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Robert LeMoyne
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Wearable and Wireless Systems for Healthcare I

Gait and Reflex Response Quantification

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In Memoriam:

David Peduto (Lt. Col. US Army) (1954–2016)
To a friend, valued research team member, and Patriot.

Jonathan Swift Ph.D. (1932–2017)
To an incredible teacher who made learning an adventure.
"Think globally, and act locally!"

Wes Stewart (1924–2017)
Cousin Wes you are a dearly cherished member of our family and the personification of America's Greatest Generation. You are deeply missed. I take comfort knowing everybody has an angel.

To my wife, thank you for everything. Love Always.

I would like to thank my Mother, Father, and brother for their support.

"Nothing transcends the power of the human spirit."
from a homeless Vietnam Veteran and very loyal friend
And in the wind he's still alive.

"To beat a tiger, one needs a brother's help."
Chinese Proverb
Thanks Tim.

Chiri mo tsumoreba yama to naru.
A favorite Japanese Proverb (in Romaji)
Translation:
Even dust piled up becomes a mountain.

Preface

The domain of wearable and wireless systems for biomedical and rehabilitation applications, such as through smartphones and portable media devices, is anticipated to grow exponentially. Even from the time of presenting the draft manuscript of this book to the time of publication, the prevalence of this subject is expected to undergo meaningful transformation and evolution. These devices enable wireless inertial sensor applications to an assortment of scenarios pertaining to rehabilitation and therapy.

Since 2010 when LeMoyne, Mastroianni, and our research team applied a novel smartphone application for quantifying Parkinson's disease tremor and gait quantification in the context of a wireless accelerometer, the opportunities have expanded considerably. The authors are delighted to provide a contribution to this exciting field with the anticipation of the considerable array of developments in years to follow. Please enjoy the knowledge and intellectual inspiration that our book provides with the goal of providing meaningful, robust, and optimal rehabilitation for many.

Flagstaff, USA — Robert LeMoyne
Pittsburgh, USA — Timothy Mastroianni

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Chapter 1
Wearable and Wireless Systems for Gait Analysis and Reflex Quantification

Abstract The capacity to quantify the movement features of a person undergoing the rehabilitation process enables therapists and clinicians to proactively optimize the therapy strategy. Wearable and wireless systems, such as the smartphone and portable media device, are equipped with accelerometers and gyroscopes that can readily quantify aspects of human movement pertinent to rehabilitation, such as gait and reflex response. The smartphone and portable media device can measure gait and reflex response through their inertial sensors, and the acquired data can be conveyed by wireless transmission to the Internet as an email attachment. This capability enables the experimental site and post-processing resources to be remotely situated. Three phases of the evolution of quantification techniques for the rehabilitation process are observed, which are characterized as a first, second, and third wave. The first wave pertains to the traditional ordinal scale approach used by expert clinicians. The second wave emphasizes the role of quantification systems that are generally constrained to a clinical setting. The third wave envisions the development of Network Centric Therapy through the application of wearable and wireless systems, such as smartphones and portable media devices, for quantifying movement characteristics, such as gait and reflex response. Network Centric Therapy encompasses a quantum leap in rehabilitation capability through Cloud Computing amalgamated with machine learning with patient and therapy team situated remotely anywhere in the world. A summary of each chapter is further presented.

Keywords Wearable and wireless systems · Smartphone · Portable media device Accelerometer · Gyroscope · Gait · Gait analysis · Reflex response · Reflex response quantification · Ordinal scale · Quantification apparatus · Network Centric Therapy

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1.1 Introduction

The capacity to quantify trends in a patient's rehabilitation enhances the acuity for a team of clinicians to refine the therapy strategy and prescription [1–6]. Inertial sensors, such as accelerometers and gyroscopes, have been proposed for the quantification of human movement characteristics, such as gait and reflex [3–7]. With recent advances in microelectronics and wireless technology wearable and wireless accelerometer and gyroscope systems have permeated the fields of biomedical engineering and healthcare with previous arrangements, such as tethered sensor systems, becoming effectively obsolete [3–6, 8].

The progressive integration of wearable and wireless systems are envisioned to enable a quantum leap with regards to the capabilities of the biomedical and healthcare environment. Inertial sensors, such as the accelerometer and gyroscope, can facilitate a therapist's acuity with regards to the nature of the patient's movement quality in the context of the therapy response. In particular wearable and wireless devices are forecasted to considerably advance the rehabilitation experience, especially with regards to gait analysis and the associated quantification of reflex characteristics.

Essentially the presence of wearable and wireless systems with inertial sensors, such as the accelerometer and gyroscope, is representative of the Internet of Things for the biomedical community. The objective of the book is to provide a perspective of the role of wireless accelerometer and gyroscope sensor apparatus that are also wearable for the advance of rehabilitation and therapy in the context of gait analysis and correlated aspects, such as reflex quantification. This book sequentially advocates the evaluation to Network Centric Therapy, which is predicted to radically advance the efficacy of the rehabilitation experience.

An advantage of the wearable and wireless accelerometer and gyroscope system is the considerable flexibility of available devices for the scenario under consideration. One of the first and most fundamental pathways was with regards to the application of wireless accelerometer nodes for the domain of gait and reflex quantification. Wireless accelerometer nodes were successfully demonstrated for the accurate and reliable quantification of gait and reflex characteristics. At this level of technology evolution wireless accelerometer nodes would locally transmit data packages by wireless connectivity to a nearby situated PC [6, 9–22].

Further research and investigation respective of the technology pathway sought to acquire wireless capabilities that could better access the Internet directly. Equipped with the proper software application the smartphone is capable of functioning as a wireless accelerometer platform and also a wireless gyroscope platform. The recorded data package could be wirelessly conveyed to the Internet as an email attachment, and the data could be post-processed remote from the experimental location. Beginning in 2010 LeMoyne and Mastroianni have thoroughly researched, developed, tested, and evaluated the role of the smartphone for the accurate and reliable quantification of gait and reflex response features [3–5, 23–37]. With the successfully demonstration of the smartphone as a gait analysis tool a multitude

of clinically relevant applications have advocated its wireless inertial sensor capability [3–5].

Another similar wearable and wireless system relative to the smartphone is the portable media device. Using the same operating system as the smartphone the portable media device is readily capable of likewise functioning as a wireless accelerometer platform and wireless gyroscope platform. The primary differentiator between the portable media device and smartphone is the device cost and wireless accessibility to the Internet. A portable media device imparts a fixed cost; however, the smartphone generally requires a marginal cost to sustain the telecommunication package. The portable media device requires localized wireless Internet connectivity, and by contrast the smartphone can access the Internet through a broad telecommunication footprint. Research, development, test, and evaluation has demonstrated the ability of the portable media device as a wireless accelerometer and gyroscope platform for the quantification of gait and reflex response similar to the capabilities of smartphone [3–5, 37–49].

Further developments with respect to the capabilities of wireless and wearable systems for quantifying rehabilitation status are evident in light of local Bluetooth wireless connectivity. The concept of Bluetooth wireless offers the capacity to locally connect the inertial sensor node to the more broadly Internet accessible devices, such as a tablet, portable media device, and smartphone. This design perspective alleviates mass encumbrance and mounting complexity of the sensor node to the patient being monitored. For example, the relevance and acuity of the Timed 25 Foot Walk test has been considerably advanced through the application of a wireless accelerometer and gyroscope sensor node locally positioned about the ankle joint. The experimental trial data package is then streamed by Bluetooth wireless connectivity to a tablet, and the tablet then transmits the data to an Internet resource, such as a Cloud Computing database [50].

These available capabilities regarding the broad domain of wearable and wireless accelerometer and gyroscope sensors coalesce to promote the potential for Network Centric Therapy. Network Centric Therapy comprises the capabilities of rehabilitation and advanced therapy in consideration of the Internet of Things. In essence Network Centric Therapy would involve Cloud Computing level storage and post-processing of therapy and rehabilitation based on quantified data from wearable and wireless accelerometer and gyroscope sensors used by the patient.

There are a considerable array of utility that Network Centric Therapy offers for the biomedical and rehabilitation community, the therapist regarding enhanced acuity and awareness of the efficacy of the therapy strategy, and the patient's experience of optimal rehabilitation and timeliness of recovery. This concept promotes augmented patient intensive and focused therapy. The inherent nature of this envisioned rehabilitation technique is logistically robust.

A patient can provide the therapist ample quantified data as to the status of the rehabilitation experience from the convenience of a familiar and therefore highly relevant home bound environment through the application of wearable and wireless sensors systems, such as accelerometers and gyroscopes. For example, a therapist