DEVELOPING ACCELEROMETER SENSOR SYSTEM FOR INSTANTANEOUS MAPPING ACCELERATION OF 1DOF ELBOW JOINT FOR EXOSKELETON ROBOT

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"I hereby declare that I have read through this report entitle "Developing Accelerometer Sensor System for Instantaneous Mapping Acceleration of 1DOF Elbow Joint for Exoskeleton Robot" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Mechatronics)"

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A report submitted in partial fulfillment of the requirements for degree of Bachelor of Electrical Engineering (Mechatronics)

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I declare that this report entitle "Developing Accelerometer Sensor System for Instantaneous Mapping Acceleration of 1DOF Elbow Joint for Exoskeleton Robot" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

An exoskeleton robot is an external structural mechanism together with a joint and links with have most similarity to the human body. When it is wearing by a user, it should provide safety, comfort wearing, high movable ranges, flexible and smooth motion generation, and adaptability. An exoskeleton robot is one of the solutions for the patient which disability problem such as partial paralyzed patient. To perform the rehabilitation process automatically, the exoskeleton robot need to be drive directly by the patient movement. A technic called mapping concept is needed to perform the task. However, it is difficult to learn and understand this unnatural mapping method. The challenge lies in learn a mapping method and design the controller by using accelerometer sensor signal as its input. By this, it would be a challenging to find and figured out these parameter and its role in controlling the exoskeleton movement. This project is to study and understands the behaviour and characteristic of the accelerometer sensor; develop a sensory system for detecting acceleration of elbow joint by using accelerometer sensor; and design a sensory system for instantaneous mapping acceleration of human elbow joint movement for 1DOF exoskeleton prototype model. The project is setup by locating the most suitable location to place the accelerometer sensor on the human upper limb. Then establish the connection between accelerometer to a computer through a microcontroller as a data translator medium. Obtained data then will be analysis and investigate to understand the mapping process. The mapping process is perform by using mapping equation to control directly the speed of the prototype model based on sensing signal from the accelerometer sensor. In hardware testing, the dc motor will operating only when the PWM value reach approximately about 70 due to the torque of the dc motor is low. With a sensor reading of 430mV/g, the prototype model will provide a full speed movement of 255 PWM value. At the end of this project, a functioning sensory system by using accelerometer sensor ADXL335 for mapping the human elbow joint acceleration to the 1DOF prototype model of an exoskeleton robot were produced by controlling the PWM value of the dc motor.

ABSTRAK

Robot *exoskeleton* merupakan struktur mekanisme luaran beserta dengan penghubung dan penggerak yang mempunyai persamaan dengan badan manusia. Apabila ia dipakai atau digunaka, ia harus menjamin keselamatan, keselesaan, lingkungan pergerakan yang tinggi, fleksibel dan menjana pergerakan yang lancer serta mempunyai kebolehsuaian yang tinggi. Robot *exoskeleton* merupakan salah satu jalan penyelesaian untuk pesakit kurang upaya seperti pesakit separa lumpuh. Pergerakan pesakit digunakan untuk memandu robot *exoskeleton* bagi menjalankan proses pemulihan secara automatik. Sistem pemetaan digunakan untuk menjalankan tugas ini. Namun demikian, sistem pemetaan ini adalah sukar untuk dipelajari dan difahami. Cabarannya wujud semasa mempelajari kaedah pemetaan dan membentuk satu pengawal baru kepada sistem ini. Projek ini bertujuan untuk mempelajari dan memahami ciri-ciri sensor pecutan; membina sistem sensor untuk mengesan pecutan sendi siku manusia; dan mereka bentuk satu sistem sensor untuk memetakan serta-merta laju pergerakan sendi siku manusia kepada sebuah model prototaip robot *exoskeleton* yang mempunyai hanya satu paksi gerakan. Projek dimulakan dengan mencari bahagian yang paling sesuai untuk ditempatkan sensor pada tangan manusia. Kemudian sambungan diantara sensor ke komputer dimulakan melalui mikropengawal yang bertindak sebagai medium pengantaraan. Data yang terkumpul akan dianalisa dan dikaji untuk memahami proses pemetaan. Proses pemetaan ini dijalankan dengan menggunakan persamaan pemetaan untuk mengawal pergerakan prototaip berdasarkan signal dari sensor yang diterima. Semasa menjalani pengujian, motor hanya akan bergerak apabila nilai PWM mencecah 70 disebabkan motor yang digumakan mempunyai daya kilas yang tidak cukup. Prototype akan bergerak laju sepenuhnya dengan nilai PWM adalah 255 apabila sensor membaca nilai 430mV/g. Di akhir proses perlaksanaan projek ini, satu sistem sensor dihasilkan untuk memetakan kelajuan sendi siku manusia kepada model prototaip robot *exoskeleton* yang hanya berputar pasa satu paksi sahaja dengan menggunakan sensor pecutan model ADXL335 untuk mengawal nilai PWM motor.

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a	-	Acceleration
Dx	-	Distance
F	-	Force
k	-	Spring constant
m	-	Mass
N	-	Number of data items in sample
v_y	-	Value for Y-axis analog input pin
zero_y	-	Value of position zero g (0g) for Y-axis
$\bar{x}$	-	Mean
x_i	-	Value for each data (i = 1, 2, 3, ...)
$\sum x$	-	Sum of all data value
Δx	-	Spring extension

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Nowadays, many sectors have interested in exoskeleton robots and it has been consider in the industry, medical applications, and military. Recently, the exoskeleton robot was carrying out for the purpose of rehabilitation process and power assist equipment for daily activities [1, 3]. The first true exoskeleton was developing on 1960. Since then, many exoskeleton robots were develop and improved to reach the purpose that state above. The exoskeleton project can be dividing into two main group that is mechanical and software part. The mechanical part included the material of the exoskeleton used and its actuator or sensor. Meanwhile the software part in the integrated of computer programing and control system that will be develop to run and control the exoskeleton robot.

This project was limited to be research on instantaneous mapping acceleration of elbow joint for only 1DOF of exoskeleton robot. This is to provide a good sensory system for an upper limb exoskeleton robot that can be integrated with the hardware system. The completed integrated system is expected able to be used mainly as rehabilitation equipment for partial paralyzed patient or power assist for an elderly person for only upper limb motion mainly on elbow joint movement.

Before a completed integrated system of hardware and software can be develops, it is important to understand the behaviour and characteristic of the sensory system that would be a major input to this project. As exoskeleton movement is based on the sensor

signal data that sense from the human upper limb (elbow joint) movement, it is importantly to setup the sensory system perfectly as much as possible. The location of the accelerometer sensor needs to be specific to provide a good signal sensing data. With this, it is important to conduct an experiment to obtain the signal data and analysed as well as investigates it and perform data mapping for the system. Without a proper analysis and investigation, the exoskeleton might not work properly or might face a problem later on.

For this project, the data analysis is proposed to be done by recorded the accelerometer sensing reading of the human elbow joint movement. Analog signal from accelerometer sensor need to be convert to digital data by using microcontroller that already installed ADC (analog to digital converter) in it. An analog signal from accelerometer sensor will be send to the microcontroller, microcontroller then will send the digital data to the computer for a recording process. The obtain data then will be analysed and investigate to find a most suitable way of deeply understanding the accelerometer characteristic and its performance. Thus, a good sensory system can be developing to provide the best way of mapping the signal data with the exoskeleton parameter.

1.2 Motivation

In our common life, heavy lifting is normal activities done by human when there want to carry something from one place to another place and it became our natural habit. Without realize, this habits could be a bad move and in return, it could harm ourselves. Aside from being immediately difficult, in long term it could affect our health and leave a side effect disease. By lifting heavy object from the ground with our bare hands, our muscle on the rear of our body would provide strength to do so. Our health especially our back could affect immediately if our muscle could not take the strain. This could drives to a damaged of ligaments and our muscle. This problem officially was facing by a lot of labour worker at the work place. For this, an exoskeleton robot could be the best solution to solve this problem by provides more strength to support while human are lifting something weighty. Thus it will reduce the chances of human to be injured or lifting to heavy.

Besides, there are patients that have their disability such as paralyzed patient or elderly persons. Disability means when someone has one or more health problem and that problem drove him/her to lose the ability of performing his/her personally meaningful or socially valued activities. To have a manual rehabilitation process for this patient is too expensive. It needs a professional to handle all the rehabilitation procedure and its equipment. Therefore, there is an idea to produce a device to decrease the cost of rehabilitation process such as professional fee and the equipment rental cost by using an exoskeleton robot. By using an exoskeleton robot, paralyzed patient can be treated automatically without any help from a professional likes before that might cost to high and wasting of time to make an appointment for the treatment. An exoskeleton robot provides daily treatment to the paralyzed patient by a little help from a family member. This might be more effective for the paralyzed patient as they are often to having more treatment. Same as elderly person, an exoskeleton provide a comfortable help by helping them in daily life such as walking routine. As we know that mostly an elderly person does not have enough strength to do their own daily routine. An exoskeleton robot could provide a power assist to keep them doing on their own daily activities. Indirectly, it could help the emotional of the elderly people too due an exoskeleton provide a solution for them to comes back to a normal life again.

As said by, R. A. R. C. Gopura [1], during the period of 1960s and 1970s, the study of active exoskeleton robots were used in the sector of military, industry, and medical applications. Furthermore, in early 1990s, some exoskeleton robots were suggested to be used for extends the strength of human power or force. Nowadays, many rehabilitation process and power assist project has been proposed by using the active upper-limb exoskeleton robot system [3].

1.3 Problem Statement

An exoskeleton robot is a moveable or wearable external structural mechanism. It is can be worn by any individual and connecting directly with the human body by using a sensory system as a tool, that why it should designed with a special specification and high consideration. Most important specification that needs to be considered in the mechanical design is it should comfort wearing, high movable ranges, low inertia, safety, and adaptability [4]. For controllability, special consideration should pay into flexible and smooth motion generation, safety, and responsiveness.

To drive the exoskeleton robot automatically, a technic called mapping concept is needed to perform the task. The acceleration of human elbow joint movement needed to be mapped to the exoskeleton parameter. The mapping method has to be perfect to complete the performing task with highly efficiency. However, it is difficult to learn and understand this unnatural mapping method. The challenge lies in learn a mapping method and design the controller by using accelerometer sensor signal as its input.

Furthermore, to provide a smooth movement of the exoskeleton robot, there would be an exoskeleton parameter that needs to take into account. By this, it would be a challenging to find and figured out these parameter and its role in controlling the exoskeleton movement for providing the smoothest movement as much as possible.

1.4 Objectives of the Project

Objectives for this project are as follow;

1) To study and understand the behaviour and characteristic of the accelerometer sensor.
2) To develop a sensory system using accelerometer sensor for detecting acceleration of elbow joint.
3) To design a sensory system for instantaneous mapping acceleration of elbow joint for 1DOF exoskeleton prototype model.

1.5 Scope

Among the scopes of this project are;

1) Concept and characteristic of sensory system (accelerometer sensor).
2) Involve only 1DOF movement.
3) Focus on mapping the accelerometer sensor signal to the DC Motor.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Exoskeleton

In the 1960s, General Electric and the United States military was co-developed a mobile machine integrated with human movements named Hardiman [3, 5]. It was the first true exoskeleton robot and it can lift a 110 kg object just like lifted of 4.5 kg object that's powered by hydraulics and electricity.

An exoskeleton is usually defined as an external structural mechanism together with a joint and links with have most similarity to the human body. After suited up the exoskeleton robot, torques can be transmits from actuators through a rigid exoskeletal links to the human joint. As point by J. C. Perry et al. [2] and Rosen J. et al. [5] an exoskeleton that will be developing to be a wearable robot should have potential applications as below:

I. Physiotherapy: The patient wearing an exoskeleton performs task-based occupational or physical therapy in an active or passive mode.
II. Assistive device (human amplifier): The operator feels scaled down loads while interacting with objects in the environment, most of the load being carried by the exoskeleton.
III. Haptic device: The subject physically interacts with virtual objects while the forces generated through the interactions are fed back to the user through the exoskeleton conveying shape, stiffness, texture, or other characteristics of the virtual objects.

IV. Master device: Replacing the virtual environment with a real robot, the operator uses the exoskeleton to control a robotic system in a teleoperation (master/slave) mode, where the exoskeleton reflects back to the user the forces generated as the slave robot interacts with the environment.

Generally, an exoskeleton robot operational is control by control system. Control system monitors electric currents such as electromyogram or EMG, signals on the wearer's body. These signals then will move through the human muscle fibres when a person is moving. A sensor with a coin-size will be placed to the wearer's skin near the elbows, shoulders, knees, and hips to detect the signals and send them to the controller. The controller (computer) then triggers the actuators to make the legs and arms of the robot to move on action. Another purpose of control system is to allow the wearer and the suit was moving properly and smoothly together [2, 5].

R. A. R. C. Gopura [3] said that robotic exoskeleton systems is significantly develop to be used for the haptic interaction, human power assist, robotic rehabilitation and human power augmentation in nowadays. Robotic exoskeleton system is connecting directly with the human user, that why it should designed with a special specification and high consideration as shown in Figure 2.1. Most important specification that needs to be considered in the mechanical design is it should comfort wearing, high movable ranges, low inertia, safety, and adaptability [4]. For controllability, special consideration should pay into flexible and smooth motion generation, safety, and responsiveness. In addition, the controller should be able to produce a motion with have most similarity to the human desired motion.

Figure 2.1: Exoskeleton Robot [6]

2.2 Human Upper Limb (Elbow Joint)

Upper limb of human body's part is often referring to the human hand or arm. But it is actually consisting of the shoulder, arm (between shoulder and elbow), elbow, forearm (between elbow and wrist), wrist, and lastly is hand as Figure 2.2 (a).

By refer to R. A. R. C. Gopura et al. [1] the elbow complex is a combination of joint that consisting by two joints, humeroradial that located between the capitulum and radial head, and the humeroulnar that located between the trochlea and the trochlear notch of the ulnar. It is includes elbow joint and radioulnar joints. The humeroradial can be model as a ball-and-socket joint too. The joint motion has been reduced from three degree of freedom (2DOF) to two degree of freedom (2DOF) due to the close association of the superior radiaulnar and the humeroulna. The elbow joint complex allows supination/pronation and flexion/extension with that means it is only allow 2DOF. It is shown in Figure 2.2 (b) and Figure 2.2 (c).

By refer to the final report of Investigation of Inertial Properties of The Human Body 1975 [8], average arm weighs it gives by around 5% to 6% of total body weight. Mean of the upper arm (arm) it gives by a total of 1.842kg for right side and a total of 1.113kg for a right side of lower arm (forearm). While the total mean of hand is gives by 0.4kg on the right hand side too. That gives a total mean arm mass of 3.356kg for right and left upper limb of human.

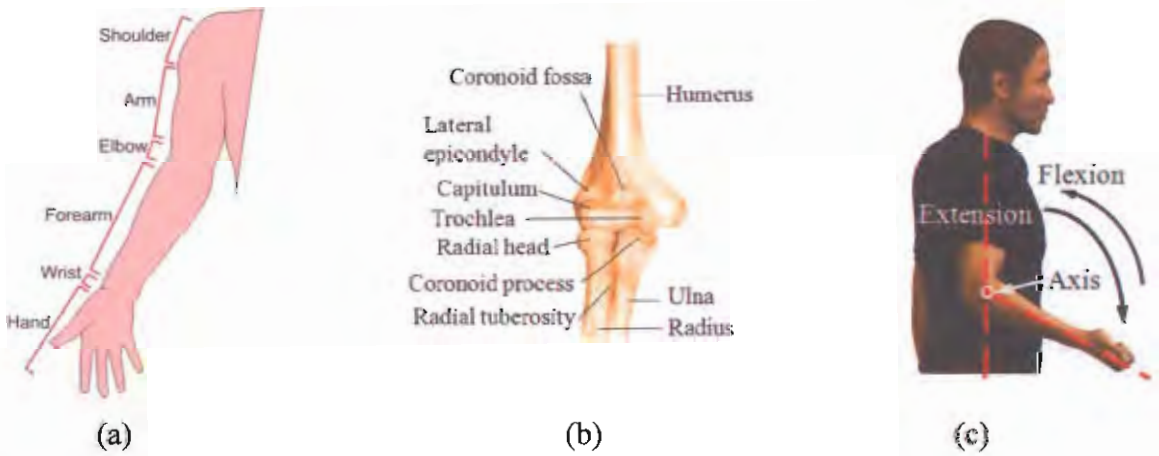

Figure 2.2: (a) Human Upper Limb [7], (b) Human Elbow Joint [1], (c) Flexion/Extension Motion [1]

2.3 Sensory System

A sensor also known as a detector and it is a device that converts a physical quantity of a measurement into a signal that can be read by an instrument or observer that they are mostly electronic devices. It is wrong to assume that sensor is only a receptor, as said by Shigeo Kobayashi et al. [9]. Sensors normally consist of a transmitter and receiver. Transmitter of a sensor is used to transmit or end a signal out from it, while a receiver is used to receive the transmit signal from transmitter. A sensor will respond to a signal when it is touched by something or when their signals were block by an object. Sensitivity of a sensor is the changing of the sensor's output with the changing in measured quantity. High sensitivity sensor can measure very small changes. While the resolution of a sensor is the ability of the sensor to detect the smallest changes that can be detected of the measuring process. A sensor is said to have a high resolution if it could detect very small changing of the sensing process. Every good sensory system should not influence the measured property, insensitive to any other property likely to be encountered in its application and most important is sensitive to the measured property only. Nima Najmaei et al. [10], state that, to integrate the existing systems, minimal computational burden and reengineering efforts should be special considered in sensory system. With that, they are expected to be simple, inexpensive, and has a high accuracy and reliable.

2.4 Accelerometer Sensor

An accelerometer is an electromechanical device that measures the acceleration force. It can measure either static or dynamic force. Static force is the constant gravity that keep pulling on our feet, while dynamic force is cause by a moving or vibrating object that produces weight in one, two, or three orthogonal axes. This instrument produces a precise output no matter they are in analog signal or digital signal, which is directly related to the acceleration that applied along the input axis of the sensor [11]. Accelerometer can be used to measure vibrations, shocks, tilt, impacts and motion of an object and a lot of activity