UNIVERSITI PUTRA MALAYSIA

RESISTIVE SENSOR ARRAY READOUT CIRCUIT FOR FOOT PLANTAR PRESSURE MEASUREMENT SYSTEM

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By

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

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I wish to dedicate the thesis to Allah, his messenger Muhammad SAW and my beloved family

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

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Chairman: Associate Professor Suhaidi Shafie, PhD
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Readout circuit is used for interfacing between sensor and digital signal processing unit. It is widely implemented in sensory system to obtain variety of useful information such as pressure and voltage etc. Readout circuit designed for large scale sensor array is important for improving the effectiveness of data acquisition system. However to design such system, many additional components are needed which contributes to complexity and increment of power consumption. This thesis focuses on the design, development and performance study of the readout circuit for large scale sensor array in term of low complexity and high accuracy. The prototype of readout circuit comprises of sensor array, signal acquisition system and graphical user interface. Sensor array has been constructed from 64 FlexiForce pressure sensor to sense pressure values on the foot plantar. Data acquisition system consisting of analogue multiplexer and microcontroller are responsible for selection and digitization of pressure data from the sensor array to the computer to be processed. Then, the processed pressure data is displayed by graphical user interface (GUI) for analysis purpose. A new mathematical equation is also proposed to identify the resistance value on each array. The proposed readout circuit has achieved the objective in terms of low complexity by using microcontroller, multiplexer and standard resistors. While in terms of accuracy, the result obtained from two different evaluations showed satisfactory performance. Results from the first evaluation involving a prototype readout circuit using standard resistors representing resistive type pressure sensor node has resistance value percentage error between 0.04% to 6.5%. Whereas the result obtained from the second evaluation using FlexiForce sensors shows that when pressure is applied on one sensor in each column, the pressure readings of other sensor placed in the same column are also change. The percentage of changes are within the range of 2.14% to 13.46% of the pressure applied onto the sensors. In this research, embedded ADC in PIC microcontroller has been utilised to reduce the complexity, while wireless data transmission has also been implemented in the system for portability.

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

PEMBACA LITAR SUSUNAN SENSOR KERINTANGAN UNTUK SISTEM PENGUKURAN PERMUKAAN KAKI

Oleh

DAYANG NURUL NAHAR BINTI TALIB

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Pembaca litar digunakan sebagai antaramuka di antara penderia dan unit pemproses litar digital. Ia banyak dilaksanakan dalam sistem pengesanan untuk mendapatkan maklumat berguna seperti tekanan, voltan dan lain-lain. Pembaca litar yang dibina untuk susunan penderia berskala besar adalah penting untuk keberkesanan bagi sistem pengumpulan data. Bagaimanapun untuk merekabentuk sistem tersebut, tambahan komponen diperlukan dan menyumbangkan kepada kepadatan dan peningkatan penggunaan kuasa. Tesis ini memberi tumpuan di dalam merekabentuk, membina dan mengkaji prestasi bagi pembaca litar berskala besar dari segi kepadatan yang rendah, ketepatan yang tinggi dan penggunaan kuasa yang rendah. Model pembaca litar ini terdiri daripada susunan penderia, sistem pengumpulan isyarat dan grafik antaramuka pengguna. Susunan penderia dibina daripada 64 penderia tekanan FlexiForce untuk mengesan bacaan tekanan pada permukaan kaki. Sistem pengumpulan data terdiri daripada analog multiplexer dan mikropengawal yang berperanan untuk pemilihan dan menukarkan dalam bentuk digital data tekanan daripada susunan litar ke komputer untuk diproses. Kemudian data yang telah diproses dipaparkan oleh grafik antaramuka pengguna untuk tujuan dianalisa. Satu persamaan matematik telah dicadangkan untuk mengenalpasti nilai rintangan pada setiap susunan. Pembaca litar yang telah dicadangkan ini telah memenuhi objektif dari segi kurang kepadatan dengan hanya menggunakan mikropengawal, multiplexer dan perintang tetap. Hasil dari penilaian pertama yang melibatkan model pembaca litar yang menggunakan perintang tetap yang mewakili penderia tekanan jenis rintangan menghasilkan peratusan ralat di antara 0.04% hingga 6.5% daripada nilai kerintangan. Manakala hasil yang diperolehi dari penggunaan penderia Flexiforce menunjukkan apabila tekanan dikenakan pada satu penderia dalam lajur yang sama, bacaan tekanan pada penderia lain dalam lajur yang sama juga akan berubah. Peratus perubahan adalah di antara 2.14% hingga 13.46% daripada nilai tekanan yang dikenakan pada penderia tersebut. Dalam penyelidikan ini juga, ADC tertanam pada mikropengawal PIC telah digunakan sepenuhnya untuk mengurangkan kepadatan litar, manakala penghantaran data tanpa wayar juga dilaksanakan untuk menjadikan ia sebagai sistem mudah alih.

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

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LIST OF ABBREVIATION

TDCA	Transistor/Diode Controlled Approach
MOAA	Multiplexer and Op-Amp Assisted Approach
IMA	Incidence Matrix Approach
RMA	Resistive Matrix Approach
USB	Universal Serial Bus
ADC	Analog to Digital Converter
GUI	Graphical User Interface
PCB	Printed Circuit Board
UART	Universal Asynchronous Receiver/Transmitter
DAQ	Data Acquisition
FSR	Force Sensing Resistor
COP	Centre of Pressure
SAU	Signal Acquisition Unit
EIT	Electrical Impedance Tomography
DOE	Design of Experiment
R	Resistance
L	Length of conductor
A	Area of cross-section of conductor
ρ	Specific resistance or resistivity of conducting material used
V	Voltage
I	Current
Ω	Ohm
m	Slope or Gradient of Line
C	Point at which the Line Crosses the Y-Axis (Y-Intercept)
w	weight
F	Force
P	Pressure
M	Mass
g	Earth Gravity
Pa	Pascal
W	Watt

CHAPTER 1

INTRODUCTION

Sensor interface circuit or readout circuit is used for interfacing between transducers or sensors and digital signal processing unit. It widely implemented in sensory systems to obtain variety of useful information such as pressure, voltage, current, temperature and also applicable for other various applications. In some applications like healthcare monitoring system, large scale sensors array is important in maximising the performance by implementing multiple sensing points. For example, the foot plantar pressure measurement system in which the resistive pressure sensor array is used to obtain pressure distribution is useful to monitor the pressure distribution under diabetic foot for diabetic patients. This system requires high accuracy sensor interface circuit to precisely map the pressure distribution.

Although the readout circuit designed for large scale sensors array is important for improving the effectiveness of data acquisition system, to design such system many additional components needed which contributes to complexity and increment of power consumption. Therefore, a well-design readout topology can reduce the complexity and contributes to low power consumption which is the most important criteria in designing a biomedical instrument.

Meanwhile, the resistive type pressure sensors are widely used in electronics system because they can be easily integrated with other systems or readout circuits [1] . Simple reasons are based on the high linearity, small size, high frequency response, low impedance and high resolution. Among others, their wide range of application area includes automotive [2][3], robotics [4][5], and biomedical instrument [6][7]. Typically, the resistive type pressure sensors namely Flexiforce sensor by Tekscan and Force Sensing Resistor by FScan are widely used to measure the pressure between two soft objects. Their sensors are based on ultra-thin and flexible printed circuit so that it can be fitted on the soft surface. These criteria are the main reason for this sensor to be used in most of the foot plantar pressure measurement. Among foot plantar pressure measurement systems implemented resistive type pressure sensors are from Rana et al [8] which constructed a plantar pressure measurement to estimate the location and the numbers of sensors to be placed per sole. While Peng et al [9] produced SENSEable shoes to ascertain weight distribution over the feet with twelve Force Sensing Resistor (FSR) sensors.

In this research, the main contribution is the custom readout circuit design for Flexiforce sensor with an improved sensing accuracy and reduced power consumption. 8x8 Flexiforce sensor array has been tested with constructed readout circuit and implemented on developed foot plantar. The developed system capable to sense pressure distribution of foot and analyse the peak pressure point values which is related to diabetic problem such as foot ulceration.

1.1 Problem Statement

Pressure measurement using plantar pressure distribution system is well known as a tool in clinical gait analysis in case of gait abnormalities [10], diabetes mellitus, peripheral neuropathies [11], as well as in footwear evaluation [12] and in sport training[13]. Research are commonly being done to analyse pressure distribution under diabetics' foot and the reading from the measurement system determine whether a patient has any possibility of recurring ulcer or symptom of developing new ulcer.

Currently, majority of foot plantar pressure measurements system uses only a few sensor nodes for pressure sensing [14],[15],[16]. The use of a small-scale sensor array reduces the sensing points especially for critical regions thus causing the incomprehensive analysis of pressure distribution reading on the foot surface. High resolution pressure distribution can be achieved by implementing multiple points sensing on the foot surface. However, the increment of sensor nodes requires readout circuit that capable to accurately read the sense pressure as well as speed and linearity. Furthermore, the readout circuit for large scale sensor array can cause circuit complexity as it requires additional component such as vertical scanner, horizontal scanner and amplifiers. In addition, too many active components contribute to higher power consumption.

The stated reasons have motivated for an improved readout circuit topology for large scale of sensor array to analyse pressure distribution on foot plantar. The circuit consist of microcontroller, multiplexer and resistor so that it reduces complexity and power consumption.

In the previous design, resistive sensor array readout circuit is categorized into three topologies, namely transistor/diode controlled approach (TDCA) [17][18], multiplexer and op-amp assisted approach (MOAA) [19][20][21], incidence matrix approach (IMA)[22][23]. These topologies utilized microcontroller to control the logic of each sensor array. TDCA has been designed using transistor or diode on each sensor array to ensure no crosstalk current allows other multiple sensors. While MOAA uses additional components such as multiplexer, switches, resistor and op-amp for the same purpose that is to prevent the existence of crosstalk current on the sensor array. IMA topology on the other hand enriched complexity to the circuit as it involved the use of large number of ADC and current source. It allows the crosstalk current to pass through the multiple sensor arrays. However, sensor resistance can be accurately calculated.

Furthermore, since this system is using resistive pressure sensor, it is mandatory to calibrate each sensor so that it validates the pressure distribution values collected because each sensor possess slightly different characteristic data from another sensor.

1.2 Objective Research

This research focuses on the design, development and performance study of the readout circuit for large scale sensor array to be used in plantar pressure distribution system. The main objectives of this research are as stated below.

i. To design, develop and evaluate the low complexity and high accuracy readout circuit for large scale resistive type pressure sensor array.
ii. To utilize ADC in PIC microcontroller in order to reduce complexity and include wireless data transmission for portable system

1.3 Scopes of Research

This research concerned the development and performance study of the prototype readout circuit topology for resistive sensor array. It is developed with the integration of sensor array with signal acquisition unit and graphical user interface to communicate to the user. This system is used to perform foot plantar pressure measurement especially for diabetic patient. The pressure distribution reading from multiple points sensing under foot anatomy have been analysis to be containing useful information for study pressure value much related to diabetic issues. This research comprised of three major phases.

The first phase focussed on constructing methodologies for prototype readout circuit topology for large scale of sensor array with minimum component. The purpose is to minimise circuit complexity and power consumption. The three main modules of a prototype readout circuit are sensor array, signal acquisition unit and graphical user interface. The design of a constructed sensor array consists of 64 resistive sensors. While the signal acquisition unit has been designed using a microcontroller and multiplexer to read the signals from sensor array. Graphical user interface has been designed to ease data collecting processes.

The second phase focussed in designing the experiment (DOE) to evaluate the performance of prototype readout circuit topology for foot plantar pressure measurement. Performance to be evaluated is the capability of the readout circuit to produce resistance values on each sensor array. In addition, it is designed to perform the experiment to evaluate pressure distribution on foot plantar.

The final phase focussed on the performed analysis of experimental result from DOE. This includes the capability of the readout circuit to read the signals from sensor array and calculate resistance values of each sensor on sensor array. Additionally, the observation from experimental result shall be elaborated thoroughly. Subsequently, the analysis of experimental results will provide recommendations and ideas to further upgrade the system.

1.4 Thesis Outline

The first chapter provided an overview of readout circuit topology for resistive sensor array and produces a current problem statement of the readout circuit topology for resistive sensor array. It began with the analysis performed in designing the readout circuit topology for resistive sensor array for foot plantar pressure measurement. This chapter also elaborated on the scope of research performed and the objective to be achieved. The outline of this thesis is also explained in detail at the end of this chapter.

Chapter two then presented the literature review related to the research made in designing readout circuit topology for resistive sensor array for foot plantar pressure measurement. The scope of literature review covers the related researches on sensor array topology, overview of the resistive sensor and the signal acquisition unit required for this research. Certain part of this chapter also show the latest literature studies on related research for foot plantar pressure measurement to ensure the research is on track. Literature studies on the subject matter will be able to provide various useful inputs in producing prototype of readout circuit topology for resistive sensor array to perform foot plantar pressure measurement.

Chapter three explained the required methodology in producing the prototype of readout circuit topology for resistive sensor array to perform foot plantar pressure measurements. This chapter begins with the detailed elaboration on the research performed at the early stage of designing a readout circuit topology for resistive sensor array with minimum component to minimise circuit complexity and power consumption. This chapter also cover the performed methodologies to produce the prototype readout circuit consisting of sensor array, signal acquisition unit and graphical user interface. And not forgetting that this chapter also explains the methodology of calibration sensor before they are used to perform the measurements. Then we have the elaboration on the design of experiments performed to evaluate performance studies for readout circuit topology.

Chapter four then concentrate on the analysis from the experimental results and discussion carried out on the readout circuit topology of resistive sensor array for foot plantar pressure measurement. This chapter include analysis made on the result from simulated circuit, proposed readout circuit utilising standard resistor and FlexiForce sensor. Completing the chapter with a thorough explanation on the analysis performed on the calibration sensor.

Chapter five is a summary of the outcome from the proposed research and future work for this readout circuit topology. This chapter concludes the research and the construction of the prototype readout circuit topology of resistive sensor array for foot plantar pressure measurement. Conclusions achieved are based on the proposed research methodology and the collected experimental results. Finally, this chapter proposed recommendations and future works for prototype readout circuit topology of resistive sensor.

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