PORTABLE SHOE INTEGRATED INSTRUMENTATION FOR GAIT ANALYSIS MEASUREMENT USING MEMS BASED DEVICES

by

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LIST OF ABBREVIATIONS

3D	3 Dimension
ABS	Accelerometer Based Sensing
AC	Alternating Current
ADL	Activity of Daily Living
AHRS	Attitude Heading Reference System
CMOS	Complementary metal-oxide-semiconductor
DoF	Degree of Freedom
EEPROM	Electrically Erasable Programmable Read-Only Memory
EFS	Electric Field Sensing
GAH	Gait Analysis Hardware
GAS	Gait Analysis Software
GAS-US	Gait Analysis Software-Ultrasonic
GAS-IMU	Gait Analysis Software-Inertial Measurement Unit
GAS-COM	Gait Analysis Software- Combination of Ultrasonic and IMU
GUI	Graphical User Interface
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IMU	Inertial Measurement Unit
IPC	Institute of Printed Circuit
LED	Light Emitting Diode
LiPO	Lithium Polymer
MEMS	Micro Electro Mechanical System
MFC	Minimum Foot Clearance
MIT	Massachusetts Institute of Technology

LIST OF ABBREVIATIONS

PCA	Printed Circuit Assembly
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PIC	Peripheral Interface Controller
PWB	Printed Wiring Board
SMT	Surface-Mount Technology
SONAR	Sound Navigation and Ranging
US	Ultrasonic Sensing

LIST OF SYMBOLS

bps	Bit per Second
g	Gram
mAh	Miliampere per Hour
$Speed_{max}$	Speed required
t_{10}	Time for 10 measurements
t_1	Time for one measurement
$t_{clearance}$	Time of flight to measure the actual clearance
t_{of}	Time-of-flight
t_{stride}	Time of stride
l	Distance
t	Time
c	Ultrasonic wave moving speed
θ	Foot Angle
v	Velocity
V	Volt
$\varphi_{landing}$	Landing Phase
$\varphi_{toe\text{-}off}$	Toe-off Phase
°	Degree
°C	Degree of Celsius
µs	Microsecond

PORTABLE SHOE INTEGRATED INSTRUMENTATION FOR GAIT ANALYSIS MEASUREMENT USING MEMS BASED DEVICES

ABSTRACT

Gait analysis measurement is a method to access and identify gait events and the measurements of dynamic and motion parameters involving the lower part of body. This significant method is widely used in sports, rehabilitation as well as the health diagnostic towards improving the quality of life. Many researchers has proposed various ways to access gait features that require specially set-up motion laboratories, high-end video based-motion imaging systems, and professionals to visually observe the gait, this makes current way of accessing gait to be very costly and limited in many ways. Therefore, this research focuses on design and development of a portable shoe integrated wireless MEMS-based and recent microelectronic based foot clearance measurement system that is cheap, portable, real life and can be used by more people. The foot clearance measurement is representing the measurement of the distance between foot and ground. A complete system called Portable Shoe Integrated Instrumentation for Gait Analysis Measurement Using MEMS Based Devices in real-time is proposed. This system is the combination of the ultrasonic sensor with the inertial measurement unit sensor. The ultrasonic sensor is used for clearance measurement and the inertial measurement unit sensor is used for orientation measurement. Based on the orientation measurement, the clearance measurement is corrected by trigonometry algorithm. The correction is due to the positioning of foot during landing phase and toe off phase. In both situations, the positioning of ultrasonic is not perpendicular to the ground. So, the algorithm is required to present the accurate data. This system comes with the custom design software called Gait Analysis Software to analyze and present the gait information of user based on gait parameters which include foot clearance and foot orientation. Thus, this research produces three custom made systems namely GAS-US System, GAS-IMU System and GAS-COM System. Each system has its own purpose. The system was tested and proven to satisfy the gait analysis requirement. From this research, it is found that the system is able to measure the gait parameter wirelessly with ease and efficiently. Hence, to conclude this system can be used as the best method for real life gait analysis measurement. The novelty of this research is the first design combination of ultrasonic sensor with the initial measurement unit sensor for foot clearance measurement.

INSTRUMENTASI KASUT MUDAH ALIH BERSEPADU UNTUK ANALISA PENGUKURAN GAYA BERJALAN MENGGUNAKAN PERALATAN BERASASKAN MEMS

ABSTRAK

Analisa pengukuran gaya berjalan adalah kaedah untuk mengakses dan mengenal pasti gaya berjalan dan pengukuran parameter dinamik dan gerakan yang melibatkan bahagian bawah badan. Kaedah ini digunakan secara meluas dalam bidang sukan, pemulihan serta kesihatan diagnostik dalam meningkatkan kualiti hidup. Ramai penyelidik telah mencadangkan pelbagai cara untuk mengakses ciri-ciri gaya berjalan termasuk makmal gerakan khas, sistem pengimejan gerakan yang termaju, dan memerlukan pakar untuk memerhatikan gaya berjalan, ini menyebabkan kaedah semasa mengakses gaya berjalan menjadi mahal dan terhad dalam keadaan tertentu. Oleh itu, kajian ini memberi tumpuan kepada reka bentuk dan pembangunan kasut bersepadu tanpa wayar mudah alih berasaskan *MEMS* dan sistem pengukuran kaki terkini berasaskan mikroelektronik yang murah, mudah alih, kegunaan kehidupan seharian dan boleh digunakan semua orang. Dimana, pengukuran kaki merujuk kepada pengukuran jarak antara kaki dengan lantai. Satu sistem lengkap yang dipanggil Instrumentasi Kasut Mudah Alih Bersepadu berasaskan MEMS untuk Analisa Pengukuran Gaya Berjalan dalam masa sebenar dicadangkan. Sistem ini adalah gabungan antara pengesan ultrasonik dan juga pengesan unit pengukuran inersia. Pengesan ultasonik digunakan untuk mengukur jarak kaki dengan lantai dan pengesan unit pengukuran inersia digunkan untuk mengukur orintasi. Berdasarkan pengukuran orientasi, pengukuran jarak kaki diperbaiki dengan algoritma trigonometri. Pembetulan disebabkan oleh kedudukan kaki pada fasa kaki mendarat dan kaki diangkat. Dalam kedua-dua situasi, kedudukan pengesan ultrasonik serenjang dengan lantai. Maka, algoritma diperlukan untuk mendapatkan data yang lebih tepat. Sistem datang dengan perisian khusus yang dipanggil Perisian Analisa Gaya Berjalan untuk menganalisa dan memaparkan maklumat gaya berjalan pengguna berdasarkan parameter gaya berjalan iaitu jarak kaki dengan lantai dan orientasi kaki. Oleh itu, kajian ini menghasilkan tiga system yang khusus iaitu Sistem GAS-US, Sistem GAS-IMU dan Sistem GAS-COM. Sistem ini telah diuji dan terbukti memenuhi keperluan analisa gaya berjalan. Daripada kajian ini, didapati bahawa sistem ini dapat mengukur parameter gaya berjalan tanpa wayar dengan mudah dan berkesan. Oleh itu, dapat disimpulkan bahawa sistem ini boleh digunakan sebagai kaedah yang terbaik untuk analisa pengukuran gaya berjalan dalam kehidupan seharian. Keunikan sistem ini adalah rekabentuk pertama dalam gabungan pengesan ultrasonik dan pengesan unit pengukuran inersia untuk pengukuran jarak kaki.

CHAPTER 1

INTRODUCTION

1.0 Introduction

Gait analysis is a very important procedure in assessing and improving many quality of life indicators. It is widely used in sports, rehabilitation and health diagnostics. Gait analysis is the study of lower limb movement patterns and involves the identification of gait events and the measurements of kinetics and kinematics parameters. These include for example, toe-off, landing, stance, swing, displacement, speed, acceleration, force, pressure and the pressure-time-integral as state in (Wahab, 2009).

Trip or fall is events which may lead someone or person to unstable position that causing the person to collapse accidently. It is a very dangerous incident among the elderly as it may cause death (Chisholm et al., 2010). Study in (Chisholm et al., 2010) state that higher ratio of mechanism caused the deaths among the elderly is fall. The very important moment that can lead to the trip or fall occurrence is identified as when the foot movement in stage of mid-swing phase. This important stage of foot movement is referred to as minimum foot clearance (MFC). Study in (Begg et al., 2007) shows the minimum foot clearance is below 5 cm while the foot trajectory during gait may go up to 17 cm. It is therefore important that the parameter foot clearance and MFC are taken as the focus of this research which in particular required the design of foot clearance measurement system. Figure 1.1 shows the gait cycle for normal human.

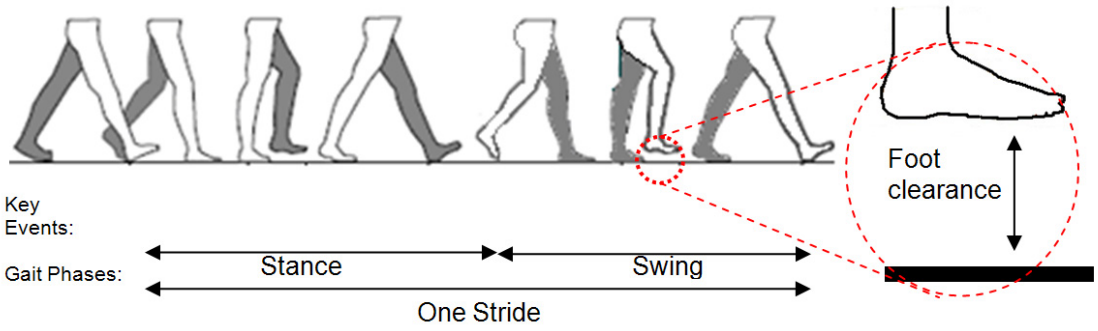

Figure 1.1: Gait Cycle (Wahab, 2009)

These days, gait analysis is still mostly carried out in a specially set-up motion laboratory using high-end motion imaging systems. In another measurement set-up, the analysis requires a physician to visually observe the gait. These two approaches are undoubtedly expensive (Morris & Joseph, 2008). For example, the use of gait mats, force sensing platforms, motion analysis systems with efficient computer processing and ultrasonic ranging system are used for indoor analysis (Wahab, 2009).

Despite the current practices, the reality proves that the demand for real life portable measurement and monitoring devices are surging fast. As an example, a portable shoe integrated system should perform better in real environment to allow comprehensive analysis and intensive monitoring. In situ measurement where the actual activities and measurement are performed such as reported in (Wahab et al., 2007; Aminian & Najafi, 2004; Wahab et al., 2006) reduces cost as the time requiring the presence of physician is reduced in addition to the cheaper device cost demanded. Otherwise, this demands that the devices be small, lightweight and easily attached to the shoes or feet. One possible way of satisfying such exclusive demands is, of course, through the application of newer device which now mostly realized using MEMS and microelectronic technology. It is this research's motivation, which is to produce and

verify that the use of the most recent technology such as MEMS and microelectronic to enhance the measurement technique of foot clearance are very required.

1.1 Problem Statement

As roughly mentioned in the previous section, the current status of the development of untethered in-shoe gait stability measurement devices is still lacking behind the reality of technology achievement. Specifically, with respect to their measurand, the current devices are not fully optimized in many aspects as follows:

- Not suitable for real world or outdoor measurement.
- Not cost effective
- Not enabling efficient signal processing
- Not fully integratable for better reliability and long lasting use
- Mostly laboratory based
- Big and complex setup
- Uncomfortable for user
- Wired connectivity

Therefore, this research focuses on design and development of a wearable shoe integrated wireless MEMS-based and recent microelectronic based foot clearance measurement system.

1.2 Research Objective and Contribution

The goals of this research are:

- Design, develop, calibrate, and analyze a wireless real-time Clearance Measurement System for gait analysis.
- Wirelessly in real-time and real world gait analysis measurement.
- Proving the concept of MEMS-based clearance measurement system towards future realization.
- Consider MEMS realizable devices such as ultrasonic sensor and inertial measurement unit sensor.

Based on requirement of gait analysis measurement, the system design consists of six parts, there are:

- Gait Analysis Hardware design
- Gait Analysis Software design
- Error correction algorithm
- System integration
- Testing setup design
- Data collection and analysis.

This system is self corrected, ready to use, hence the graphical data visualization output can be analyzed for information on the gait of the user which is known as foot clearance.

This research is aimed at developing such system but using MEMS sensor and system component purchase off-the-shelf to prove the concept. Feasibility of developing Portable Shoe Integrated Instrumentation for Gait Analysis Measurement Using MEMS

Based Devices for clearance measurement is therefore considered in this research. If the system is realizable using MEMS based devices, it can then be integrated with microelectronic circuitry on the same silicon in future researches. So, eventhough this work does not involve MEMS realization, it is aimed at proving the concept. Finally, the novelties of this research are:

- Wireless monitoring
- Real life measurement
- New custom design software for gait analysis
- First design combination of US & IMU for foot clearance measurement

1.3 Research Methodology

This section elaborates on the steps and tools used during throughout the research duration to accomplish the research target. This research takes the advantages of LabVIEW 2010 as a graphical user interface for data visualization. In addition, the PIC and Arduino microcontroller is used along with the ultrasonic sensor and IMU sensor to determine the foot clearance and orientation. The steps involved in the research for this system design and analysis are enlisted below:

1.3.1 Designing gait analysis hardware

This step involves designing and realizing the gait analysis hardware. Several designs have been made with certain improvement through the experiment finding. There are six designs of gait analysis hardware with each design had difference approach.