537	0.539	0.449	0.488	0.610	0.543	0.460	0.486	0.593	0.595	0.535	0.582	0.584	0.494	0.454	0.512
7.23	0.38	0.534	0.404	0.498	0.462	0.477	0.481	0.543	0.479	0.452	0.348	0.458	0.479	0.489	0.443	0.547	0.446	0.434	0.424	0.478

Table 7.6 The sample of training data for male

Actual Age	Age	Metacarpal	Proximal Phala	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala	Metacarpal	Proximal Ph	Middle Phal	Distal Phala
0.28	0.00	0.000	0.000	0.038	0.000	0.000	0.035	0.136	0.126	0.000	0.008	0.042	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.060
0.64	0.02	0.070	0.018	0.000	0.050	0.044	0.025	0.095	0.161	0.013	0.000	0.006	0.052	0.041	0.033	0.041	0.042	0.056	0.017	0.000
0.81	0.03	0.065	0.014	0.043	0.080	0.078	0.005	0.107	0.170	0.073	0.034	0.055	0.045	0.082	0.069	0.041	0.017	0.043	0.022	0.044
1.71	0.08	0.132	0.145	0.153	0.134	0.150	0.143	0.136	0.231	0.119	0.088	0.109	0.125	0.139	0.089	0.047	0.131	0.146	0.125	0.022
1.54	0.07	0.122	0.096	0.096	0.129	0.117	0.045	0.000	0.228	0.106	0.027	0.055	0.127	0.145	0.522	0.000	0.125	0.130	0.103	0.000
1.07	0.04	0.084	0.053	0.129	0.086	0.075	0.000	0.089	0.201	0.076	0.027	0.061	0.074	0.153	0.049	0.052	0.073	0.106	0.065	0.060
2.74	0.13	0.168	0.131	0.240	0.227	0.197	0.138	0.136	0.314	0.218	0.142	0.189	0.181	0.232	0.170	0.163	0.187	0.226	0.131	0.103
2.79	0.14	0.156	0.187	0.225	0.190	0.195	0.158	0.278	0.266	0.185	0.142	0.225	0.140	0.210	0.130	0.203	0.146	0.226	0.202	0.157
2.96	0.14	0.185	0.134	0.115	0.196	0.234	0.197	0.172	0.276	0.240	0.165	0.153	0.156	0.262	0.198	0.163	0.136	0.203	0.125	0.038
3.4	0.17	0.278	0.226	0.320	0.295	0.295	0.330	0.326	0.375	0.296	0.291	0.262	0.235	0.306	0.267	0.245	0.231	0.303	0.277	0.233
3.6	0.18	0.338	0.255	0.306	0.286	0.278	0.271	0.349	0.392	0.291	0.245	0.281	0.273	0.306	0.283	0.297	0.263	0.317	0.299	0.293
3.22	0.16	0.285	0.216	0.287	0.270	0.265	0.696	0.308	0.370	0.271	0.249	0.287	0.250	0.287	0.263	0.233	0.236	0.270	0.245	0.217
4.93	0.25	0.391	0.262	0.383	0.396	0.293	0.276	0.420	0.494	0.342	0.253	0.353	0.384	0.374	0.292	0.303	0.369	0.373	0.288	0.299
4.99	0.25	0.329	0.276	0.306	0.289	0.295	0.271	0.391	0.401	0.311	0.284	0.317	0.286	0.314	0.267	0.302	0.248	0.303	0.234	0.277
4.07	0.20	0.230	0.156	0.192	0.276	0.281	0.266	0.219	0.375	0.276	0.238	0.207	0.243	0.300	0.251	0.313	0.207	0.280	0.234	0.163
5.77	0.30	0.516	0.488	0.517	0.493	0.529	0.591	0.497	0.589	0.560	0.510	0.408	0.504	0.557	0.534	0.419	0.486	0.530	0.603	0.352
5.94	0.31	0.460	0.424	0.483	0.483	0.451	0.449	0.503	0.550	0.430	0.364	0.475	0.475	0.478	0.393	0.413	0.456	0.476	0.429	0.401
5.99	0.31	0.463	0.421	0.464	0.498	0.443	0.468	0.532	0.580	0.461	0.391	0.360	0.484	0.500	0.401	0.413	0.458	0.503	0.462	0.391
5.68	0.29	0.391	0.325	0.479	0.426	0.409	0.419	0.426	0.491	0.403	0.360	0.402	0.377	0.426	0.377	0.372	0.325	0.403	0.386	0.347
5.53	0.28	0.391	0.336	0.364	0.384	0.384	0.409	0.397	0.464	0.387	0.376	0.348	0.359	0.404	0.377	0.320	0.369	0.393	0.359	0.331
5.06	0.26	0.439	0.364	0.402	0.400	0.407	0.458	0.420	0.530	0.403	0.399	0.348	0.418	0.418	0.389	0.407	0.417	0.363	0.343	0.347
5.39	0.28	0.357	0.346	0.440	0.375	0.365	0.399	0.474	0.470	0.395	0.368	0.445	0.384	0.402	0.372	0.453	0.365	0.400	0.397	0.374
6.61	0.34	0.492	0.414	0.388	0.496	0.457	0.473	0.462	0.581	0.491	0.467	0.323	0.475	0.508	0.449	0.401	0.473	0.493	0.370	0.331
6.66	0.34	0.549	0.428	0.426	0.509	0.465	0.385	0.432	0.598	0.471	0.383	0.415	0.473	0.489	0.352	0.366	0.460	0.456	0.250	0.282
6.82	0.35	0.556	0.438	0.473	0.480	0.471	0.443	0.491	0.581	0.473	0.371	0.402	0.464	0.486	0.360	0.401	0.428	0.480	0.365	0.369
6.49	0.34	0.516	0.488	0.512	0.514	0.513	0.517	0.532	0.578	0.468	0.456	0.457	0.484	0.497	0.478	0.424	0.450	0.513	0.500	0.391
6.9	0.36	0.480	0.421	0.450	0.477	0.474	0.424	0.432	0.572	0.443	0.425	0.415	0.467	0.489	0.389	0.396	0.438	0.470	0.413	0.341
7.2	0.37	0.600	0.505	0.627	0.539	0.521	0.527	0.597	0.622	0.580	0.510	0.567	0.516	0.587	0.494	0.506	0.303	0.517	0.533	0.429
7.35	0.38	0.513	0.460	0.464	0.482	0.451	0.399	0.574	0.583	0.481	0.383	0.475	0.471	0.481	0.409	0.488	0.446	0.463	0.397	0.445
7.35	0.38	0.568	0.481	0.560	0.490	0.493	0.552	0.551	0.590	0.453	0.441	0.482	0.507	0.494	0.457	0.483	0.488	0.493	0.533	0.423
7.13	0.37	0.571	0.474	0.589	0.547	0.546	0.562	0.544	0.617	0.549	0.517	0.598	0.533	0.582	0.498	0.576	0.523	0.533	0.571	0.407

APPENDIX C

	Task Name	Q4			Q1			Q2			Q3			Q4		
		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
1	**Object Oriented Analysis Design**															
2	**Planning**															
3	Meeting with Supervisor				1d											
4	Identifying the requirement, problem and objective						3d									
5	Meeting with supervisor				1d											
6	Reviewing the existing method						2d									
7	Meeting with Supervisor				1d											
8	Correction Chapter 1 & 2				5d											
9	Submission Part Chapter 1 and 2				1d											
10	**Analysis**															
11	Meeting with Supervisor				1d											
12	Correction Chapter 3				3d											
13	Meeting with Supervisor				1d											
14	Designing regression model						15d									
15	Meeting with Supervisor					1d										
16	Reviewing Chapter 1 to 3					11d										
17	Meeting with Supervisor						1d									
18	Submission PSM 1 Proposal						1d									
19	**Development**															
20	Meeting with Supervisor										1d					
21	Software Installation										4d					
22	Develop Multiple Linear Regression Model										12d					
23	Meeting with Supervisor											1d				
24	Develop ANN Model											20d				
25	**Maintanance**															
26	Meeting with Supervisor												1d			
27	Evaluation and Validation												3d			
28	Meeting with Supervisor												1d			
29	Correction Chapter 4-5												5d			
30	Documentation												10d			
31	Meeting with Supervisor													1d		
32	Submission PSM 2 Report													1d		
33																
34																

Table 7.7 Timeline of conducting research

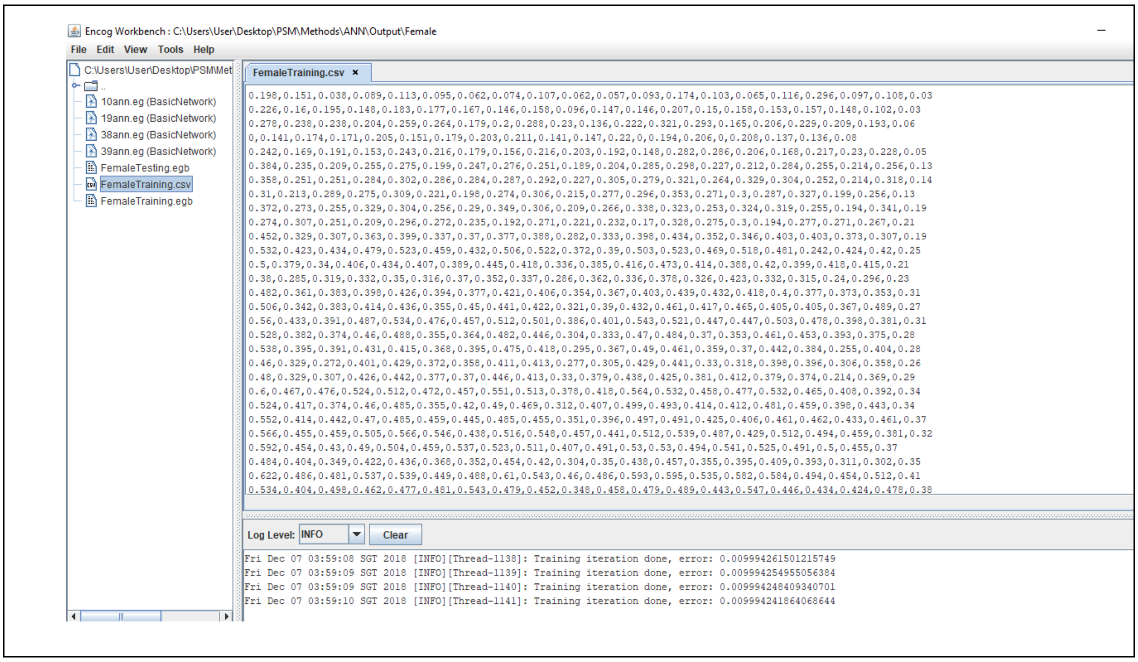

Figure 7.1 Insert normalized data into Encog Workbench 3. 3.0

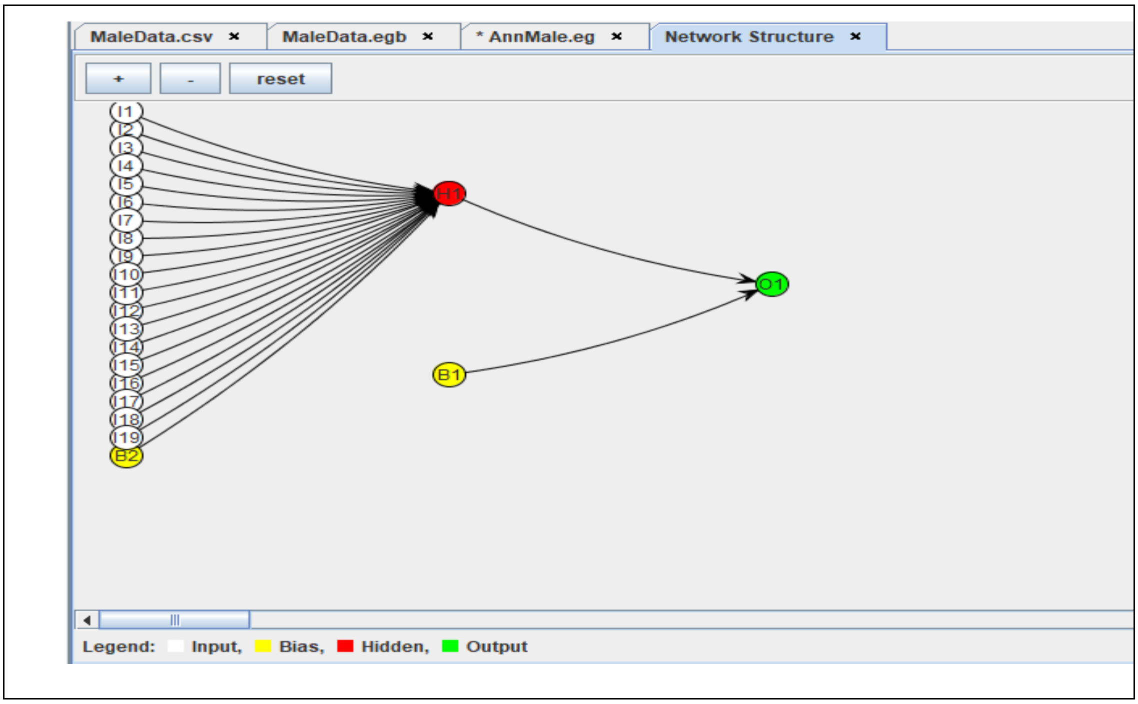

Figure 7.2 Hidden layer network

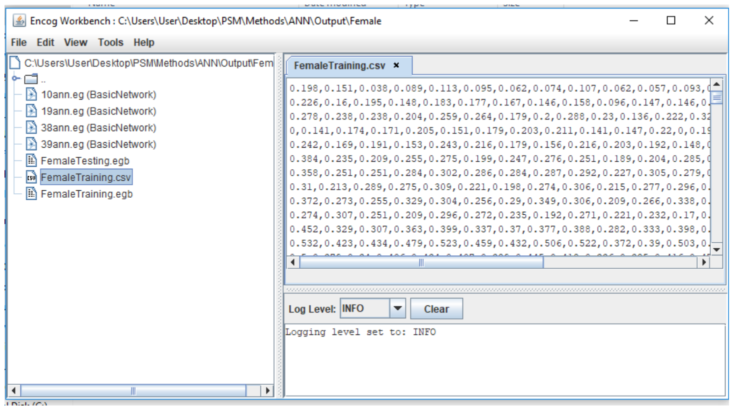

Figure 7.3 The training and testing data for female in Encog Workbench 3.3.0

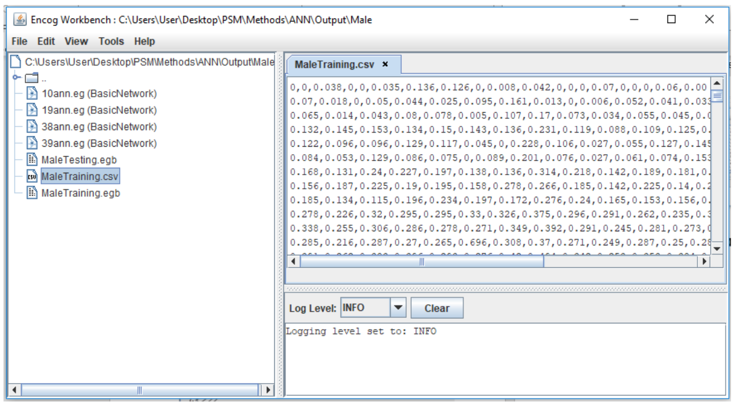

Figure 7.4 The training and testing data for male in Encog Workbench 3.3.0