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OPTIMIZATION TECHNIQUES FOR UNDERFOOT PRESSURE MEASUREMENT

OMAR HUSSEIN ALWAN

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By

OMAR HUSSEIN ALWAN

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

March 2017

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

OPTIMIZATION TECHNIQUES FOR UNDERFOOT PRESSURE MEASUREMENT

By

OMAR HUSSEIN ALWAN

March 2017

Chairman : Associate Professor Wan Zuha bin Wan Hasan, PhD
Faculty : Engineering

A plantar foot pressure measurement provides important information which can be used as a helpful tool for evaluating patients with foot complaints. Foot plantar pressure systems are devices that are used to measure underfoot pressure. They can be classified into two types: platform systems and insole systems. An insole system is flexible and portable, thereby allowing a wider variety of studies to be carried out with different gait tasks, footwear designs and terrains, while a platform system is fixed and limited to the measurement of underfoot pressure in a static condition, and is usually used for the detection of ulceration. Currently, underfoot pressure ranges have not been effectively established, and there is insufficient information about the minimum and maximum values of underfoot pressure. Likewise, constraints with regard to the implementation of insole systems still persist and are represented by the need to put a spacer on the sensor during measurements, with the problem of sensor parameters changing after the calibration. Therefore, optimization of measurement techniques have been proposed for the implementation of an insole system to measure the underfoot pressure to overcome these drawbacks.

This research was approved by the Human Research Ethics Committee of Universiti Putra Malaysia. The research was aimed at measuring the pressure of 15 points under the foot for 12 samples, divided into two groups (male and female). Two techniques were used to implement the insole system for the effective measurement of underfoot pressure, namely a sensor optimization of the output voltage swing, and the setting of the physical characteristics of a spacer to be placed on the sensors. In addition, a self-calibration technique was employed with the insole system to maintain the sensor measurements and to solve the problem of the changing of the sensor parameters after a period of time following the calibration. The performance of the proposed device after the application of these techniques was tested with an insole system based on the calculation of the body weight. The results showed that the proposed insole plantar pressure device was able to measure the plantar pressure ranges effectively and was

able to calculate the body weight with a measurement error of up to 5.07 % of the real value of the body weight using a weight scale. This was compared to the use of a commercial device (novel EMED system) which calculated the body weight with a measurement error of up to 9.2 %, or the use of the current insole system without any optimization technique, which calculated the body weight with a measurement error of up to 9.06 % from the real value. This work will contribute towards the benefit of the social and industrial sectors in terms of measurement precision.

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

TEKNIK PENGOPTIMUMAN UNTUK PENGUKURAN TEKANAN BAWAH KAKI

Oleh

OMAR HUSSEIN ALWAN

Mac 2017

Pengerusi : Profesor Madya Wan Zuha bin Wan Hasan, PhD
Fakulti : Kejuruteraan

Pengukuran tekanan tapak kaki menyediakan maklumat penting tentang struktur dan fungsi kaki, dan ia adalah alat yang berguna untuk menilai pesakit berpenyakit kaki. Sistem-sistem tekanan tapak kaki adalah alat-alat yang digunakan untuk mengukur tekanan di bawah kaki. Mereka boleh diklasifikasikan kepada dua jenis: sistem-sistem platform dan sistem-sistem lapik dalam kasut. Sistem lapik dalam kasut adalah fleksibel dan mudah alih, dengan itu membolehkan lebih banyak jenis kajian yang boleh dijalankan yang merangkumi tugas-tugas gaya berjalan yang berbeza, reka bentuk kasut dan rupa bumi, manakala sistem platform adalah tetap dan terhad kepada pengukuran tekanan bawah kaki dalam keadaan statik, dan biasanya digunakan untuk mengesan pengulseran. Pada masa ini, julat tekanan bawah kaki belum ditetapkan dengan berkesan, dan tidak terdapat maklumat yang mencukupi mengenai nilai-nilai minimum dan maksimum tekanan bawah kaki. Begitu juga, kekangan berkaitan dengan pelaksanaan sistem lapik dalam kasut masih berterusan dan diwakili oleh keperluan untuk meletakkan peruang di sensor semasa ukuran, serta masalah parameter sensor yang berubah selepas penentukuran. Oleh itu, pengoptimuman teknik pengukuran telah dicadangkan bagi pelaksanaan sistem lapik dalam kasut untuk mengukur tekanan bawah kaki bagi mengatasi kelemahan-kelemahan ini.Kajian ini telah diluluskan oleh Jawatankuasa Etika Penyelidikan Manusia Universiti Putra Malaysia. Kajian ini bertujuan untuk mengukur tekanan 15 titik di bawah kaki bagi 12 sampel yang dibahagikan kepada dua kumpulan (lelaki dan perempuan). Dua teknik telah digunakan untuk melaksanakan sistem lapik dalam kasut bagi pengukuran tekanan bawah kaki yang berkesan, iaitu pengoptimuman sensor untuk ayunan voltan output dan penetapan ciri-ciri fizikal peruang yang akan diletakkan di atas sensor. Di samping itu, teknik penentukuran-sendiri telah digunakan dengan sistem lapik dalam kasut untuk mengekalkan ukuran-ukuran sensor dan untuk menyelesaikan masalah parameter sensor yang berubah selepas satu tempoh masa berikutan penentukuran. Prestasi peranti yang dicadangkan selepas penggunaan teknik-teknik ini telah diuji dengan sistem lapik dalam kasut berdasarkan penghitungan berat badan. Hasil kajian menunjukkan bahawa peranti tekanan tapak

kaki lapik dalam kasut yang dicadangkan itu dapat menghitung julat tekanan tapak kaki dengan berkesan dan menghitung berat badan dengan ralat pengukuran sehingga 5.07% daripada nilai sebenar berat badan menggunakan skala berat badan. Ini telah dibandingkan dengan penggunaan peranti komersial (sistem EMED baru) yang menghitung berat badan dengan ralat pengukuran sehingga 9.2%, atau penggunaan sistem lapik dalam kasut semasa tanpa sebarang teknik pengoptimuman, yang menghitung berat badan dengan ralat pengukuran sehingga 9.06% daripada nilai sebenar. Kajian ini akan memberi manfaat kepada sektor-sektor sosial dan industri dari segi ketepatan pengukuran, penggunaan teknik pengoptimuman dan menyelesaikan masalah parameter sensor yang berubah selepas penentukuran.

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I also would like to thank Universiti Putra Malaysia UPM for accepting me in the Faculty of Engineering.

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This thesis was submitted to the Senate of 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:

Wan Zuha bin Wan Hasan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Azura Bt. Che Soh ,PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Haslina Binti Jaafar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Member Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ________________________
Name of Chairman of Supervisory Committee: Associate Professor Dr. Wan Zuha bin Wan Hasan

Signature: ________________________
Name of Member of Supervisory Committee: Associate Professor Dr. Azura Bt. Che Soh

Signature: ________________________
Name of Member of Supervisory Committee: Dr. Haslina Binti Jaafar

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
BW	Body Weight
CDPS	Capacitive Differential Pressure Sensor
COP	Center Of Pressure
CPS	Capacitive Pressure Sensor
FSR	Force-Sensing Resistor
IPPD	Insole Plantar Pressure Device
NN	Neural Network
RA	Rheumatoid Arthritis
UTM	Universal Test Machine

CHAPTER 1

INTRODUCTION

1.1 Overview

Feet are very important for human beings to provide stability and support while standing, walking and running. The functions of the foot are summarized as a shock absorber, a mobile adapter, and a rigid lever for the human body [1]. The underfoot pressure provides helpful and important information in research into gait and posture for diagnosing lower limb problems, for footwear designs, sports biomechanics, injury prevention and other applications. This research provides a precise measurement of underfoot pressure, which is important because these measurements can be used by clinicians and doctors for the early detection of the abovementioned problems. Underfoot pressure measurement systems are classified as one of two types: platform systems or insole systems.

The insole plantar pressure device (IPPD) plays a crucial role in the screening, treatment and behaviour modification of patients who are at risk of or are already experiencing a variety of foot and gait problems. The IPPD is used for assessing and improving the quality of life. For example, in sports, it is used to improve and monitor the performance of athletes, to enable people to monitor their health condition, and for them to practise sport postures anywhere at any time [2]. In addition, for patients who are suffering from diabetes, it is used to screen the development of foot ulceration. In terms of gait stability, it has proven to be very helpful in assessing and improving balance among the elderly [3]. It is also used to prevent the risk of ulceration or peripheral neoropathy in patients with diabetes and other sicknesses [4].

The need for an accurate underfoot pressure measurement system is driven by the increasing population of elderly people and the rise in the number of diseases related to a hectic lifestyle. However, underfoot pressure ranges measured through the use of plantar pressure measurement systems in relation to increasing body weight have not been effectively established yet to prove that this cumulative pressure is equal to the body weight of the sample. Commercial devices and current insole system devices can extract these ranges, but with a lot of measurement error in terms of body weight. This error is represented by a difference in the measurement in terms of the calculation of the body weight between the current insole system, current commercial devices and a weight scale. The proposed IPPD was used to obtain the pressure based on increasing the body weight effectively with less measurement error as compared to commercial devices and the current insole system. These pressure values are useful as a reference for researchers to compare their results. To ensure that the pressure range values had been effectively set, the proposed device had to fulfil certain requirements and apply optimization measurement techniques, which included optimization the sensor for voltage output swing, correctly setting the parameters which can affect the measurement represented by the material type and thickness to place on the sensor during the measurement, and applying the self-calibration technique. This research definitely has the potential to find a reference of underfoot pressure range values based on increasing the body weight with less measurement error in terms of the human body weight.

1.2 Problem Statement

Foot plantar pressure systems are used extensively to measure the pressure pattern underneath the human body so as to provide valuable information about the function of the underfoot pressure. Most underfoot plantar pressure systems are applied to solve problems with regard to gait and posture. Applications of the insole system have been used for many purposes such as to investigate the relationship between increasing body mass and peak/mean pressure [5], or to distinguish the phases of the normal gait cycle in real time [6]. These systems have been used for the reason of extracting the real-time measurements and replicate the shape of the ground reaction force and ankle moment in a stroke patient. Despite different purposes and aims, insole systems lack the ability to measure the body weight for such application to improve the precision of the extracted values [7, 8].

Presently, not many researchers have paid attention to pressure range values and suitable measurement procedures for improving the self-calibration and physical characteristics of the material used for footwear in relation to increasing human body weight. In addition, the current commercial devices which can extract these pressure values are not very precise in their calculation of the body weight. According to an investigation by [9,10] on the impact of increasing body weight (obesity), it was reported that there were disparities in the measurement of the peak plantar pressure in the regions affected by body weight. Furthermore, in addressing the plantar pressure difference during standing and walking in obese and non-obese subjects, it was reported that there was an increase in the value of the peak plantar pressure while walking in all the sections of the foot between the obese and non-obese subjects [9]. Moreover, the studies stated that the significant factor that influenced the foot plantar pressure measurement was the increase in human body weight [11]. The initial evidence indicated that the increase in body weight was a factor that could influence the distribution of plantar pressure in the foot [9, 12]. The researchers suggested that clinicians dealing with foot problems should consider the effect of increased body weight on plantar loading in obese patients [12]. The relationship between increasing body mass and mean as well as peak pressure was dependent upon the plantar region [13]. From the review of these previous studies, it can be seen that the pressure values were not taken into consideration in pressure measurements using the current insole system. Therefore, a significant technique was necessary for attaining points in order to find a suitable pressure range when using the plantar system, particularly the minimum and maximum pressure values that are related to the body mass or the peak plantar pressure during walking and standing conditions. Thus, it was necessary to find the underfoot pressure values based on increasing body weight so that they can be used as a reference by other researchers to compare their results with the extracted results. These pressure values can also be used to differentiate between people without foot complications and people, such as diabetics, with foot complications, as mentioned by [14].

Consistent with [15], Tek-scan, the manufacturer of Flexi force pressure sensors, states that when the footprint of the applied load is larger than the sensing area, it is necessary to use a spacer. This is a piece of material (smaller than the sensing area), that is placed on the sensing area to ensure that the entire load path goes through this area. It is necessary to investigate whether this spacer is required during calibrations and experiments to extract a precise measurement. In addition, the characteristics of this space, in terms of the type of material and the thickness need to be explored.

Furthermore, based on the elementary results of experiments with the Flexiforce pressure sensors, and according to the Flexiforce pressure sensor calibration guide, it is recommended that the conditioning of the sensor be repeated after a period of time [16]. It can be concluded that there is a problem if the sensors need to be recalibrated after a particular period to maintain the same measurements.

1.3 Research Objectives

The aim of this research was to develop and implement an IPPD that is able to measure the pressure under the foot effectively. In this work, the underfoot pressure was measured in terms of the body weight. Furthermore, it was also vital to reduce measurement error by obtaining the lowest percentage of error in terms of the body weight calculations with applying optimization techniques. In order to realize the above aims, it was necessary to fulfil the following objectives.

1. To improve sensor sensitivity based on maximum applied pressure and maximum weight involved for this device through optimization measurement.
2. To improve pressure distribution by applying a suitable spacer and specify the characteristics of this material in terms of the type and thickness of the material.
3. To reduce pressure error due to sensor resistance changing by implementing the self-calibration procedure.

1.4 Scope and Limitations of the Study

This research focused on the development of an IPPD for measuring the pressure under the foot. The IPPD was used to find the pressure values limits under the foot for 15 positions that are considered as important points for supporting the body weight. This research managed to achieve its objectives through the participation of 12 samples approved by the Human Research Ethics Committee of Universiti Putra Malaysia for two group of male and female with the group of age named as a young adult. In this project, the researcher also focused on providing a precise measurement of plantar pressure with lower measurement error compared to the current insole system and existing commercial devices, such as the novel system by EMED, which are based on body weight calculations. There were also a few factors that could have influenced and limited the experimental data while the research was being conducted.

First, the IPPD had a limitation in terms of the foot size, where it was set for a Euro foot size of 43, which is equivalent to a UK size of 10. Second, the IPPD was implemented to measure the pressure under the foot for a specific range of samples with a maximum weight of 100 kg. So, samples that were beyond this range could not be involved with this device. In addition, the experiment was carried out in an indoor environment because the insole system was not wireless but had to have a wired connection.

1.5 Research Contributions

The findings of this research will benefit the society and the industrial sector in view of the fact that plantar pressure measurements play an important role as key health indicators. This research will contribute to the industrial sector by providing an IPPD with optimization measurement techniques that can give precise measurements of underfoot pressure in terms of calculating the body weight as compared with the current insole system and existing commercial devices, such as the novel EMED system. This will help companies to improve measurements by foot plantar pressure devices based on this measurement technique. It is also very important to have a self-calibration technique to ensure that foot plantar pressure devices provide precise meansurements and that the same measurements are maintained by the sensors.

This research will also contribute to clinical measurements in providing detailed and useful information concerning underfoot pressure represented by information on the minimum and maximum pressure in relation to increasing body weight. This information can be a helpful guide for the early detection of gait and ulceration problems by clinicians and doctors.

1.6 Layout of the Thesis

This thesis starts with Chapter 1, which presents a general introduction to the subject and the problem statement. It also introduces the aims, objectives, and contribution of the study, and gives a brief summary of the structure of the thesis.

Next, Chapter 2 gives a description of the insole plantar pressure device, the factors that can affect the plantar pressure, and the various self-calibration techniques.

Chapter 3 describes the research methodology that was carried out to achieve the objectives, and discusses the steps that were taken to implement the insole plantar pressure device.

Subsequently, Chapter 4 presents the results and discussion, and verifies the results against the current insole system and a commercial device.

Finally, Chapter 5 gives a summary and the conclusion according to the findings of this research. Suggestions and recommendations for future research in the area are also presented in this final chapter.

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