

**DEVELOPMENT OF OPTICAL SENSOR DEVICE FOR
PEDOBAROGRAPH ACQUISITION**

YUTTAPONG AUNHATHAWEE SUP

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entitled
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PEDOBAROGRAPH ACQUISITION**

.....
Mr. Yuttapong Aunhathaweesup
Candidate

.....
Asst. Prof Supaporn Kiattisin,
Ph.D. (Electrical and Computer
Engineering)
Major advisor

.....
Asst. Prof Adisorn Leelasantitham,
Ph.D. (Electrical Engineering)
Co-advisor

.....
Lect. Sotarath Thammaboosadee,
Ph.D. (Information Technology)
Co-advisor

.....
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

.....
Asst. Prof Supaporn Kiattisin,
Ph.D. (Electrical and Computer
Engineering)
Program Director
Master of Science Program in
Technology of Information System
Management
Faculty of Engineering
Mahidol University

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was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science
(Technology of Information System Management)

on
March 10, 2014

.....
Mr. Yuttapong Aunhathaweep
Candidate

.....
Lect. Surapong Pongyupinpanich,
Ph.D. (Electronic and Informatic
Engineering)
Chair

.....
Asst. Prof Supaporn Kiattisin,
Ph.D. (Electrical and Computer
Engineering)
Member

.....
Asst. Prof Adisorn Leelasantitham,
Ph.D. (Electrical Engineering)
Member

.....
Lect. Sotarath Thammaboosadee,
Ph.D. (Information Technology)
Member

.....
Lect. Waranyu Wongseree,
Ph.D. (Electrical Engineering)
Member

.....
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

.....
Lect. Worawit Israngkul,
M.S. (Technical Management)
Dean
Faculty of Engineering
Mahidol University

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Yuttapong Aunhathaweesup

DEVELOPMENT OF OPTICAL SENSOR DEVICE FOR PEDOBAROGRAPH
ACQUISITION

YUTTAPONG AUNHATHAWEESUP 5537228 EGTI/M

M.Sc. (TECHNOLOGY OF INFORMATION SYSTEM MANAGEMENT)

THESIS ADVISORY COMMITTEE: SUPAPORN KIATTISIN, Ph.D., ADISORN
LEELASANTITHAM, Ph.D., SOTARAT THAMMABOOSADEE, Ph.D.

ABSTRACT

This thesis compares many techniques for demonstrating different pedobarograph systems to measure foot pressure, which can be used as a clinical tool. This tool can aid a surgeon's decision making. This thesis presents the development of an optical sensor device for the acquisition of pedobarograph data through the use of measuring foot pressure, which is relative to weight. The optical sensor is inexpensive and easily available while the Tekscan® (electronic matrix force plate) is expensive and imported from overseas. For the proposed methods, weighted (or inputted) images from the foot pressure are captured from illuminated slicing. Such weighted images are computed by image processing, e.g., Gaussian filtering, canny edge detection, region of interest, and illuminated slicing. Then, statistical analysis using ANOVA and the correlation technique was used to verify the results of the pedobarograph between the optical sensor and Tekscan®. The sample was 58 feet from 29 normal subjects. The results show that the F-statistics value was approximately at 1,855.632, the significance value was equal to 0.001 ($P < 0.05$), and the correlation coefficient was 0.764, indicating a strong relationship. This means that the optical sensor can be used as a substitute for the Tekscan® device.

KEY WORDS: OPTICAL SENSOR DEVICE / PEDOBAROGRAPH / FOOT
PRESSURE / MATRIX FORCE PLATE / CORRELATION

45 pages

การพัฒนาอุปกรณ์ตรวจจับแสงเพื่อใช้ในการเก็บข้อมูลน้ำหนักแรงกดบริเวณฝ่าเท้า

DEVELOPMENT OF OPTICAL SENSOR DEVICE FOR PEDOBAROGRAPH ACQUISITION

ยุทธพงศ์ อุณหวิทย์ 5537228 EGTI/M

วท.ม. (เทคโนโลยีการจัดการระบบสารสนเทศ)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์ : สุภาภรณ์ เกียรติสิน, Ph.D., อติสร ลีลาสันติธรรม, Ph.D.,
โยทศรีรัต ธรรมบุษดี, Ph.D.

บทคัดย่อ

การวิจัยนี้ได้นำเสนอกระบวนการเปรียบเทียบเทคโนโลยีในการตรวจวัดน้ำหนักแรงกดบริเวณฝ่าเท้าที่มีความแตกต่างกันในกระบวนการตรวจวัดสองชนิดคือเครื่องมือตรวจวัดน้ำหนักแรงกดโดยใช้เทคโนโลยีของแสงและเทคโนโลยีของอิเล็กทรอนิกส์ งานวิจัยนี้ได้นำเสนอการพัฒนาเครื่องมือตรวจวัดและระบบตรวจวัดน้ำหนักแรงกดบริเวณฝ่าเท้าผ่านการวัดน้ำหนักแรงกดที่มีความสัมพันธ์กับน้ำหนักตัวที่กดลงบริเวณฝ่าเท้า โดยการใช้อุปกรณ์ตรวจจับแสงมาประยุกต์ใช้ในการตรวจวัดน้ำหนักแรงกดจะช่วยให้มีค่าใช้จ่ายต่ำและสามารถหาใช้งานได้ง่ายในขณะที่การใช้แผ่นอิเล็กทรอนิกส์จะมีค่าใช้จ่ายสูงและจะต้องนำเข้าจากต่างประเทศ ในการพัฒนาได้นำเสนอวิธีการคือ เก็บภาพเท้าที่มีความสว่างจากค่าแสง โดยภาพจะถูกคอมพิวเตอร์ประมวลผล ด้วยกระบวนการต่อไปนี้ การลดรายละเอียดของภาพ, การหาขอบภาพ, กระบวนการหาพื้นที่ๆสนใจ และการตัดภาพตามความสว่าง และใช้หลักทางสถิตินำมาวิเคราะห์ความสัมพันธ์ของข้อมูลระหว่างเครื่องมือทั้งสองชนิด โดยใช้ ANOVA F-Statistics และทำการหาความสัมพันธ์กันของข้อมูล โดยงานวิจัยได้ทำการทดสอบจากกลุ่มตัวอย่าง จำนวน 29 คน (58 เท้า) ได้ผลลัพธ์ F-Statistics ที่ 1,855.632 และมีค่า Significant เท่ากับ 0.001 และค่าสัมประสิทธิ์สหสัมพันธ์เป็น 0.764 แสดงให้เห็นความสัมพันธ์ที่แข็งแกร่ง ซึ่งจะแสดงว่าเซ็นเซอร์แบบแสงสามารถใช้ทดแทนแบบอิเล็กทรอนิกส์ได้

CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT (ENGLISH)	iv
ABSTRACT (THAI)	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
CHAPTER 1 INTRODUCTION	1
1.1 Background and problem statement	1
1.2 Objectives	2
1.3 Scope of the study	2
1.4 Expected Result	3
CHAPTER 2 LITERATURE REVIEW	4
2.1 Foot anatomy	5
2.2 Instruments for measuring barefoot pressure	5
2.2.1 Tekscan® segmented and matrix force plates.	7
2.2.2 Optical pedobarograph	9
2.3 Image Processing	10
2.3.1 RGB Systems	11
2.3.2 Gaussian filtering	12
2.3.3 Image Segmentation	13
2.3.4 Canny edge detection	14
2.4 Statistical Analysis	15
2.4.1 F-Statistics	15
2.4.2 Correlation	15
CHAPTER 3 RESEARCH METHODOLOGY	17
3.1 Development Optical Pedobarograph	18
3.2 Development program pressure analyzer	21

CONTENTS (cont.)

	Page
3.2.1 The Image Processing Results	21
3.2.2 Design interface of systems	22
3.3 Collect data from optical pedobarograph and Tekscan®	23
3.4 Extraction data from image and processing	24
3.5 Convert data to comparison unit.	27
3.6 Statistics test correlation of data.	27
3.7 Required tools and Time frame	28
3.7.1 Hardware for image processing	28
3.7.2 Software	28
CHAPTER 4 RESULTS AND DISCUSSION	29
4.1 Image processing Results	29
4.2 Correlation - Statistics analysis	31
CHAPTER 5 CONCLUSION	34
REFERENCES	35
APPENDICES	37
Appendix A Subject characteristics	38
Appendix B Development of optical sensor device for Pedobarograph acquisition	40
BIOGRAPHY	45

LIST OF TABLES

Table		Page
4.1	Descriptive statistics of sample of study	29
4.2	One-way analysis of variance (ANOVA) table result	32
4.3	Correlations of Tekscan® and Podoscope	33

LIST OF FIGURES

Figure	Page
2.1 Pedobarography	4
2.2 Top view of foot bones	5
2.3 Tekscan® force plates device.	8
2.4 Tekscan® sensor architecture.	9
2.5 Podoscope architecture.	10
2.6 Block diagram of podoscope data acquisition and image processing.	11
2.7 Red-YellowGreen-Blue LED spectra in RGB Systems.	12
2.8 2-D Gaussian distribution with mean (0, 0) and $\sigma = 1$	13
2.9 Image Segmentation original to segmentation image	14
2.10 Canny edge detection method	14
3.1 Method diagram of correlation.	17
3.2 Podoscope architecture.	18
3.3 Acrylic sheet.	19
3.4 Laser in Acrylic tube.	19
3.5 Light transmit in acrylic sheet.	20
3.6 Green color LED type SMD.	20
3.7 Finalize Optical Pedobarograph.	21
3.8 Result imread function in MATLAB.	22
3.9 Development interface with Microsoft Visual Studio.	22
3.10 F-Scan application collect data from pressure sensor.	23
3.11 Podogram Analyzer application collect data from optical sensor.	23
3.12 F-Scan application collect data from pressure sensor.	24
3.13 Step of extraction data from	24
3.14 Original Image to Pressure image with application Podogram Analyzer	25
3.15 Original Image to Gaussian blur filter	25
3.16 Original Image to region of interest	26
3.17 Original region of interest to pressure image with image shading color	26

LIST OF FIGURES (cont.)

Figure	Page
4.1 Data of foot. (A) foot print from podoscope, (B) Pedobarographs with image processing, (C) Pedobarographs from Tekscan®	30
4.2 Data acquire from Tekscan® dimension 31x15 sensors.	30
4.3 Data process from Optical Pedobarograph dimension 31x15 pixels	31
4.4 Area under the pressure for transducer location of the foot	32

CHAPTER 1

INTRODUCTION

1.1 Background and problem statement

Foot is responsibility heaviest organ in the body and its treatment is very important part of human life. There have been found for the people with a foot wrong more than 70% because of wearing the wrong shape. This distortion is a disease i.e. diabetes. There are many types of the research study about pressure in relation to the weight of the foot. Design of equipment is to support the heel and foot area reducing the pressure on the main body.

It is an important issue for foot disorders in diabetic patients affecting life quality of patients and their families for a major economic problems in the country. As a result, medical treatment expense will be a high costing including chronic wound, surgery and an artificial leg (from a study in Siriraj Hospital, Thailand from B.C. 2002 to 2004 found that the cost of amputation patients is average to 80,000 Baht, the highest cost up to eight hundred thousand). The International Working Group on Diabetic Foot Diabetes Federation's world leads to research for prevention of caring the foot problems e.g. the supplemental material insole in shoes, or the shoes to prevent foot ulcers in people with diabetes.

Instruments for measuring barefoot pressure are as follows.

1. Barefoot measurements: footprints, mat and plate
2. Cumulative techniques
 - a. Foot printing.
 - b. Microcapsules.
 - c. Foil Pedobarography
3. Optical techniques
 - a. Optical Pedobarographs.
 - b. Photo elasticity.
 - c. Textured mat cinephotography.

- d. Liquid crystals
- 4. Electromechanical techniques
 - a. Segmented and matrix force plates.
 - b. Capacitance mats.
 - c. Piezoelectric multi-element plates.
 - d. Force-sensitive resistor (FSR) arrays.
 - e. Contact-area-force-plate hybrids.
 - f. In-shoe measurements: discrete sensors and arrays

The foot-pressured results are compared between Optical Pedobarographs and Segmented and matrix force plates in terms of accuracy and low cost. It is to record dynamic variations in downward pressure by different areas of the sole of a foot as a person stands upright or walks.

1.2 Objectives

- 1) To study the instruments for measuring barefoot pressure in terms of accuracy and low cost.
- 2) To study the acquisition method between optical pedobarograph and segmented and matrix force plates.
- 3) To create the optical pedobarograph device for support medical, sports biomechanics and gait biometrics.

1.3 Scope of the study

- 1) To development Optical Pedobarograph device and Software Analysis.
- 2) The data comes from volunteer with foot type normal/high/low arch.

1.4 Expected result

- 1) To learn and understand know-how about workflow of diagnosis of acquisition method of instrument foot pressure.
- 2) The Optical Pedobarograph can be support medical, sports biomechanics and gait biometrics.
- 3) The correlation of the result between Optical Pedobarograph and Tekscan® with high Correlation

CHAPTER 2

LITERATURE REVIEW

Currently, Medical could diagnose the foot pressure by objective measurement with many tools are barefoot measurements footprints, mat and plate, Cumulative techniques, Optical Techniques, Electromechanical techniques.

The result from all tools is Pedobarography (Figure 2.1) is the study of pressure fields acting between the plantar surface of the foot and a supporting surface. Used most often for biomechanical analysis of gait and posture, pedobarography is employed in a wide range of applications including sports biomechanics and gait biometrics.

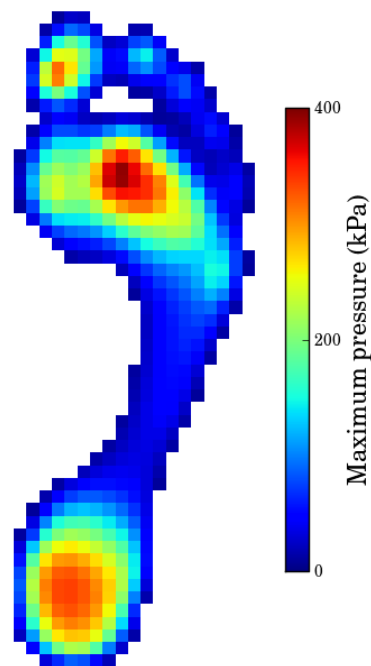


Figure 2.1 Pedobarography

2.1 Foot anatomy

The foot (figure 2.2) is an anatomical structure found in many vertebrates. It is the terminal portion of a limb which bears weight and allows locomotion. In many animals with feet, the foot is a separate organ at the terminal part of the leg made up of one or more segments or bones, generally including claws or nails.

The human foot and ankle is a strong and complex mechanical structure containing exactly 26 bones, 33 joints, and more than a hundred muscles, tendons, and ligaments. The foot can be subdivided into the forefoot, midfoot, hindfoot. Bones of feet is segment 4 groups

1. Phalanges
2. Metatarsus : first, second, third, fourth and fifth metatarsal bone
3. Tarsus, Calcaneus, Cuneiformes, Cuboid and Navicular
4. Tibia, Fibula

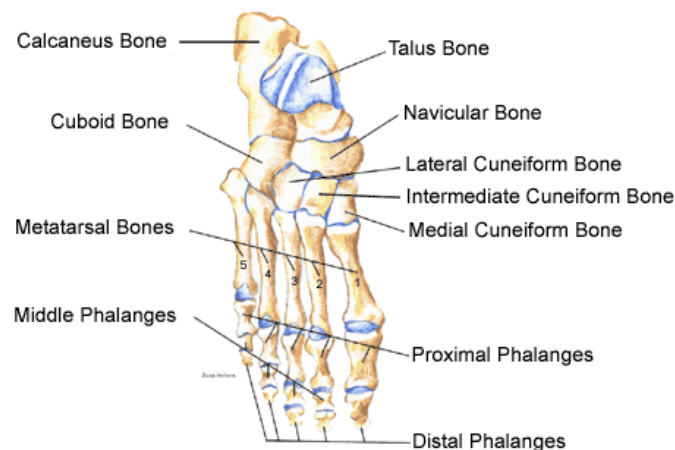


Figure 2.2 Top view of foot bones

2.2 Instruments for measuring barefoot pressure

Measurements of plantar pressure provide an indication of foot and ankle functions during gait and other functional activities, because the foot and ankle provide both the necessary support and flexibility for weight bearing and weight shifting while performing these activities. Although plantar pressure data have been recognized as an important element in the assessment of clients with diabetes and peripheral neuropathy,

information derived from plantar pressure data also can assist in determining and managing the impairments associated with various musculoskeletal, integumentary, and neurological disorders.

Instruments for measurements types

1. Barefoot measurements : footprints, mat and plate
2. Cumulative techniques
 - a. Foot printing.
 - b. Microcapsules.
 - c. Foil Pedobarography
3. Optical techniques
 - a. Optical Pedobarographs.
 - b. Photo elasticity.
 - c. Textured mat cinephotography.
 - d. Liquid crystals
4. Electromechanical techniques
 - a. Segmented and matrix force plates.
 - b. Capacitance mats.
 - c. Piezoelectric multi-element plates.
 - d. Force-sensitive resistor (FSR) arrays.
 - e. Contact-area-force-plate hybrids.
 - f. In-shoe measurements : discrete sensors and arrays

The use of force platforms is the method most commonly used to assess the interaction of the foot and supporting surface. Although the force platform provides valuable information regarding both the vertical and shear components of the ground reaction force, it provides little information on how the planter surface of the foot is loaded with respect to the supporting surface. When evaluating patients, atypical amounts of loading or patterns of loading may be reflective of a systemic or localized lower-extremity pathology and may be indicators (risk factors) for or predictors of further pathology or worsening of the existing pathology. In addition, force platforms have very specific requirements for attachment to the supporting surface on which data collection will occur. Such is not the case with numerous commercially available

systems for measuring plantar pressure (Tekscan®, Optical Pedobarograph, F-Scan system). Thus, plantar pressure measurement systems offer the clinician a high degree of portability, permitting utilization among multiple clinic sites. Foot pressure can calculate with equation (1) with force per unit area.

Pressure (p) is defined as force (F) per unit area (A)

$$Pressure (p) = F/A \quad (1)$$

Force, when measured using a force platform, is the net result of the components of the ground reaction or resultant force acting on the foot. The components of the ground reaction force are in the fore-aft, medial-lateral, and vertical directions. When assessing plantar pressure, a discrete sensor or a matrix of multiple sensors

The research use optical technique and electromechanical technique for comparative the result. To proving the correlation of result can be used optical technique for substituting the Tekscan®.

2.2.1 Tekscan® segmented and matrix force plates.

Tekscan® is foot pressure distribution and timing information provide valuable insight on a variety of biomechanical and neurological disorders, as well as aiding in 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.

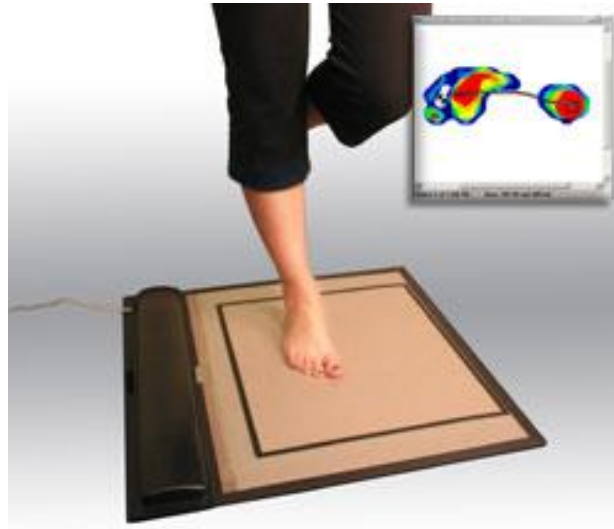


Figure 2.3 Tekscan® force plates device.

The foot pressure measurement can be used in real clinical settings for

- Gait analysis and biomechanics
- Diabetic offloading
- Sports medicine and rehabilitation
- Pre- and post-treatment evaluation
- Orthotic prescription confirmation

The F-Scan system provides dynamic pressure, force and timing information for foot function and gait analysis. Information obtained from the F-Scan is used in real-world applications, like designing and testing orthotics, offloading diabetic feet, and evaluating footwear and techniques in elite athletes.

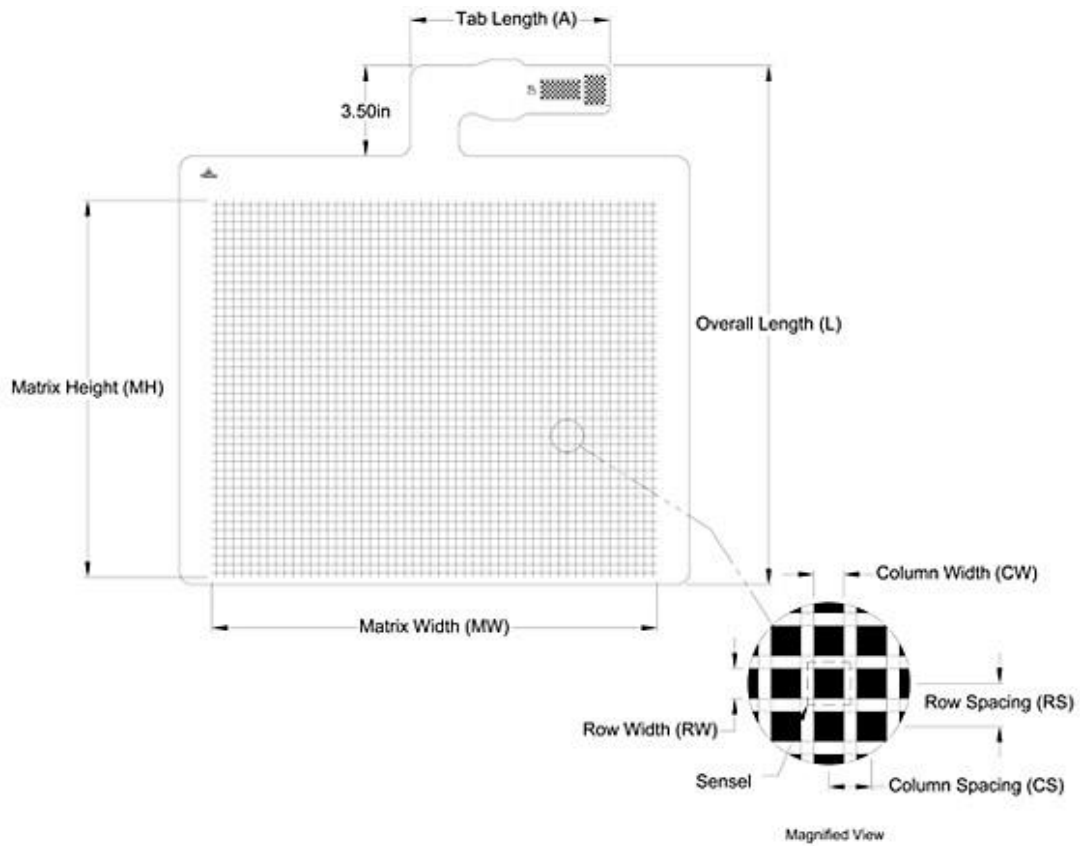


Figure 2.4 Tekscan® sensor architecture.

Pressure sensors is resistive technology and sensing area is 17.16" x 14.52" (435.9 x 368.8 mm) can be assess subjects while walking and standing using 2,288 sensing elements. Pressure range is 125 psi/862 kPa.

2.2.2 Optical Pedobarograph

Podoscope device is used to acquire or get the data, as shown in Figure. 2.5, the device is an optical Pedobarograph developed in the field of foot pressure sensing. It consists of an acrylic sheet covered by a thin film of a material such as a pressure indicating film, light-emitting diode illuminating from the side edge of acrylic sheet. The light internally is reflected at internal transparent acrylic plate and its light is controlled by the LED controller. Pressure indicating film is used for applying the pressure sensing to the top surface pushed the interface film into a close contact with acrylic sheet by deforming of the foot. The light intensity is captured from CCD camera

emitting to the mirror of 45 degree from the pressure indicating film. The captured image is depicted for the pressure data which is a color zones of the pressure.

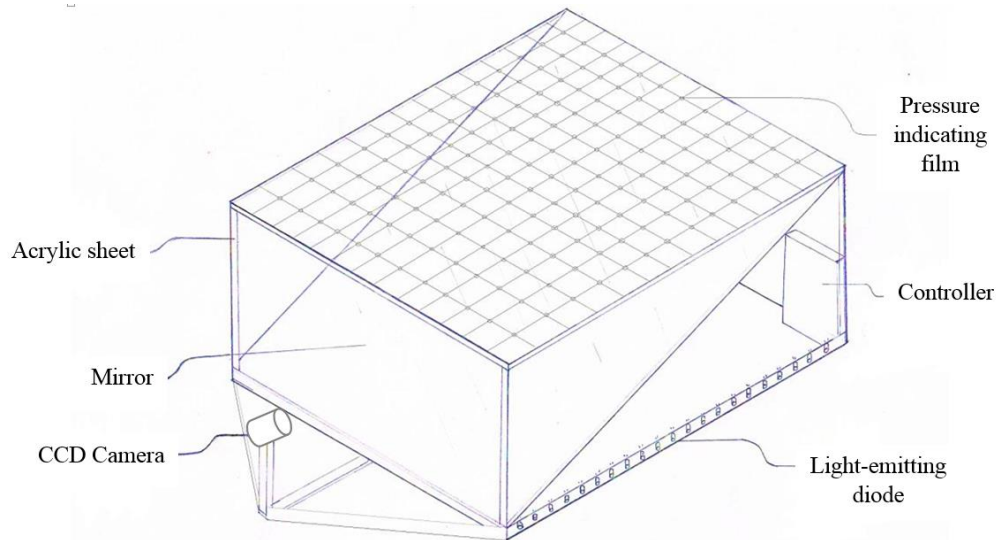


Figure 2.5 Podoscope architecture.

Diagrams of data acquisition and image processing system which is a process to convert the footprint image to the pressure image. Firstly, a man (subject) stands on the podoscope, and then the CCD camera will capture the footprint image. Secondly, footprint image is processed by image processing with Gaussian filtering to blur image, canny edge detection, region of interest (ROI) and illuminate slicing. Lastly, the resulted image is called as the Pedobarograph.

2.3 Image Processing

Image processing is usually concerned with the computer manipulation and analysis of pictures. Typical procedures in computer image-processing are concerned with improvement of degraded (low-contrast or noisy) pictures, restoration and reconstruction, segmenting of pictures into parts and pattern recognition of properties of the pre-processed pictures. To solve these problems, digitized pictures are processed by local operations in a sequential manner. Here we describe a special light-sensitive (Light-emitting diode green color, Wavelength range (nm) $500 < \lambda < 570$) are process with RGB Systems model.

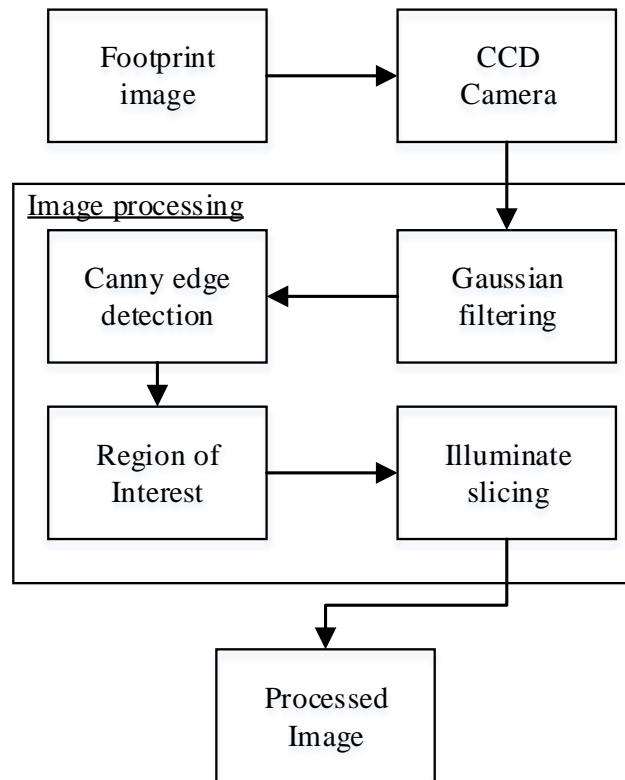


Figure 2.6 Block diagram of podoscope data acquisition and image processing.

2.3.1 RGB systems

White light can be formed by mixing differently colored lights; the most common method is to use red, green, and blue (RGB). Hence the method is called multi-color white LEDs. Because these need electronic circuits to control the blending and diffusion of different colors, and because the individual color LEDs typically have slightly different emission patterns even if they are made as a single unit, these are seldom used to produce white lighting. Nevertheless, this method is particularly interesting in many uses because of the flexibility of mixing different colors in principle, this mechanism also has higher quantum efficiency in producing white light.

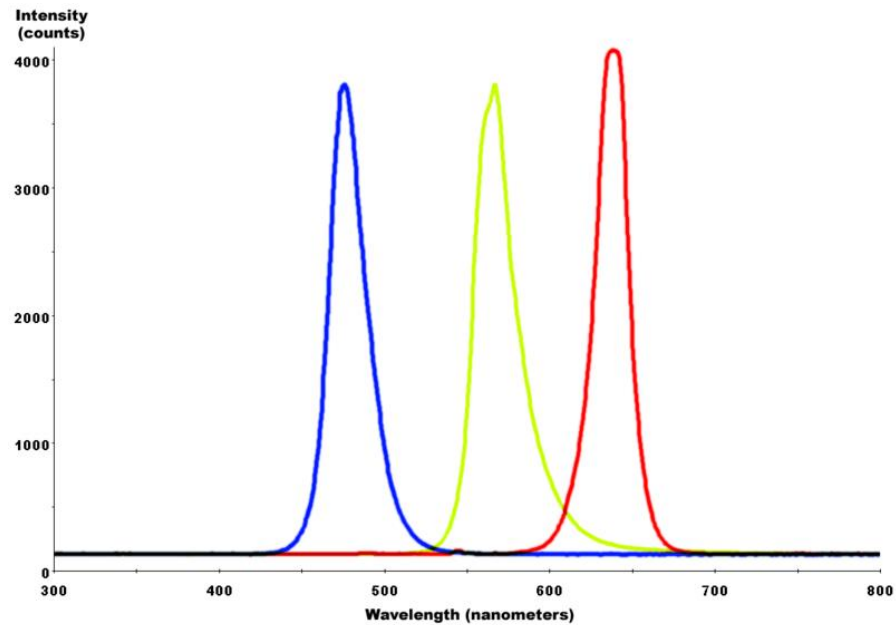


Figure 2.7 Red-YellowGreen-Blue LED spectra in RGB Systems.

2.3.2 Gaussian filtering

The idea of Gaussian smoothing is to use this 2-D distribution as a ‘point-spread’ function, and this is achieved by convolution. Since the image is stored as a collection of discrete pixels we need to produce a discrete approximation to the Gaussian function before we can perform the convolution. In theory, the Gaussian distribution is non-zero everywhere, which would require an infinitely large convolution kernel, but in practice it is effectively zero more than about three standard deviations from the mean, and so we can truncate the kernel at this point.

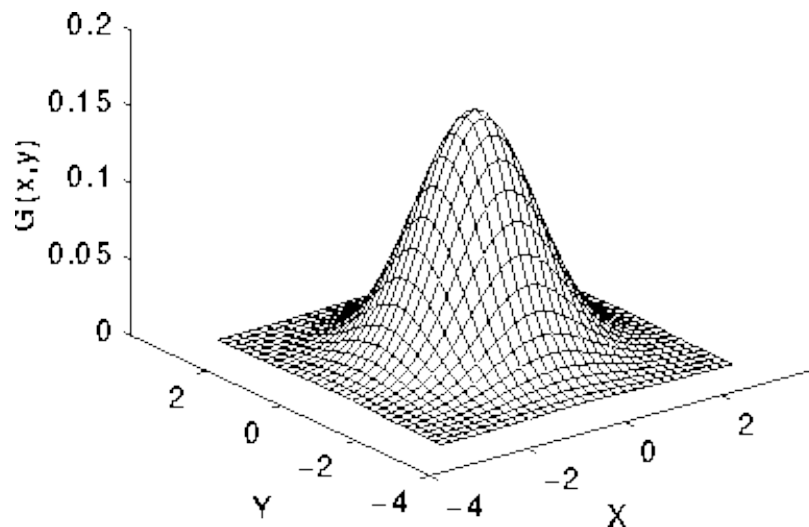


Figure 2.8 2-D Gaussian distribution with mean (0, 0) and $\sigma = 1$

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

The noises can be gotten rid of by smoothing. In this work it uses Gaussian spatial filter for smoothening. It is more favored than Box filter because it preserves the edges. It is a low pass filter uses Gaussian function to build two-dimensional filter kernel. In this work Gaussian filter with kernel size 5x5 and sigma=1.4 is used. The two-dimensional digital Gaussian filter is shown as following

2.3.3 Image segmentation

Image Segmentation is the process of partitioning a digital image into multiple regions or sets of pixels. Actually, partitions are different objects in image which have the same texture or color. The result of image segmentation is a set of regions that collectively cover the entire image, or a set of contours extracted from the image. All of the pixels in a region are similar with respect to some characteristic or computed property, such as color, intensity, or texture. Adjacent regions are significantly different with respect to the same characteristics.

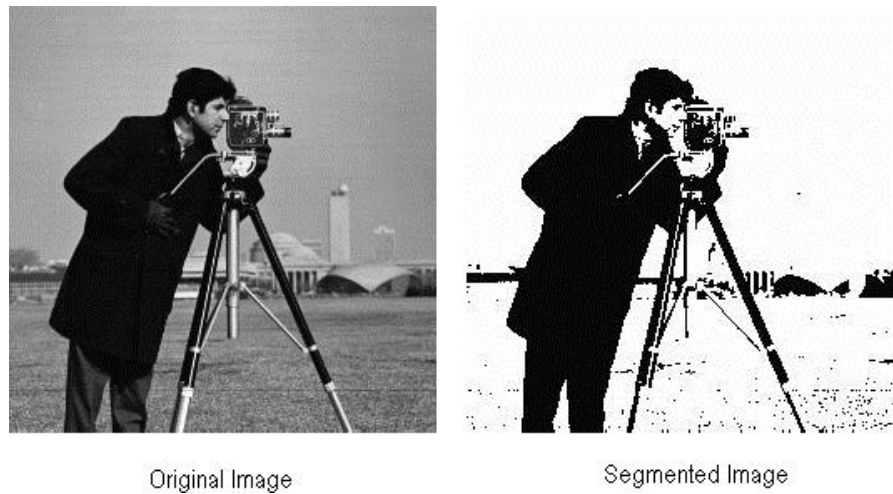


Figure 2.9 Image Segmentation original to segmentation image

Edge detection is one of the most frequently used techniques in digital image processing. The boundaries of object surfaces in a scene often lead to oriented localized changes in intensity of an image, called edges. This observation combined with a commonly held belief that edge detection is the first step in image segmentation, has fueled a long search for a good edge detection algorithm to use in image processing.

2.3.4 Canny edge detection

The notion of the canny edge detection is differentiation to discover the data's maximum-minimum. It is believed that a point is the edge. Canny edge detection algorithm is classical. It is also a strong way for detecting the edge in gray-scale images. Furthermore, the two important parts of the method are NMS introduction (Non-Maximum Suppression) and double threshold of the gradient image. We proposed an efficient version of the canny edge step by step following this diagram.

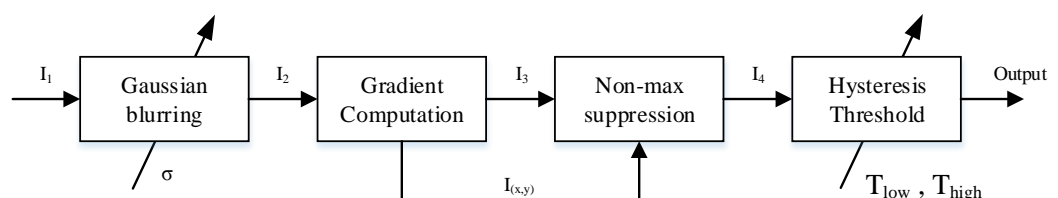


Figure 2.10 Canny edge detection method

First, we choose the Gaussian filter as our smoothing operator (I_1 as foot images). Second, we implement of gradient filters by write the code with I_2 for filtering an image in the method gradient. Then, we have to compute the position of the points (Non-Maximum Suppression). Finally, the contour segments above a Thigh (high threshold) are grown in a way to include all connected points greater than T_{low} (low threshold)

2.4 Statistical Analysis

2.4.1 F-Statistics

The hypothesis that the means of a given set of normally distributed populations, all having the same standard deviation, are equal. This is perhaps the best-known F-test, and plays an important role in the analysis of variance (ANOVA). F-statistics can also be thought of as a measure of the correlation Pedobarograph between optical sensor device and electrical matrix force plate(Tekscan®).

$$d(x_i, y_j) = \sqrt{\sum_{r=1}^n w_r (a_r(x_i) - a_r(x_j))^2} \quad (3)$$

Where \bar{Y}_i is the sample mean in the i^{th} group, n_i is the number of observations in the i^{th} group, \bar{Y} is the overall mean of the data, and K is the number of groups. Y_{ij} is the j^{th} observation in the i^{th} out of K groups and N is the overall sample size.

2.4.2 Correlation

The correlation is a term that refers to the strength of a relationship because they can indicate a predictive relationship between dataset that can be exploited in practice.

$$r_{xy} = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}} \quad (4)$$

x and y are results of measurements that contain measurement error x_i and y_i where $i = 1, 2, \dots, n$, then the sample correlation coefficient can be used to estimate the population Pearson correlation

CHAPTER 3

RESEARCH METHODOLOGY

The method diagrams of correlation. Which is a process the data to correlation statistical test. Part I, process the data from optical pedobarograph by extraction data from image and covert to 8 bit grayscale. The data is transformed to the matrix resolution of 31x15 in the lastly. Part II, The data from Tekscan® has selection frame of data for statistical test.

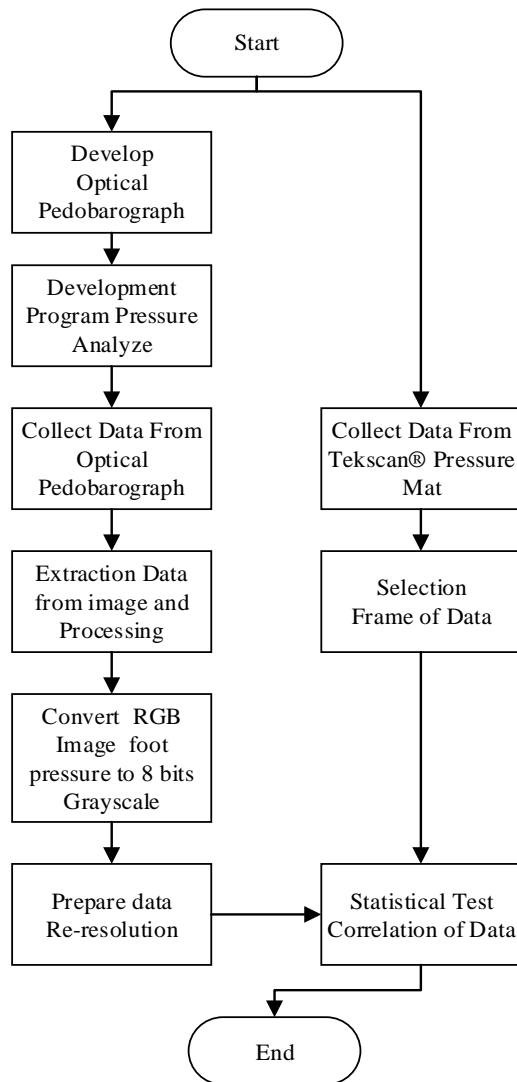


Figure 3.1 Method diagram of correlation.

3.1 Development Optical Pedobarograph

The Optical Pedobarograph is design to use resources in local. From figure 3.2 show the architecture of Optical Pedobarograph. It made from acrylic sheet thickness 15mm transparent and mirror for reflex foot image to CCD camera. Always on light-emitting diode(LED) Green Light Wavelength

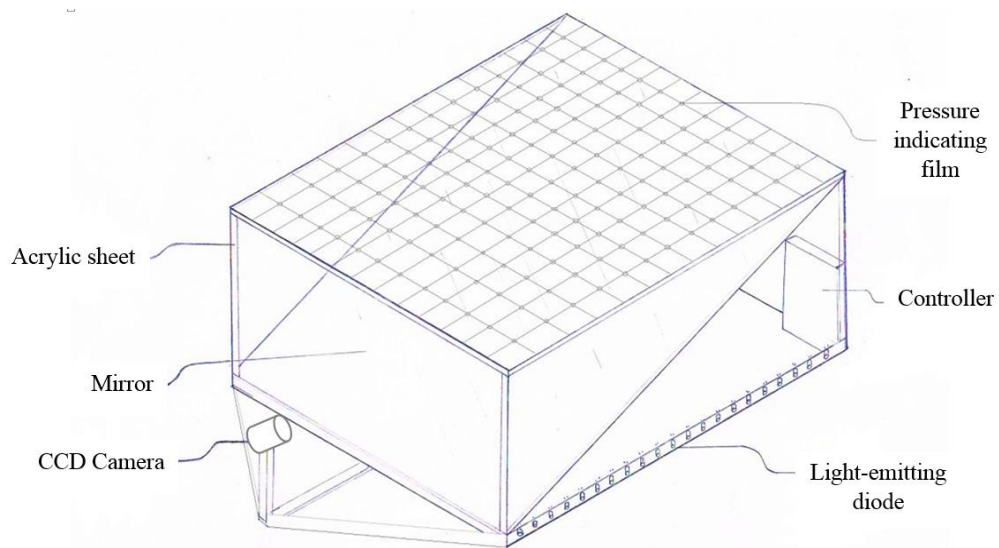


Figure 3.2 Podoscope architecture.

Material: Acrylic sheet property, it can function as a waveguide, or “light plate”, to transmit light. The light guiding of light by refraction. Practical applications, such as close internal illumination during dentistry

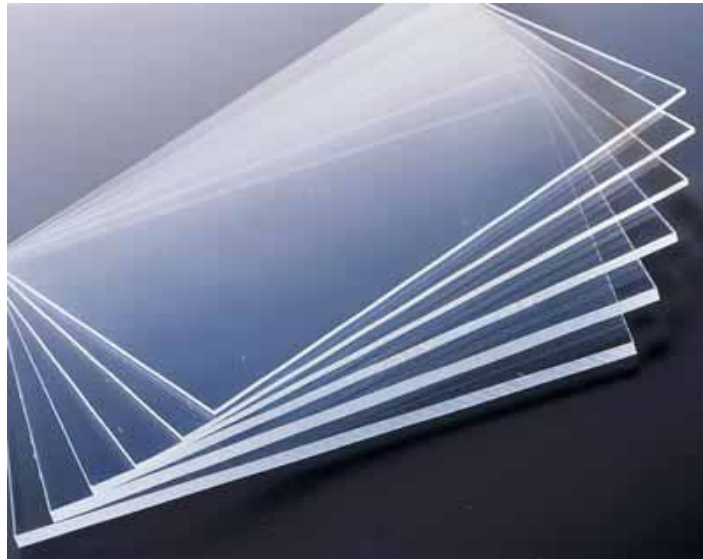


Figure 3.3 Acrylic sheet.

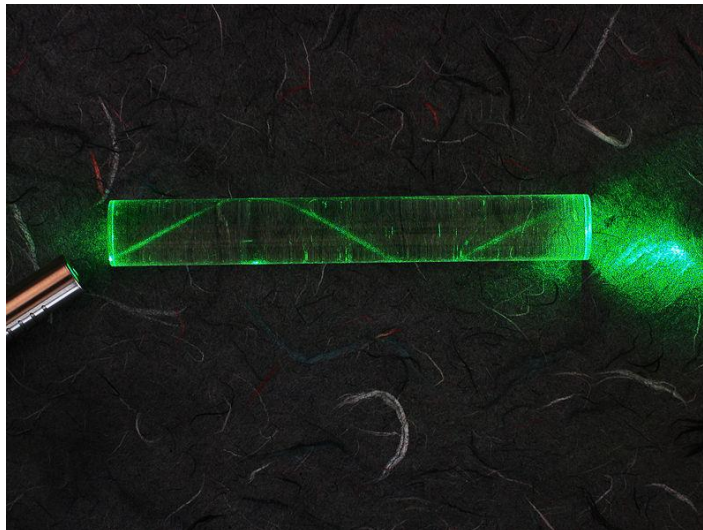


Figure 3.4 Laser in Acrylic tube.

The light is transmit from the side of acrylic and reflex in elements. Acrylic sheet is phosphoric in color from light source. The light source is light emitting diode (LED) green color wavelength is $500 < \lambda < 570$ (nm).

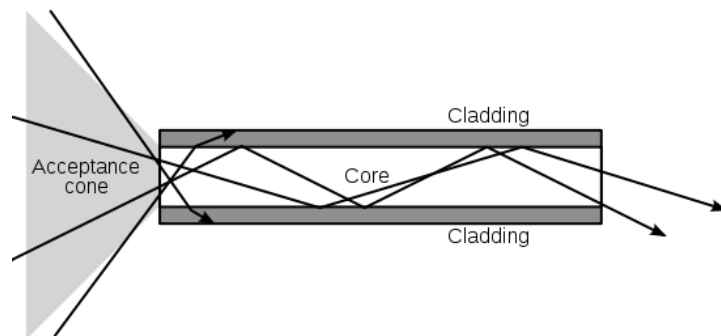


Figure 3.5 Light transmit in acrylic sheet.

The Light source is light-emitting diode (LED). It is a two-lead semiconductor light source that resembles a basic pn-junction diode, except that an LED also emits light. When an LED's anode lead has a voltage that is more positive than its cathode lead by at least the LED's forward voltage drop, current flows. Electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

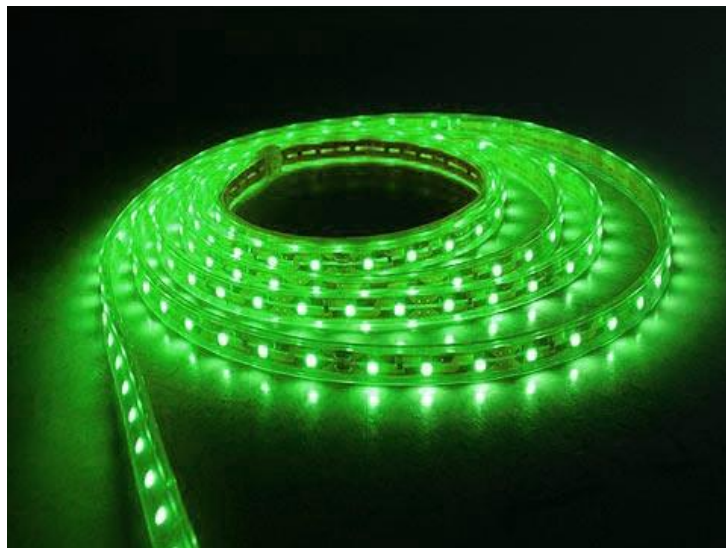


Figure 3.6 Green color LED type SMD.

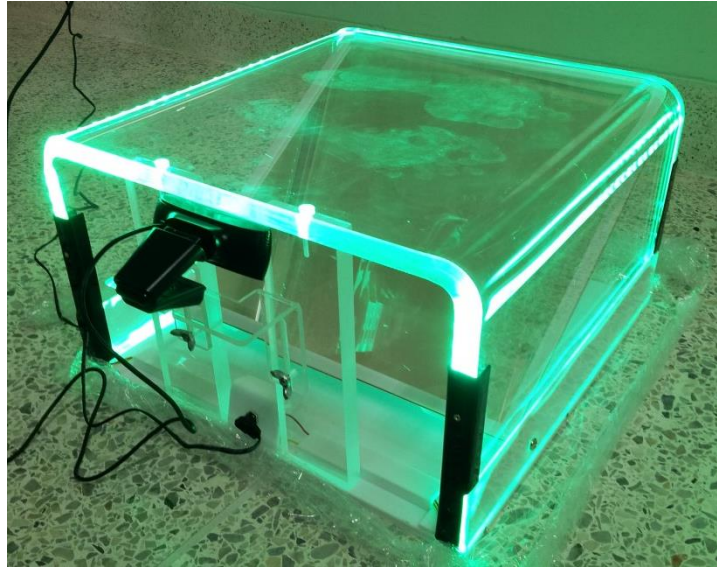


Figure 3.7 Finalize Optical Pedobarograph.

3.2 Development program pressure analyzer

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

3.2.1 The image processing results

The first develop source code in MATLAB program for converting images to dataset. The Color image is show on dataset in RGB model

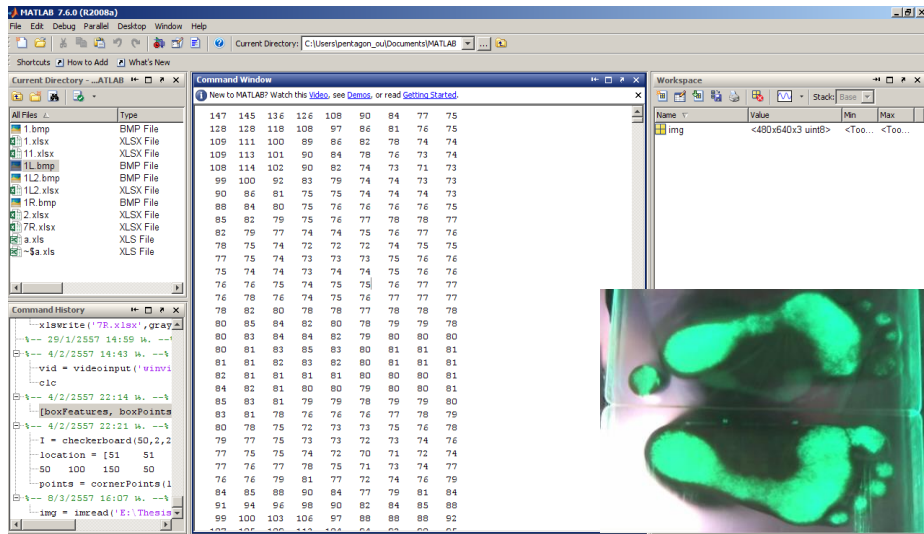


Figure 3.8 Result inread function in MATLAB.

3.2.2 Design interface of systems

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop console and graphical user interface applications along with Windows Forms or WPF applications. Manage interface of application with C# Language and include resource library from MATLAB programming.

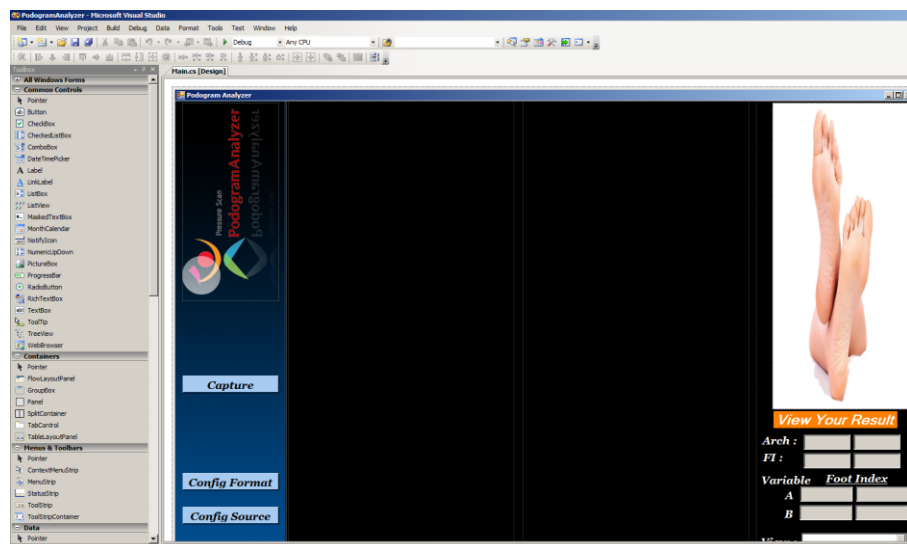


Figure 3.9 Development interface with Microsoft Visual Studio.

3.3 Collect data from optical pedobarograph and Tekscan®

Collect data from subject in standing posture, on Optical Pedobarograph is capture when subject is stability constant and Tekscan® is capture 30 minute from subject is stability constant and selection frame. Image from Optical Pedobarograph use thin film transducer (elastic rubber).

Tekscan® Software is F-Scan calibrate system with weight and gender interface is figure 3.9. Optical Pedobarograph is acquire data fom application Podogram Analyzer with multiple color of pressure.

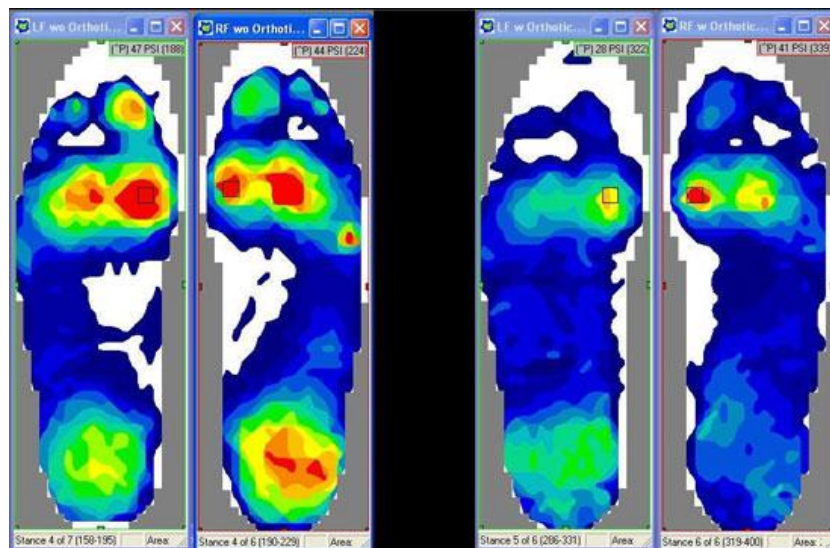


Figure 3.10 F-Scan application collect data from pressure sensor.

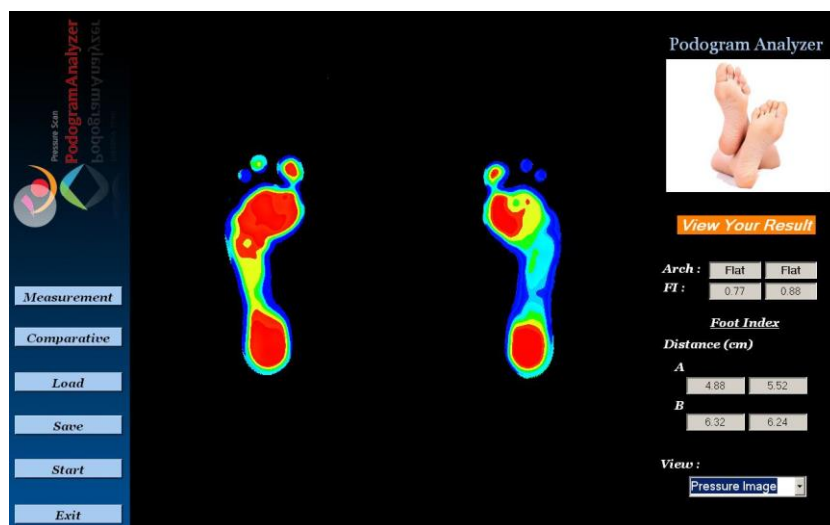


Figure 3.11 Podogram Analyzer application collect data from optical sensor.

Output of instrument Optical Pedobarograph and Tekscan® show in figure 3.10 and figure 3.11

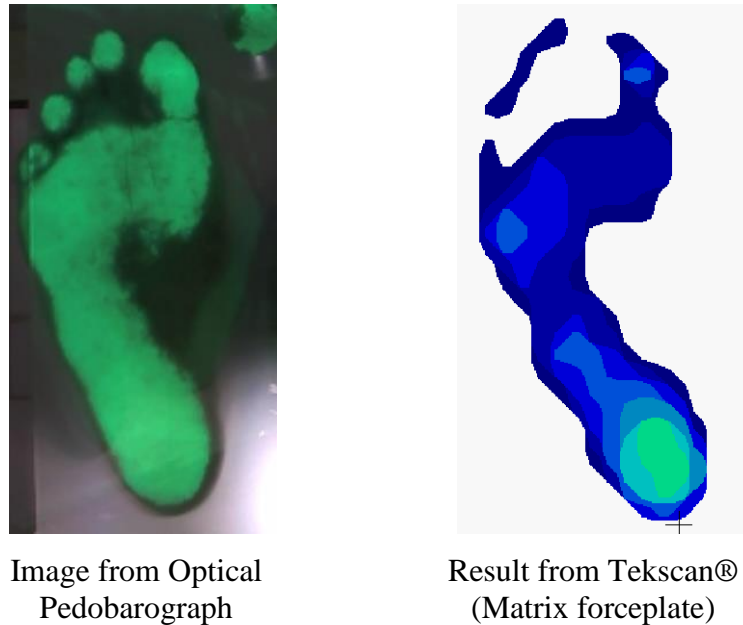


Figure 3.12 F-Scan application collect data from pressure sensor.

3.4 Extraction data from image and processing

The foot image is extraction data with image processing with 5 step. First, Capture image from Camera with jpg type and re-resolution to 640x320 pixels (300k pixels). Second, reduce noise and sharpen with Gaussian blur. Third, edge detection

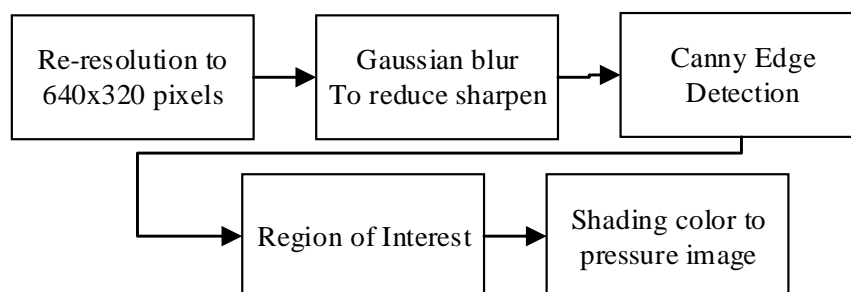


Figure 3.13 Step of extraction data from

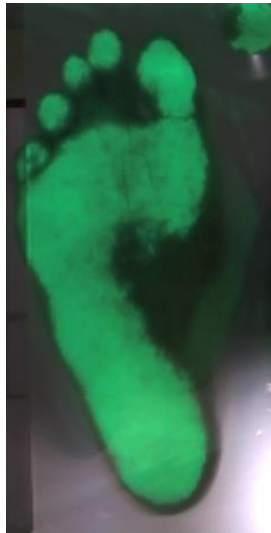
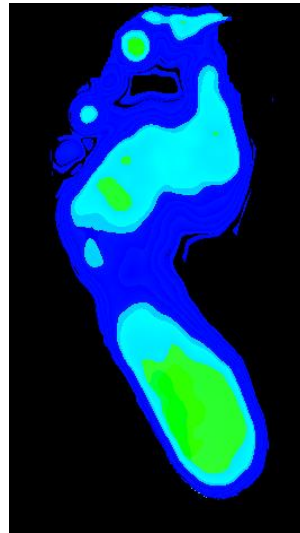


Image from Optical Pedobarograph



Foot pressure image from extraction data

Figure 3.14 Original Image to Pressure image with application Podogram Analyzer



Original image

Gaussian filter

Figure 3.15 Original Image to Gaussian blur filter

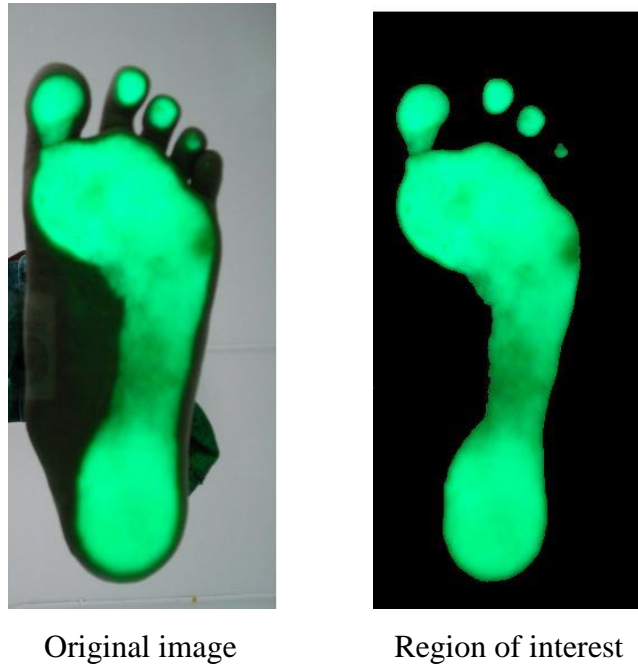


Figure 3.16 Original Image to region of interest

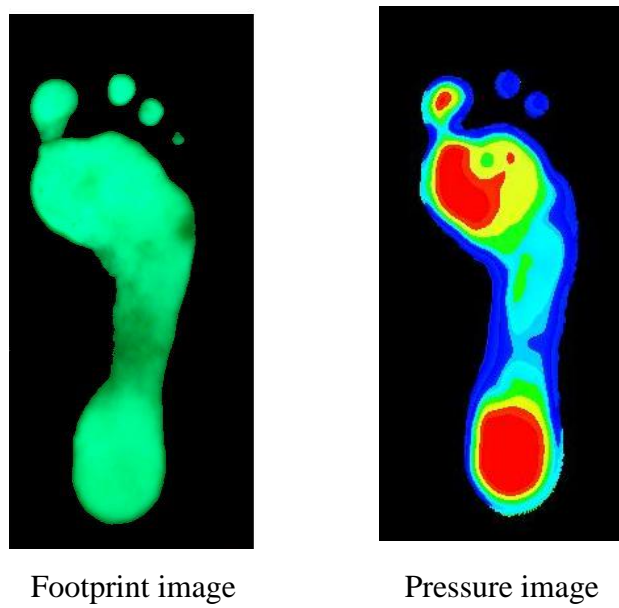


Figure 3.17 Original region of interest to pressure image with image shading color

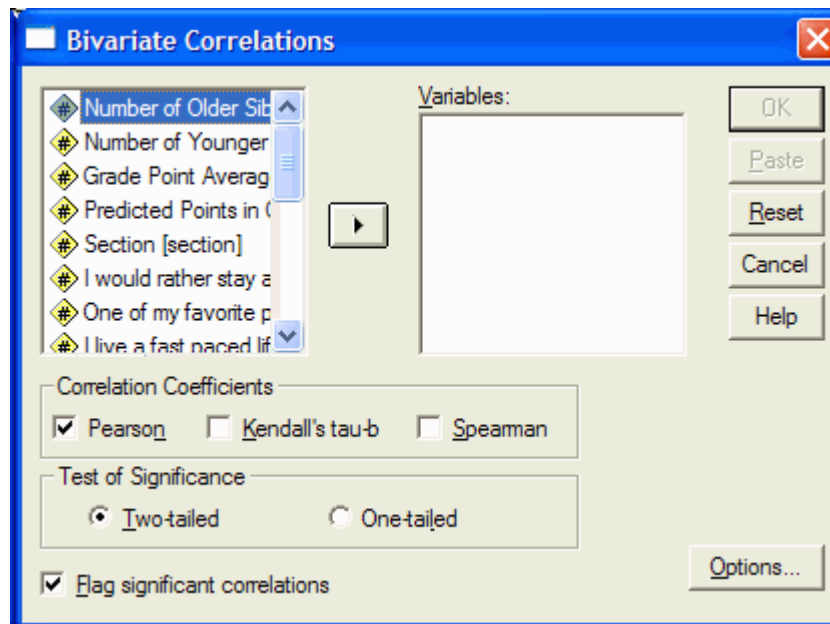


Figure 3.19 Correlation function in SPSS

3.7 Required tools

3.7.1 Hardware for image processing

Personal computer is used for developing application and controls devices

Processor	:	Intel® Core™ 2 Duo CPU 2.16GHz
Memory	:	DDRII 2.00 GB
Hard Drive	:	320 GB
Interface	:	USB 2.0

3.7.2 Software

Programming Language :

Matlab R2008b (used for development the system)

Microsoft Visual Studio 2010

PASW® Statistics 18

Operating System :

Windows 7 Ultimate 32 bits

CHAPTER 4

RESULTS AND DISCUSSION

The research used samples of study consist of 29 subjects: 18 Males (62.07%) and 11 Females (37.93%). The descriptive statistic can be summarized as follows. Mean of age at the time of test study is 29.48 ± 4.46 (range, 23-39 years). There are totals of 58 feet; the mostly normal arch of 36 feet (62.07%), the high-arch of 18 feet (31.03%) and the flatfoot of 4 feet (6.9%). Fifteen subjects (51.72%) are the normal range of BMI. Eight subjects (27.59%) are the underweight, and six subjects (20.69%) are the overweight.

Table 4.1 Descriptive statistics of sample of study

Variable	Mean	SD
Age	29.48	4.463
Weight	62.5	14.990
Height	168.5	10.280
BMI	21.058	3.633

4.1 Image processing results

The conditions of the sample testing for Pedobarograph of podoscope and Tekscan® are the optical sensor of pixel unit illuminating 8 bits/pixel and electronic matrix force plate unit (kPa.s/sensors). For comparison of the Pedobarographs [6] using the statistical analysis, the F-statistical is to analysis of variance and the correlation is to predictive relationship between Optical Pedobarograph (Developed) and Electronic matrix force plate (Tekscan®).

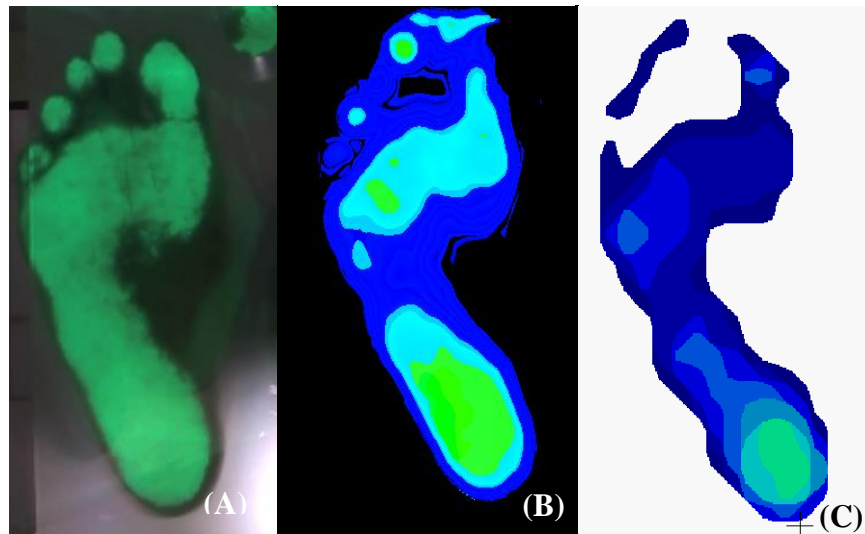


Figure 4.1 Data of foot. (A) foot print from podoscope, (B) Pedobarographs with image processing, (C) Pedobarographs from Tekscan®

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	10.35	0	0	0	0	0	0	0	0	0
0	0	0	5.18	20.7	32.35	0	0	7.76	7.76	0	0	0	0	0
0	0	5.18	11.64	0	0	0	0	0	27.17	67.28	0	0	0	0
0	0	0	16.82	0	0	0	0	0	67.28	129.39	18.11	0	0	0
0	0	10.35	0	0	0	0	0	0	15.53	25.88	0	0	0	0
0	6.47	23.29	0	0	0	0	0	0	5.18	12.94	0	0	0	0
0	0	0	0	0	9.06	15.53	11.64	10.35	14.23	23.29	18.11	0	0	0
0	10.35	0	0	18.11	25.88	33.64	28.47	20.7	20.7	31.05	28.47	0	0	0
0	18.11	0	11.64	37.52	33.64	36.23	31.05	28.47	18.11	31.05	31.05	0	0	0
0	12.94	7.76	33.64	41.4	43.99	34.93	32.35	23.29	23.29	28.47	23.29	0	0	0
0	16.82	33.64	46.58	42.7	41.4	33.64	25.88	20.7	20.7	15.53	6.47	0	0	0
0	33.64	59.52	51.75	47.87	37.52	29.76	11.64	10.35	14.23	7.76	0	0	0	0
0	47.87	64.69	59.52	46.58	38.82	19.41	0	0	0	0	0	0	0	0
0	18.11	59.52	49.17	41.4	32.35	22	0	0	0	0	0	0	0	0
0	0	33.64	43.99	33.64	20.7	16.82	0	0	0	0	0	0	0	0
0	0	7.76	36.23	32.35	28.47	18.11	0	0	0	0	0	0	0	0
0	0	0	15.53	23.29	25.88	27.17	20.7	0	0	0	0	0	0	0
0	0	0	0	27.17	33.64	38.82	34.93	11.64	0	0	0	0	0	0
0	0	0	0	34.93	43.99	51.75	34.93	20.7	0	0	0	0	0	0
0	0	0	0	24.58	50.46	59.52	49.17	43.99	16.82	5.18	0	0	0	0
0	0	0	0	5.18	41.4	43.99	54.34	46.58	38.82	28.47	11.64	0	0	0
0	0	0	0	0	10.35	41.4	49.17	51.75	51.75	46.58	43.99	12.94	0	0
0	0	0	0	0	0	22	43.99	56.93	67.28	69.87	62.11	38.82	0	0
0	0	0	0	0	0	0	38.82	46.58	69.87	87.98	87.98	62.11	9.06	0
0	0	0	0	0	0	0	22	54.34	75.04	87.98	90.57	80.22	36.23	0
0	0	0	0	0	0	0	0	54.34	69.87	81.51	85.4	85.4	56.93	0
0	0	0	0	0	0	0	0	20.7	67.28	75.04	90.57	81.51	49.17	0
0	0	0	0	0	0	0	0	0	34.93	64.69	82.81	72.46	27.17	0
0	0	0	0	0	0	0	0	0	0	24.58	42.7	27.17	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.2 Data acquire from Tekscan® dimension 31x15 sensors.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	4	72	62	64	55	75	12	0	0	0
0	0	0	0	9	72	64	73	168	137	56	3	0	0	0
0	0	0	0	37	164	108	34	53	36	31	1	0	0	0
0	0	0	3	33	91	55	30	34	38	49	11	0	0	0
0	0	2	23	34	23	12	13	26	84	137	16	0	0	0
0	1	28	34	32	24	21	18	28	95	158	36	3	0	0
0	10	97	71	30	30	35	36	35	110	173	87	8	0	0
0	7	52	38	34	46	115	100	116	172	168	124	15	0	0
1	33	32	30	80	159	169	175	176	173	169	161	28	1	0
8	32	26	66	168	167	172	178	177	171	168	170	43	0	0
2	19	47	156	167	169	171	176	176	173	167	122	28	0	0
2	36	136	168	166	168	172	98	104	90	36	35	21	0	0
4	58	170	169	168	169	134	35	34	34	35	34	9	0	0
3	38	96	118	148	134	44	34	35	33	34	19	2	0	0
0	26	65	68	37	35	34	34	21	10	4	0	0	0	0
0	10	67	111	35	36	35	34	8	0	0	0	0	0	0
0	0	28	35	34	34	35	34	15	0	0	0	0	0	0
0	0	4	33	34	34	34	35	32	2	0	0	0	0	0
0	0	0	24	44	124	138	58	35	21	0	0	0	0	0
0	0	0	18	82	174	174	169	94	34	16	0	0	0	0
0	0	0	5	77	170	168	168	170	119	43	14	0	0	0
0	0	0	0	26	154	168	168	168	170	144	48	8	0	0
0	0	0	0	2	68	166	157	164	167	167	136	24	0	0
0	0	0	0	0	14	133	153	162	166	167	168	60	1	0
0	0	0	0	0	2	61	159	154	164	168	167	113	14	0
0	0	0	0	0	0	12	128	152	166	168	167	158	26	0
0	0	0	0	0	0	0	50	155	166	168	168	169	34	0
0	0	0	0	0	0	0	9	115	167	169	168	153	24	0
0	0	0	0	0	0	0	0	26	127	170	160	63	11	0
0	0	0	0	0	0	0	0	0	20	46	35	10	0	0

Figure 4.3 Data process from Optical Pedobarograph dimension 31x15 pixels

4.2 Correlation - Statistics analysis

This research use the SPSS program for statistical analysis Pedobarograph. The data is sliced crosswise forefoot (toes, metatarsal head) midfoot and hidefoot (heel) to 31 sections. Then we summary data each section and input data to SPSS for analysis relations. From the Table I, the F-statistics is approximately at 1,855.632. The significant equal 0.001 ($P < 0.005$) the coefficient is significantly. From Table II, the correlation coefficient (r) of Tekscan® and podoscope is equal to 0.764 ($P < 0.001$) indicating a strong relationship. In gait Lab, it can use to test patient based on barefoot plantar pressure. Although this medical device can applied to physical science, sports science, rehabilitation to estimate off-loading, shoes fitting and support. Figure 4.1 shows the pressure of sections of Tekscan® and podoscope. The graph curve is similarity, the Linear of Curve is similarity slope. Therefore the optical Pedobarograph can use to substitute the electronic Pedobarograph.

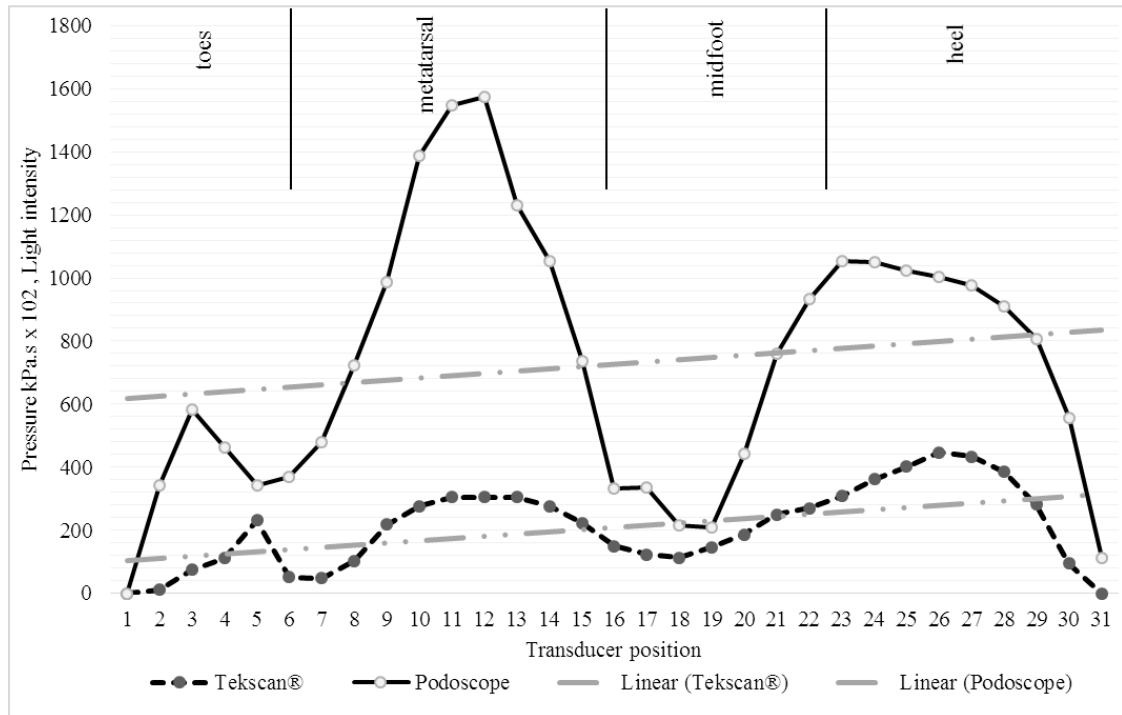


Figure 4.4 Area under the pressure for transducer location of the foot

Table 4.2 One-way analysis of variance (ANOVA) table result

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	519.577	29	18.556	1855.632	.001
Within Groups	.020	2	.010		
Total	519.597	31			

The result of One-way analysis of variance (ANOVA) in data groups between group 29 set and significant equal 0.001 ($P < 0.005$) the coefficient is significantly.

Table 4.3 Correlations of Tekscan® and Podoscope

	Correlations	Tekscan®	Podoscope
Tekscan®	Pearson Correlation	1	.764**
	Sig. (2-tailed)		.000
	N	31	31
Podoscope	Pearson Correlation	.764**	1
	Sig. (2-tailed)	.000	
	N	31	31

** . Correlation is significant at the 0.01 level (2-tailed).

These results has suggested that the relationship between Optical Pedobarograph (Developed) and Electronic matrix force plate (Tekscan®) has been correlated in terms of quantitative and qualitative for the measurement. The correlation coefficient (r) of Tekscan® and podoscope is equal to 0.764 ($P < 0.001$) indicating a strong relationship. This means that the optical Pedobarograph can be used for substituting the Tekscan®.

The optical sensor device for acquisition of the developed Pedobarograph is relationship with electric matrix force plate (Tekscan®). The optical sensor is utilized in terms of low cost and easy available while electronic matrix force plate (Tekscan®) is high cost and imported from overseas. Therefore, it can be substituted for Tekscan® and it can reduce the cost of equipment purchased from abroad.

CHAPTER 5

CONCLUSION

These results has suggested that the relationship between Optical Pedobarograph (Developed) and Electronic matrix force plate (Tekscan®) has been correlated in terms of quantitative and qualitative for the measurement. The correlation coefficient (r) of Tekscan® and podoscope is equal to 0.764 ($P < 0.001$) indicating a strong relationship. This means that the optical Pedobarograph can be used for substituting the Tekscan®.

The optical sensor device for acquisition of the developed Pedobarograph is relationship with electric matrix force plate (Tekscan®). The optical sensor is utilized in terms of low cost and easy available while electronic matrix force plate (Tekscan®) is high cost and imported from overseas. Therefore, it can be substituted for Tekscan® and it can reduce the cost of equipment purchased from abroad.

Development in the future will be developed with the integration of electronic sensors with making it more precisely. The prices are different than in developed markets over 10 times.

REFERENCES

- 1 Sriussadaporn S, Mekanandha P, Vannasaeng S, Nitiyanant W, Komoltri C, Ploybutr S, et al. *Factors Associated with Diabetic Foot Ulceration in Thailand: a Case-control Study*. Diabetic medicine. 1997;14(1):50-6.
- 2 Bus SA, Ulbrecht JS, Cavanagh PR. *Pressure relief and load redistribution by custom-made insoles in diabetic patients with neuropathy and foot deformity*. Clinical Biomechanics. 2004;19(6):629-38.
- 3 Kadhim M, Holmes Jr L, Miller F. *Correlation of radiographic and Pedobarograph measurements in planovalgus foot deformity*. Gait & Posture. 2012;36(2):177-81.
- 4 Cobb J, Claremont D. *Transducers for foot pressure measurement: survey of recent developments*. Medical and Biological Engineering and Computing. 1995;33(4):525-32.
- 5 Urry S. *Plantar pressure-measurement sensors*. Measurement Science and Technology. 1999;10(1):R16.
- 6 Van Schie C, Abbott C, Vileikyte L, Shaw J, Hollis S, Boulton A. *A comparative study of the Podotrack, a simple semiquantitative plantar pressure measuring device, and the optical Pedobarograph in the assessment of pressures under the diabetic foot*. Diabetic medicine. 1999;16(2):154-9.
- 7 Soames R, Blake C, Stott J, Goodbody A, Brewerton D. *Measurement of pressure under the foot during function*. Medical and Biological Engineering and Computing. 1982;20(4):489-95.
- 8 Charanya G, Mothiram Patil K, Thomas VJ, Narayanamurthy V, Parivalavan R, Visvanath K. *Standing foot pressure image analysis for variations in foot sole soft tissue properties and levels of diabetic neuropathy*. ITBM-RBM. 2004;25(1):23-33.
- 9 Patil M, Vasanth Bhat V, Bhatia M, Parivalavan R, Narayanamurthy V, Ganesan V, editors. *New methods and parameters for dynamic foot pressure analysis*

- in diabetic neuropathy*. Engineering in Medicine and Biology Society, 1997 Proceedings of the 19th Annual International Conference of the IEEE; 1997: IEEE.
- 10 Mohammed H, Alani A, Attar F, Adedepo A. *Foot Pressure Comparison Between Hallux Rigidus Patients and Normal Asymptomatic Matched Individuals Using Pedobarograph*. Journal of Orthopaedics, Trauma and Rehabilitation. 2012;16(1):13-5.
 - 11 Orlin MN, McPoil TG. *Plantar pressure assessment*. Physical therapy. 2000;80(4):399-409
 - 12 Bus SA, Ulbrecht JS, Cavanagh PR. *Pressure relief and load redistribution by custom-made insoles in diabetic patients with neuropathy and foot deformity*. Clinical Biomechanics. 2004;19(6):629-38.
 - 13 Holsinger, Kent E.; Weir, Bruce S. (2009). "*Genetics in geographically structured populations: Defining, estimating and interpreting FST*". Nature Reviews Genetics 10 (9): 639–50.
 - 14 Rabbani KS-e, Ishraque SZ, Islam MS, Rabbani RM. *Improvisation of an optical pressure sensor based dynamic foot pressure measurement system*. Bangladesh Journal of Medical Physics. 2013;4(1):51-8.

APPENDICES

APPENDIX A
SUBJECT CHARACTERISTICS

Samples of study detail

No.	Gender	Age	Weight	Height	Foot type (Left)	Foot type (Right)	BMI
1	M	39	64	176	H	H	20.66116
2	M	34	60	160	H	H	23.4375
3	F	25	50	155	H	H	20.81165
4	F	29	41	150	N	N	18.22222
5	F	30	75	160	N	N	29.29688
6	M	36	90	183	F	F	26.8745
7	M	28	84	179	H	H	26.21641
8	M	29	58	165	N	N	21.30395
9	M	31	50	169	N	N	17.50639
10	M	28	90	181	N	N	27.47169
11	F	24	47	168	H	H	16.65249
12	M	26	55	178	N	N	17.35892
13	M	33	75	178	H	H	23.67125
14	M	25	65	170	N	N	22.49135
15	M	27	61	175	H	H	19.91837
16	M	36	97	183	N	N	28.96473
17	M	23	50	165	N	N	18.36547

No.	Gender	Age	Weight	Height	Foot type (Left)	Foot type (Right)	BMI
18	M	27	65	165	N	N	23.87511
19	F	28	46	158	N	N	18.42653
20	M	29	79	182	N	N	23.84978
21	M	29	65	181	H	H	19.84066
22	F	26	70	171	N	N	23.93899
23	M	23	61	173	N	N	20.38157
24	F	32	41	150	N	N	18.22222
25	F	29	64	162	F	F	24.38653
26	F	30	43	153	N	N	18.369
27	M	36	53	161	H	H	20.44674
28	F	24	65	157	N	N	26.37024
29	F	39	65	168	N	N	23.03006

APPENDIX B

DEVELOPMENT OF OPTICAL SENSOR DEVICE FOR PEDOBAROGRAPH ACQUISITION

Yuttapong Aunhathaweep, Adisorn Leelasantitham, Supaporn Kiattisin
Technology of Information Systems Management
Faculty of Engineering, Mahidol University
Putthamonthon Nakhonpathom, Thailand
pentagon.ou@gmail.com, ladisorn@hotmail.com, tom_kiattisin@hotmail.com

Abstract— There have been many techniques for demonstrating different Pedobarograph systems to measure a foot pressure that can be used for a clinical tool. This tool can aid a surgeon's decision making. This paper presents development of optical sensor device for acquisition of Pedobarograph through the use of measuring the pressure foot which is relative to the weight. The optical sensor is utilized in terms of low cost and easy available while electronic matrix force plate (Tekscan®) is high cost and imported from overseas. For the proposed methods, weighted (or inputted) images from the pressure foot are captured from illuminated. Such weighted images are computed by image processing e.g Gaussian filtering, canny edge detection, region of interest, illuminate slicing. Then, statistical analysis using ANOVA testing and correlation technique will be used to verify the resulting of Pedobarograph between optical sensor and Tekscan® (electronic commercial product). The samples is 58 feet from 28 normal Subjects. The results show that F-statistics is approximately at 1,855.632, Significant (Sig.) value is equal to 0.001 ($P < 0.05$) and correlation coefficient is 0.764 indicating a strong relationship. This means that the optical sensor can be used for substituting the Tekscan®

Keywords— *Optical sensor device, Pedobarograph, Foot pressure, Tekscan, Matrix force plate, Correlation*

INTRODUCTION

Foot is responsibility heaviest organ in the body and its treatment is very important part of human life. There have been found for the people with a foot wrong more than 70% because of wearing the wrong shape. This distortion is a disease i.e. diabetes. There are many types of the research

study about pressure in relation to the weight of the foot. Design of equipment is to support the heel and foot area reducing the pressure on the main body.

It is an important issue for foot disorders in diabetic patients affecting life quality of patients and their families for a major economic problems in the country. As a result, medical treatment expense will be a high costing including chronic wound, surgery and an artificial leg (from a study in Siriraj Hospital, Thailand from B.C. 2002 to 2004 found that the cost of amputation patients is average to 80,000 Baht, the highest cost up to eight hundred thousand) [1]. The International Working Group on Diabetic Foot Diabetes Federation's world leads to research for prevention of caring the foot problems e.g. the supplemental material insole in shoes [2,12], or the shoes to prevent foot ulcers in people with diabetes.

Instruments for measuring barefoot pressure [3,4,5,7,10,11] are as follows.

1. Barefoot measurements : footprints, mat and plate
2. Cumulative techniques
 - a. Foot printing.
 - b. Microcapsules.
 - c. Foil Pedobarography
3. Optical techniques
 - a. Optical Pedobarographs.
 - b. Photo elasticity.
 - c. Textured mat cinephotography.
 - d. Liquid crystals
4. Electromechanical techniques
 - a. Segmented and matrix force plates.
 - b. Capacitance mats.
 - c. Piezoelectric multi-element plates.

- d. Force-sensitive resistor (FSR) arrays.
- e. Contact-area-force-plate hybrids.
- f. In-shoe measurements : discrete sensors and arrays

The foot-pressured results in this paper are compared between Optical Pedobarographs and Segmented and matrix force plates in terms of accuracy and low cost. It is to record dynamic variations in downward pressure by different areas of the sole of a foot as a person stands upright or walks.

MATERIALS AND METHODS

A. Optical sensor device

Podoscope device is used to acquire or get the data, as shown in Fig. 1, The device is an optical Pedobarograph developed [6,14] in the field of foot pressure sensing. It consists of an acrylic sheet covered by a thin film of a material such as a pressure indicating film, light-emitting diode illuminating from the side edge of acrylic sheet. The light internally is reflected at internal transparent acrylic plate and its light is controlled by the LED controller. Pressure indicating film is used for applying the pressure sensing to the top surface pushed the interface film into a close contact with acrylic sheet by deforming of the foot. The light intensity is captured from CCD camera emitting to the mirror of 45 degree from the pressure indicating film. The captured image is depicted for the pressure data which is a color zones of the pressure.

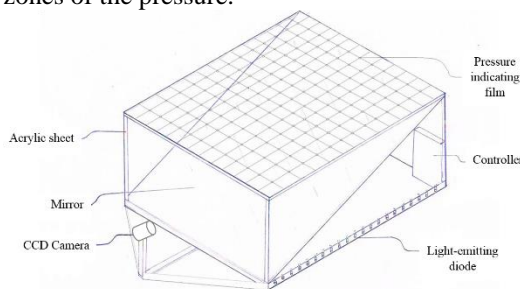


Fig. 1. Podoscope device

Figure 2 shows block diagrams of data acquisition and image processing system which is a process to convert the footprint image to the pressure image. Firstly, a man (subject) stands on the podoscope, and then the CCD camera will capture the footprint image. Secondly, footprint image is processed by image processing with Gaussian filtering to blur image, canny edge detection, region of interest(ROI) and illuminate slicing. Lastly, the resulted image is called as the Pedobarograph.

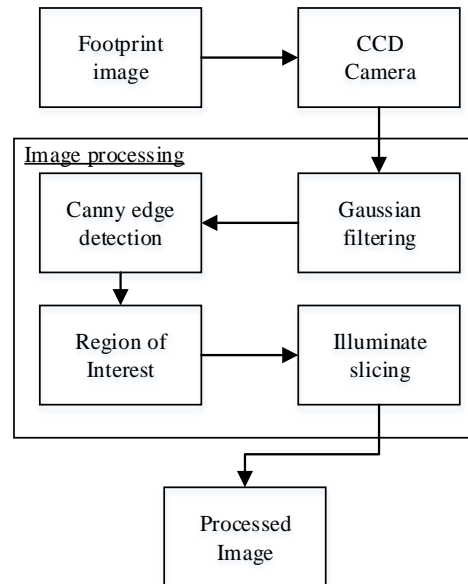


Fig. 2. Block diagram of podoscope device data acquisition and image processing system

B. Subject Characteristics

The data is collected from the records system of subject height, weight, age, sex, foot types (High Arch, Normal Arch, Flat foot), Body Mass Index (BMI) and the footprint image. The subject image who stands in a pose is captured by a camera [8,9].

C. Photographic record

Figure 3 shows three views of the foot data. (A) is footprint from podoscope, (B) is Pedobarographs with image processing from podoscope and (C) is Pedobarographs with electronic matrix load cell from Tekscan®. The data acquires from optical Pedobarograph and Tekscan® which the data from optical Pedobarograph has converted to matrix dimension 31x15 and it is similar to Tekscan®, as show at Figures 4 and 5.

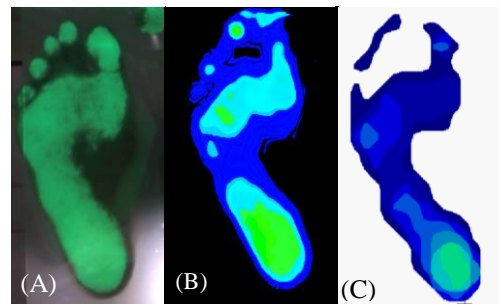


Fig. 3. Data of foot. (A) foot print from podoscope, (B) Pedobarographs with image processing, (C) Pedobarographs from Tekscan®

x and y are results of measurements that contain measurement error x_i and y_i where $i = 1, 2, \dots, n$, then the sample correlation coefficient can be used to estimate the population Pearson correlation

EXPERIMENTAL RESULTS

Samples of study consist of 29 subjects: 18 Males (62.07%) and 11 Females (37.93%). The descriptive statistic can be summarized as follows. Mean of age at the time of test study is 29.48 ± 4.46 (range, 23-39 years). There are totals of 58 feet; the mostly normal arch of 36 feet (62.07%), the high-arch of 18 feet (31.03%) and the flatfoot of 4 feet (6.9%). Fifteen subjects (51.72%) are the normal range of BMI. Eight subjects (27.59%) are the underweight, and six subjects (20.69%) are the overweight.

The conditions of the sample testing for Pedobarograph of podoscope and Tekscan® are the optical sensor of pixel unit illuminating 8 bits/pixel and electronic matrix force plate unit (kPa.s/sensors). For comparison of the Pedobarographs [6] using the statistical analysis, the F-statistical is to analysis of variance and the correlation is to predictive relationship between Optical Pedobarograph (Developed) and Electronic matrix force plate (Tekscan®). We use the SPSS program for statistical analysis Pedobarograph. The data is sliced crosswise forefoot (toes, metatarsal head) midfoot and hiefoot (heel) to 31 sections. Then we summary data each section and input data to SPSS for analysis relations. From the Table I, the F- F-statistics is approximately at 1,855.632. The significant equal 0.001 ($P < 0.005$) the coefficient is significantly. From Table II, the correlation coefficient (r) of Tekscan® and podoscope is equal to 0.764 ($P < 0.001$) indicating a strong relationship. In gait Lab, it can use to test patient based on barefoot plantar pressure. Although this

medical device can applied to physical science, sports science, rehabilitation to estimate off-loading, shoes fitting and support.

Figure 7 shows the pressure of sections of Tekscan® and podoscope. The graph curve is similarity, the Linear of Curve is similarity slope. Therefore the optical Pedobarograph can use to substitute the electronic Pedobarograph.

TABLE I. ONE-WAY ANALYSIS OF VARIANCE (ANOVA) TABLE RESULT

	Sum of Square	f	Mean Square	F	Sig.
Between Groups	19,577	9	18,556	1855.632	.001
Within Groups	.020	2	.010		
Total	19,597	31			

TABLE II. CORRELATIONS OF TEKSCAN® AND PODOSCOPE

		Tekscan®	Podoscope
Tekscan®	Pearson Correlation	1	.764**
	Sig. (2-tailed)		.000
	N	31	31
Podoscope	Pearson Correlation	.764**	1
	Sig. (2-tailed)	.000	
	N	31	31

** . Correlation is significant at the 0.01 level (2-tailed).

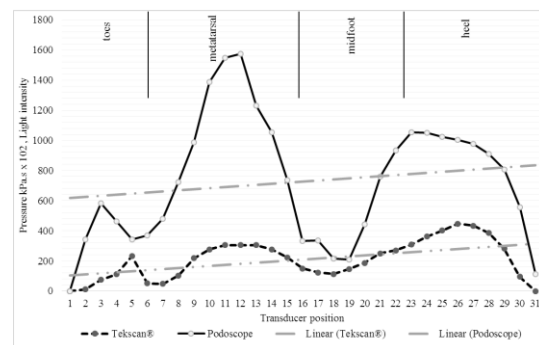


Fig. 7. Area under the pressure for transducer location of the foot

Conclusions

These results has suggested that the relationship between Optical Pedobarograph (Developed) and Electronic matrix force plate (Tekscan®) has been correlated in terms of quantitative and qualitative for the measurement. The correlation coefficient (r) of Tekscan® and podoscope is equal to 0.764 ($P < 0.001$) indicating a strong relationship. This means that the optical Pedobarograph can be used for substituting the Tekscan®.

The optical sensor device for acquisition of the developed Pedobarograph is relationship with electric matrix force plate (Tekscan®). The optical sensor is utilized in terms of low cost and easy available while electronic matrix force plate (Tekscan®) is high cost and imported from overseas. Therefore, it can be substituted for Tekscan® and it can reduce the cost of equipment purchased from abroad.

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REFERENCES

- [1] Sriussadaporn S, Mekanandha P, Vannasaeng S, Nitiyanant W, Komoltri C, Ploybutr S, et al. Factors Associated with Diabetic Foot Ulceration in Thailand: a Case-control Study. *Diabetic medicine*. 1997;14(1):50-6.
- [2] Bus SA, Ulbrecht JS, Cavanagh PR. Pressure relief and load redistribution by custom-made insoles in diabetic patients with neuropathy and foot deformity. *Clinical Biomechanics*. 2004;19(6):629-38.
- [3] Kadhim M, Holmes Jr L, Miller F. Correlation of radiographic and Pedobarograph measurements in planovalgus foot deformity. *Gait & Posture*. 2012;36(2):177-81.
- [4] Cobb J, Claremont D. Transducers for foot pressure measurement: survey of recent developments. *Medical and Biological Engineering and Computing*. 1995;33(4):525-32.
- [5] Urry S. Plantar pressure-measurement sensors. *Measurement Science and Technology*. 1999;10(1):R16.
- [6] Van Schie C, Abbott C, Vileikyte L, Shaw J, Hollis S, Boulton A. A comparative study of the Podotrack, a simple semiquantitative plantar pressure measuring device, and the optical Pedobarograph in the assessment of pressures under the diabetic foot. *Diabetic medicine*. 1999;16(2):154-9.
- [7] Soames R, Blake C, Stott J, Goodbody A, Brewerton D. Measurement of pressure under the foot during function. *Medical and Biological Engineering and Computing*. 1982;20(4):489-95.
- [8] Charanya G, Mothiram Patil K, Thomas VJ, Narayanamurthy V, Parivalavan R, Visvanath K. Standing foot pressure image analysis for variations in foot sole soft tissue properties and levels of diabetic neuropathy. *ITBM-RBM*. 2004;25(1):23-33.
- [9] Patil M, Vasanth Bhat V, Bhatia M, Parivalavan R, Narayanamurthy V, Ganesan V, editors. New methods and parameters for dynamic foot pressure analysis in diabetic neuropathy. *Engineering in Medicine and Biology Society, 1997 Proceedings of the 19th Annual International Conference of the IEEE; 1997: IEEE*.
- [10] Mohammed H, Alani A, Attar F, Adedepo A. Foot Pressure Comparison Between Hallux Rigidus Patients and Normal Asymptomatic Matched Individuals Using Pedobarograph. *Journal of Orthopaedics, Trauma and Rehabilitation*. 2012;16(1):13-5.
- [11] Orlin MN, McPoil TG. Plantar pressure assessment. *Physical therapy*. 2000;80(4):399-409.
- [12] Bus SA, Ulbrecht JS, Cavanagh PR. Pressure relief and load redistribution by custom-made insoles in diabetic patients with neuropathy and foot deformity. *Clinical Biomechanics*. 2004;19(6):629-38.
- [13] Holsinger, Kent E.; Weir, Bruce S. (2009). "Genetics in geographically structured populations: Defining, estimating and interpreting FST". *Nature Reviews Genetics* 10 (9): 639–50.
- [14] Rabbani KS-e, Ishraque SZ, Islam MS, Rabbani RM. Improvisation of an optical pressure sensor based dynamic foot pressure measurement system. *Bangladesh Journal of Medical Physics*. 2013;4(1):51-8.

BIOGRAPHY

NAME	Mr. Yuttapong Aunhathaweesup
DATE OF BIRTH	8 March 1989
PLACE OF BIRTH	Nakhonpathom, Thailand
INSTITUTIONS ATTENDED	Kasetsart University, 2009-2012 Bachelor of Engineering (Computer Engineering) Mahidol University, 2013-2014 Master of Science (Technology of Information System Management)
HOME ADDRESS	39/19 M.6 Sampran Sampran Nakhonpathom 73110 Tel 085-377-6801 Email: pentagon.ou@gmail.com
PUBLICATION / PRESENTATION	Aunhathaweesup Y. , Leelasantitham A. , Kiattisin S., Development of Optical Sensor Device for Pedobarograph Acquisition., The International Electrical Engineering Congress (iEECON), Thailand, 19-21 March. 2014