DESIGN AND DEVELOPMENT OF IOT ENABLED BIO-SIGNAL COLLECTION SYSTEM FOR WHEELER REHABILITATION FITNESS ASSESSMENT

PUA ZHEN YING

This Report is submitted in Partial Fulfillment of Requirements for the Bachelor Degree of Electronic Engineering (Telecommunication Electronic) with Honours

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka

June 2017
UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER
BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Design and Development of IoT Enabled Bio-Signal Collection System For Wheeler Rehabilitation Fitness Assessment
Sesi Pengajian : 2016/2017

Saya .......................................................... PUA ZHEN YING ..........................................................

mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hak milik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan ( √ ):

☐ SULIT* *(Mengandungi maklumat yang berdjarah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐ TERHAD** *(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☐ TIDAK TERHAD

(TANDATANGAN PENULIS)

Tarikh: 5/6/2017

Disahkan oleh:

(TANDATANGAN PENYELIA)

Tarikh: 5/6/2017
"I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledge."

Signature: ..................................................
Author: PUA ZHEN YING
Date: 6/6/2017
"I acknowledge that I have read this report and in my opinion, this report is sufficient in term of scope and quality for the award of Bachelor Degree of Electronic Engineering (Electronic Telecommunication) with Honours"
To my beloved project supervisor, family and friends.
ACKNOWLEDGEMENT

Firstly, I am grateful to complete my Final Year Project in Universiti Teknikal Malaysia Melaka (UTeM). This project would not be completed without the constant support and endless effort of a numbers of individuals. During this period, I had gained new knowledge and experience. I want to take this chance to express my deepest gratitude and appreciation towards my project supervisor, Dr. Lim Kim Chuan and my project co-supervisor, Dr. Ho Yih Hwa on behalf of Faculty of Electronic and Computer Engineering, who concerns and takes care about me along the way in completing my project. This project cannot be finished without his advises and cooperation in guiding me and giving encouragement when I was facing problem and difficulty. Also, I would like to thank my family members for their faith in me and understanding. They are always being my side for giving me their best support whenever and wherever I need. Their motivational skills are unsurpassed. Their ceaseless mental and moral supports motivate me in accomplishing this project. Last but not least, I also appreciate those who spent their precious time to assist and help me in solving my problems throughout this project, especially the laboratory assistants and my dear friends. I would like to send my warmest regards for their seamless caring and continuous encouragement which strengthen my confidence to finish my project. I am indebted to those people who gave me their helping hands.
ABSTRACT

Learning how to propel with wheelchair is the most crucial part of the rehabilitation process especially for those who suffered from lower limb spinal cord injury (SCI) due to partial recovery from SCI are only within 18 months and the chances of recovery deteriorates as time goes by [4]. In a long-term, SCI patients rely on wheelchair towards their independence life through rehabilitation program. Therefore, it is essential to identify patient’s strength or weakness during rehabilitation in order to suggest suitable rehabilitation programme to patient. However, it is difficult for physiotherapist to monitor patients’ training as patients propel around rehabilitation center at their own. Moreover, there are up to 20 patients for monitoring at each training session. This project comprises the design and development of a system to allow physiotherapist to setup and monitor the rehabilitation progress of patients. An user interface (UI), cloud server with database to log the data of the sensors installed on wheelchair and display the real-time fitness assessment data are designed and developed in this project. Besides, this system also notify physiotherapist of patient’s abnormal heart rate during training. Due to the reason that mobile IoT applications streams small packet of data and away from a convenient power supply, Bluetooth Low Energy (BLE) is used to transmit sensors data. The patient’s BLE enabled smartphone, running Apps developed with Ionic framework, then streams sensors data to cloud server. With this system applied, patient’s rehabilitation progress will be enhanced when physiotherapist can seamlessly access to the real-time data of the patient and subsequently provides quantitative and qualitative feedback through the developed system. The management of rehabilitation center will then be able to properly allocate center resources according to the patient attention priority from the feedback system. The developed system gave an instant data update for every second with low power consumption of 306mW – 357mW.
ABSTRAK

CONTENTS

CHAPTER ITEM PAGE
PROJECT TITLE i
STATUS VERIFICATION FORM ii
DECLARATION iii
SUPERVISOR VERIFICATION iv
DEDICATION v
ACKNOWLEDGEMENT vi
ABSTRACT vii
ABSTRAK viii
CONTENTS ix
LIST OF TABLES xiii
LIST OF FIGURES xiii
LIST OF ABBREVIATIONS xvii

I INTRODUCTION 1

1.1 Introduction 1
1.2 Problem Statement 2
1.3 Objectives 3
1.4 Scope of Work 4
1.5 Chapters Review 4

II LITERATURE REVIEW 5
2.1 Bio-signal
2.2 Electrocardiogram (ECG)
  2.1.1 Photoplethysmogram (PPG)
2.3 Heart Rate Monitors
2.4 Internet of Things (IoT)
2.5 Bluetooth
  2.4.1 Classic Bluetooth
  2.4.2 Bluetooth Low Energy (BLE)
2.6 Data Transmission Protocol
  2.5.1 HTTP
  2.5.2 Websocket
2.7 Web Development
  2.6.1 Front-end Web Development
  2.6.2 Back-end Web Development
  2.6.3 Database
  2.6.4 Web Application Framework
2.8 Cloud Platform
  2.7.1 Google Cloud Platform (GCP)
  2.7.2 Amazon Web Services (AWS)
  2.7.3 Microsoft Azure
2.9 Related Work Studies
  2.8.1 Summary of Related Works Studies

III METHODOLOGY

3.1 Method Selection
  3.1.1 Bluetooth Technology Selection
  3.1.2 Heart Rate Monitor
  3.1.3 Data Transmission Protocol
  3.1.4 Web Development
    3.1.4.1 Front-end Web Development
3.1.4.2 Back-end Web Development  40
3.1.4.3 Database  41
3.1.5 Cloud Platform  42
3.2 System Overview  43
3.2.1 System Block Diagram  43
3.2.2 System Development Flow Chart  45
3.3 Design Algorithm  47
3.3.1 Heart Rate Acquisition  47
3.3.2 Cloud Server Development  52
3.3.2.1 Web Page Routing  54
3.3.2.2 Send and Receive data from client  55
3.3.2.3 Login Authentication  56
3.3.2.4 Calculate Target Heart Rate Zone  61
3.3.2.5 Abnormal Heart Rate detection and send notifications  62
3.3.2.6 Patient’s Live Achievement Update  66
3.3.2.7 Display Patient’s Previous Record  68
3.3.2.8 Patient registration and Patient’s Goals display  69
3.3.2.9 Make SQL Request to Database  69
3.3.3 Database Development  71
3.3.4 Microsoft Azure Implementation  71

IV  RESULT AND DISCUSSION  73

4.1 Rehabilitation Process Monitoring  73
4.2 Determination of Patient’s Difficulties during Rehabilitation  77
4.3 Patient’s Abnormal Heart Rate Detection  79
4.4 Suitable Rehabilitation Activities Planning  80
4.5 User Login Authentication  83
4.6 Database Storage  86
4.7 Microsoft Azure Implementation  88
4.8 System performance assessment  88
4.8.1 Transmission Data Rate 88
4.8.2 Power Consumption 89
4.8.3 System Achievement Analysis 90

V CONCLUSION AND FUTURE WORK 92

5.1 Conclusion 92
5.2 Future Work and Recommendations 93

REFERENCE 94
<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Physiological origins of Bio-signals</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>ECG waveform features</td>
<td>9</td>
</tr>
<tr>
<td>2.8.1</td>
<td>Related work studies summary</td>
<td>35</td>
</tr>
<tr>
<td>3.1.1</td>
<td>Comparison between Classic Bluetooth and BLE</td>
<td>37</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Comparison of heart rate monitors</td>
<td>38</td>
</tr>
<tr>
<td>3.1.3</td>
<td>Comparison of HTTP protocol and Websocket protocol</td>
<td>39</td>
</tr>
<tr>
<td>3.1.4.3</td>
<td>Comparison of Relational Database and NoSQL Database</td>
<td>42</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Devices and Platform needed in system design</td>
<td>44</td>
</tr>
<tr>
<td>3.2.2(a)</td>
<td>System Development Flow Chart Part A</td>
<td>45</td>
</tr>
<tr>
<td>3.2.2(b)</td>
<td>System Development Flow Chart Part B</td>
<td>46</td>
</tr>
<tr>
<td>4.8.1</td>
<td>Transmission data rate comparison</td>
<td>89</td>
</tr>
<tr>
<td>4.8.2</td>
<td>System power consumption</td>
<td>89</td>
</tr>
<tr>
<td>4.8.3</td>
<td>System achievement analysis</td>
<td>91</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Total Rehabilitation to be received by the patient at the rehabilitation centre</td>
<td>2</td>
</tr>
<tr>
<td>2.1</td>
<td>Classifications of Bio-signals</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>ECG Waveform</td>
<td>8</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Light absorption at the skin</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Chest-strap monitors VS Wrist-worn Monitors</td>
<td>11</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Classic Bluetooth Protocol Architecture</td>
<td>14</td>
</tr>
<tr>
<td>2.4.2(a)</td>
<td>BLE communication between Central and Peripheral Device</td>
<td>17</td>
</tr>
<tr>
<td>2.4.2(b)</td>
<td>Advertising process in BLE</td>
<td>18</td>
</tr>
<tr>
<td>2.4.2(c)</td>
<td>GATT transactions</td>
<td>19</td>
</tr>
<tr>
<td>2.4.2(d)</td>
<td>Single Mode BLE protocol stack</td>
<td>20</td>
</tr>
<tr>
<td>2.5.1(a)</td>
<td>Polling</td>
<td>22</td>
</tr>
<tr>
<td>2.5.1(b)</td>
<td>Long Polling</td>
<td>22</td>
</tr>
<tr>
<td>2.5.1(c)</td>
<td>HTTP streaming</td>
<td>23</td>
</tr>
<tr>
<td>2.6.1(a)</td>
<td>Webpage with CSS</td>
<td>26</td>
</tr>
<tr>
<td>2.6.1(b)</td>
<td>Webpage without CSS</td>
<td>26</td>
</tr>
<tr>
<td>3.1.3</td>
<td>HTTP protocol VS Websocket Protocol</td>
<td>38</td>
</tr>
<tr>
<td>3.2.1</td>
<td>System Block Diagram</td>
<td>43</td>
</tr>
<tr>
<td>3.2.2(a)</td>
<td>System Development Flow Chart Part A</td>
<td>45</td>
</tr>
<tr>
<td>3.2.2(b)</td>
<td>System Development Flow Chart Part B</td>
<td>46</td>
</tr>
</tbody>
</table>
3.3.1 Summary of Heart Rate Acquisition using Ionic Apps 52
3.3.2 Summary of Cloud Server function 53
3.3.2.3 Login authentication process flow 56
3.3.2.4(a) Karvonen Formula 62
3.3.2.4(b) Training Level and Percentage 62
3.3.2.5(a) Notification sending process flow 63
3.3.2.5(b) Web push notification sending 65
3.3.2.5(c) Process of email notification 66
4.1(a) Target Setting for performance evaluation 74
4.1(b) Rehabilitation achievement live update (web based) 75
4.1(c) Smart Wheelchair 75
4.1(d) Polar H7 heart rate sensor 76
4.1(e) Mobile apps that acquires heart rate 76
4.2(a) Chart showing patient’s stamina achievement 78
4.2(b) Chart showing patient’s weakness during wheelchair propelling 78
4.3(a) Web push notification 79
4.3(b) Email notification 80
4.3(c) Patient’s location 80
4.4(a) Patient’s overall performance achievement on 12 May 2017 81
4.4(b) Patient’s weakness during wheelchair propelling on 12 May 2017 81
4.4(c) Example of patient’s stamina achievement on 12 May 2017 82
4.4(d) Patient’s rehabilitation goal and other information 82
4.4(e) New patient registration 83
4.5(a) Successful user account registration 84
4.5(b) User account does not exist 84
4.5(c) User account password reset 85
4.5(d) Email received for password reset 85
4.5(e) User Interface for password reset 86
4.6(a) Login password 87
4.6(b) Patient’s performance data stored after each evaluation 87
4.6(c) Auto-generated table for patient’s performance data 87
4.6(d) Subscription keys for web push and email notification 87
4.6(e) Patient registration with rehabilitation goal 87
4.7 Microsoft Azure deployment successful 88
4.8.2 System power consumption measurement 90
4.8.3 PERKESO Rehabilitation Centre visit 91
LIST OF ABBREVIATIONS

BLE – Bluetooth Low Energy
ECG – Electrocardiogram
GCM – Google Cloud Messaging
HTML – Hyper Text Markup Language
HTTP – Hyper Text Transfer Protocol
IOT – Internet of Things
SCI – Spinal Cord Injury
SDPY – Speedy
SQL – Structured Query Language
TCP – Transmission Control Protocol
UI – User Interface
URI – Uniform Resource Identifier
CHAPTER I

INTRODUCTION

1.1 Introduction

Spinal cord injury (SCI) is a damage to the spinal cord that results in a loss of function, mobility, and feeling. Frequent causes of damage are trauma or disease with Motor Vehicle Accidents as the leading cause of SCI with 44% [1]. According to the National Institute of Neurological Disorders and Stroke of United States, there are more than 250,000 Americans are living with spinal cord injuries with new cases of 12,000 every year in the United States alone and the involved cost could be up to USD347,896.00 at the first year [2], [3]. However, there is currently no cure for spinal cord injury [4]. With physiotherapy exercises, one may recover some function within 18 months [4]. But as time goes on, the chances of paralyzed muscles starting to work again are small [5]. Hence, in a long term, wheelchair is the most important tool for SCI patients to be mobile in social life [6].

Rehabilitation program not only prepares patients to be mobile in daily life with wheelchair but also both mentally and physically ready to go back home, returning to the community, and ready for the workplace (refer to Figure 1.1). Seamlessly connecting all the stakeholders (wheeler, therapist, family and friends, social worker, and the management of the rehabilitation center) not only help to streamline the care processes but also to improve the patient care both quantitatively and qualitatively. As shown in Figure 1.1, physiotherapist needs to help patient to be independent in wheelchair propulsion by suggesting suitable techniques, management needs to properly allocate center resources and properly assign patient to suitable rehabilitation department according to their attention priority from the feedback system, social worker needs to find suitable job for patients according to their rehabilitation performance, family and friends can be supportive when patients are having bad
performance, and lastly, patients themselves have to work hard in training when they found that their performance is bad from the feedback system. Connecting the bio-feedback data collected by additional sensors which attached on wheelchair to the cloud server can be achieved easily with the matured Internet of Things (IoT) enabled technologies and platforms. Useful feedback information such as heart rate of the patient undergoing the therapy at certain inclination, workout limit, and achievement level of rehabilitation activities planned by the therapists can then be seamlessly accessed by relevant stakeholders. These collected bio-feedback data is important in helping physiotherapist to suggest suitable wheelchair propulsion method and rehabilitation process.

Figure 1.1: Total Rehabilitation to be received by the patient at the rehabilitation centre

1.2 Problem Statement

As part of the physical rehabilitation program, patients are required to complete a wheelchair track of around 2.5km independently where the kilometer varies depending on patient's rehabilitation goals. Throughout the wheelchair track, the patients may face difficulties such as inclined track, rough roads, or terrain holes where each of the patients may have different progress and difficulties. It is challenging for physiotherapist to monitor up to 20 patients for each session while identifying their difficulties and performance during rehabilitation (refer section 4.2.3). Furthermore, patients propel in wheelchair at their own around the center which makes it even harder
for physiotherapist to monitor the patients, not to mention when there is patient emergency out of physiotherapist’s monitoring sight. By the end of each session, it is difficult for physiotherapist to recall each patient’s performance and log in the data into system manually.

Furthermore, the rehabilitation performance of patient is often inaccessible to all the rehabilitation stakeholders who help to streamline the rehabilitation care process. Besides, some of the patients might have pessimistic attitude during rehabilitation process after they met accident and lost their freedom to a wheelchair. They tend to give up training even though their workout limit is not reached yet.

From recent related work studies (section 2.10), it was found that most of the system does not have a user interface that connects all required parties while having a network delay of 16-18s in data transmission. Since power consumption is a major concern in IoT application, it is desirable to achieve low power consumption. However, one of the studied projects achieved power consumption of 750mW which can be further improved to make sure the designed IoT application does not drain out devices’ power supply too soon.

1.3 Objectives

The aim of this study is to design and develop an IoT enabled Bio-signal collection system for wheeler rehabilitation fitness assessment with objectives as shown below:

a) To develop an algorithm to acquire patient’s heart rate data as one of the identification of patient’s performance, difficulties, and workout limit during the rehabilitation process.

b) To create connected IoT system with cloud server and database to seamlessly connects all the stakeholders throughout the rehabilitation process.

c) To develop physiotherapist notification when detected patient’s abnormal ECG activity.
1.4 Scope of Work

This project comprised of developing an algorithm to acquire patient’s heart rate data (bio-signal data) with the use of Polar H7 heart rate sensor via BLE link to a developed Ionic mobile application. Then, a cloud server is developed to receive transmitted data from Ionic mobile application such as heart rate data and data collected by other project members which are wheelchair inclination, distance travelled on wheelchair, and wheelchair location. The cloud server is also developed using Node.js to do web page routing, user login authentication, detect abnormal heart rate and send notifications and more (refer to section 3.3.3). A user interface is also created using HTML to display patient’s rehabilitation performance and information. Besides, a database is developed using MySQL workbench to store patient’s performance record, login password, patient’s information and more for server to access when needed. After testing on the developed server, database and user interface, the developed system is implemented to the Microsoft Azure cloud platform. The system is developed to monitor the rehabilitation process of 1 patient due to the limitation of equipment and devices available. By the end of this study, a working prototype consists of microcontroller, heart rate sensor, cloud server, cloud database, and web application are produced.

1.5 Chapters Review

Chapter I describes the general overview of this project. This chapter presents the introduction, problem statement, objectives, scope of work and review of all chapters included in this thesis.

Chapter II discusses the terminology of devices, sensors, and technology being used in this project. The technology to be discussed includes the Bluetooth Low Energy and Websocket. This chapter also presents the previous and related work to this project.

Chapter III presents the methodology of heart rate acquisition, data transmission, cloud server and database development, and Microsoft Azure implementation. Chapter IV delivers the results and discussions obtained in this studies. The last chapter, Chapter V gives the conclusion and future work of this project.
CHAPTER II

LITERATURE REVIEW

This chapter presents the terminology of bio-signal, IoT, BLE and some other technologies being used in this project. Followed by the literature review of some of the available technologies in the market. Then, a study of recent related works is presented in the last section of this chapter.

2.1 Bio-signal

The biomedical signals, referred to as bio-signals, are essential not only for classical applications concerning medical diagnosis and therapy, but also important for the analysis and monitoring of future applications. A bio-signal can be defined as a description of a physiological phenomenon or any signal in living beings that can be continually measured and monitored [7], [8]. They can also be described as time records of a biological event inside the body (such as heart beats or muscle contraction), chemical and mechanical activities that happens during these events that produce signals which can be measured and analysed [8]. The physiological mechanisms of interest are nearly unlimited, hence the number of possible bio-signals is very large. However, there are 3 ways of defining bio-signals classification which are existence of bio-signals, dynamic nature of bio-signals, and origin of bio-signals [7].

As the first classification method, the existence of bio-signals could be taken as a basic bio-signals classification. In particular, this classification groups are comprised of Permanent bio-signals and Induced bio-signals. Permanent bio-signals exist naturally at any time and without any artificial impact, trigger, or excitation from outside the body (Figure 2.1: Classifications of Bio-signals [8]). For example, the ECG that is induced by electrical heart muscle excitation with the typical peaks P-Q-R-S-T
and the acoustic bio-signal that is induced by the consecutive heart valve closures with the typical first and second heart sounds that belong to the group of permanent bio-signals. On the other hand, the group of Induced bio-signals defines bio-signals as artificially triggered, excited, or induced (Figure 2.1: Classifications of Bio-signals [8]). As compared to the permanent bio-signals, induced bio-signals exist only for a certain duration of excitation. When the artificial impact is over, the induced bio-signals will start to decay. An example would be the electric plethysmography, where an artificial current is induced in the tissue and reflects tissue impedance changes [7].

The second classification method considers the dynamic nature of bio-signals, which are Static bio-signals and Dynamic bio-signals. A static bio-signal carries information in a steady state with slow changes over time. As shown in Fig. 1.3b, body temperature would be a static bio-signal that exhibits slow changes over the time. By contrast, dynamic bio-signal convey information of interest with extensive changes in the time domain. For example, the heart rates would constitute a highly dynamic bio-signal as shown in Fig. 1.3b [7].

The third classification method uses the origin of bio-signals for their classification. The most prominent origins encompass the following bio-signals:

<table>
<thead>
<tr>
<th>Types of Bio-signals</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioelectric signals</td>
<td>Generated by nerves and muscles tissues as the result of the changes in the electric currents which are produced by the sum potential differences across the tissues and organs. Best known example is the Electrocardiogram (ECG).</td>
</tr>
<tr>
<td>Biomagnetic signals</td>
<td>A signal measured from activities which are linked to magnetic field from an organ. This is because different organs such as heart, lungs, brain will generate a weak magnetic field. For example: Magnetoencephalogram (MEG)</td>
</tr>
<tr>
<td>Biochemical signals</td>
<td>A signals contain information about the changes in concentration of various chemical agents in the body. For example, glucose level.</td>
</tr>
<tr>
<td>Biomechanical signals</td>
<td>Produced by the mechanical functions of biological signals such as motion, displacement and pressure. For example: blood pressure measurements.</td>
</tr>
<tr>
<td>Bioacoustic signals</td>
<td>A special subset of biomechanical signals that involve in vibration basically motion. For example: signals from respiratory system and muscles.</td>
</tr>
</tbody>
</table>
Biooptical signals: Generated by the optical or light-induced attributes of biological systems. They may occur naturally or induced.

In this study, the bio-signal refers to the Electrocardiogram (ECG) or Photoplethysmogram (PPG) which can be described by heart rates measurement.

Figure 2.1: Classifications of Bio-signals [8]