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Modeling Hand Anthropometric Dimensions of the Jordanian Population: The Application of Multivariate Linear Regression and Adaptive Neuro-Fuzzy Techniques

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Abstract

Globalization and the free trade agreements forced most of the Industrialized Developing Countries (IDC) to export hand tools and equipments from the Industrialized Countries (ID). However, due to the lack of anthropometric data base for the IDC one can't determine how suitable these tools is except to say that anecdotal evidence indicates that improvements may be necessary for comfort, health and safety. In this paper, eighteenth hand dimensions were collected for the Jordanian population from different sectors. Furthermore, both Multivariate Linear Regression and Adaptive Neuro-Fuzzy Inference System have been formulated, built, and compared to predict a set of hand dimensions as a function of several hand anthropometric dimensions including age, body weight, gender, and stature. The models were compared to the actual measured values in order to determine the error of both prediction techniques and validate the results. The paper emphasizes that it is necessary to develop a precise model to appropriately design hand tools and other applications for different kinds of precession equipments.

Keywords
Hand Dimensions; Jordan; Modeling; Multivariate Regression; Adaptive Neuro-Fuzzy Inference System

1 Introduction

Ergonomic is the measurement, analysis, evaluation, and design of a system that involves the interaction between human, machine, task, and environment for the purpose of enhancing performance, safety, and health [1]. To enhance this interaction knowledge about human body dimensions, physical strength, as well as capabilities are required. Anthropometry –the science of human measurements- is of vital importance to ergonomics and designers. Various researchers have pointed out the importance of using relevant anthropometric data in equipment design, since mismatches between human anthropometric and equipment dimensions have a great impact on productivity, accident rate, injuries, and cumulative traumas [2-5]. For these purposes, researchers in different countries, mainly the Industrialized Developing Countries (IDC) gathered a large set of hand dimensions for various nationalities, such as ethnic Vietnamese living in USA [3], United Kingdom females [6], Hong Kong Chinese females [7], Indian agricultural workers [8], Western Nigerian rural farm workers [4], Mexicans [9], and Bangladesh females [10].

Furthermore, hand anthropometric measurements is further emphasized in its use, sometimes with other variables, in the development of predictive models of other body dimensions and hand strength using single and multiple linear regression models – predicting body anthropometric dimensions for Indian agricultural workers [8], predicting hand length and grip strength for Indian female workers [11], predicting single and multiple digit finger strength [12]. Recently, with the rapid development of data modeling, alternative approaches such as neural networks and neuro-fuzzy methods have become more popular and easier to operate in different areas such as thermal power plant, electricity consumption, and energy consumption [13-15]. However, ergonomics have not taken fully advantage of this technique [14].

Direct measurements for small segmental hand dimensions such as breadth and depth at 2nd joint digit 5, with high accuracy, may not be easy and quick to achieve, thus, prediction of these segments from variables that are simple to measure such as length of the hand, maximum depth of the hand, weight and height might be an alternative approach. This study demonstrates and compares the application of multivariate regression and Adaptive Neuro-

Fuzzy Inference System (ANFIS) models in predicting small segmental anthropometric dimensions by collecting eighteenth hand dimensions for 120 and 115 Jordanian females and males respectively from different working sectors such as carpenters, vehicle drivers, electrical technician, nurses, students, secretary, and others.. The square root of average squared error (RASE) of testing group is used as a performance measure in our comparison between the multivariate linear regression and neuro-fuzzy models. These models may be used to predict segmental hand anthropometric dimensions in situation where the capabilities for direct measurement for specific population may be difficult; this would be of great help for hand tool designers.

2 Methods

2.1 Subjects

Convenience sample of 120 females and 115 males adults were randomly selected and voluntary participated as subjects in this study. Subjects were selected from the capital city Amman, which contains the majority of industries, universities, and schools, from Zarqa and the rest from Irbid. All were of good health, as self-reported. The purposes of this study were explained to each subject prior to the experiment. Their age ranged from 15-64 years with a mean of 27. The subjects were mainly carpenters, vehicle drivers, electrical technician, police, engineers, nurses, students, secretary, teachers, and others. The purpose of the study was explained to each subject prior to the experiment. Permission to conduct this study was granted from the Hashemite University research council.

2.2 Apparatus and Measurements

Eighteenth hand dimensions have been measured using an electronic digital caliper, with an accuracy of 0.01 mm. A great care was made so as to use, read and record the readings from the tools as accurate as possible. Some measurements have been selected randomly and repeated to recheck the accuracy of the measurements. All these measurements have been taken for right hand. The definitions and methods used of these measurements taken mostly from previous researchers [16] [9].

2.3 Data Analysis and Methods

The data were summarized and analyzed with the aid of the Statistical Analysis System (SAS) software on a desktop computer and the summary data tabulated below (Table 1). Descriptive statistics are given as mean, standard deviation and important percentiles (25th, 75th, and 95th).

Table 1. Summary data of hand dimensions (mm) of Jordanian adult females and males

Anthropometric Dimension	Mean		S.D		Percentile Values for Females			Percentile Values for Males		
	♀	♂	♀	♂	25th	75th	95th	25th	75th	95th
Fingertip to root digit 5*	56.63	61.12	3.4	4.69	54.68	58.69	61.69	57.89	63.7	68.93
Fingertip to root digit 3*	75.15	81.26	3.62	7.14	72.51	77.64	80.02	77.94	84.44	90.43
Second joint to root digit 5**	18.34	19.05	1.79	2.13	17.3	19.53	21.12	17.85	20.52	22.28
Second joint to root digit 3**	26.11	27.75	2.57	2.63	24.69	27.79	30.05	25.77	29.43	32.32
Breadth at tip of digit 5*	10.53	12.28	0.87	1.12	10	11.16	11.97	11.47	13.16	13.85
Breadth at tip of digit 3*	13.64	15.8	1	1.28	12.97	14.32	15.28	14.85	16.56	17.92
Breadth at second joint of digit 5*	15.3	17.4	1.05	1.34	14.46	15.98	17.03	16.39	18.44	19.39
Breadth at second joint of digit 3*	18.11	20.41	1.1	1.41	17.34	18.86	19.81	19.53	21.31	22.4
Depth at tip digit 5*	10.92	12.04	0.94	1.12	10.27	11.53	12.4	11.29	12.7	13.91
Depth at tip digit 3*	12.92	13.84	1.02	1.66	12.18	13.61	14.51	13.24	14.53	16.05
Depth at second joint digit 5*	13.94	15.35	1.17	1.28	13.18	14.67	15.98	14.58	16.24	17.29

Depth at second joint digit 3*	16.37	18.58	1.24	1.43	15.46	17.26	18.51	17.6	19.7	20.76
Maximum breadth of the hand*	93.99	104.2	5.63	10.94	89.76	97.21	102.85	101.64	108.62	113.79
Breadth of the knuckles*	77.82	87.7	3.92	4.82	74.87	80.31	83.53	83.7	91.18	95.43
Length of the hand*	171.27	191.2	7.44	10.2	167	176.75	181.45	185	198	207
3rd digit to Base of the thumb*	124.49	137.69	6.48	18.33	120.54	128.74	136.54	134.54	144.44	152.95
Depth of the knuckles*	28.36	30.31	2.26	2.4	26.78	29.84	32.01	28.51	32.06	34.61
Maximum depth of the hand*	40.35	43.9	4.26	3.93	37.44	43.22	47.83	41.18	46.45	49.81

**Statistically significant gender difference at α=0.05.
*Statistically significant gender difference at α=0.01.

3 Statistical and ANFIS Analysis Methods

Multivariate linear regression analysis is widely used to analyze multifactor data by building an equation that relates the dependent variable to a set of predictor or independent variables. The formulated model will be used to predict the dependent variables given different values for the predicted (independent) variables. On the other hand, the relationship between the response and the independent variables might be nonlinear; therefore, Adaptive Neuro-Fuzzy Inference System (ANFIS) technique can be the solution in these cases. In fact, hand anthropometric dimensions could be nicely modeled as fuzzy properties. Fuzzy logic can model nonlinear functions of arbitrary complexity. It provides an alternative solution to nonlinear modeling because it is closer to the real world. Nonlinearity and complexity is handled by rules, membership functions, and the inference process which results in improved performance, simpler implementation, and reduced design costs. Neuro-fuzzy is an associative memory system that consists of fuzzy nodes instead of simple input and output nodes. ANFIS is a fuzzy system in a neural-network-like structure, in order to teach a fuzzy system through a neural network, the fuzzy parameters (premise and consequent) should be updated online in this network. To achieve this goal of learning fast enough, each layer of ANFIS is learnt separately not like the way neural nets learn, this achieved faster learning because of the much fewer epochs needed than when using neural networks in a whole learning strategy.

In this study, after identifying the most important variables using ANOVA, three segmental anthropometric dimensions will be developed using the multivariate linear regression analysis and the ANFIS method. The data set has been randomly divided into two groups: training group which is used to build the model and testing group which is used to validate the model. The square root of average squared error (RASE) of testing group, given by Equation 1 [17], is used as a performance measure in our comparison between the two models.

$$RASE = \sqrt{ASE} = \sqrt{SSE / n} \quad (1)$$

$$SSE = \sum_{i=1}^{n} (E - \hat{E})^2{}_i \quad (2)$$

Where SSE is the sum of squared error, n the number of observations of testing group, E the actual anthropometric dimension, $\hat{E}$ the predicted anthropometric dimension, and ASE the average squared error.

4 Results and discussions

4.1 Variable selection

Three segmental anthropometric dimensions models have been built using multivariate linear regression and ANFIS, these dimensions are: breadth at second joint of digit 5, depth at second joint of digit 5, and depth at second joint of digit 3 as a function of maximum breadth of hand, breadth of the knuckles, length of the hand, maximum depth of the hand, age, weight, stature, and gender. Analysis of variance (ANOVA) was used to predict the most important variables using the least square method. In order to decide whether or not a variable is significant, the *P*-value associated with each parameter has been estimated, in this paper, the variable that has a *P*-value smaller than 0.1 was considered as an important variable. Therefore, maximum breadth of hand, weight, and gender were not significant at the 0.1 level. The multivariate regression models have been built using only the significant variables, Table 2 shows the results of the three models, with the variation inflation factor (VIF), the coefficient of multiple determination (R^2), the adjusted R^2, and the predicted R^2.

Table 2. Regression summary outputs for the Jordanian hand anthropometric dimensions

Coefficient**	**Breadth at second joint of digit 5**	**Depth at second joint of digit 5**	**Depth at second joint of digit 3**
Intercept	0.27	-0.44	-3.57
Age	0.0137 [1.1]	0.0437 [1.1]	0.0474 [1.1]
Stature	N/A	0.01966 [2.2]	0.0383 [2.1]
Length of the hand	- 0.00247 [2.5]	N/A	N/A
Maximum depth of the hand	0.0402 [1.7]	0.0377 [1.7]	N/A
Breadth of the knuckles	0.172 [3.1]	0.109 [3.0]	0.16 [2.1]
R^2	79.5%	58.5%	69.1%
Adjusted R^2	78.9%	57.5%	68.5%
Predicted R^2	78.05%	55.81%	67.4%

**: Values in bracket are the variation inflation factor *(VIF).*

4.2 Model Adequacy Check for Multivariate Regression Analysis

Several assumptions have been verified in order to check the adequacy of the models. First, to check that the residuals have constant variance and are normally distributed, a graphical analysis of the residuals can be used to check these assumptions [18]. The analysis demonstrates satisfactory results since the residuals are contained within a horizontal band (the constant variance assumption is satisfied) and since the cumulative normal distribution is approximately a straight line (the normality assumption is also satisfied). Secondly, no leverage and influence points were detected in all models. Thirdly, larger variation inflation factors (VIFs), usually larger than 10 (Montgomery et al., 2007) [17], indicate that the associated regression coefficients are poorly estimated because of multicollinearity. Multicollinearity. as can be shown from Table 2, the variation inflation factor (VIF) for the parameters is less than 10. Fourthly, each model seems to represent its data's behavior acceptably since the coefficient of multiple determination (R2), the adjusted R2, and the predicted R2 statistics are approximately high for all models as shown from Table 2; these are the most popular measures of goodness-of-fit.

4.3 ANFIS Modeling of Hand Anthropometric Dimensions

The fuzzy logic toolbox of Matlab 7 was used to obtain the results. ANFIS was not used in the first stage to predict that age and stature are needed to be fuzzified, but ANOVA test was used instead, to decide on the most significant variables which were found to be the Age and Stature. Thereafter, forty fuzzy rules were used to build the fuzzy systems for modeling the hand anthropometric dimensions. As an example, Figure 1 shows the training curve for building a fuzzy model for the breadth at 2nd joint digit 5. 550 neural nets learning epochs were used to get a low error of training (i.e., root mean square error (RMSE) = 0.704). A comparison between the actual and ANFIS predicted output after training is shown in Figure 2, which shows that the system is well-trained to model the actual breadth at 2^{nd} joint digit 5. Sixty eight data points, which are different from the training data, were used to validate the system. A two (triangular) type membership functions for each input resulted in high accurate prediction results. Figure 3 shows the final fuzzy system for predicting the breadth at 2^{nd} joint digit 5. The same technique has been used to predict the remaining two anthropometric dimensions.

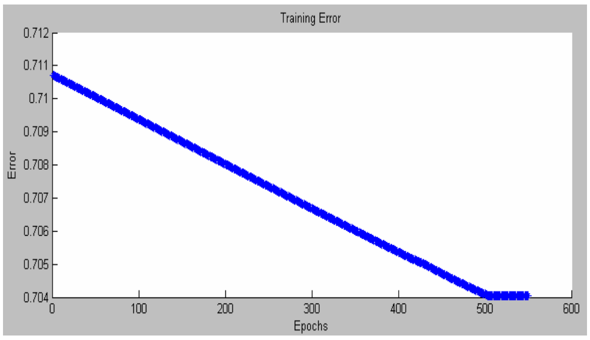

Figure 1: Training curve of fuzzy model for breadth at 2nd joint digit 5

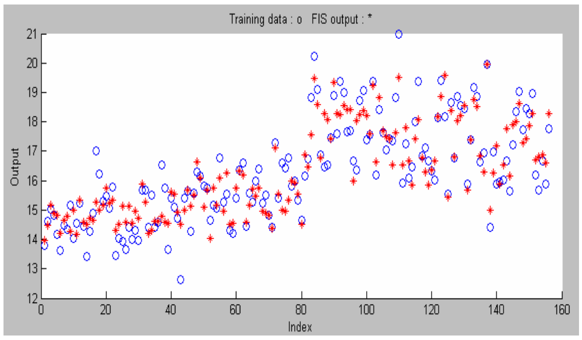

Figure 2: Actual and predicted values of breadth digit 5 dimension

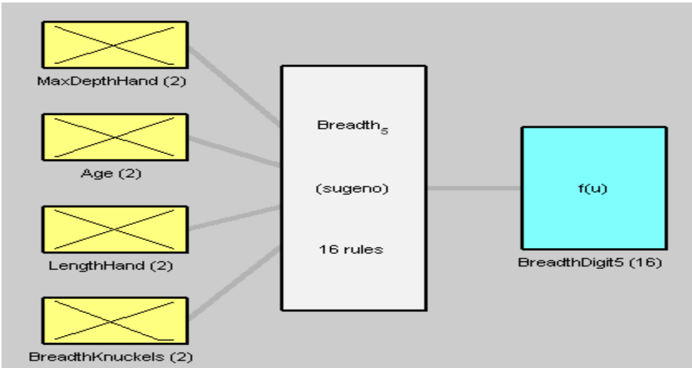

Figure 3: The final fuzzy system for predicting breadth at 2nd joint digit 5

4.4 Models Comparison

The multivariate linear regression and ANFIS prediction models for Jordanian population were validated by feeding into the models the data points that were not used in model's building. The RASE values of the three models using the multivariate linear regression and neuro-fuzzy techniques are given in Table 3.

Table 3. RASE and average error of multivariate linear regression and neuro-fuzzy models

RASE (mm)	**Regression**	**Neuro-Fuzzy**
Breadth at second joint of digit 5	0.711	0.731
Depth at second joint of digit 5	0.877	0.804
Depth at second joint of digit 3	0.909	0.952

In General, as given in Table 3, the difference between prediction accuracy with neuro-fuzzy and regression is not significant and almost have the same performance. This could be basically due to the hand anthropometric dimension data does not have highly nonlinear nature, where intelligent methods prove much better than other conventional techniques. Consequently, the performance of both techniques was shown to be almost the same.

5 Conclusions

This study has provided data for eighteenth hand dimensions that may be useful for the design for hand tools and apparel (e.g. gloves) for the Jordanian population until more informative data become available. The results show that all hand anthropometric dimensions for the Jordanian males are longer than the hand dimensions for the Jordanian females, confirming a previous research papers [3,9, 10]. Thus designers should consider these findings when designing tools that could be used by both genders especially hand grip tools. Furthermore, prediction of segmental hand anthropometric dimensions plays an important role when direct measurements may not be easy and quick to achieve. In this study, multivariate linear regression method and an adaptive neuro-fuzzy inference system are used to model and predict three hand anthropometric dimensions namely, breadth at second joint of digit 5, depth at second joint digit 5, and depth at second joint digit 3. The final models are compared to the actual models in order to determine the error of both prediction techniques and validate the results, the RASE is used as a performance measure in our comparison between the two models. The results show that multivariate linear regression model performs slightly better than ANFIS. However, difference is not significant and both models can be considered generally comparable. This result should be analyzed further by modeling more segmental dimensions for Jordanian and other populations.

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