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

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Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
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1

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To my beloved project supervisor, family and friends.

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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.

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ABSTRAK

Pembelajaran lojakkan dengan kerusi roda adalah penting dalam proses pemulihan, terutamanya bagi mereka yang mangalami SCI pada bahagian rendah anggota badan. Pemulihan separa daripada SCI cuma dalam tempoh 18 bulan dan peluang pemulihan merosot sepanjang masa. [4] Dalam jangka masa panjang, pesakit SCI bergantung kepada kerusi roda ke arah kehidupan mereka yang bebas melalui program pemulihan. Oleh itu, pengenal pastian kekuatan atau kelemahan pesakit semasa pemulihan adalah penting untuk mencadangkan program pemulihan yang sesuai kepada pesakit. Namun, pemantauan latihan pesakit adalah sukar bagi ahli fisioterapi kerana pesakit melakukan pemulihan dengan keupayaan mereka sendiri di sekitar pusat pemulihan. Tambahan pula, bilangan pesakit bagi setiap sesi pemantauan latihan adalah sehingga 20 orang. Projek ini mangandungi reka bentuk dan pembangunan sesuatu system untuk setup serta memantau proses pemulihan pesakit. Sesuatu portal pengguna, pelayan awam dengan pangkalan data awam yang log data daripada sensor yang dipasang pada kerusi roda dan memaparkan data langsung penilaian kecergasan telah direka dan dibangunkan dalam projek ini. Sistem ini juga memberitahu ahli fisioterapi tentang kadar jantung pesakit yang luar biasa semasa proses pemulihan. Oleh sebab aplikasi IoT menghantar paket data kecil dan jauh daripada bekalan tenaga, BLE telah digunakan untuk menghantar data sensor. Seterusnya, telefon pintar yang dilengkapi BLE, menjalankan aplikasi yang telah dibangunkan dengan Ionic Framework untuk menyampaikan data sensor ke pelayan awam. Dengan aplikasi sistem ini, proses pemulihan pesakit dapat dipertingkatkan apabila ahli fisioterapi dapat akses data langsung pesakit serta memberi maklum balas kuantitatif dan kualitatif melalui sistem pemantauan yang secara berlangsung ini. Pihak pengurusan pusat pemulihan dapat memperuntukkan sumber pusat mengikut keutamaan perhatian pesakit daripada sistem maklum balas. Sistem yang dibangunkan memyampai maklumat langsung setiap saat dan mencapai penggunaan kuasa yang serendah 306mW - 357mW.

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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**

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2.1	Bio-signal	5
2.2	Electrocardiogram (ECG)	8
2.1.1	Photoplethysmogram (PPG)	9
2.3	Heart Rate Monitors	10
2.4	Internet of Things (IoT)	11
2.5	Bluetooth	13
2.4.1	Classic Bluetooth	14
2.4.2	Bluetooth Low Energy (BLE)	15
2.6	Data Transmission Protocol	20
2.5.1	HTTP	21
2.5.2	Websocket	23
2.7	Web Development	24
2.6.1	Front-end Web Development	25
2.6.2	Back-end Web Development	27
2.6.3	Database	28
2.6.4	Web Application Framework	29
2.8	Cloud Platform	30
2.7.1	Google Cloud Platform (GCP)	31
2.7.2	Amazon Web Services (AWS)	31
2.7.3	Microsoft Azure	31
2.9	Related Work Studies	31
2.8.1	Summary of Related Works Studies	34

III METHODOLOGY 36

3.1	Method Selection	36
3.1.1	Bluetooth Technology Selection	36
3.1.2	Heart Rate Monitor	37
3.1.3	Data Transmission Protocol	38
3.1.4	Web Development	40
3.1.4.1	Front-end Web Development	40

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	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

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	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**

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LIST OF TABLES

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

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LIST OF FIGURES

NO	TITLE	PAGE
1.1	Total Rehabilitation to be received by the patient at the rehabilitation centre	2
2.1	Classifications of Bio-signals	7
2.2	ECG Waveform	8
2.1.1	Light absorption at the skin	10
2.3	Chest-strap monitors VS Wrist-worn Monitors	11
2.4.1	Classic Bluetooth Protocol Architecture	14
2.4.2(a)	BLE communication between Central and Peripheral Device	17
2.4.2(b)	Advertising process in BLE	18
2.4.2(c)	GATT transactions	19
2.4.2(d)	Single Mode BLE protocol stack	20
2.5.1(a)	Polling	22
2.5.1(b)	Long Polling	22
2.5.1(c)	HTTP streaming	23
2.6.1(a)	Webpage with CSS	26
2.6.1(b)	Webpage without CSS	26
3.1.3	HTTP protocol VS Websocket Protocol	38
3.2.1	System Block Diagram	43
3.2.2(a)	System Development Flow Chart Part A	45
3.2.2(b)	System Development Flow Chart Part B	46

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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

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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

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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

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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

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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.

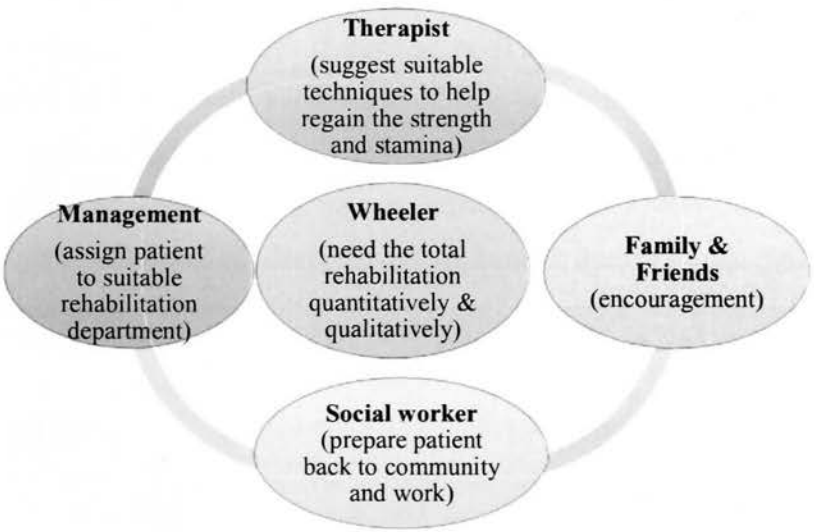

Figure 1.1: Total Rehabilitation to be received by the patient at the rehabilitation centre

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

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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.

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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.

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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

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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 constrast, *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 2.1: Physiological origins of Bio-signals [8]

Types of Bio-signals	**Description**
Bioelectric signals	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).
Biomagnetic signals	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)
Biochemical signals	A signals contain information about the changes in concentration of various chemical agents in the body. For example, glucose level.
Biomechanical signals	Produced by the mechanical functions of biological signals such as motion, displacement and pressure. For example: blood pressure measurements.
Bioacoustic signals	A special subset of biomechanical signals that involve in vibration basically motion. For example: signals from respiratory system and muscles.

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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.

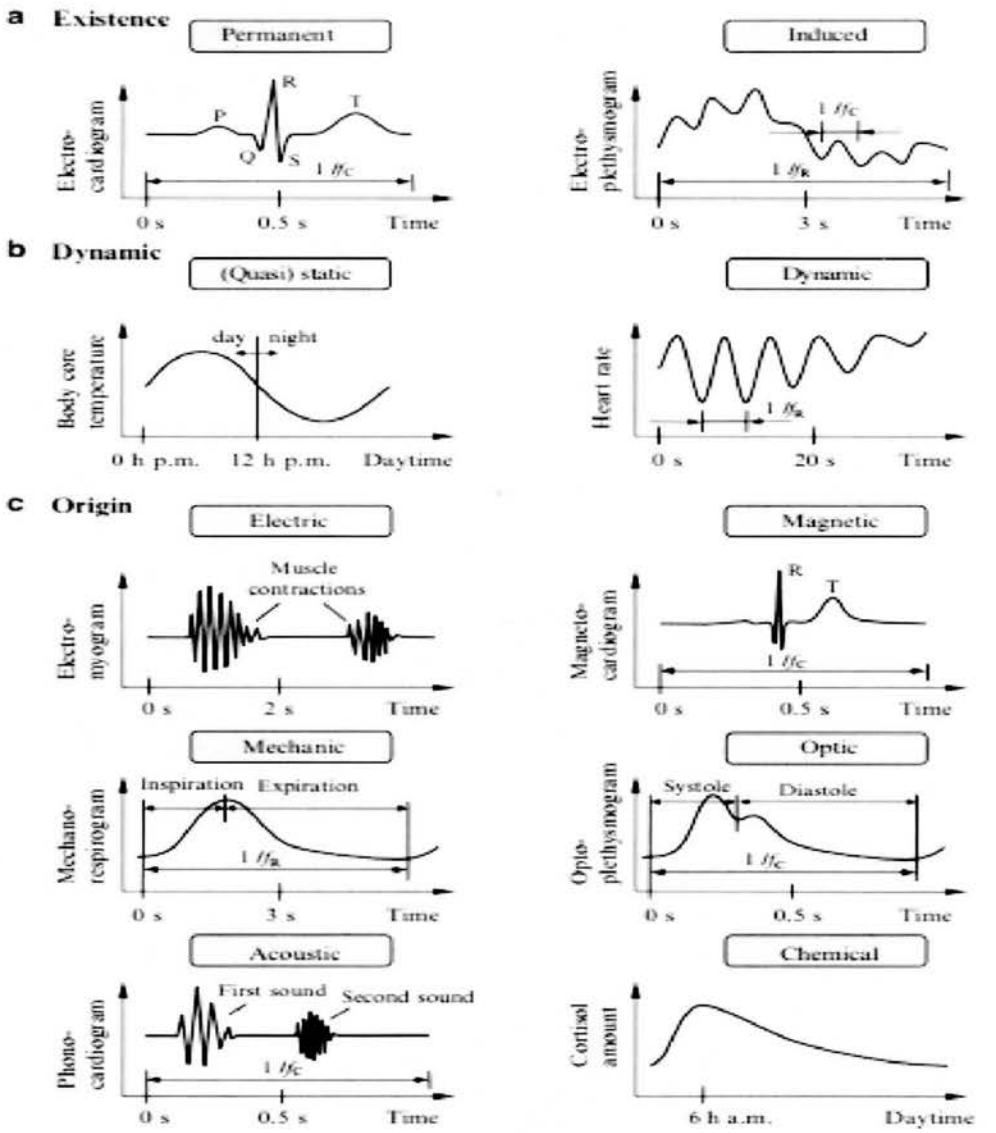

Figure 2.1: Classifications of Bio-signals [8]

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