UNIVERSITI PUTRA MALAYSIA

MEASUREMENT AND MODELING OF HAND GRIP STRENGTH AND ENDURANCE OF MALAYSIAN FEMALE

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

January 2015

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of the Master of Science

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January 2015

Chair: Y.M. Raja Mohd Kamil bin Raja Ahmad, PhD, Ir

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Gripping is an important physical activity in daily routine. The capability of muscular force during gripping can be evaluated in terms of Hand grip Strength (HGS) and Hand grip Endurance (HGE). There are two types of movements that are associated with HGE which are dynamic or repetitive (HGEd) and static (HGEs) movements. In the literature, there are many studies which have been performed to investigate the relationship between demographics and hand anthropometric dimensions factors with HGS. These factors have been used as predictive factor for rehabilitation and recovery. However there is lack of studies showing the relationship combined of demographics and hand anthropometric dimensions to HGE which are important factors in hand rehabilitation and recovery. The aim of this project is to develop predictive model of young female HGS and HGE based on the demographic and hand anthropometric collected. Thus, the specific objectives of this study are; (1) to develop a optimal grip size electronic hand grip strength measuring system that records and analyze the HGS and HGE time series signals, (2) to determine the correlation between demographic and hand anthropometric dimensions, and the HGS as well as HGE of young Malaysian female, and (3) to develop an intelligent predictive model of HGS and HGE. There are three assessments in evaluating the HGS, HGEd and HGEs: single- repetition, 20-repetition and 30-seconds static hold. In addition 6 demographics and 9 hand anthropometrics data are recorded from each volunteer in order to investigate the correlation between HGS, HGEd and HGEs and these data. By using all the associated data, the predictive model of HGS, HGEd and HGEs are developed using Adaptive Neuro Fuzzy Inference System (ANFIS) model. In this study 45 females of the age group 18 to 30 years were recruited. The assessment of grip strength and endurance was measured using the fabricated hand grip measuring device and followed the America Society of Hand Therapy (ASHT) protocols of seating to maintain the consistency of each volunteer's measurement. By comparing with similar study performed on western

population, the results show that the female HGS in this study is much higher probably due to optimal grip size of the fabricated measuring device. Meanwhile for HGEd and HGEs, these measurements are lower and it is found that the hand dominant was significantly stronger than non-hand dominant for HGS, HGEd and HGEs. In addition the HGS was correlated with weight, Body Mass Index (BMI), hand breadth across thumb, wrist thickness and wrist circumference. Meanwhile HGEd and HGEs were correlated with age and occupation but not correlated with any of the hand anthropometric dimensions. Non-parametric predictive model based on ANFIS is used to develop the predictive HGS and HE model. In developing predictive ANFIS modeling, the input selection was executed and the most significant inputs with respect to HGS, HGEd and HGEs for both hands are obtained. In ANFIS model, there is small discrepancy between actual and predicted average output for training and checking datasets. Nevertheless, this study has shown that ANFIS can be potentially used as an effective predictive model with larger dataset.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PENGUKURAN DAN PEMODELAN KEKUATAN GENGGAMAN DAN DAYA TAHAN TANGAN DIKALANGAN WANITA MALAYSIA

Oleh

NOR HADZFIZAH BINTI MOHD RADI

Januari 2015

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Genggaman adalah aktiviti fizikal yang penting dalam kehidupan seharian. Kebolehan ketahanan otot semasa menggenggam boleh dinilai dalam terma Kekuatan Genggaman Tangan (HGS) dan Daya Tahan Tangan (HGE). Pergerakan HGE terbahagi kepada dua jenis iaitu pergerakan dinamik atau perulangan (HGEd) dan statik (HGEs). Dalam literatur, banyak kajian telah dibuat untuk mengkaji hubungkait antara faktor demografi dan antropometri tangan dengan HGS, yang merupakan sebagai faktor ramalan untuk rehabilitasi dan pemulihan. Namun, terdapat kekurangan kajian yang menunjukkan hubungkait antara gabungan demografi dan antropometri tangan dengan HGE, yang juga boleh diambil kira sebagai faktor penting dalam rehabilitasi tangan dan pemulihan. Matlamat projek ini adalah untuk membina model ramalan bagi HGS dan HGE di kalangan wanita muda berasaskan demografi dan antropometri tangan yang direkodkan. Oleh itu, objektif kajian ini adalah; (1) untuk membangunkan sistem pengukuran dan merekodkan kekuatan genggaman tangan elektronik yang mempunyai saiz yang optimal dan dapat menganalisis HGS dan HGE dalam isyarat masa siri, (2) untuk menentukan korelasi antara demografi dan antropometri tangan dengan HGS serta HGE di kalangan remaja wanita di Malaysia, dan (3) untuk membangunkan model ramalan pintar HGS dan HGE. Terdapat tiga penilaian dalam menilai HGS, HGEd dan HGEs: pengulangan tunggal, 20-pengulangan dan 30 saat memegang statik. Di samping itu 9 data demografi dan 15 data antropometri tangan direkodkan dari setiap sukarelawan untuk menyiasat hubungan antara HGS, HGEd dan HGEs dengan data tersebut. Dengan menggunakan semua data yang berkaitan, model ramalan HGS, HGEd dan HGEs dibangunkan dengan menggunakan model Adaptive Neuro Fuzzy Inference System (ANFIS). Kajian ini mengambil 45 sukarelawan wanita bagi kumpulan umur 18 hingga 30 tahun. Penilaian kekuatan genggaman dan daya tahan diukur menggunakan alat pengukur yang direka dan mengikuti protokol cara duduk oleh America Society of Hand Therapy (ASHT) untuk mengekalkan

keseragaman data setiap sukarelawan. Dengan membandingkan kajian yang sama dilakukan ke atas penduduk barat, pengukuran HGS dalam kajian ini menunjukkan lebih tinggi ini berkemungkinan kerana saiz alat pengukur yang optimal. Manakala bagi HGEd dan HGEs, pengukuran ini adalah lebih rendah dan didapati tangan yang dominan adalah jauh lebih kuat daripada tangan bukan dominan untuk HGS, HGEd dan HGEs. Dalam korelasi didapati HGS mempunyai korelasi dengan berat badan, Index Jisim Badan (BMI), lebar tangan termasuk ibu jari, ketebalan pergelangan tangan dan lilitan pergelangan tangan. Manakala HGEd and HGEs mempunyai kolerasi dengan umur dan pekerjaan langsung tiada kaitan dengab dimensi anthropometri tangan. Model ramalan non-parametrik berdasarkan ANFISdigunakan untuk membangunkan model bagi HGS dan HGE. Dalam membangunkan model ramalan ANFIS, pilihan input dilaksanakan dan input yang paling signifikan dengan HGS, HGEd dan HGEs untuk kedua-dua tangan diperolehi. Dalam model ANFIS, terdapat perbezaan kecil di antara keluaran purata sebenar dengan keluaran purata ramalan bagi kedua-dua set data untuk latihan dan periksa. Walau bagaimanapun, kajian ini telah menunjukkan bahawa ANFIS berpotensi digunakan sebagai model ramalan yang efektif dengan dataset yang lebih besar.

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ACKNOWLEDGEMENTS

First of foremost I would like to thank Allah s.w.t. for giving me the patience and blessing to complete my master.

I am extremely grateful to my supervisor, Ir. Dr. Raja Mohd Kamil bin Raja Ahmad for his time, ideas and stimulating support during the course of my research work at Universiti Putra Malaysia (UPM). I really appreciate his concerns and advice, which had kept me going. I also would like to thank my co-supervisor, Dr. Siti Anom binti Ahmad for her support and concern during my research.

Not to forget, a lot of thanks to Mr. Wildan Ilyas from Strength of Material Lab, Department of Mechanical and Manufacturing Engineering, UPM for his favor in handling the calibration process.

I am grateful to my husband, Ahmad Dainney bin Zainuddin, for his help in upbringing our kids, Diya Medina and Umar Madani, during my busy days. My deepest gratitude goes to my parents, Ayah, Mohd Radi bin Saat and Mak, Maznah binti Abas for their moral support has encouraged me to complete my research. And not to forget my siblings, thank you so much.

Finally, I would like to thank the Universiti Malaysia Pahang (UMP) and Ministry of Higher Education Malaysia (MOHE) for financial sponsorship during my study.

I certify that a Thesis Examination Committee has met on 30 January 2015 to conduct the final examination of Nor Hadzfizah binti Mohd Radi on her thesis entitled “Measurement and Modeling of Hand Grip Strength and Endurance of Malaysian Female” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS

HGS	Hand grip Strength
HGE	Hand grip Endurance
HGEd	Hand grip Endurance dynamic
HGEs	Hand grip Endurance static
CTD	Cumulative Trauma Disorder
BMI	Body Mass Index
GUI	Graphic User Interface
ASHT	America Society of Hand Therapy
ANFIS	Adaptive Neuro Fuzzy Inference ystem
DC	Direct Current
DAQ	Data Acquisition
AC	Alternate Current
VDC	Voltage Direct Current
A/D	Analog to Digital
VI	Vitual Instrument
UMP	Universiti Malaysia Pahang
UPM	University Putra Malaysia
CPU	Central Processing Unit
HGShd	Hand grip Strength Hand dominant
HGSnhd	Hand grip Strength Non-hand dominant
HGEdhd	Hand grip Endurance dynamic Hand dominant
HGEdnhd	Hand grip Endurance dynamic Non-hand dominant
HGEshd	Hand grip Endurance static Hand dominant
HGEsnhd	Hand grip Endurance static Non-hand dominant
RMSE	Root Means Square Error
FIS	Fuzzy Inference System
MF	Membership Function
SD	Standard Deviation

CHAPTER 1

INTRODUCTION

1.1 Background

The anatomy of the hand is complicated and interesting. Its uniqueness is absolutely essential for our daily routine. The function of upper limb especially the hand in normal human daily activity includes light activity such as opening a door by squeezing the doorknob, and heavy activity such as lifting heavy box and transporting it to another place. Hand functions are classified into prehensile (grasping or gripping) and non-prehensile (non-grasp) like pushing and lifting (Napier, 1956). Of all human physical activities none is more important than gripping that generally employs a combination of hand-wrist-forearm movements (Adams, 2006; Imrhan, 2006).

Gripping is one of the hand activities that involves the movement of approximately 35 muscles in the forearm and hand. During gripping activities, the muscles of the flexor mechanism in the hand and forearm create grip strength while the extensors of the forearm stabilize the wrist (Waldo, 1996). There are two types of gripping namely, power grip and precision grip. For the power grip, the object is pressed against the palm of the hand for the generation of force by the fingers and thumb (Napier, 1956) as depicted in Figure 1.1(a). For the precision grip, the object is manipulated between the thumb and the fingertips in a fine movement without the involvement of the palm (Napier, 1956) as depicted in Figure 1.1(b). Power grip is commonly used as an index to assess impairment and treatment outcome of hand function (Talsania and Kozin, 1998).

(a) (b)

Figure 1.1. Example of gripping. (a) Power grip. (b) Precision grip.
(Source: Napier, 1956)

The capability of muscular force during power grip can be evaluated in terms of Hand grip Strength (HGS) and Hand grip Endurance (HGE). The HGS is typically examining maximum force during a single repetition. Meanwhile the HGE is examining activities that refers to the ability of maintaining a constant desired force over time (Nicolay and Walker, 2005). There are two types of movements that are associated with HGE which are dynamic or repetitive (HGEd) and static (HGEs) movements. An example of HGEd is typing using the typewriter, while carrying a furniture is an example for HGEs.

It is important to study both HGS and HGE due to the increasing prevalence of Cumulative Trauma Disorders (CTD's) such as carpal tunnel syndrome, strained muscle, tendonitis, rheumatoid arthritis and many others. Evaluation of HGS and HGE may help to identify individuals at risk of CTDs and improvement of treatment and rehabilitation processes (Robertson et al., 1996). In addition, due to the importance of gripping in many daily activities, HGS is often used in several fields for example, in medical, as an indicator of overall physical strength and health (Boissy et al., 1999; Chilima and Ismail, 2001; Pieterse et al., 2002; Massy-Westropp et al., 2004; Kaburagi et al., 2011) and medical therapy for rehabilitation and recovery (Bohannon, 2001) as well as sports that involves hand performance such as tennis and weightlifting (Fry et al., 2006; Lucki and Nicolay, 2007). The information of HGS can also be used in designing ergonomic hand tools (Nicolay and Walker, 2005; Imrhan, 2006). Other study that focuses on women health, states that normal grip strength is highly related to normal bone mineral density in postmenopausal women (Kärkkäinen et al., 2009) and they suggest that grip strength is a potential screening tool for women at risk of osteoporosis (Di Monaco et al., 2000).

1.2 Problem Statements

There are many studies which have been done to investigate the correlation of socio-demographic variables, for example, age, gender, BMI, occupation and ethnics with hand grip strength (Nicolay and Walker, 2005; Bandyopadhyay, 2008; Koley and Singh, 2009; Wu et al., 2009). Similar studies on factors that influenced hand grip strength, which are, hand dominance, gender, occupation, height and weight have also been done on Malaysian population, (Kamarul et al., 2006b; Moy et al., 2011; Hossain et al., 2012). Comparing the studies between Asian and Western populations indicate the studies using Western based data do not necessarily applies to Malaysian population as reported (Kamarul et al., 2006a).

Those studies concluded that Western norm of hand grip strength measurement were different to the Asian people, since the hand dimension of Asian were slightly smaller that Westerners. Furthermore there are many studies which have been done to check the relationship such as demographic factors with HGS. This has been used as a predictive factor for rehabilitation and recovery. However there is lack of evidence showing the relationship of

demographics and hand anthropometric dimensions to HGE which is considered to be factors for hand rehabilitation and recovery. And to narrow down, there is lack of study for Malaysian population that has been done to investigate the influences of demographic hand anthropometric dimensions to HGS and HGE.

Hence, the need of study arises due to the lack of study in Malaysian population. This study is conducted to investigate two main points. Firstly is the relationship between HGS and demographic data as well as anthropometric of hand dimensions. The second study is the relationship between HGE and demographic data as well as anthropometric of hand dimensions. And this study is constrained to Malaysian women population only. In the process of this investigation the hand grip strength, hand gripping system is designed for Asian hand size. In addition, the HGS and HGE data analysis for Malaysian population are compared with the Western population based study.

This study is useful for post hand surgery rehabilitation tracking. For example, a carpal tunnel syndrome patient will undergo rehabilitation process to regain their grip strength and endurance back to his or her original level However the actual level cannot be determined since the patient whom admitted for surgery has a compromised hand function. Due to that motivation, there need such model of HGS and HGE to predict his or her normal level of grip strength based on Asian population.

1.3 Objectives

By referring to the problems explained in Section 1.2, this research focuses on developing models that can be used to predict HGS and HGE using demographic and hand anthropometric dimensions information of young Malaysian female.

The objectives of the research are listed as follows:

1) To develop a electronic hand grip strength measuring system that records and analyze the HGS and HGE time series signals.
2) To determine the correlation between demographic and hand anthropometric dimensions, and the HGS as well as HGE of young Malaysian female.
3) To develop an intelligent predictive model of HGS and HGE.

1.4 Scope

The scope of the research includes the recruitment of selected 45 female volunteers with age mean of 22.40 ± 3.71 years. Volunteers were taken from students and staff of the Electrical and Electronic Engineering Faculty, Universiti Malaysia Pahang. This group of volunteers is assumed to represent young Malaysian female population. The inclusion and exclusion criteria in recruiting the volunteers are listed as follows:

Inclusion criteria:

i. Normal healthy female volunteer in age group of 18 to 30 years. (Which was assessed by questionnaire SF-36)
ii. Volunteer with right hand dominance or left hand dominance. (Dominant hand is defined as the preferred hand used in daily activity like writing, eating and handling heavy objects).

Exclusion criteria:

i. any history of hand, forearm, elbow or shoulder problems
ii. any injury to upper extremity

After considering the inclusion and exclusion criteria, volunteers' HGS and HGE were assessed for both hands. The device which is designed for the assessment fulfills the criteria of optimal grip span sizes which can produce maximal grip strength. This device is linked to the designed Graphic User Interface (GUI) that records grip force applied versus time. During the assessment, volunteers followed the data collection protocol outlined by American Society of Hand Therapist (ASHT).

There are several assumptions that have been made during the experiments. Firstly, the volunteers exerted maximum effort during all tests. Then, the testing environment was sufficiently stable to rule out any effect due to factors such as room temperature and lighting. Lastly an adjustable chair is assumed comfortable for all volunteers to alter the seat height to accommodate their different size.

1.5 Thesis Outline

This thesis is divided into six main chapters that are organized as follows. In Chapter 1, introductory which includes the background, problem statement, objectives and scope of the research are presented. Literature reviews related to this research are covered in Chapter 2. Chapter 3 presents the development of hand grip strength and endurance measuring system. In this section the

description of the related hardware components and the software designed to carry out the experiment are presented. Next, the details of data collection process, analysis of the data and the development of the intelligent predictive model are presented in Chapter 4. Chapter 5 presents the result of the correlation and discusses the performance analysis of ANFIS predictive model. Lastly, the conclusion of this project and some recommendations for future work are discussed in Chapter 6.

REFERENCES

Adams, S. K. (2006). Hand Grip and Pinch Strength. *International Encyclopedia of Ergonomics and Human Factors, Second Edition - 3 Volume Set*: CRC Press.

Agnew, P. J., & Maas, F. (1982). Hand Function Related to Age and Sex. *Archives of Physical Medicine and Rehabilitation, 63*(6), 269-271.

Ahmad., R. K. R., Yap, A.-P., Lin, P.-Q., Kamarul, T. (2010) Linear and Nonlinear Modeling of Adult Malaysian Population's Hand Grip Strength. *Mathematical/Analytical Modelling and Computer Simulation (AMS), 2010 Fourth Asia International Conference on* , 258-260.

Aldair, A. A., & Wang, W. J. (2011). Design an Intelligent Controller for Full Vehicle Nonlinear Active Suspension Systems. *International Journal on Smart Sensing and Intelligent Systems, 4*(2), 224-243.

Ali Akcayol, M. (2004). Application of adaptive neuro-fuzzy controller for SRM. *Advances in Engineering software, 35*(3), 129-137.

Anakwe, R. E., Huntley, J. S., & McEachan, J. E. (2007). Grip Strength and Forearm Circumference in a Healthy Population. *Journal of Hand Surgery European Volume , 32*(2), 203-209.

Andrews, A. W., Thomas, M. W., Bohannon, R. W. (1996). Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Physical Therapy, 76*(3), 248–259.

Areed, F. G., Haikal, A. Y., & Mohammed, R. H. (2010). Adaptive Neuro-fuzzy Control of an Induction Motor. *Ain Shams Engineering Journal, 1*(1), 71-78.

Armstrong, C. A., & Oldham, J. A. (1999). A Comparison of Dominant and Non-dominant Hand Strengths. *Journal of Hand Surgery Bristish Volume, 24*(4), 421-425.

Arroyo, P., Lera, L., Sanchez, H., Bunout, D., Santos, J. L., & Albala, C. (2007). Anthropometry, Body Composition and Functional Limitations in the Elderly. *Revista medica de Chile, 135*(7), 846-854.

Atsalakis, G. S., & Valavanis, K. P. (2009). Forecasting Stock Market Short-term Trends using a Neuro-fuzzy Based Methodology. *Expert Systems with Applications, 36*(7), 10696-10707.

Azamathulla, H. M., Chang, C. K., Ab Ghani, A., Ariffin, J., Zakaria, N. A., & Abu Hasan, Z. (2009). An ANFIS-based Approach for Predicting the Bed Load for Moderately Sized Rivers. *Journal of Hydro-environment Research, 3*(1), 35-44.

Baba, A. (1999). Statistik Penyelididkan dalam Pendidikan dan Sains Sosial. . *Bangi : Penerbit Universiti Kebangsaan Malaysia.*

Bandyopadhyay, A. (2008). Body Composition and Hand Grip Strength in Male Brick-field Workers. *Malaysian Journal of Medical Sciences, 15*(1), 31-36.

Baseri, H., & Alinejad, G. (2011). ANFIS Modeling of the Surface Roughness in Grinding Process. *World Academy of Science Engineering and Technology, 5*(1), 400-404.

Baylar, A., Hanbay, D., & Ozpolat, E. (2008). An Expert System for Predicting Aeration Performance of Weirs by using ANFIS. *Expert Systems with Applications, 35*(3), 1214-1222.

Björing, G., Johansson, L., & Hägg, G. M. (1999). Choice of Handle Characteristics for Pistol Grip Power Tools. *International Journal of Industrial Ergonomics, 24*(6), 647-656.

Bohannon, R. W. (1997). Reference values for extremity muscle strength obtained by handheld dynamometer from adults aged 20 to 79 years. *Archives of Pysical Medicine and Rehabilitation, 78,* 26-32.

Bohannon, R. W. (2001). Dynamometer Measurements of Hand-grip Strength Predict Multiple Outcomes. *Perceptual and Motor Skills, 93*(2), 323-328.

Bohannon, R. W. (2008). Hand-grip Dynamometry Predicts Future Outcomes in Aging Adults. *Journal of Geriatric Physical Therapy, 31*(1), 3-10.

Bohannon, R. W., Peolsson, A., Massy-Westropp, N., Desrosiers, J., & Bear-Lehman, J. (2006). Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. *Physiotherapy, 92*(1), 11-15.

Boissy, P., Bourbonnais, D., Carlotti, M. M., Gravel, D., & Arsenault, B. A. (1999). Maximal grip force in chronic stroke subjects and its relationship to global upper extremity function. *Clinical Rehabilitation, 13*(4), 354-362.

Campbell, M. J. & Swinscow, T. D. V., (2011). *Statistics at square one*, Chichester: John Wiley & Sons.

Chandrasekaran, B., Ghosh, A., Prasad, C., Krishnan, K., & Chandrasharma, B. (2010). Age and anthropometric traits predict handgrip strength in healthy normals. *Journal of Hand and Microsurgery, 2*(2), 58-61.

Chang, F.-John, & Chang, Y.-Ting. (2006). Adaptive neuro-fuzzy inference system for prediction of water level in reservoir. *Advances in Water Resources, 29*(1), 1-10.

Chatterjee, S., Chowdhuri, B. J. (1991). Comparison of grip strength and isometric endurance between the right and left hands of men and their relationships with age and other physical parameters. *Journal of Human Ergology, 20*(1), 41-50.

Chilima, D. M., & Ismail, S. J. (2001). Nutrition and handgrip strength of older adults in rural Malawi. *Public Health Nutrition, 4*(1), 11-17.

Chong, C. K., Tseng, C. H., Wong, M. K., & Tai, T. Y. (1994). Grip and pinch strength in Chinese adults and their relationship with anthropometric factors. *Journal of the Formosan Medical Association, 93*(7), 616-621.

Coronell, C., Orozco-Levi, M., Mendez, R., Ramírez-Sarmiento, A., Galdiz, J. B., & Gea, J. (2004). Relevance of assessing quadriceps endurance in patients with COPD. *European Respiratory Journal, 24*(1), 129-136.

Coldham, F., Lewis, J., & Lee, H. (2006). The reliability of one vs. three grip trials in symptomatic and asymptomatic subjects. J*ournal of Hand Therapy, 19*(3), 318-26.

Danker-McDermot, H. (2004). A Fuzzy/Neural Approach to Cost Prediction with Small Data Sets*. Master's thesis, University of New Orleans Theses and Dissertations.*

De, A. K., Debnath, P. K., Dey, N. K., & Nagchaudhuri, J. (1980). Respiratory performance and grip strength tests in Indian school bodys of different socio-economic status. *British Journal of Sports Medicine, 14*(2-3), 145-148.

Dempsey, P. G., & Ayoub, M. M. (1996). The influence of gender, grasp type, pinch width and wrist position on sustained pinch strength. *International Journal of Industrial Ergonomics, 17*(3), 259-273.

Desrosiers, J., Bravo, G., & Hebert, R. (1997). Isometric grip endurance of healthy elderly men and women. *Archives of Gerontology and Geriatrics, 24*(1), 75-85.

Desrosiers, J., Bravo, G., Hebert, R., & Dutil, E. (1995). Normative data for grip strength of elderly men and women. *American Journal of Occupational Therapy, 49*(7), 637-644.

Di Monaco, M., Di Monaco, R., Manca, M., & Cavanna, A. (2000). Handgrip strength is an independent predictor of distal radius bone mineral density in postmenopausal women. *Clinical Rheumatology, 19*(6), 473-476.

Eksioglu, M. (2004). Relative optimum grip span as a function of hand anthropometry. *International Journal of Industrial Ergonomics, 34*(1), 1-12.

Elabd, S., & Schlenkhoff, A. (2009). ANFIS and BP neural network for travel time prediction. *World Academy of Science, Engineering and Technology, 57*, 116-121.

Ertem, K., Harma, A., Cetin, A., Elmali, N., Yologlu, S., Bostan, H., Sakarya, B. (2005). An investigation of hand dominance, average versus maximum grip strength, body mass index and ages as determinants for hand evaluation. *Isokinetics and Exercise Science, 13*(3), 223-227.

Fess, E., & Moran, C. (1981). Clinical assessment recommendations. *American Society of Hand Therapists.*

Fess, E. (1987). A method of checking Jamar dynamometer reliability. *Journal of Hand Therapy, 1* (1), 28-32.

Firrell, J. C., & Crain, G. M. (1996). Which setting of the dynamometer provides maximal grip strength? *Journal of Hand Surgery, 21*(3), 397-401.

Fransson, C., & Winkel, J. (1991). Hand strength: the influence of grip span and grip type. *Ergonomics, 34*(7), 881-892.

Fry, A. C., Ciroslan, D., Fry, M. D., LeRoux, C. D., Schilling, B. K., & Chiu, L. Z. (2006). Anthropometric and performance variables discriminating elite American junior men weightlifters. *Journal of Strength and Conditioning Research, 20*(4), 861-866.

Goodwin, L. D., & Leech, N. L. (2006). Understanding Correlation: Factors That Affect the Size of r. *The Journal of Experimental Education, 74*(3), 249-266.

Grigorie, T. L., & Botez, R. M. (2009). Adaptive neuro-fuzzy inference system-based controllers for smart material actuator modelling. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 223*(6), 655-668.

Güneri, A. F., Ertay, T., & Yücel, A. (2011). An approach based on ANFIS input selection and modeling for supplier selection problem. *Expert Systems with Applications, 38*(12), 14907-14917.

Günther, C. M., Bürger, A., Rickert, M., Crispin, A., & Schulz, C. U. (2008). Grip strength in healthy caucasian adults: reference values. *The Journal of Hand Surgery, 33*(4), 558-565.

Hanten,, W. P., Chen W. Y., Austin, A. A., Brooks, R. E., Carter, H. C., Law, C. A., Morgan, M. K., Sanders, D. J., Swan, C. A., Vanderslice, A. L. (1999). Maximum grip strength in normal subjects from 20 to 64 years of age. *Journal of Hand Therapy, 12*(3), 193-200.

Hosoz, M., Ertunc, H. M., & Bulgurcu, H. (2011). An adaptive neuro-fuzzy inference system model for predicting the performance of a

refrigeration system with a cooling tower. *Expert Systems with Applications, 38*(11), 14148-14155.

Hossain, M. G., Zyroul, R., Pereira, B. P., & Kamarul, T. (2012). Multiple regression analysis of factors influencing dominant hand grip strength in an adult Malaysian population. *Journal of Hand Surgery European Volume, 37*(1), 65-70.

Hossain, S. J., & Ahmad, N. (2012). Surface Roughness Prediction Model for Ball End Milling Operation Using Artificial Intelligence. *Management Science and Engineering, 6*(2), 41-54.

Nuzzo, R. (2014). Scientific method: Statistical errors . *Nature 506* (7487): 150.

Imrhan, S. N. (2006). Hand Grip Characteristics and Strength. *International Encyclopedia of Ergonomics and Human Factors, Second Edition - 3 Volume Set*: CRC Press.

Imrhan, S. N. (1999). The influence of grip width on two-handed grip strengths in females. *International Journal of Industrial Ergonomics, 25*(2), 187-194.

Incel, N. A., Ceceli, E., Durukan, P. B., Erdem, H. R., & Yorgancioglu, Z. R. (2002). Grip strength: effect of hand dominance. *Singapore Medical Journal, 43*(5), 234-237.

Innes E. (1999). Handgrip strength testing: A review of literature. *Australian Occupational Therapy Journal, 46*(3), 120–140.

Jang, J.-S. R. (1992). Self-learning fuzzy controllers based on temporal backpropagation. *Neural Networks, IEEE Transactions on, 3*(5), 714-723.

Jang, J.-S. R. (1993). ANFIS: adaptive-network-based fuzzy inference system. *Systems, Man and Cybernetics, IEEE Transactions on, 23*(3), 665-685.

Jang, J.-S. R. (1996). Input selection for ANFIS learning. *Fuzzy Systems, 1996, Proceedings of the Fifth IEEE International Conference on (Volume:2),* 1493-1499.

Jang, J.-S. R. Jang & Gulley, N. (1995). The Fuzzy Logic Toolbox for use with MATLAB, The MathWorks, Inc., Natick, Massachusetts.

Jurimae, T., Hurbo, T., & Jurimae, J. (2009). Relationship of handgrip strength with anthropometric and body composition variables in prepubertal children. *Journal of Comparative Human Biology, 60*(3), 225-238.

Kaburagi, T., Hirasawa, R., Yoshino, H., Odaka, Y., Satomi, M., Nakano, M., Fujimoto, E., Kabasawa, K., & Sato, K. (2011). Nutritional status is strongly correlated with grip strength and depression in community-living elderly Japanese. *Public Health Nutrition, 14*(11), 1893-1899.

Kamarul, T., Ahmad, T. S., & Loh, W. Y. (2006a). Hand grip strength in the adult Malaysian population. *Journal of Orthopaedic Surgery (Hong Kong), 14*(2), 172-177.

Kamarul, T., Ahmad, T. S., & Loh, W. Y. (2006b). A novel and improved method of predicting hand grip strength in the adult Malaysian population. *Medical Journal of Malaysia, 61 Suppl B*, 37-44.

Kaminsky, E. J., & Douglas, F. (2003). A fuzzy-neural highly accurate cost estimating model (HACEM). *The Proceedings of 7th Joint Conference on Information Sciences,* 1035-1039.

Kannathal, N., Lim, C. M., Rajendra A. U., & Sadasivan, P. K. (2006). Cardiac state diagnosis using adaptive neuro-fuzzy technique. *Medical Engineering & Physics, 28*(8), 809-815.

Kärkkäinen, M., Rikkonen. T., Kröger, H., Sirola. J., Tuppurainen, M., Salovaara, K., Arokoski, J., Jurvelin, J., Honkanen, R., Alhava, E. (2009). Physical tests for patient selection for bone mineral density measurements in postmenopausal women. *Bone, 44*(4), 660-665.

Khajeh, A., Modarress, H., & Rezaee, B. (2009). Application of adaptive neuro-fuzzy inference system for solubility prediction of carbon dioxide in polymers. *Expert Systems with Applications, 36*(3), 5728-5732.

Koley, S., & Singh, A. P. (2009). An association of dominant hand grip strength with some anthropometric variables in Indian collegiate population. *Anthropologischer Anzeiger, 67*(1), 21-28.

Koley, S., Kaur, S., & Sandhu, J. (2011). Correlations of handgrip strength and some anthropometric variables in Indian inter-university female handball players. *Sport Science Review, 20*(3-4), 57-68.

Kurnaz, S., Cetin, O., & Kaynak, O. (2010). Adaptive neuro-fuzzy inference system based autonomous flight control of unmanned air vehicles. *Expert Systems with Applications, 37*(2), 1229-1234.

Li, K., Hewson, D. J., Duchene, J., & Hogrel, J. Y. (2010). Predicting maximal grip strength using hand circumference. *Manual Therapy, 15*(6), 579-585.

Leonard, Y., & Deurenberg-Yap, M., Health Promotion Board, The Redefined BMI for Asians, *SNDA Newsline*. September to December 2005, pp. 6-7.

Lucki, N. C., & Nicolay, C. W. (2007). Phenotypic plasticity and functional asymmetry in response to grip forces exerted by intercollegiate tennis players. *American Journal of Human Biology, 19*(4), 566-577.

Massy-Westropp, N., Rankin, W., Ahern, M., Krishnan, J., & Hearn, T. C. (2004). Measuring grip strength in normal adults: Reference ranges and a comparison of electronic and hydraulic instruments. *Journal of Hand Surgery, 29*(3), 514-519.

Massy-Westropp, N. M., Gill, T. K., Taylor, A. W., Bohannon, R. W., & Hill, C. L. (2011). Hand Grip Strength: age and gender stratified normative data in a population-based study. *BMC research notes, 4*(1), 127.

Mateo Lázaro, M. L., Penacho Lázaro, M. A., Berisa Losantos, F., & Plaza Bayo, A. (2008). New tables on hand strength in the adult population from Teruel. *Nutricion hospitalaria, 23*(1), 35-40.

Mathiowetz, V. (2002). Comparison of Rolyan and Jamar dynamometers for measuring grip strength. *Occupational therapy international, 9*(3), 201-209.

Mathiowetz, V., Kashman, N., Volland, G., Weber, K., Dowe, M., & Rogers, S. (1985). Grip and pinch strength: normative data for adults. *Archives of Physical Medicine and Rehabilitation, 66*(2), 69-74.

Mitsionis, G., Pakos, E. E., Stafilas, K. S., Paschos, N., Papakostas, T., & Beris, A. E. (2009). Normative data on hand grip strength in a Greek adult population. *International orthopaedics, 33*(3), 713-717.

Mohammad, Y. A. A. (2005). Anthropometric characteristics of the hand based on laterality and sex among Jordanian. *International Journal of Industrial Ergonomics, 35*(8), 747-754.

Molenaar, H. M., Zuidam, J. M., Selles, R. W., Stam, H. J., & Hovius, S. E. (2008). Age-specific reliability of two grip- strength dynamometers when used by children. *Journal of Bone and Joint Surgery, American Volume, 90*(5), 1053-1059.

Moradkhani, H., Hsu, K.-lin., Gupta, H. V., & Sorooshian, S. (2004). Improved streamflow forecasting using self-organizing radial basis function artificial neural networks. *Journal of Hydrology, 295*(1), 246-262.

Moy, F., Chang, E., & Kee, K. (2011). Predictors of Handgrip Strength among the Free Living Elderly in Rural Pahang, Malaysia. *Iranian Journal of Public Health, 40*(4), 44-53.

Myers, R. H., Montgomery, D. C., & vining, G. G. (2002). Generalized Linear Models: With Applications in Engineering and Sciences. J*ohn Wiley & Sons,* New York.

Napier, J. R. (1956). The prehensile movements of the human hand. *Journal of Bone & Joint Surgery British Volume, 38-B*(4), 902-913.

Nicolay, C. W., Kenney, J. L., & Lucki, N. C. (2008). Grip strength and endurance throughout the menstrual cycle in eumenorrheic and women using oral contraceptives. *International Journal of Industrial Ergonomics, 38*(2), 211-221.

Nicolay, C. W., & Walker, A. L. (2005). Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. *International Journal of Industrial Ergonomics, 35*(7), 605-618.

Norman, K., Stobäus, N., Gonzalez, M. C., Schulzke, J., & Pirlich, M. (2011). Hand grip strength: outcome predictor and marker of nutritional status. *Clinical Nutrition, 30*(2), 135-142.

Pieterse, S., Manandhar, M., & Ismail, S. (2002). The association between nutritional status and handgrip strength in older Rwandan refugees. *European Journal of Clinical Nutrition, 56*(10), 933-939.

Puh, U. (2010). Age-related and sex-related differences in hand and pinch grip strength in adults. *International Journal of Rehabilitation Research, 33*(1), 4-11.

Polat, K. & Günes, S. (2007). An expert system approach based on principal component analysis and adaptive neuro-fuzzy inference system to diagnosis of diabetes disease. *Digital Signal Process, 17*(4), 702-710.

Rantanen, T., Masaki, K., Foley, D., Izmirlian, G., White, L., & Guralnik, J. M. (1998). Grip strength changes over 27 yr in Japanese-American men. *Journal of Applied Physiology, 85*(6), 2047-2053.

Reuter, S. E., Massy-Westropp, N., Evans, A. M. (2011). Reliability and validity of indices of hand-grip strength and endurance. *Australian Occupational Therapy Journal, 58*(2), 82-87.

Robertson, L. D., Mullinax, C. M., Brodowicz, G. R., & Swafford, A. R.. (1996). Muscular fatigue patterning in power grip assessment. *Journal of Occupational Rehabilitation, 6*(1), 71-85.

Rosenblatt, J. (2001). Basic statistical methods and models for the sciences: CRC Press.

Roy, S. S. (2005). Design of adaptive neuro-fuzzy inference system for predicting surface roughness in turning operation. *Journal of Scientific and Industrial Research, 64*(9), 653.

Ruiz-Ruiz, J., Mesa, J. L., Gutierrez, A., & Castillo, M. J. (2002). Hand size influences optimal grip span in women but not in men. *Journal of Hand Surgery (American Volume), 27*(5), 897-901.

Russell, D. M., Leiter, L. A., Whitwell, J., Marliss, E. B., & Jeejeebhoy, K. N. (1983). Skeletal muscle function during hypocaloric diets and fasting: a comparison with standard nutritional assessment parameters. *The American journal of clinical nutrition, 37*(1), 133-138.

Shetty S. C., Parakandy S. G., & Nagaraja S. C. (2012). Influence of various anthropometric parameters on handgrip strength and endurance in young males and females. *International Journal of Biological & Medical Research, 3*(3), 2153 -2157.

Singh, R., Kainthola, A., & Singh, T. N. (2012). Estimation of elastic constant of rocks using an ANFIS approach. *Applied Soft Computing, 12*(1), 40-45.

Sisto, S. A., & Dyson-Hudson, T. (2007). Dynamometry testing in spinal cord injury. *Journal of rehabilitation research and development*, *44*(1), 123-136.

Sivakumar, R., Manic, K. S., Nerthiga, V., Akila, R., & Balu, K. (2010). Application of Fuzzy Model Predictive Control in Multivariable Control of Distillation Column. *International Journal of Chemical Engineering and Applications, 1*(1), 39-42.

Subasi, A. (2007). Application of adaptive neuro-fuzzy inference system for epileptic seizure detection using wavelet feature extraction. *Computers in Biology and Medicine, 37*(2), 227–244.

Talsania, J. S., & Kozin, S. H. (1998). Normal digital contribution to grip strength assessed by a computerized digital dynamometer. *Journal of Hand Surgery(British Volume), 23*(2), 162-166.

Tian, L., & Collins, C. (2005). Adaptive neuro-fuzzy control of a flexible manipulator. *Mechatronics, 15*(10), 1305-1320.

Toosi, A. N., Kahani, M., & Monsefi, R. (2006). Network Intrusion Detection based on Neuro-fuzzy classification. *Paper presented at the Computing & Informatics, 2006. ICOCI'06. International Conference on*.

Trampisch, U. S., Franke, J., Jedamzik, N., Hinrichs, T., & Platen, P. (2012). Optimal Jamar dynamometer handle position to assess maximal isometric hand grip strength in epidemiological studies. *Journal of Hand Surgery American Volume, 37*(11), 2368-2373.

Vasu, M., & Mital, A. (2000). Evaluation of the validity of anthropometric design assumptions. *International Journal of Industrial Ergonomics, 26*(1), 19-37.

Vaz, M., Hunsberger, S., & Diffey, B. (2002). Prediction equations for handgrip strength in healthy Indian male and female subjects encompassing a wide age range. *Annals of Human Biology, 29*(2), 131-141.

Virant-Klun, I., & Virant, J. (1999). Fuzzy Logic Alternative for Analysis in the Biomedical Sciences. *Computers and Biomedical Research, 32*(4), 305-321.

Visnapuu, M., & Jürimäe, T. (2007). Handgrip strength and hand dimensions in young handball and basketball players. *The Journal of Strength & Conditioning Research, 21*(3), 923-929.

Wahida Banu, R. S. D., Shakila Banu, A, & Manoj, D. (2011). Identification and control of nonlinear systems using soft computing techniques. *International Journal of Modeling and Optimization, 1*(1), 24-28.

Waldo, B. R. (1996). Grip Strength Testing. *Strength & Conditioning Journal, 18*(5), 32-35.

Wang, Y.-Ming, & Elhag, T. (2008). An adaptive neuro-fuzzy inference system for bridge risk assessment. *Expert Systems with Applications, 34*(4), 3099-3106.

Watanabe, T., Owashi, K., Kanauchi, Y., Mura, N., Takahara, M., & Ogino, T. (2005). The short-term reliability of grip strength measurement and the effects of posture and grip span. *The Journal of hand surgery, 30*(3), 603-609.

Williamson, T. L., & Rice, V. J. (1992). Re-evaluation of the Caldwell Regimen: the effect of instruction on handgrip strength in men and women. *Advances in Industrial Ergonomics and Safety IV. Taylor & Francis, London*, 675-682.

Wu, S. W., Wu, S. F., Liang, H. W., Wu, Z. T., & Huang, S. (2009). Measuring factors affecting grip strength in a Taiwan Chinese population and a comparison with consolidated norms. *Applied Ergonomics, 40*(4), 811-815.