**UNIVERSITI PUTRA MALAYSIA**

# *PEAK PRESSURE ANALYSIS OF FOOT PLANTAR DISTRIBUTION BASED ON IMAGE PROCESSING ALGORITHM*

**ALI HUSSEIN SABRY**

# PEAK PRESSURE ANALYSIS OF FOOT PLANTAR DISTRIBUTION BASED ON IMAGE PROCESSING ALGORITHM

By

**ALI HUSSEIN SABRY**

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

**July 2018**

## DEDICATION

*This work is dedicated to…..*

*My family…*

*My country…*

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

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**Chairman : Associate Professor Wan Zuha B Wan Hasan, PhD**
**Faculty : Engineering**

Plantar pressure measurement is used to access the external loads, which interpreted in order to distinguish between normal and abnormal. Plantar pressure also provides valuable insight in gait analysis and pasture research. Several factors have been associated with the distribution of plantar foot pressure, including the body weight, age, foot structure, and standing/walking strategy.Foot ulceration due to diseasesis the main consideration because of the excessive foot plantar pressures in a particular area over time can give rise to such ulcers, but a lack in formulating accurately the distribution of pressure over the foot plantar and describing the relationship of the most parameters that effect on.The study objective is to examine the Body Mass Index through analyzing the relationships of seven levels of plantar pressure that distribute over the touch insole area with the four effective continuous predictor parameters (body mass, foot size, age,and gender), that have a direct effect on dynamic plantar pressure. The other main goal of this work is to create an algorithm which has the ability to formulate accurately and reliably the distribution of pressure over the foot plantar. Plantar pressure was profiled as an image at four measurement categories during standing and walking within two conditions of loading perspective; free, and loaded by carrying a simple weight during the subject inspect. Repeatability test together with the image processing tool is considered to classify seven levels of the plantar pressure and select the suitable category of measurements according to the relationships of each level with the studied parameters. The outcome of the repeatability test indicates that the dynamic with load (DL) is the best measurement category to consider in the plantar pressure data analysis. Seven levels of pressure have been successfully classified via image processing capabilities to simplify the creation of three modeling equations; polynomial, 3rd order, 5th, and 1st order equations to model each of the human body weight, foot size, and the age respectively. The present meta-analysis of the 79 subjects showed significant outcomes through the model equations that

evaluated by $R^2$ values, where 0.866 for human body weight equation, 0.602 for the age equation, and 0.308 for the foot size equation, all of them are formulated as a function of plantar pressure values. The proposed image processing that based on the related parameters. Thus, the image information of the pressure sensor can solve the balancing problem for those who have a problem during standing and walking.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**ANALISIS PENYEBARAN PUNCAK TEKANAN DIBAWAH TAPAK KAKI BERDASARKAN ALGORITMA PEMPROSESAN IMEJ**

Oleh

**ALI HUSSEIN SABRY**

**Julai 2018**

**Pengerusi : Profesor Madya Wan Zuha B Wan Hasan, PhD**
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Pengukuan tekanan plantar digunakan untuk mengakses beban luaran, yang ditafsirkan untuk membezakan antara normal dan tidak normal. Tekanan plantar juga memberikan wawasan yang berharga dalam analisis gait dan penyelidikan postur. Beberapa faktor telah dikaitkan dengan pengedaran tekanan kaki plantar, termasuk: berat badan, umur, struktur kaki, dan strategi berdiri berjalan. Ubat ulser kaki disebabkan oleh penyakit adalah pertimbangan utama kerana tekanan plantar kaki yang berlebihan di kawasan tertentu dari masa ke masa dapat menimbulkan ulser, tetapi kekurangan dalam merumuskan secara tepat pengedaran tekanan ke atas tapak kaki dan menggambarkan hubungan yang paling parameter yang mempengaruhi. Objektif kajian adalah untuk mengkaji Indeks Massa Tubuh dengan menganalisis hubungan tujuh tahap tekanan plantar yang mengedarkan di atas kawasan insole sentuhan dengan empat parameter peramal berterusan yang berkesan (jisim badan, saiz kaki, umur dan jantina), yang mempunyai arah langsung kesan pada tekanan plantar dinamik. Matlamat utama lain dalam kerja ini adalah untuk mencipta algoritma yang mempunyai keupayaan untuk merumuskan tepat dan tepat pengagihan tekanan ke atas tapak kaki. Dengan mengikuti pemeriksaan anggota bawah klinikal, tekanan plantar EMED digunakan dalam kajian ini. Tekanan plantar telah dipapar sebagai imej pada empat kategori pengukuran semasa berdiri dan berjalan dalam dua keadaan memandang perspektif; Percuma, dan Sarat dengan membawa berat yang sederhana semasa pemeriksaan subjek. Ujian pengulangan bersama dengan alat pemprosesan imej dianggap mengklasifikasikan tujuh tahap tekanan plantar dan memilih kategori pengukuran yang sesuai mengikut hubungan setiap peringkat dengan parameter yang dipelajari. Ujian pengulangan yang dinamik dengan beban (DL) adalah yang terbaik untuk dipertimbangkan antara pengukuran yang dijalankan. Tujuh tahap tekanan telah berjaya dikelaskan melalui kod pemprosesan imej. Tiga persamaan pemodelan; persamaan eksponen, polinomial, dan persamaan linear telah dibangunkan untuk memodelkan berat badan manusia, saiz kaki, dan umur masing-masing. Meta-

analisis semasa dari 79 subjek menunjukkan perwakilan yang signifikan yang dinilai oleh nilai $R^2$ untuk berat badan manusia 0.8661, untuk umur 0.1088, dan 0.3 untuk saiz kaki, semua adalah sebagai fungsi nilai tekanan penanam. Algoritma berasaskan pemprosesan imej yang dicadangkan juga boleh mempromosikan lebih banyak model berguna mengenai analisis kaki.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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| | |
|---|---|
| Fsize | Foot size |
| DL | Dynamic with load |
| D | Dynamic |
| S | Static |
| SL | Static with load |
| PPR | Plantar Pressure Ranges |
| GUI | Graphical User Interface |
| P_i | Range of values |
| BW | Body Weight |
| a1,a2…a5 | The coefficients of the weight formula. |
| $Pt_i$ | Total pressure |
| Mag | Magenta, 7$^{th}$ level of pressure (kPa) >300 |
| Red | Red, 6$^{th}$ level of pressure (kPa) 220~295 |
| Yel | Yellow, 5$^{th}$ level of pressure (kPa) 150~215 |
| Gr | Green, 4$^{th}$ level of pressure (kPa) 100~145 |
| Cy | Cyan, 3$^{rd}$ level of pressure (kPa) 60~95 |
| Blu | Blue, 2$^{nd}$ level of pressure (kPa) 30~55 |
| Blk | Black, 1$^{st}$ level of pressure (kPa) 10~25 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

The human foot is an amazingly engineered arrangement of bones, ligaments, tendons, and muscles that allow mobility by absorbing and supporting up vigorous pressure from everyday activities.

The foot is the most important anatomical part of the body to help along with the body's natural balance-keeping system. The function of the foot is providing a first stage of cushioning of the impact forces during walking, running, climbing, and other activities and transferring forces produced by the muscles to the ground. During daily activities, interactive forces are transferred between the body and the ground. As mentioned above, plantar pressure measurement can be used to access the external loads, which interpreted in order to distinguish between normal and abnormal. Plantar pressure also provides valuable insight in gait analysis and posture research.

Foot pressure distribution and timing information provide valuable insight on a variety of biomechanical and neurological disorders, as well as aiding in the treatment and prevention of wounds caused by high foot pressure. Accurate measurement of foot pressure distribution throughout the gait cycle illuminates gait asymmetries and provides insight on lower limb dysfunction, helping clinicians find and treat the root cause of biomechanical problems that can lead to pain throughout the lower body. The magnitude of the ground reaction force acting on the plantar foot (bottom of the foot)present in bipedal standing is in the order of0.5 $\times$body weight (BW), 1.0$\times$ BW whilst walking, and (2.5 to 3.0)$\times$BW during running. It is the largest external force experienced a byany region of the human body[1], [2].

This work discusses the variables with a realistic potential contribution to the outcome factors that are based on indications from the literature reviewed and the potential predictor parameters that provided by EMED system.

## 1.2 EMED Hardware

emed systems are available in six models: x, XL, q, n, c and a. All three systems collect and display the plantar pressure measurement from the emed platforms. The premier of the platforms is the emed-x Figure 1.1.

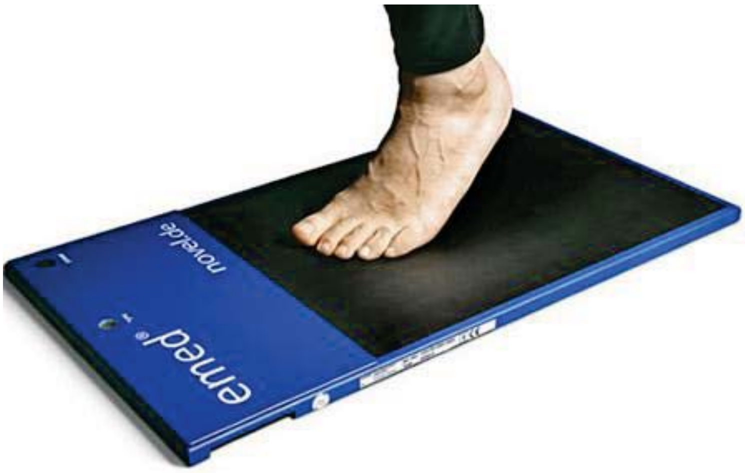


**Figure 1.1 : EMED-x**[3]

The emed®-x system is the premier version of the novel pedography measurement platforms. This system functions like all emed® platforms with calibrated capacitive sensors. The emed systems work with a notebook or desktop PC and connect directly to the USB interface of the PC. The emed-x system can be used either in a high speed mode with a sensor resolution of 1 sensor/cm² and a frame rate of 400 Hz or in a high sensor resolution mode with a sensor resolution of 4 sensors/cm² and a frame rate of 100 Hz. With a user-defined sensor area, the platform can be scanned at a rate greater than 400 Hz. The emed®-x supplies frame by frame in- and out- synchronization for motion analysis, digital video, and EMG and a built-in synchronization LED. Synchronization via the microphone input of the digital video camera allows simultaneous collection of dynamic pressure measurement and multiple digital video cameras. The emed systems can be started from novel databases and include extensive software for patient monitoring and foot analysis (see analysis and reporting section [3] for more information).

**Table 1.1 : Technical data for emed-a, systems**[3]

| Specification | EMED-a |
|---|---|
| Dimensions | 610x323x 16(18) |
| Sensor area | 380x240 |
| Number of sensors | 1760 |
| Platform thickness (mm) | 18 |
| Sensor resolution (sensors/cm^2) | 2 |
| Sampling frequency (Hz) | 50/60* |
| Pressure range (kPa) | 10-950 |
| Pressure threshold (kPa) | 10 |
| Accuracy | ±7% ZAS |
| Hysteresis | <3% |
| Temperature range (°C) | 15-40 |
| Maximum total force (N) | 67,000 |
| Crosstalk (db) | -40 |
| Cable length (m) | 5 |
| Connection to computer | USB |
| Operating systems | Windows 7, 8, 10 |
| Synchronization | None |

*User must specify either a 50 or 60 Hz platform

## 1.3 Problem Statement

The main consideration for the foot ulceration is the pressure distribution [4][5]because of the excessive foot plantar pressures in a particular area over time can give rise to such ulcers. Referring to the foot peak pressure and its distribution, several factors have been associated including; the body weight, age, foot structure, and standing/walking strategy. Gaps in this knowledge have been raised:

- A need for more analysis and description of the plantar pressure distribution in a selected group of healthy recruited people is required toward future reference information for a healthy foot to highlight their differences in standing and gait

cycle, which follow the involvement of the foot in systemic diabetic neuropathy.
- There is a lack in terms of accurate formulation for the pressure distribution over the foot plantar due to measurement category and the test conditions.
- Foot plantar pressure distribution has limitations in terms of accurate analysis and formulating the effect of different parameters on the distribution of foot plantar pressure.

Image processing-based algorithm is proposed to promote more useful models to formulate the plantar pressure distribution with the body weight, foot size, and age.

## 1.4 Objectives

The objectives of this study are:

1. To investigate the differences of pressure distribution on the touch insole area by considering EMED Plantar Pressure and classify the measurements according to classified pressure levels.
2. To examine the suitable measurement category, during standing and walking within two conditions of loading perspective for the processed image.
3. To analyze and formulate the main parameters that affect the foot plantar pressure distribution, such as; the body weight, age, and foot structure with the classified levels of the pressure.

## 1.5 Scope of Work

The study initially performs foot examine and ensure that the participants have no lower limb ailments, in good general health, within the age category of 20–63, and without any prior no history of lower limb surgery ulceration neurological or orthopedic impairments.

This work discusses the variables with a realistic potential contribution to the outcome factors that are based on indications from the literature reviewed and the potential predictor parameters that provided by EMED system. The data initially obtained from EMED are organized, classified, and processed for as preparation for analysis and modeling. Some preliminary arrangements are carried out on the foot planter data, for instance, these may involve placing data into rows and columns in a table format as structured data for further analysis. This work uses the Microsoft Excel for the data organization and MATLAB for the data processing and analysis.

The study focuses to examine the Body Mass Index through analyzing the relationships of 7 levels of plantar pressure that distribute over the touch insole area with the four effective continuous predictor parameters (body mass, foot size, age, and gender), that have a direct effect on dynamic plantar pressure. The other main goal of this work is to create an algorithm which has the ability to formulate accurately and reliably the distribution of pressure over the foot plantar. Plantar pressure is profiled as an image at four measurement categories during standing and walking within two conditions of loading perspective; Free, and Loaded by carrying a simple weight during the subject inspect. Repeatability test together with the image processing tool either considered to classify seven levels of the plantar pressure and select the suitable category of measurements according to the relationships of each level with the studied parameters.

## 1.6 Research Contributions

Pressure distribution measurement techniques are useful in analyzing the mechanical behavior of the human foot during static and dynamic loading situations in adult subjects. Foot complications are common in diabetic patients and are considered one of the most expensive complications to treat. The main contribution of this research is as follows:

- Classification7 levels of the plantar pressure and selecting the suitable category of measurements according to the relationships of each level with the studied parameters.
- Image processing algorithm has been employed to classify the levels of the plantar pressure. The proposed image processing-based algorithm can also promote more useful models concerning foot analysis.
- Three modeling equations; exponential, polynomial, and linear equations have been developed to model the human body weight, foot size, and age respectively.

## 1.7 Thesis layout

The **first chapter** gives an overview of the foot, of its anatomy and its functions. Furthermore, a definition of all the phases of the gait cycle is provided.

In the **second chapter**, the literature review concerning the previous related work has been discussed in some details. In particular, it has been emphasized in the relationship of a healthy foot with the human weight, age, and foot structure to be a reference for the diabetic foot and its consequences.

The **third chapter** explains the details all the materials and method used to perform this work as a proposed methodology, focusing on collecting data classification, the instruments used as a plantar pressure, the pressure mapping, and in the protocols of modeling the distribution of the foot pressure.

The **fourth chapter** is dedicated to discussion on the results of the data analysis, image processing outcome, Modelling, and the graphical user interfacing in particular on how to obtain a model of the foot pressure as a function of the three considered parameters.

The **fifth chapter** concludes the achievements of the method used to perform this work of thesis and recommend steps for the future to expand the application of the developed work.

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