UNIVERSITI PUTRA MALAYSIA

QUANTIFICATION OF GENTLE PULL USING PINCH-PULL GRIPPING SYSTEM BASED ON FUGL MEYER AND MANUAL MUSCLE TEST PROTOCOLS FOR REHABILITATION

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By

Abdallah S Z Alsayed

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

June 2020

DEDICATION

This thesis is wholeheartedly dedicated to:

My praiseworthy parents (SAMIR AND MAHA),

My brothers and sister

And lastly, we dedicated this work to the Almighty GOD, thank you for the guidance, strength, power of mind, protection and skills and for giving us a healthy life. All of these, we offer to you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chair : Raja Mohd Kamil bin Raja Ahmad, PhD
Faculty : Engineering

Fugl Meyer Assessment (FMA) and Manual Muscle Test (MMT) protocols are widely used in post-stroke rehabilitation assessment. In the protocol related to pinch function evaluation, the patients are required to pinch a pincer object and the therapists would apply some resistance equivalent to 4/5 score of MMT to distinguish between subjects whom is fully recovered and yet to recover. The resistance applied by the therapist using 4/5 MMT is also described as applying gentle pull in FMA protocol. Subject's ability or inability to pinch and resist the gentle pull would lead to either score 1 (not recovered) or score 2 (recovered). However, the gentle pull (4/5 MMT) is subjective which may result in intra-rater and inter-rater variations. In this study, the gentle pull is determined quantitatively using a developed pinch-pull gripping system. The pinch-pull gripping system consists of a customized pinch force load cell measuring the pinch force, pulling force load cell measuring the pulling force, linear actuator applying the automatic pull, and displacement sensor to track the pinch slip. In determining the quantitative value of gentle pull, four therapists were recruited at Universiti Putra Malaysia Teaching Hospital and instructed to pinch a pincer object and exert a gentle pull equivalent to 4/5 MMT as they would apply in clinical practice. The results showed that the quantitative value of the therapist's gentle pull is 6.59±0.94 N. In order to investigate if this gentle pull force is able to distinguish the normal volunteers, fifty normal volunteers representing score 2 were recruited and their pulling forces were measured and compared with the quantitative value of the gentle pull. The volunteers were instructed to pinch the pincer object and resist the automatic pull of the linear actuator as much as possible before the pincer object slips away from their fingers. The results show that the normal volunteers exerted mean pulling forces at slip away of 14.84±3.57 N and 13±2.72 N for right and left hands, respectively. This indicates that the normal volunteers attributed to score 2 is able to resist the gentle pull

exerted by the therapist. Furthermore, the amount of gentle pull applied by the therapists is indeed suitable and that the pinch-pull gripping system is able to measure the pulling force accurately. The results also show that despite the volunteers exhibiting a small slip displacement, they could still resist the increase in the pulling force up to slip away. Thus, the presence of slip displacement prior to slip away is inadequate to judge the subject's ability to resist the gentle pull. In rehabilitation, the pinch-pull gripping system can be used to evaluate the recovery of pinch function. In order to achieve a full recovery, the patient should be able to pinch the pincer object and resist the 6.59 N pull exerted by the pinch-pull gripping system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KUANTIFIKASI TARIKAN LEMBUT DENGAN MENGGUNAKAN SISTEM PENARIKAN DENGAN MENCUBIT BERDASARKAN FUGL MEYER DAN PROTOKOL UJIAN OTOT BAGI PEMULIHAN

Oleh

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Pengerusi : Raja Mohd Kamil bin Raja Ahmad, PhD
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Protokol Fugl Meyer Assessment (*FMA*) dan Manual Muscle Test (*MMT*) digunakan secara meluas dalam penilaian pemulihan selepas strok. Dalam protokol yang berkaitan dengan penilaian fungsi mencubit, pasien diminta untuk mencubit objek pincer dan ahli terapi akan menerapkan beberapa ketahanan yang setara dengan skor *MMT* 4/5 untuk membezakan antara subjek yang pulih sepenuhnya dan belum pulih. Rintangan yang diterapkan oleh ahli terapi menggunakan 4/5 *MMT* juga digambarkan sebagai menerapkan tarikan lembut dalam protokol *FMA*. Kemampuan atau ketidakmampuan subjek untuk mencubit dan menahan tarikan lembut akan menyebabkan skor 1 (tidak pulih) atau skor 2 (pulih). Walau bagaimanapun, tarikan lembut (4/5 *MMT*) bersifat subjektif yang boleh mengakibatkan variasi dalam penilai dan antara penilai. Dalam kajian ini, tarikan lembut ditentukan secara kuantitatif menggunakan sistem mencengkeram cubitan-tarikan yang dikembangkan. Sistem mencengkeram cubitan-tarikan terdiri dari sel beban daya cubit yang disesuaikan yang mengukur daya cubit, sel beban daya tarik mengukur daya tarik, penggerak linear yang menerapkan tarikan automatik, dan sensor perpindahan untuk mengesan kegelinciran cubitan. Dalam menentukan nilai kuantitatif tarikan lembut, empat ahli terapi direkrut di Hospital Pegajaran Universiti Putra Malaysia dan diarahkan untuk mencubit objek penjepit dan melakukan tarikan lembut setara dengan 4/5 *MMT* seperti yang berlaku dalam praktik klinikal. Hasil kajian menunjukkan bahawa nilai kuantitatif tarikan lembut ahli terapi adalah 6,59 ± 0,94 N. Untuk mengkaji apakah daya tarikan lembut ini dapat membezakan sukarelawan normal, lima puluh sukarelawan normal yang mewakili skor 2 direkrut dan daya tarikan mereka diukur dan berbanding dengan nilai kuantitatif tarikan lembut. Para sukarelawan diarahkan untuk mencubit objek pincer dan menahan tarikan automatik linear penggerak sebanyak mungkin sebelum objek pincer terlepas dari jari mereka. Hasil kajian menunjukkan bahawa sukarelawan

normal menggunakan daya tarik rata-rata pada jarak 14.84 ± 3.57 N dan 13 ± 2.72 N untuk tangan kanan dan kiri, masing-masing. Ini menunjukkan bahawa sukarelawan normal yang dikaitkan dengan skor 2 mampu menahan tarikan lembut yang dilakukan oleh ahli terapi. Tambahan pula, jumlah tarikan lembut yang dilakukan oleh ahli terapi sememangnya sesuai dan sistem mencengkeram cubitan-tarikan mampu mengukur daya tarikan dengan tepat. Hasilnya juga menunjukkan bahawa walaupun para sukarelawan menunjukkan pergeseran kegelinciran yang kecil, mereka masih dapat menahan peningkatan daya tarik hingga tergelincir. Oleh itu, kehadiran kegelinciran sebelum tergelincir tidak memadai untuk menilai kemampuan subjek untuk menolak tarikan lembut tersebut. Dalam pemulihan, sistem mencengkeram penarik dapat digunakan untuk menilai pemulihan fungsi mencubit. Untuk mencapai pemulihan sepenuhnya, pesakit harus dapat mencubit objek pincer dan menahan tarikan 6.59 N yang dilakukan oleh sistem mencengkeram pinch-pull.

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I certify that a Thesis Examination Committee has met on 8 October 2020 to conduct the final examination of Abdallah SZ Alsayed on her thesis entitled "Quantification of Gentle Pull Using Pinch-Pull Gripping System Based on Fugl Meyer and Manual Muscle Test Protocols for Rehabilitation" 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 Doctor of Philosophy.

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I hereby confirm that:

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LIST OF ABBREVIATIONS

FMA	Fugl Meyer Assessment
MMT	Manual Muscle Test
ARAT	Action Research Arm Test
WMFT	Wolf Motor Function Test
FSR	Force Sensing Resistors
MVC	Maximum Voluntary Contraction
FEA	Finite Element Analysis
CAD	Computer Aided Design
RMSE	Root Mean Square Error
LVDT	Linear Variable Differential Transformer
UPM	Universiti Putra Malaysia

CHAPTER 1

INTRODUCTION

1.1 Overview

A stroke, sometimes called a “brain attack”, is a neurological deficit of brain occurred when the blood flow in the arteries of the brain is cut off which leads to death or disability (Gubbi, Rao, Fang, Yan, & Palaniswami, 2013). Worldwide, stroke is the major cause of death and long-term disability (Lim, Kim, & Kang, 2018). Each year, approximately 15 million people experience a stroke. Of these, 10 million are either temporarily or permanently disabled (Langhorne, Bernhardt, & Kwakkel, 2011). In Malaysia, stroke is the third leading cause of neurological disability according to the Institute for Health Metrics and Evaluation (IHME) (Wan, Hairi, Jenn, & Kamarulzaman, 2014). The stroke disability can take different forms such as motor deficits, language deficits, and cognitive deficits. Of these deficits, 70% of stroke survivors experience motor deficits which include limitation of using hand function in daily life activities (Santisteban et al., 2016). Hand function includes the ability to perform coarse and fine movements, as well as power grasp. Several studies show that the recovery of fine movements related to pinch function takes longer than coarse movements related to power grasp function, and both required long-term recovery (Pessina, Bowley, Rosene, & Moore, 2019). Pinch strength is a common and useful indicator of pinch impairment (El-Katab, Omichi, Srivareerat, & Davenport, 2016). Pinch function impairment is defined as the inability of thumb-index finger to produce strength with sufficient magnitude and directional control, leading to object slipping (K. Li, Nataraj, Marquardt, & Li, 2013).

Available technology for pinch strength assessment involves measurement of maximal static pinch force such as pinch gauge and pinch dynamometer. However, most daily activities involve dynamic pinching (Pennati et al., 2020). Thus, the static pinch force measurement alone cannot assess the pinch impairment completely. There is no single gold standard pinch assessment used in clinical practice and research. Alternative assessments such as Action Research Arm Test (ARAT) (Grattan, Velozo, Skidmore, Page, & Woodbury, 2019), Wolf Motor Function Test (WMFT) (Edwards, Lang, Wagner, Birkenmeier, & Dromerick, 2012), Manual Muscle Test (MMT), and Upper extremity Fugl Meyer Assessment (FMA) (Wolbrecht et al., 2018) which are commonly used as standard assessments for pinch function. Among all available assessments, FMA is arguably the most comprehensive clinical tool for measuring pinch impairment after stroke (Page, Hade, & Persch, 2015). It involves step-by-step procedures and protocol which are performed by therapists. In FMA, the therapists test the patient’s ability to use his index-thumb finger to pinch a pincer object (in which pen or pencil are customarily used) and then test the patient’s ability to exert enough force to stabilize the pincer object against a gentle pull applied by the therapist. In clinical practice, the therapist would apply some resistance equivalent to 4/5 score of MMT and use this reference as a gentle pull such that to prompt the patient to provide enough effort to resist, but not to break the patient ability to resist the gentle pull (See et al., 2013). The scoring criteria of the pinch function are based on a three ordinal scale: Score 0 (severe impairment) given when the patient is unable to execute the pinching at all; Score 1 (moderate impairment) is given when the patient can hold the pincer object, but not against the gentle pull (4/5 MMT); Score 2 (no impairment) is given when the patient firmly holds the pincer object against the gentle pull (4/5 MMT) (See et al., 2013). Score 1 indicates that the pinch function of the patient is not yet recovered, while score 2 indicates a full recovery.

1.2 Motivation and Problem Statement

The motivation for carrying out this research stemmed from the lack of studies related to quantification of gentle pull based on FMA protocol. In the clinical practice of pinch evaluation, See and his colleagues (See et al., 2013) have suggested the 4/5 MMT as the amount of gentle pull to distinguish between score 1 (not recovered) and score 2 (recovered). However, the 4/5 MMT is a qualitative description for the gentle pull which opens the possibility for low intra-rater and inter-rater reliability. Up to now, there is no quantitative value for the gentle pull that would minimizes the subjectivity in exerting the gentle pull among therapists. In addition, the body posture is not standardized among the therapists such that different postures may result in different amount of gentle pull at each posture.
In the last five years, the research community has been working on automating the pinch evaluation based on FMA protocol. Otten and co-authors (P. Otten, J. Kim, & S. Son, 2015a; Otten, Son, & Kim, 2014) have used a hand glove system with built-in Force Sensing Resistors (FSR) to measure the pinch force when the gentle pull is applied. However, some post-stroke survivors have difficulties in wearing the hand glove due to muscle contracture and spasticity. In later studies conducted by Lee et al. (S.-H. Lee, Song, & Kim, 2016a; S. Lee, Lee, & Kim, 2017) the FSR sensors were attached to the pincer object directly such that the patient is no longer required to wear gloves. Furthermore, these studies (Otten, Kim et al. 2015, Lee, Lee et al. 2017) still used a subjective selection for the threshold pinch force based on a therapist to distinguish between scores 1 and 2. In addition, the systems developed in these studies did not measure the quantitative value of gentle pull and the pulling force of subjects which are essential to distinguish between score 1 and score 2..

The systems developed in the (P. Otten, J. Kim, & S. H. Son, 2015b) and (S. Lee, Lee, & Kim, 2018) are subjected to some limitations due to the FSR sensors used to measure the pinch force. FSR sensors have been widely used in upper extremity assessment and rehabilitation systems, but they suffer from performance variation as well as low performance (Paredes-Madrid, Emmi, Garcia, & De Santos, 2011; Parmar, Khodasevych, & Troynikov, 2017). The variation in performance can be attributed to the conductive material on the sensor layers being sensitive to temperature and deformation on the surface (Rivera, Carrillo, Chacón, Herrera, & Bojorquez, 2007). In addition, the variation in performance can be attributed to the inability to follow the standard calibration procedures resulting in different calibration results compared to those in the manufacturer's datasheet. On the other hand, low performance is attributed to variation in voltage gain, high hysteresis, and low repeatability (A. Almassri et al., 2018). Likitlersuang et al. (Likitlersuang, Leineweber, & Andrysek, 2017) investigated the performance of thin-film sensors (FlexiForce) when attached to human skin. The results showed a large measurement error of 23% using the standard calibration procedures. Moreover, the pressure distribution of fingertip skin on the sensing area is non-uniform in the case of slipping that leads to inaccurate force measurements.

1.3 Research Questions and Hypotheses

Due to the previous gaps in the current research related to pinch evaluation based on FMA and MMT protocols, this study is conducted to address the following research questions: 1) How gentle pull of therapists can be quantitatively measured; 2) What is the quantitative value of therapist's gentle pull; 3) Is the quantitative value of gentle pull suitable to distinguish the pulling forces of normal volunteers.

According to the FMA and MMT protocols, the subject should resist the gentle pull (4/5 MMT) to avoid slip away. The pincer object would totally slip when the subject is no longer able to exert enough pinch force. In this study, the normal volunteers represent the score 2 of FMA. Hence it is hypothesized that all volunteers will exert pulling forces higher than the quantitative value of therapist's gentle pull (4/5 MMT).

1.4 Research Objectives

By referring to the problems explained in the previous section, the main contribution of this study is represented by quantifying the gentle pull (4/5 MMT) of the therapists based on Fugl Meyer and Manual Muscle Test protocols as used in the clinical practice. The research objectives are listed as follows:

1. To develop a pinch-pull gripping system for gentle pull measurements based on FMA and MMT protocols.
2. To determine the quantitative value of therapist's gentle pull (4/5 MMT) using the developed pinch-pull gripping system.
3. To compare the quantitative value of therapist's gentle pull (4/5 MMT) with the pulling force of normal volunteers.

1.5 Research Scope and Limitation

- In this study, the pinch-pull gripping system is an initial prototype used in the lab environment. The pincer object is small diameter cylindrical object to mimic a pencil or pen like object used in FMA. To avoid any damage to the pincer object while pinching, the pincer object is made of copper alloy. Using another material to fabricate the pincer object would result in different pinch and pulling force measurements due to the fact that each material has a different coefficient of friction. The other components, including load cell, LVDT sensor, and linear actuator, are available on the shelf without requiring any customization. Using these components allow fast and accurate system development which serves the purpose of data collection of gentle pull, pulling force, and slip displacement. In determining the threshold value to distinguish between score 1 and score 2, first approach is the classification based technique which can be adopted such that pulling force measurements can be collected from two clusters of normal volunteers and stroke patients. Then, the threshold value between the two clusters can be determined as the gentle pull that distinguishes between score 1 and score 2. Second approach is the threshold values decided based on the amount of gentle pull exerted by the therapists in practice. This predefined threshold is used to differentiate between score 1 and score 2. Thus, by measuring the gentle pull of therapists quantitatively, the threshold value to differentiate between score 1 and score 2 is determined. In this study, the second approach has been adopted through collaboration with a medical doctor at the department of rehabilitation medicine of UPM hospital and the involvement of 4 occupational therapists.

- This study recruits a cohort of young adult males in order to validate the pinch-pull gripping system by comparing the data of normal volunteers representing score 2 and therapist's gentle pull used to distinguish between score 1 and score 2. This population is selected to ensure the recruitment of a large enough pool of volunteers to investigate the pulling force values in a homogenous population (volunteers have the same characteristics). The sample size to represent Malaysia population would be very large (minimum 800 volunteers) in the case that females and people of different ages are involved. Therefore, the comparison between genders and ages is not covered, as this study mainly concentrates on developing a pinch-pull gripping system to measure the quantitative value of therapist's gentle pull and pulling force of normal volunteers based on FMA and MMT protocol. The single-gender group is taken from the Malaysian male students at the Electrical and Electronic Engineering Department, Universiti Putra Malaysia. The right-handers represent 93% of Malaysia population (Nasir, Jaafar et al. 2019) so that they are only recruited in this study. In addition, construction workers and sportsmen are not included due to the fact that these groups have stronger pinch force than the average population as indicated by (Angst et al., 2010).

- This research has several limitations. The pinch and pulling force measurements are evaluated among a cohort of young adult males to ensure recruitment of a large enough sample size to represent a homogenous population. The result of this study motivate further study to generalize the pinch and pulling force data for Malaysians, including female volunteers and people of different ages. During the observational experiment, the finger's moisture and hydration of the volunteers are considered to have the same influence on resisting the pulling force generated from the linear actuator. The results of previous studies indicated that the skin's friction increase when the moisture level is increased by wetting the fingers (Derler, Gerhardt, Lenz, Bertaux, & Hadad, 2009). In addition, the contact area between finger-pad and pincer object is not investigated such that previous studies reported that the contact area has positive relationship with the ability to exert higher pinch force (Barrea, Delhaye, Lefèvre, & Thonnard, 2018). The influence of arm muscles on the pulling force is not investigated among the volunteers to know which muscles are activated while resisting the pulling force. The total slip moment at which the volunteers experience a continuous slipping is not investigated such that it is important to know whether the volunteers release the pincer object due to overwhelming pulling force generated from the linear actuator, or there is no enough contact space at the free end on the pincer object.

1.6 Thesis Layout

This thesis is composed of six chapters. A brief overview, problem statement, objectives, and scope of this study are presented in Chapter 1.

Chapter 2 is a review of previous studies leading to pinching assessment after stroke. It provides a brief introduction on stroke and pinch impairments. Then, the previous studies related to pinch assessment, Fugl Meyer, Manual Muscle Test are reviewed leading to the gap of this study.

Chapter 3 describes the methodology to achieve the research objectives. Section 3.2 presents the methods conducted to develop the pinch-pull gripping system, while Section 3.3 presents the methods conducted to determine the quantitative value of gentle pull from therapists. Section 3.4 presents the methods to compare the pulling force of normal volunteers with gentle pull of the therapists.

Chapter 4 presents the results and discussion obtained from the methods conducted in Chapter 3 including the results of calibration and validation of the pinch-pull gripping system, quantitative value of therapist's gentle pull, and comparison between normal volunteers and therapists.

In Chapter 5, the conclusions for the achieved objectives are presented. Also, recommendations for further research are presented.

REFERENCES

Alciatore, D., & Miranda, R. (1995). The best least-squares line fit Graphics Gems V (pp. 91-97): Elsevier.

Allgöwer, K., & Hermsdörfer, J. (2017). Fine motor skills predict performance in the Jebsen Taylor Hand Function Test after stroke. Clinical Neurophysiology, 128(10), 1858-1871.

Almassri, A., Wan Hasan, W., Ahmad, S., Shafie, S., Wada, C., & Horio, K. (2018). Self-calibration algorithm for a pressure sensor with a real-time approach based on an artificial neural network. Sensors, 18(8), 2561.

Almassri, A. M., Hasan, W. W., Ahmad, S. A., & Ishak, A. J. (2013). A sensitivity study of piezoresistive pressure sensor for robotic hand. Paper presented at the RSM 2013 IEEE Regional Symposium on Micro and Nanoelectronics.

Almassri, A. M., Wan Hasan, W., Ahmad, S. A., Ishak, A. J., Ghazali, A., Talib, D., & Wada, C. (2015). Pressure sensor: state of the art, design, and application for robotic hand. Journal of Sensors, 2015.

Andersen, K. K., & Olsen, T. S. (2018). Risk of ischemic and hemorrhagic strokes in occult and manifest cancers. Stroke, 49(7), 1585-1592.

Angst, F., Drerup, S., Werle, S., Herren, D. B., Simmen, B. R., & Goldhahn, J. (2010). Prediction of grip and key pinch strength in 978 healthy subjects. BMC musculoskeletal disorders, 11(1), 94.

Aslam, M., & Tang, T. (2014). A high resolution capacitive sensing system for the measurement of water content in crude oil. Sensors, 14(7), 11351-11361.

Avisse, J.-B., & Chiron, J. (2000). Wheatstone bridge with temperature gradient compensation: Google Patents.

Barnes, M. (2003). Principles of neurological rehabilitation. Journal of Neurology, Neurosurgery & Psychiatry, 74(suppl 4), iv3-iv7.

Barrea, A., Bulens, D. C., Lefèvre, P., & Thonnard, J.-L. (2016). Simple and reliable method to estimate the fingertip static coefficient of friction in precision grip. IEEE transactions on haptics, 9(4), 492-498.

Barrea, A., Delhaye, B. P., Lefèvre, P., & Thonnard, J.-L. (2018). Perception of partial slips under tangential loading of the fingertip. Scientific reports, 8(1), 1-8.

Bhattacharyya, R., Goswami, S., Ghosh, K. C., Ghosh, S., & Mondal, G. P. (2016). Clinical features and imaging of central poststroke pain. Indian Journal of Pain, 30(1), 34.

Bhuanantanondh, P., Nanta, P., & Mekhora, K. (2018). Determining sincerity of effort based on grip strength test in three wrist positions. Safety and health at work, 9(1), 59-62.

Blennerhassett, J. M., Carey, L. M., & Matyas, T. A. (2006). Grip force regulation during pinch grip lifts under somatosensory guidance: comparison between people with stroke and healthy controls. Archives of physical medicine and rehabilitation, 87(3), 418-429.

Blennerhassett, J. M., Matyas, T. A., & Carey, L. M. (2007). Impaired discrimination of surface friction contributes to pinch grip deficit after stroke. Neurorehabilitation and neural repair, 21(3), 263-272.

Bleyenheuft, Y., & Gordon, A. M. (2014). Precision grip in congenital and acquired hemiparesis: similarities in impairments and implications for neurorehabilitation. Frontiers in human neuroscience, 8, 459.

Bouton, C. E., Shaikhouni, A., Annetta, N. V., Bockbrader, M. A., Friedenberg, D. A., Nielson, D. M., . . . Mysiw, W. J. (2016). Restoring cortical control of functional movement in a human with quadriplegia. Nature, 533(7602), 247.

Caulfield, A. F., Flower, O., Pineda, J. A., & Uddin, S. (2017). Emergency neurological life support: acute non-traumatic weakness. Neurocritical care, 27(1), 29-50.

Charan, J., & Biswas, T. (2013). How to calculate sample size for different study designs in medical research? Indian journal of psychological medicine, 35(2), 121.

Cheng, Y., Su, C., Jia, Y., & Xi, N. (2015). Data correlation approach for slippage detection in robotic manipulations using tactile sensor array. Paper presented at the 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).

Ciesla, N., Dinglas, V., Fan, E., Kho, M., Kuramoto, J., & Needham, D. (2011). Manual muscle testing: a method of measuring extremity muscle strength applied to critically ill patients. JoVE (Journal of Visualized Experiments)(50), e2632.

Conable, K. M., & Rosner, A. L. (2011). A narrative review of manual muscle testing and implications for muscle testing research. Journal of chiropractic medicine, 10(3), 157-165.

Conrad, M. O., Qiu, D., Hoffmann, G., Zhou, P., & Kamper, D. G. (2017). Analysis of muscle fiber conduction velocity during finger flexion and extension after stroke. Topics in stroke rehabilitation, 24(4), 262-268.

Coupar, F. M. (2012). Exploring upper limb interventions after stroke. University of Glasgow.

Daneman, R. (2012). The blood–brain barrier in health and disease. Annals of neurology, 72(5), 648-672.

das Nair, R., Cogger, H., Worthington, E., & Lincoln, N. B. (2016). Cognitive rehabilitation for memory deficits after stroke. Cochrane database of systematic reviews(9).

Davis, F., Andrews, A., Sackey, M., & Owusu-Ofori, S. (2017). Effects of varying friction coefficient on rolling pressure distribution. Journal of Science and Technology (Ghana), 37(2), 11-25.

Deakin, A., Hill, H., & Pomeroy, V. M. (2003). Rough guide to the Fugl-Meyer Assessment: upper limb section. Physiotherapy, 89(12), 751-763.

Derler, S., Gerhardt, L.-C., Lenz, A., Bertaux, E., & Hadad, M. (2009). Friction of human skin against smooth and rough glass as a function of the contact pressure. Tribology International, 42(11-12), 1565-1574.

Diermayr, G., McIsaac, T. L., & Gordon, A. M. (2011). Finger force coordination underlying object manipulation in the elderly–a mini-review. Gerontology, 57(3), 217-227.

Dimitriou, P. (2018). Independence of fingertip force coordination to interference from common tasks. Social Sciences.

Dionísio, A., Duarte, I. C., Patrício, M., & Castelo-Branco, M. (2018). Transcranial magnetic stimulation as an intervention tool to recover from language, swallowing and attentional deficits after stroke: a systematic review. Cerebrovascular Diseases, 46(3-4), 176-183.

Drewniak, E. I., Crisco, J. J., Spenciner, D. B., & Fleming, B. C. (2007). Accuracy of circular contact area measurements with thin-film pressure sensors. Journal of biomechanics, 40(11), 2569-2572.

Duncan, S. F., Saracevic, C. E., & Kakinoki, R. (2013). Biomechanics of the hand. Hand clinics, 29(4), 483-492.

Dvir, Z., & Prushansky, T. (2008). Cervical muscles strength testing: methods and clinical implications. Journal of manipulative and physiological therapeutics, 31(7), 518-524.

Edwards, D. F., Lang, C. E., Wagner, J. M., Birkenmeier, R., & Dromerick, A. W. (2012). An evaluation of the Wolf Motor Function Test in motor trials early after stroke. Archives of physical medicine and rehabilitation, 93(4), 660-668.

El-Katab, S., Omichi, Y., Srivareerat, M., & Davenport, A. (2016). Pinch grip strength as an alternative assessment to hand grip strength for assessing muscle strength in patients with chronic kidney disease treated by haemodialysis: a prospective audit. Journal of human nutrition and dietetics, 29(1), 48-51.

Ellis, M. D., Schut, I., & Dewald, J. P. (2017). Flexion synergy overshadows flexor spasticity during reaching in chronic moderate to severe hemiparetic stroke. Clinical Neurophysiology, 128(7), 1308-1314.

Ertelt, D., Small, S., Solodkin, A., Dettmers, C., McNamara, A., Binkofski, F., & Buccino, G. (2007). Action observation has a positive impact on rehabilitation of motor deficits after stroke. Neuroimage, 36, T164-T173.

Fakhari, A., Keshmiri, M., & Kao, I. (2016). Development of realistic pressure distribution and friction limit surface for soft-finger contact interface of robotic hands. Journal of Intelligent & Robotic Systems, 82(1), 39-50.

Feigin, V. L., Norrving, B., & Mensah, G. A. (2017). Global burden of stroke. Circulation research, 120(3), 439-448.

Ferguson-Pell, M., Hagisawa, S., & Bain, D. (2000). Evaluation of a sensor for low interface pressure applications. Medical engineering & physics, 22(9), 657-663.

Figliola, R. S., & Beasley, D. E. (2014). Theory and design for mechanical measurements: John Wiley & Sons.

Fish, J., & Soechting, J. (1992). Synergistic finger movements in a skilled motor task. Experimental brain research, 91(2), 327-334.

Francomano, M., Accoto, D., & Guglielmelli, E. (2012). Experimental characterization of a flexible thermal slip sensor. Sensors, 12(11), 15267-15280.

Frenkel-Toledo, S., Yamanaka, J., Friedman, J., Feldman, A. G., & Levin, M. F. (2019). Referent control of anticipatory grip force during reaching in stroke: an experimental and modeling study. Experimental brain research, 237(7), 1655-1672.

Frisoli, A., Procopio, C., Chisari, C., Creatini, I., Bonfiglio, L., Bergamasco, M., . . . Carboncini, M. C. (2012). Positive effects of robotic exoskeleton training of upper limb reaching movements after stroke. Journal of neuroengineering and rehabilitation, 9(1), 36.

Fritz, S. L., Blanton, S., Uswatte, G., Taub, E., & Wolf, S. L. (2009). Minimal detectable change scores for the Wolf Motor Function Test. Neurorehabilitation and neural repair, 23(7), 662-667.

Fugl-Meyer, A. R., Jääskö, L., Leyman, I., Olsson, S., & Steglind, S. (1975). The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scandinavian journal of rehabilitation medicine, 7(1), 13-31.

Grattan, E. S., Velozo, C. A., Skidmore, E. R., Page, S. J., & Woodbury, M. L. (2019). Interpreting action research arm test assessment scores to plan treatment. OTJR: occupation, participation and health, 39(1), 64-73.

Gu, G. M., Shin, Y. K., Son, J., & Kim, J. (2012). Design and characterization of a photo-sensor based force measurement unit (FMU). Sensors and Actuators A: Physical, 182, 49-56.

Gubbi, J., Rao, A. S., Fang, K., Yan, B., & Palaniswami, M. (2013). Motor recovery monitoring using acceleration measurements in post acute stroke patients. Biomedical engineering online, 12(1), 33.

Häger-Ross, C., Cole, K. J., & Johansson, R. S. (1996). Grip-force responses to unanticipated object loading: load direction reveals body-and gravity-referenced intrinsic task variables. Experimental brain research, 110(1), 142-150.

Hall, D. (2019). (e) in Normandy: The sociolinguistics, phonology and phonetics of the Loi de Position. Journal of French Language Studies, 29(1), 1-33.

Hendricks, H. T., Van Limbeek, J., Geurts, A. C., & Zwarts, M. J. (2002). Motor recovery after stroke: a systematic review of the literature. Archives of physical medicine and rehabilitation, 83(11), 1629-1637.

Hepp-Reymond, M.-C., Huesler, E. J., & Maier, M. A. (1996). Precision grip in humans: temporal and spatial synergies Hand and brain (pp. 37-68): Elsevier.

Hermsdörfer, J., Hagl, E., Nowak, D., & Marquardt, C. (2003). Grip force control during object manipulation in cerebral stroke. Clinical Neurophysiology, 114(5), 915-929.

Heron, M. P. (2016). Deaths: leading causes for 2013.

Heyer, P., Orihuela-Espina, F., Castrejón, L. R., Hernández-Franco, J., & Sucar, L. E. (2017). Sensor Abstracted Extremity Representation for Automatic Fugl-Meyer Assessment Applications for Future Internet (pp. 152-163): Springer.

Hogrel, J., Ollivier, G., & Desnuelle, C. (2006). Manual and quantitative muscle testing in neuromuscular disorders. How to assess the consistency of strength measurements in clinical trials? Revue neurologique, 162(4), 427-436.

Hsu, H.-Y., Kuan, T.-S., Yang, H.-C., Tsai, C.-L., Yeh, C.-H., Lin, C.-C., & Kuo, L.-C. (2019). Effects of the Surface Texture and Weight of a Pinch Apparatus on the Reliability and Validity of a Hand Sensorimotor Control Assessment. Archives of physical medicine and rehabilitation, 100(4), 620-626.

Hu, W., Wei, N., Li, Z.-M., & Li, K. (2018). Effects of muscle fatigue on directional coordination of fingertip forces during precision grip. PloS one, 13(12), e0208740.

Iijima, A., Shimizu, K., Kobashi, H., Saito, A., & Kamiya, K. (2015). Repeatability, reproducibility, and comparability of subjective and objective measurements of intraocular forward scattering in healthy subjects. BioMed research international, 2015.

Ikeda, A., Kurita, Y., Ueda, J., Matsumoto, Y., & Ogasawara, T. (2004). Grip force control for an elastic finger using vision-based incipient slip feedback. Paper presented at the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)(IEEE Cat. No. 04CH37566).

Jaric, S., & Uygur, M. (2013). Assessment of hand function through the coordination of contact forces in manipulation tasks. Journal of human kinetics, 36(1), 5-160.

Jayakumar, P., Williams, M., Ring, D., Lamb, S., & Gwilym, S. (2017). A systematic review of outcome measures assessing disability following upper extremity trauma. Journal of the American Academy of Orthopaedic Surgeons. Global research & reviews, 1(4).

Jokinen, H., Melkas, S., Ylikoski, R., Pohjasvaara, T., Kaste, M., Erkinjuntti, T., & Hietanen, M. (2015). Post-stroke cognitive impairment is common even after successful clinical recovery. European journal of neurology, 22(9), 1288-1294.

Jones, C. L., & Kamper, D. G. (2018). Involuntary neuromuscular coupling between the thumb and finger of stroke survivors during dynamic movement. Frontiers in neurology, 9, 84.

Julianjatsono, R., Ferdiana, R., & Hartanto, R. (2017). High-resolution automated Fugl-Meyer Assessment using sensor data and regression model. Paper presented at the 2017 3rd International Conference on Science and Technology-Computer (ICST).

Kamper, D., Harvey, R. L., Suresh, S., & Rymer, W. Z. (2003). Relative contributions of neural mechanisms versus muscle mechanics in promoting finger extension deficits following stroke. Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine, 28(3), 309-318.

Kang, N., & Cauraugh, J. H. (2015). Paretic hand unimanual force control: Improved submaximal force production and regularity. Neuroscience research, 94, 79-86.

Kessner, S. S., Bingel, U., & Thomalla, G. (2016). Somatosensory deficits after stroke: a scoping review. Topics in stroke rehabilitation, 23(2), 136-146.

Khatri, R., McKinney, A. M., Swenson, B., & Janardhan, V. (2012). Blood–brain barrier, reperfusion injury, and hemorrhagic transformation in acute ischemic stroke. Neurology, 79(13 Supplement 1), S52-S57.

Kilbreath, S., & Gandevia, S. (1994). Limited independent flexion of the thumb and fingers in human subjects. The Journal of Physiology, 479(3), 487-497.

Kim, M., Won, C. W., & Kim, M. (2018). Muscular grip strength normative values for a Korean population from the Korea National Health and Nutrition Examination Survey, 2014–2015. PloS one, 13(8), e0201275.

Kneebone, I. I. (2016). A framework to support cognitive behavior therapy for emotional disorder after stroke. Cognitive and Behavioral Practice, 23(1), 99-109.

Kotrlik, J., & Higgins, C. (2001). Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. Information technology, learning, and performance journal, 19(1), 43.

Krakauer, J. W., & Carmichael, S. T. (2017). Broken Movement: The Neurobiology of Motor Recovery After Stroke: MIT Press.

Lang, C. E., & Beebe, J. A. (2007). Relating movement control at 9 upper extremity segments to loss of hand function in people with chronic hemiparesis. Neurorehabilitation and neural repair, 21(3), 279-291.

Lang, C. E., DeJong, S. L., & Beebe, J. A. (2009). Recovery of thumb and finger extension and its relation to grasp performance after stroke. Journal of neurophysiology, 102(1), 451-459.

Lang, C. E., & Schieber, M. H. (2004). Reduced muscle selectivity during individuated finger movements in humans after damage to the motor cortex or corticospinal tract. Journal of neurophysiology, 91(4), 1722-1733.

Lang, C. E., Wagner, J. M., Bastian, A. J., Hu, Q., Edwards, D. F., Sahrmann, S. A., & Dromerick, A. W. (2005). Deficits in grasp versus reach during acute hemiparesis. Experimental brain research, 166(1), 126-136.

Langhorne, P., Bernhardt, J., & Kwakkel, G. (2011). Stroke rehabilitation. The Lancet, 377(9778), 1693-1702.

Lebosse, C., Renaud, P., Bayle, B., & de Mathelin, M. (2011). Modeling and evaluation of low-cost force sensors. IEEE Transactions on Robotics, 27(4), 815-822.

Lee, S.-H., Song, M., & Kim, J. (2016a). Towards clinically relevant automatic assessment of upper-limb motor function impairment. Paper presented at the Biomedical and Health Informatics (BHI), 2016 IEEE-EMBS International Conference on.

Lee, S.-H., Song, M., & Kim, J. (2016b). Towards clinically relevant automatic assessment of upper-limb motor function impairment. Paper presented at the 2016 IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI).

Lee, S., Lee, Y.-S., & Kim, J. (2017). Automated evaluation of upper-limb motor function impairment using Fugl-Meyer assessment. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26(1), 125-134.

Lee, S., Lee, Y.-S., & Kim, J. (2018). Automated evaluation of upper-limb motor function impairment using Fugl-Meyer assessment. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26(1), 125-134.

Lepot, M., Aubin, J.-B., & Clemens, F. (2017). Interpolation in time series: An introductive overview of existing methods, their performance criteria and uncertainty assessment. Water, 9(10), 796.

Li, K., Nataraj, R., Marquardt, T. L., & Li, Z.-M. (2013). Directional coordination of thumb and finger forces during precision pinch. PloS one, 8(11), e79400.

Li, K. W., & Yu, R. (2011). Assessment of grip force and subjective hand force exertion under handedness and postural conditions. Applied ergonomics, 42(6), 929-933.

Li, M., Hang, K., Kragic, D., & Billard, A. (2016). Dexterous grasping under shape uncertainty. Robotics and Autonomous Systems, 75, 352-364.

Li, S. (2017). Spasticity, Motor Recovery, and Neural Plasticity after Stroke. Frontiers in neurology, 8(120). doi: 10.3389/fneur.2017.00120

Li, S., Zhuang, C., Hao, M., He, X., Marquez Ruiz, J. C., Niu, C. M., & Lan, N. (2015). Coordinated alpha and gamma control of muscles and spindles in movement and posture. Frontiers in computational neuroscience, 9, 122.

Li, W., Qu, S., & Zhou, Z. (2006). Reciprocating sliding behaviour of human skin in vivo at lower number of cycles. Tribology Letters, 23(2), 165.

Li, Z.-M., Dun, S., Harkness, D. A., & Brininger, T. L. (2004). Motion enslaving among multiple fingers of the human hand. Motor control, 8(1), 1-15.

Likitlersuang, J., Leineweber, M. J., & Andrysek, J. (2017). Evaluating and improving the performance of thin film force sensors within body and device interfaces. Medical engineering & physics, 48, 206-211.

Lim, H. S., Kim, S. M., & Kang, D. W. (2018). Quantitative Predictive Models for the Degree of Disability After Acute Ischemic Stroke. The Journal of Clinical Pharmacology, 58(4), 549-557.

Lorussi, F., Carbonaro, N., De Rossi, D., Paradiso, R., Veltink, P., & Tognetti, A. (2016). Wearable textile platform for assessing stroke patient treatment in daily life conditions. Frontiers in bioengineering and biotechnology, 4, 28.

Lyahou, K. F., van der Horn, G., & Huijsing, J. H. (1997). A noniterative polynomial 2-D calibration method implemented in a microcontroller. IEEE Transactions on Instrumentation and Measurement, 46(4), 752-757.

Lyle, R. C. (1981). A performance test for assessment of upper limb function in physical rehabilitation treatment and research. International Journal of Rehabilitation Research, 4(4), 483-492.

Mackay, J., & Mensah, G. A. (2004). The atlas of heart disease and stroke: World Health Organization.

Makikawa, M., & Hirai, S. (2013). Flexible fabric Sensor toward a humanoid robot's skin: fabrication, characterization, and perceptions. IEEE Sensors Journal, 13(10), 4065-4080.

Malaysia Demographics Profile 2019. https://www.indexmundi.com/malaysia/demographics_profile.html, Accessed on 08/06/2020.

Malhotra, K., Gornbein, J., & Saver, J. L. (2017). Ischemic strokes due to large-vessel occlusions contribute disproportionately to stroke-related dependence and death: a review. Frontiers in neurology, 8, 651.

Masen, M. A. (2011). A systems based experimental approach to tactile friction. Journal of the mechanical behavior of biomedical materials, 4(8), 1620-1626.

Mathiowetz, V., Weber, K., Volland, G., & Kashman, N. (1984). Reliability and validity of grip and pinch strength evaluations. The Journal of hand surgery, 9(2), 222-226.

Matute, A., Paredes-Madrid, L., Moreno, G., Cárdenas, F., & Palacio, C. A. (2018). A novel and inexpensive approach for force sensing based on FSR piezocapacitance aimed at hysteresis error reduction. Journal of Sensors, 2018.

McDonnell, M. N., Hillier, S. L., Ridding, M. C., & Miles, T. S. (2006). Impairments in precision grip correlate with functional measures in adult hemiplegia. Clinical Neurophysiology, 117(7), 1474-1480.

Meydan, T., & Healey, G. (1992). Linear variable differential transformer (LVDT): linear displacement transducer utilizing ferromagnetic amorphous metallic glass ribbons. Sensors and Actuators A: Physical, 32(1-3), 582-587.

Miall, R. C., Rosenthal, O., Ørstavik, K., Cole, J. D., & Sarlegna, F. R. (2019). Loss of haptic feedback impairs control of hand posture.

Murphy, M. A., Resteghini, C., Feys, P., & Lamers, I. (2015). An overview of systematic reviews on upper extremity outcome measures after stroke. BMC neurology, 15(1), 29.

Murray, J., Young, J., & Forster, A. (2009). Measuring outcomes in the longer term after a stroke. Clinical rehabilitation, 23(10), 918-921.

Naghdi, S., Ansari, N. N., Mansouri, K., & Hasson, S. (2010). A neurophysiological and clinical study of Brunnstrom recovery stages in the upper limb following stroke. Brain injury, 24(11), 1372-1378.

Neupane, D. (2014). Comparison of some FEM codes in static analysis.

Olesh, E. V., Yakovenko, S., & Gritsenko, V. (2014). Automated assessment of upper extremity movement impairment due to stroke. PloS one, 9(8), e104487.

Oña, E. D., Jardón, A., Monge, E., Molina, F., Cano, R., & Balaguer, C. (2018). Towards Automated Assessment of Upper Limbs Motor Function Based on Fugl-Meyer Test and Virtual Environment. Paper presented at the International Conference on NeuroRehabilitation.

Organization, W. H. (2006). Neurological disorders: public health challenges: World Health Organization.

Otten, P., Kim, J., & Son, S. (2015a). A framework to automate assessment of upper-limb motor function impairment: A feasibility study. Sensors, 15(8), 20097-20114.

Otten, P., Kim, J., & Son, S. H. (2015b). A framework to automate assessment of upper-limb motor function impairment: A feasibility study. Sensors, 15(8), 20097-20114.

Otten, P., Son, S. H., & Kim, J. (2014). Automating stroke patient evaluation using sensor data and SVM. Paper presented at the 2014 IEEE 7th International Conference on Service-Oriented Computing and Applications.

Page, S. J., Hade, E., & Persch, A. (2015). Psychometrics of the wrist stability and hand mobility subscales of the Fugl-Meyer assessment in moderately impaired stroke. Physical therapy, 95(1), 103-108.

Page, S. J., Levine, P., & Hade, E. (2012). Psychometric properties and administration of the wrist/hand subscales of the Fugl-Meyer Assessment in minimally impaired upper extremity hemiparesis in stroke. Archives of physical medicine and rehabilitation, 93(12), 2373-2376. e2375.

Paredes-Madrid, L., Emmi, L., Garcia, E., & De Santos, P. G. (2011). Detailed study of amplitude nonlinearity in piezoresistive force sensors. Sensors, 11(9), 8836-8854.

Park, J., Kim, S. J., Na, Y., Kim, Y., & Kim, J. (2019). Development of a Bendable Outsole Biaxial Ground Reaction Force Measurement System. Sensors, 19(11), 2641.

Parmar, S., Khodasevych, I., & Troynikov, O. (2017). Evaluation of flexible force sensors for pressure monitoring in treatment of chronic venous disorders. Sensors, 17(8), 1923.

Pasumarty, S. M., Johnson, S. A., Watson, S. A., & Adams, M. J. (2011). Friction of the human finger pad: influence of moisture, occlusion and velocity. Tribology Letters, 44(2), 117.

Paternostro-Sluga, T., Grim-Stieger, M., Posch, M., Schuhfried, O., Vacariu, G., Mittermaier, C., . . . Fialka-Moser, V. (2008). Reliability and validity of the Medical Research Council (MRC) scale and a modified scale for testing muscle strength in patients with radial palsy. Journal of rehabilitation medicine, 40(8), 665-671.

Pennati, G. V., Plantin, J., Carment, L., Roca, P., Baron, J.-C., Pavlova, E., . . . Lindberg, P. G. (2020). Recovery and Prediction of Dynamic Precision Grip Force Control After Stroke. Stroke, 51(3), 944-951.

Perna, R., & Temple, J. (2015). Rehabilitation outcomes: ischemic versus hemorrhagic strokes. Behavioural neurology, 2015.

Persson, H. C., Parziali, M., Danielsson, A., & Sunnerhagen, K. S. (2012). Outcome and upper extremity function within 72 hours after first occasion of stroke in an unselected population at a stroke unit. A part of the SALGOT study. BMC neurology, 12(1), 162.

Pessina, M. A., Bowley, B. G., Rosene, D. L., & Moore, T. L. (2019). A method for assessing recovery of fine motor function of the hand in a rhesus monkey model of cortical injury: an adaptation of the Fugl–Meyer Scale and Eshkol–Wachman Movement Notation. Somatosensory & motor research, 36(1), 69-77.

Petersen, M., Heckmann, U., Bandorf, R., Gwozdz, V., Schnabel, S., Bräuer, G., & Klages, C.-P. (2011). Me-DLC films as material for highly sensitive temperature compensated strain gauges. Diamond and Related Materials, 20(5-6), 814-818.

Pramanik, C., & Saha, H. (2006). Low pressure piezoresistive sensors for medical electronics applications. Materials and Manufacturing Processes, 21(3), 233-238.

Price, A., Balakirsky, S., & Christensen, H. (2018). Robust grasp preimages under unknown mass and friction distributions. Integrated Computer-Aided Engineering(Preprint), 1-12.

Qian, Q. (2018). Investigation of multi-joint coordinated upper limb rehabilitation assisted with electromyography (EMG)-driven neuromuscular electrical stimulation (NMES)-robot after stroke. The Hong Kong Polytechnic University.

Rabadi, M. H., & Rabadi, F. M. (2006). Comparison of the action research arm test and the Fugl-Meyer assessment as measures of upper-extremity motor weakness after stroke. Archives of physical medicine and rehabilitation, 87(7), 962-966.

Raghavan, P. (2007). The nature of hand motor impairment after stroke and its treatment. Current treatment options in cardiovascular medicine, 9(3), 221-228.

Raghavan, P., Krakauer, J. W., & Gordon, A. M. (2006). Impaired anticipatory control of fingertip forces in patients with a pure motor or sensorimotor lacunar syndrome. Brain, 129(6), 1415-1425.

Raghavan, P., Santello, M., Krakauer, J., & Gordon, A. (2006). Shaping the hand to object contours after stroke [abstract 655.14]. Neuroscience 2006, 14-18.

Rashidi, F. R. M., Hasan, W., Hamidon, M., & Shafie, S. (2017). An implementation of modified nodal array approach in designing a readout circuit for piezoresistive pressure sensor array. Paper presented at the 2017 IEEE 3rd International Symposium in Robotics and Manufacturing Automation (ROMA).

Richardson, A. G., Attiah, M. A., Berman, J. I., Chen, H. I., Liu, X., Zhang, M., . . . Lucas, T. H. (2016). The effects of acute cortical somatosensory deafferentation on grip force control. Cortex, 74, 1-8.

Rivera, J., Carrillo, M., Chacón, M., Herrera, G., & Bojorquez, G. (2007). Self-calibration and optimal response in intelligent sensors design based on artificial neural networks. Sensors, 7(8), 1509-1529.

Roberge, J.-P., Ruotolo, W., Duchaine, V., & Cutkosky, M. (2018). Improving industrial grippers with adhesion-controlled friction. IEEE Robotics and Automation Letters, 3(2), 1041-1048.

Roberts, A., & Brackley, C. (1992). Friction of surgeons' gloves. Journal of Physics D: Applied Physics, 25(1A), A28.

Sadun, A., Jalani, J., & Sukor, J. (2016). Force Sensing Resistor (FSR): a brief overview and the low-cost sensor for active compliance control. Paper presented at the First International Workshop on Pattern Recognition.

Sanders, Q., Chan, V., Augsburger, R., Cramer, S. C., Reinkensmeyer, D. J., & Do, A. H. (2020). Feasibility of Wearable Sensing for In-Home Finger Rehabilitation Early After Stroke. IEEE Transactions on Neural Systems and Rehabilitation Engineering.

Sani, H. N., & Meek, S. G. (2011). Characterizing the performance of an optical slip sensor for grip control in a prosthesis. Paper presented at the 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems.

Santisteban, L., Térémetz, M., Bleton, J.-P., Baron, J.-C., Maier, M. A., & Lindberg, P. G. (2016). Upper limb outcome measures used in stroke rehabilitation studies: a systematic literature review. PloS one, 11(5), e0154792.

Schmitt, W. H., & Cuthbert, S. C. (2008). Common errors and clinical guidelines for manual muscle testing:" the arm test" and other inaccurate procedures. Chiropractic & osteopathy, 16(1), 16.

Schwarz, A., Kanzler, C. M., Lambercy, O., Luft, A. R., & Veerbeek, J. M. (2019). Systematic review on kinematic assessments of upper limb movements after stroke. Stroke, 50(3), 718-727.

See, J., Dodakian, L., Chou, C., Chan, V., McKenzie, A., Reinkensmeyer, D. J., & Cramer, S. C. (2013). A standardized approach to the Fugl-Meyer assessment and its implications for clinical trials. Neurorehabilitation and neural repair, 27(8), 732-741.

Sell, J., Enser, H., Schatzl-Linder, M., Strauß, B., Jakoby, B., & Hilber, W. (2017). Nested, meander shaped strain gauges for temperature compensated strain measurement. Paper presented at the 2017 IEEE SENSORS.

Seo, N. J., Armstrong, T. J., & Drinkaus, P. (2009). A comparison of two methods of measuring static coefficient of friction at low normal forces: a pilot study. Ergonomics, 52(1), 121-135.

Seo, N. J., Fischer, H. W., Bogey, R. A., Rymer, W. Z., & Kamper, D. G. (2011). Use of visual force feedback to improve digit force direction during pinch grip in persons with stroke: a pilot study. Archives of physical medicine and rehabilitation, 92(1), 24-30.

Shigley, J. E. (1972). Mechanical engineering design.

Shrestha, P., Thapa, S., Shrestha, S., Lohani, S., BK, S., MacCormac, O., . . . Devkota, U. P. (2017). Renal impairment in stroke patients: A comparison between the haemorrhagic and ischemic variants. F1000Research, 6.

Simbaña, E. D. O., Baeza, P. S.-H., Jardón, A., & Balaguer, C. (2019). Review of Automated Systems for Upper Limbs Functional Assessment in Neurorehabilitation. IEEE Access.

Singer, B., & Garcia-Vega, J. (2017). The Fugl-Meyer upper extremity scale. Journal of physiotherapy, 63(1), 53.

Sivamani, R. K., Wu, G. C., Gitis, N. V., & Maibach, H. I. (2003). Tribological testing of skin products: gender, age, and ethnicity on the volar forearm. Skin Research and Technology, 9(4), 299-305.

Straathof, P. T., Lobo-Prat, J., Schilder, F., Kooren, P. N., Paalman, M. I., Stienen, A. H., & Koopman, B. F. (2016). Design and control of the A-Arm: An active planar arm support for adults with Duchenne muscular dystrophy. Paper presented at the 2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob).

Sugathan, H. K., Kilpatrick, M., Joyce, T. J., & Harrison, J. W. (2012). A biomechanical study on variation of compressive force along the Acutrak 2 screw. Injury, 43(2), 205-208.

Sullivan, K. J., Tilson, J. K., Cen, S. Y., Rose, D. K., Hershberg, J., Correa, A., . . . Wu, S. S. (2011). Fugl-Meyer assessment of sensorimotor function after stroke: standardized training procedure for clinical practice and clinical trials. Stroke, 42(2), 427-432.

Suntrup, S., Kemmling, A., Warnecke, T., Hamacher, C., Oelenberg, S., Niederstadt, T., . . . Dziewas, R. (2015). The impact of lesion location on dysphagia incidence, pattern and complications in acute stroke. Part 1: dysphagia incidence, severity and aspiration. European journal of neurology, 22(5), 832-838.

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. Research in Science Education, 48(6), 1273-1296.

Takamuku, S., & Gomi, H. (2019). Better grip force control by attending to the controlled object: Evidence for direct force estimation from visual motion. Scientific reports, 9(1), 1-12.

Tarchanidis, K. N., & Lygouras, J. N. (2003). Data glove with a force sensor. IEEE Transactions on Instrumentation and Measurement, 52(3), 984-989.

Taylor, R. (1990). Interpretation of the correlation coefficient: a basic review. Journal of diagnostic medical sonography, 6(1), 35-39.

Tekscan. (2008). FlexiForce® Sensors User Manual.

Teshigawara, S., Ishikawa, M., & Shimojo, M. (2008). Development of high speed and high sensitivity slip sensor. Paper presented at the 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems.

Teshigawara, S., Tsutsumi, T., Shimizu, S., Suzuki, Y., Ming, A., Ishikawa, M., & Shimojo, M. (2011). Highly sensitive sensor for detection of initial slip and its application in a multi-fingered robot hand. Paper presented at the 2011 IEEE International Conference on Robotics and Automation.

Tom, H. (1992). Advanced tactile sensing for robotics (Vol. 5): World scientific.

Tomlinson, S., Lewis, R., & Carré, M. (2007). Review of the frictional properties of finger-object contact when gripping. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 221(8), 841-850.

Valero-Cuevas, F. J., Smaby, N., Venkadesan, M., Peterson, M., & Wright, T. (2003). The strength–dexterity test as a measure of dynamic pinch performance. Journal of biomechanics, 36(2), 265-270.

Vatani, M., Engeberg, E. D., & Choi, J.-W. (2013). Force and slip detection with direct-write compliant tactile sensors using multi-walled carbon nanotube/polymer composites. Sensors and Actuators A: Physical, 195, 90-97.

Villán-Villán, M. A., Pérez-Rodríguez, R., Gómez, C., Opisso, E., Tormos, J. M., Medina, J., & Gómez, E. J. (2015). A First Step for the Automation of

Fugl-Meyer Assessment Scale for Stroke Subjects in Upper Limb Physical Neurorehabilitation. Paper presented at the ICIMTH.

Volz, L. J., Sarfeld, A.-S., Diekhoff, S., Rehme, A. K., Pool, E.-M., Eickhoff, S. B., . . . Grefkes, C. (2015). Motor cortex excitability and connectivity in chronic stroke: a multimodal model of functional reorganization. Brain Structure and Function, 220(2), 1093-1107. doi: 10.1007/s00429-013-0702-8

Wan, N. C., Hairi, N. N. M., Jenn, N. C., & Kamarulzaman, A. (2014). Universal health coverage in Malaysia: issues and challenges. Revisiting Malaysia's Population–Development Nexus, 175.

Warman, P. H., & Ennos, A. R. (2009). Fingerprints are unlikely to increase the friction of primate fingerpads. Journal of Experimental Biology, 212(13), 2016-2022.

Webster, J. G., & Eren, H. (2016). Measurement, instrumentation, and sensors handbook: spatial, mechanical, thermal, and radiation measurement: CRC press.

Welmer, A.-K., Holmqvist, L. W., & Sommerfeld, D. K. (2008). Limited fine hand use after stroke and its association with other disabilities. Journal of rehabilitation medicine, 40(8), 603-608.

Westling, G., & Johansson, R. (1984). Factors influencing the force control during precision grip. Experimental brain research, 53(2), 277-284.

Wolbrecht, E. T., Rowe, J. B., Chan, V., Ingemanson, M. L., Cramer, S. C., & Reinkensmeyer, D. J. (2018). Finger strength, individuation, and their interaction: relationship to hand function and corticospinal tract injury after stroke. Clinical Neurophysiology, 129(4), 797-808.

Wolf, S. L., Catlin, P. A., Ellis, M., Archer, A. L., Morgan, B., & Piacentino, A. (2001). Assessing Wolf motor function test as outcome measure for research in patients after stroke. Stroke, 32(7), 1635-1639.

Woodbury, M. L., Velozo, C. A., Richards, L. G., & Duncan, P. W. (2013). Rasch analysis staging methodology to classify upper extremity movement impairment after stroke. Archives of physical medicine and rehabilitation, 94(8), 1527-1533.

Woytowicz, E. J., Rietschel, J. C., Goodman, R. N., Conroy, S. S., Sorkin, J. D., Whitall, J., & Waller, S. M. (2017). Determining levels of upper extremity movement impairment by applying a cluster analysis to the Fugl-Meyer assessment of the upper extremity in chronic stroke. Archives of physical medicine and rehabilitation, 98(3), 456-462.

Xing, J., & Chen, J. (2015). Design of a Thermoacoustic sensor for low intensity ultrasound measurements based on an artificial neural network. Sensors, 15(6), 14788-14808.

Xu, J., Haith, A. M., & Krakauer, J. W. (2015). Motor control of the hand before and after stroke Clinical systems neuroscience (pp. 271-289): Springer.

Yi, C., Li, K. W., Tang, F., Zuo, H., Ma, L., & Hu, H. (2018). Pulling strength, muscular fatigue, and prediction of maximum endurance time for simulated pulling tasks. PloS one, 13(11), e0207283.

Yozbatiran, N., Der-Yeghiaian, L., & Cramer, S. C. (2008). A standardized approach to performing the action research arm test. Neurorehabilitation and neural repair, 22(1), 78-90.

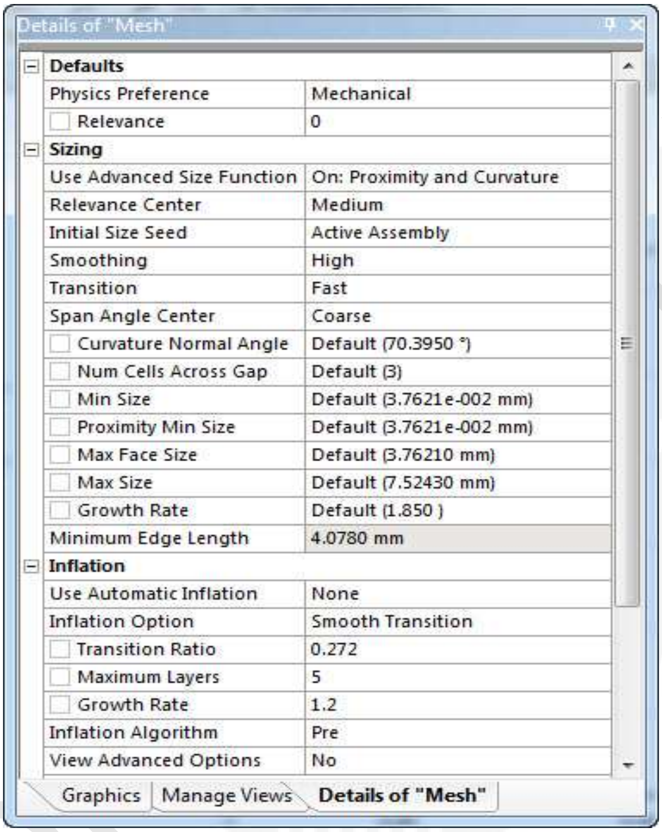
Yuan, L. Z., Chung, O. C., & Yie, L. W. (2012). Designing of Foot Imbalance Scanning System. Procedia Engineering, 41, 15-21.

Zheng, Y., Zhao, M., Jiang, J., & Song, L. (2019). Dynamic Force Transducer Calibration Based on Electrostatic Force. IEEE Access, 7, 48998-49003.

APPENDICES

Appendix A1

Mesh Settings used in ANSYS



Details of "Mesh"

Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity and Curvature
Relevance Center	Medium
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Fast
Span Angle Center	Coarse
Curvature Normal Angle	Default (70.3950 °)
Num Cells Across Gap	Default (3)
Min Size	Default (3.7621e-002 mm)
Proximity Min Size	Default (3.7621e-002 mm)
Max Face Size	Default (3.76210 mm)
Max Size	Default (7.52430 mm)
Growth Rate	Default (1.850)
Minimum Edge Length	4.0780 mm
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No

Graphics | Manage Views | Details of "Mesh"

Appendix A2

Certificate of Test and Calibration for S-Type Load Cell

LCM SYSTEMS
Solutions in Load Cell Technology

CERTIFICATE OF TEST AND CALIBRATION

DATE OF TEST: 09/02/2018
CERTIFICATE No.: LG07
TEST LOCATION: LCM SYSTEMS
MODE: TENSION
LOAD CELL TYPE: STA-1-50
SERIAL No.: 29040659

LOADCELL CONNECTIONS:	
GREEN : POSITIVE SUPPLY	BLACK : NEGATIVE SUPPLY
BLUE : POSITIVE SENSE	BROWN : NEGATIVE SENSE
RED : POSITIVE SIGNAL	WHITE : NEGATIVE SIGNAL
SCREEN	

AMPLIFIER TYPE: SGA-A 110-230 Vac
SERIAL No.: 17298770

SWITCH SETTINGS	
SW1 ON	1 & 4
SW2 ON	NONE
SW3 ON	NONE
SW4 ON	2, 7 & 8

LOAD kg	AMP O/P (Vdc) READING 1	AMP O/P (Vdc) READING 2
0.00	0.000	0.000
10.00	1.001	1.001
20.00	2.002	2.001
30.00	3.001	3.001
40.00	4.001	3.998
50.00	5.002	4.997

CALIBRATION FIGURE: 1.830

CALIBRATION CARRIED OUT BY: S Winter

S.Winter
LCM Systems Ltd.

This calibration has been performed on a test machine that has been independently calibrated and certified to BS EN ISO 7500-1 by a UKAS accredited calibration laboratory.

Registered Office and Trading Address
Unit 15, Newport Business Park • Barry Way • Newport • Isle of Wight • PO30 5GY • United Kingdom
Tel: +44 (0)1983 249264 • Fax: +44(0)1983 249266 • Email: info@lcmsystems.com
www.lcmsystems.com
Registered in England No. 2057541

Appendix A3

AC Servo Specifications

Basic Specification	Input Power	200W	Main Circuit	Single/3-phase, 200 - 240V ±10%, 50/60Hz
			Control Circuit	Single phase, 200 - 240V ±10%, 50/60Hz
		400W	Main Circuit	Single/3-phase, 200 - 240V ±10%, 50/60Hz
			Control Circuit	Single phase, 200 - 240V ±10%, 50/60Hz
		750W	Main Circuit	Single/3-phase, 200 - 240V ±10%, 50/60Hz
			Control Circuit	Single phase, 200 - 240V ±10%, 50/60Hz
	Withstand voltage			Primary to earth: withstand 1500 VAC, 1 min, (sensed current: 20 mA) [220V Input]
	Environment	Temperature		Ambient temperature:0°C to 50°C(If the ambient temperature of servo drive is greater than 45°C, please install the drive in a well-ventilated location) Storage temperature: -20°C to 65°C
		Humidity		Both operating and storage : 10 to 85%RH or less
		Altitude		Lower than 1000m
		Vibration		5.88m/s^2 or less, 10 to 60Hz (No continuous use at resonance frequency)
	Control method			IGBT PWM Sinusoidal wave drive
	Encoder feedback			2500 line incremental encoder 15-wire or 9-wire
	I/O	Control Signal	Input	8 Configurable Optically isolate digital general inputs, 5-24VDC, max input current 20mA 4 Configurable Optically isolate digital high speed inputs, 5-24VDC, max input current 20mA
			Output	5 Configurable optically isolated digital outputs, 30VDC, max output current 30mA One motor brake control output, 30VDC 100mA max
		Analog signal	Input	2 inputs (12Bit A/D : 2 input)
		Pulse signal	Input	2 inputs (Photo-coupler input, Line receiver input) Photocoupler input is compatible with both line driver I/F and open collector I/F. Line receiver input is compatible with line driver I/F.
			Output	4 outputs (Line driver: 3 outputs, open collector: 1 outputs)
	Communication	USB Mini		Connection with PC or 1 : 1 communication to a host.
		RS232		RS-232 Communication
		RS485		RS-485 Communication
		CAN bus		CANopen Communication
		Ethernet		EtherNET/IP，eSCL
	Front panel			1. 4 keys (MODE, UP, DOWN, SET) 2. LED (5-digit)
	Regeneration Resistor			Built-in regenerative resistor (external resistor is also enabled.)
	Control mode			(1) Position mode (2) Analog Velocity mode (3) Analog Position mode (4) Position mode (5) Velocity Change mode (6) Command Torque mode (7) Command Velocity mode
	Control input			(1) Servo-ON input (2) Alarm clear input (3) CW/CCW Limit (4) Pulse& Direction or CW/CCW input (5) Gain Switch (6) Control mode Switch (7) Pulse Inhibition (8) General Input
	Control output			(1) Alarm output (2) Servo-Ready output (3) External brake release (4) Speed arrival output (5) Torque arrival output (6) Tach Out (7) General Output (8)Position arrival output

Appendix B1

SF-36 Questionnaire

SF-36v2™ Health Survey Standard Version

Please answer all questions.

THANK YOU FOR YOUR COOPERATION

General Details

Name	:
Age	:
Contact No.	:(H/P)-
	(Email)-

This survey asks for your views about your health. This information will help you keep track of how you feel and how well you are able to do your usual activities.

Please answer every question. Some questions may look like others, but each one is different. Please take the time to read and answer each question carefully and check-marking on the circle that best describes your answer. ***Thank you for completing this survey!***

1) In general, would you say your health is:

Excellent	Very good	Good	Fair	Poor
○	○	○	○	○

2) <u>Compared to one year ago</u>, how would you rate your health in general <u>now</u>?

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago
○	○	○	○	○

3) The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
a. Vigorous Activities, such as running, lifting heavy objects, participating in strenuous sports	○	○	○
b. Moderate Activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	○	○	○
c. Lifting or carrying groceries	○	○	○
d. Climbing several flights of stairs	○	○	○
e. Climbing one flight of stairs	○	○	○
f. Bending, kneeling, or stooping	○	○	○
g. Walking more than a mile	○	○	○
h. Walking several hundred yards	○	○	○
i. Walking one hundred yards	○	○	○
j. Bathing or dressing yourself	○	○	○

4) During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a. Cut down on the amount of time you spent on work or other activities	○	○	○	○	○
b. Accomplished less than you would like	○	○	○	○	○
c. Were limited in the kind of work or other activities	○	○	○	○	○
d. Had difficulty performing the work or other activities (for example, it took extra effort)	○	○	○	○	○

5) **During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a. Cut down on the amount of time you spent on work or other activities	○	○	○	○	○
b. Accomplished less than you would like	○	○	○	○	○
c. Did work or activities less carefully than usual	○	○	○	○	○

6) **During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?**

Not at all	Slightly	Moderately	Quite a bit	Extremely
○	○	○	○	○

7) **How much bodily pain have you had during the past 4 weeks?**

None	Very Mild	Mild	Moderate	Severe	Very Severe
○	○	○	○	○	○

8) **During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?**

Not at all	A little bit	Moderately	Quite a bit	Extremely
○	○	○	○	○

9) **These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks...**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a. Did you feel full of life?	○	○	○	○	○
b. Have you been very nervous?	○	○	○	○	○
c. Have you felt so down in the dumps that nothing could cheer you up?	○	○	○	○	○
d. Have you felt calm and peaceful?	○	○	○	○	○
e. Did you have a lot of energy?	○	○	○	○	○
f. Have you felt downhearted and depressed?	○	○	○	○	○
g. Did you feel worn out?	○	○	○	○	○
h. Have you been happy?	○	○	○	○	○
i. Did you feel tired?	○	○	○	○	○

10) **During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?**

All of the time	Most of the time	Some of the time	A little of the time	None of the time
○	○	○	○	○

11) How TRUE or FALSE is each of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
a. I seem to get sick a little easier than other people	○	○	○	○	○
b. I am as healthy as anybody I know	○	○	○	○	○
c. I expect my health to get worse	○	○	○	○	○
d. My health is excellent	○	○	○	○	○

Appendix B2

Ethical Approval Sheet

Ref. no: UPM/TNCPI/RMC/JKEUPM/1.4.18.2 (JKEUPM)
Date: 12/2/2018

Dear Prof / Dr. / Mr. / Ms.,

APPLICATION FOR JKEUPM ETHICAL CLEARANCE: APPROVED

With reference to the above, I am pleased to inform you that your application for ethical clearance for the research project entitled 'Objective and Automated Pinch Grasp Measurement System for Hand Function Evaluation in Fugl Meyer Assessment (FMA) Standard ' has been approved.

Please note that the official letter of approval will be issued as soon as possible. However, the ethical clearance is considered effective from the date of this email, and you may now proceed with your research.

Kindly please remind the ethical approval is required in the case of amendments/ changes to the study documents/ study sites/ study team.

Researchers should also complete a Study Final Report upon study completion. The form can be obtained from the Ethics Committee for Research Involving Human Subjects (JKEUPM) website (http://www.rmc.upm.edu.my/documentfile).

If you have any enquiries, please contact Ms. Nursuraya (03-89471605) or Ms. Nor Ellia (03-89471244).

Note: Please use this reference number for any transaction.
- JKEUPM-2017-248
Thank you.
Yours faithfully,

Prof. Dr. Zamberi Sekawi

Chair

Ethics Committee for Research Involving Human Subjects

Universiti Putra Malaysia

Appendix B3

Z-Table

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

BIODATA OF STUDENT

Abdalla Alsayed received a PhD in Biomedical and Msc in Control and Automation Engineering at UPM University. He received a B.Sc of Electrical Engineering at Islamic university of Gaza, Palestine, Gaza, in 2012. His main research interests include rehabilitation and assessment, sensor and measurements, control systems, automation systems, and AI for medicine.

LIST OF PUBLICATIONS

Alsayed, A., Kamil, R., Ramli, H., & As'arry, A. (2020). An Automated Data Acquistion system for Pinch Grip Assessment Based on Fugl Meyer Protocol: A Feasibility Study. Applied Sciences, 10(10), 3436.

Alsayed, A., Kamil, R., Ramli, H.R. and As'arry, A., 2019. Design and Calibration of Pinch Force Measurement Using Strain Gauge for Post-Stroke Patients. International Journal of Integrated Engineering, 11(4).

Abdallah Alsayed, Raja Kamil, Hafiz Rashidi Ramli, Azizan As'arry. "Design and Fabrication Pinch Force Measurement Based on Strain Gauge for Post-Stroke Patients", The 6th Symposium on Applied Engineering and Sciences 2018 (SAES 2018), Extended Abstract List, pp. 191-194, (Dec, 2018).