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Development of an Upper Limb Exoskeleton for Rehabilitation with Feedback from EMG and IMU Sensor

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Abstract

The research project consist of development of an upper limb exoskeleton using rapid prototyping for rehabilitation with feedback from the EMG and IMU sensor. The project is about designing a 3D modelling structure for the system implementation for the rehabilitation mechanism. A control unit circuitry has to be designed in order the implemented system able to be controller and monitored upon the desire motional flow. Besides, the actuator of the rehabilitation system has to imply the motional flow of the good hand during the rehabilitation process takes place. In order to monitor the working mechanism of the entire mechanism, GUI in the state of offline and online has been designed and developed in line with the system implementation. Upon the completion of the system implementation testing of component has been conducted. The accuracy of the IMU sensor can be designated up to 97% and an average of 85% to the theoretical value. Besides, the system's performance also been evaluated at the level best of the function ability which is to be 71%. The GUI interfacing to the online monitoring system has an accuracy of 99.1% of data transfer with 3 second delay upon the connectivity.

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Keywords: Exoskeleton; EMG ; IMU; Rehabilitation;

1. Introduction

Nowadays, robotic are widely used in various field of studies and industries either for research purpose or as multilevel tasking productive machine. As in the medical care line, robotics is used in different level of disciplines as well as in various line of highly specialised application in such of minimally invasive surgery. Besides, this application is highly significant during complicated moments in the medical line.

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As the era grows higher and moves up front, the aging factor comes into role play whereby most of the chronic disease related to the musculoskeletal and nervous system provokes within the aged civilised people. According to the World Health Organisation (WHO) statistic's nearly one billion people worldwide are suffering due to the neurological and musculoskeletal disease and estimated around 6.8 million people are losing their life each year. The only solution they can rely upon is to rehabilitate them using low cost rehabilitation equipment and exercise in order to carry out their daily routine without fail. Most of the neural and musculoskeletal disease victim can be seen infected on their limbs where it is the most crucial part of the body to function. Around 40 percent of these patients are able to recover and resume in their working environment while only one third of the patients permanently have to be dependent on their daily routine with a bit of aid.

Generally, motor skills of an individual are to be used as an independent living with strong connection of acting as arms, whereas hands are the humans body part to be used in everyday chores as a vital support for living. As in the project based report, an innovated exoskeleton arm through assistive technologies for daily activities as well as for long term rehabilitation activities for home development had been researched, designed and developed. Along with the designation of the system, robotic arm composed of exoskeleton concept, data acquisition and processing in the term of EMG and IMU sensor to the physiological directory concept and online data monitoring data had been developed which able to operate with both the virtual and real environment.

1.2. Research Problem

Generally, there are two different types of exoskeleton limb therapy whereby it can be classified as end – effectors based structure and also exoskeleton systems. In most of the cases, both the combinational system is to be used in the therapy since the combinational system provides much effective results[1]. However, there are several situations and cases only require single system for the rehabilitation process. Therefore, the designation of the exoskeleton arm depends upon the required rehabilitation process and physiotherapy rehabilitation methodology. The rehabilitation are the variable of the subject matter whereby the designation of the exoskeleton arm can be alter according to the type of rehabilitation process needed by the patient[2].

Generally there are four typical motion of the rehabilitation process whereby it can be known as semi exoskeleton with fixed base, mobile exoskeleton, wire based and end – effector based. In these modern era, end – effector – based type rehabilitation process are commonly used as the treatment provides more effectiveness with less cost[3]. However, the end – effector based structure does not provide a stand for its system stabilization compare to the exoskeleton structure. Despite having effective treatment methodology, the efficiency of the structural unable to be retrieved if to be compare to the exoskeleton structure[3]. Similar system was developed for lower limb rehabilitation and by using EMG sensor to obtain feedback from the limb movement[4,5,6].

The main purpose and rationale of the project is to develop a system which autonomously enhance the ability of stroked and paralyzed patient or to be more specified neurological and musculoskeletal disease patients to carry out their daily routine such as lifting an object, which eases them to do simple activities and able them to continue with their daily routine without any aid or depending on another individual's help. This biomedical enhancement is quite related to the physiotherapy methodology as it is related to physical activities. These systems are designed and implemented mainly referring to the physiological scope and the concepts of rehabilitation.

2.0 System Design and Working Principals

In the section of system implementation, working principal is one of the desired and important sub-sections to be defined as the working mechanism of the exoskeleton can be summarise upon the section. The main vision of this experimented project is to enhance the system rehabilitation process through the monitoring as well as system simulated mechanism where the exoskeleton arm able to perform the exact motion of the simulated mechanism.

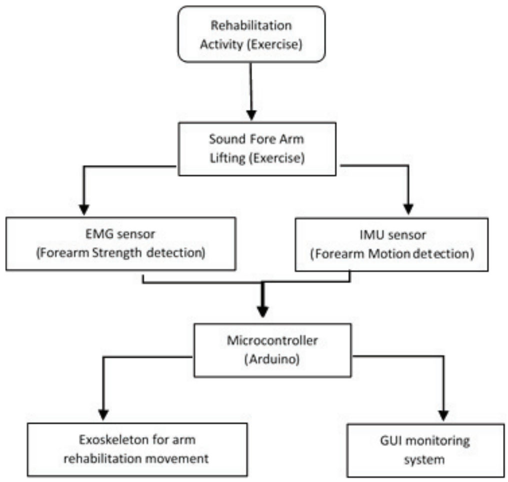

Fig. 1. System working

Referring to the above Figure 1, rehabilitation exercises for arm have to be carried out in to determine the muscular position for two different motions of the hand posture. This will ease the detection and placement of the electrodes upon the connection of the sensor to the skin surface. The EMG and IMU sensor are placed in the good arm and the signal form the good arm will be used to move the exoskeleton which is attached to rehabilitating arm.

2.1 Forearm Lifting

The forearm lifting mechanism also another type of rehabilitation exercise whereby it can be done by lifting the arm in the posture of flexion and extension of the elbow. This can be performed by lifting range value of weights depending on the muscular strength. The part of muscle with involve during the rehabilitation exercise for the flexion is the biceps brachii muscle meanwhile for the extension of the arm will be controlled using the triceps brachii muscle [7]. However, by examining the conceptual movement of the project's prototype, the dominant muscular and nervous part of the system requires the biceps brachii muscle as to perform the flexion motion rather than the extension of the system will be aided by the elastic mechanism.

2.2 System Working

Upon the completion of the rehabilitation exercise with the determined muscle of interest, the flow of the working mechanism will be then continuing to the connection process of the EMG sensors. The EMG sensors are quite essential in the sense of detecting and channelling the data from the muscular system to the microcontroller to interpret the data. In order to establish the connection between the surface of the muscle and the EMG sensor circuitry, electrodes has to be used as the mediator and the signal interpreter. As been mention in the earlier sub-sections, the electrodes which had been used are the Ag-AgCl electrodes due to the capability of the electrodes to reduce the noise interference.

As for the project mechanism, the placement of the electrodes has to be in line with the position of the muscle by placing the one of the electrode at the top of the muscle meanwhile another to the bottom of the selected muscle. Besides, another set of electrode has to be placed to the bone as a reference electrode. On the other hand, IMU sensors had been used as the working mechanism of the system has in line working sensor projectile with the interference of the EMG sensor. Since the project aim and objective to design a system with EMG and IMU sensor feedback, the system has to be compressed with the working mechanism of the both sensors. IMU sensors can be defined as the Initial Measurement Unit is the build in gyroscope with accelerometer type of sensor where used to measure the distance and deflection of an object. In the project, the IMU sensors has been implemented in the sense of determining the angle of fore arm deflection as the data can be directly used to reflect the exoskeleton system. The implementation of the IMU sensor will be placed in line with the EMG sensor as the feedbacks from both of the sensor will enable the motion of the exoskeleton arm. Without the response of either one sensor will eliminate the working sequence of the exoskeleton arm.

However, the data to be received and interpreted has to be done using the microprocessor (Arduino UNO). The input signal from the EMG signal will be in the form of analogue as it has to be converted into digitalised signal before the inputs to be sent to the LabView software for the GUI display. Since the Arduino board is the analogue to digital convertor, the process can be made simpler by connection the both end joins to the microcontroller and set an output to the LabView as well to the input port of the exoskeleton. Furthermore, the microcontroller also has to communicate with the IMU sensor using I^2C serial bus to generate the raw reading exerted by the sensor and to be displayed in the LabView software.

The exoskeleton system is the end point of the working mechanism. The interpretation of data and data conversion enable the work flow of the mechanism as the entire exoskeleton system will display the capability of the accuracy of the working mechanism of the system. The exoskeleton will function according to the input from the EMG sensor and IMU sensor in the sense of forearm lifting and hand gripping. The level of deflection and extension will be done using the motion from the good hand.

The position of the exoskeleton arm will be determined using the attached IMU sensor on top of the both wrist on the both the hands. The interface has to be done by tracking the axial flow of the distance between the sensors. The posture of the exoskeleton has to follow the positioning of the good hand posture as the IMU sensor reading of the both hand has to be same. The action will be done using the motion controller which the microcontroller will adjust the pulse width modulation and directional rotation according to the axial position difference. The microcontroller will also will vary the speed as well as the torque of the motor upon the designative impulse from the EMG sensor which had been positioned on the good hand. Depending on the command and signal input, the exoskeleton system will behave accordingly.

2.3 Exoskeleton Arm Design

The hardware part of the exoskeleton is design to rehabilitate the upper limb exoskeleton. The design of the exoskeleton is the mechanism to lift and mimic the motion of the good hand lifting posture up to the similar level of the good arm. The inputs for the mechanism is the tip point value from the output port of the good hand as the indicator of the exoskeleton tip the end position of the structural design.

In line with the positioning of the good hand posture, the exoskeleton does have slight difference in the reading of the position as the angular deflection of the sensor may vary upon the hand positioning. The expected percentage of error has to minimal and about+ 0.2% or -0.2% of the difference by comparing both the readings. Besides, the accuracy of the positioning structural can be expected to be around 97.5% when the angular position to be seen between the hands. This is due to the DC motor's lifting mechanism as the system might overshoot slightly. The setup is show in figure 3.

2.4 Graphical User Interface and Online Monitoring System

Graphical user interface (GUI) is the offline monitoring system which has been done using the LabView software based on pc monitoring mechanism as shown in Figure 2. The functionality of the GUI is to monitor the working principal as well as the ongoing data transfer and data acquisition of the system. The GUI system will be connected to the exoskeleton system via Arduino microcontroller. Therefore, the system input from the sensor; EMG sensors and IMU sensor able to be monitored in much simpler data from the GUI rather than observing the data from the serial monitoring mechanism. The monitoring system able to monitor both of the hand's posture with the angular motion display from the IMU sensor reading. The data of the angular movement from the IMU determine the positional structure flow of the graphical display of the hand as the mechanism will indicate the level of elevation of the hand from the initial position. Moreover, the number of repetition of the rehabilitation also will be recorded upon the motion of the hand. However, the system does experience several minor lagging of data receiving as the connectivity in between the Arduino and the LabView concerns. The lagging of data took around 3second to display or to refresh the new data tabulation.

In addition, an online monitoring system through the GUI system has been designed through the LabView software and able to display the exact value of the GUI display. The online monitoring is to enable the physicians to monitor their patients' performance and development. The online monitoring system also able to control the programmable flow; by starting the stimulation or even stopping the simulation. The online monitoring system has been done as per the objectives of the project. The data transfer from the GUI mechanism to the online monitoring system has and delay of 3 second and sometimes the lagging factor depending on the connectivity of the internet from the domain user to the host.

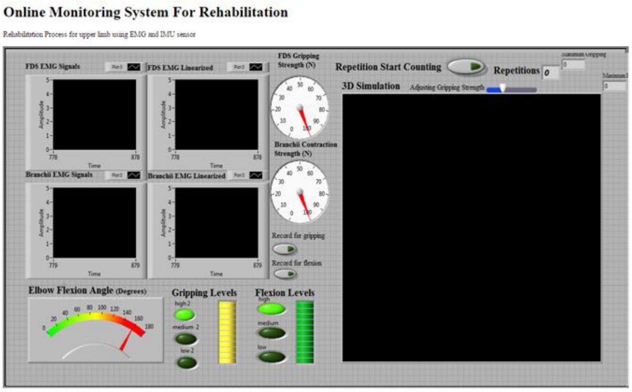

Fig. 2. Online Monitoring System *Results*

Before the testing using the exoskeleton system, each subject are required to perform both the muscular; FDS and bicep branchii maximum contraction as to initialise the value and to evaluate the capability of the mechanism upon the usability. The initialisation value has been recorded in the case of misinterpretation of the system can be avoided. After the testing, the subject had been tested with the exoskeleton arm upon the hand lifting and extension of the arm. The percentage of the system's performance had been recorded in the Table 1.

a b

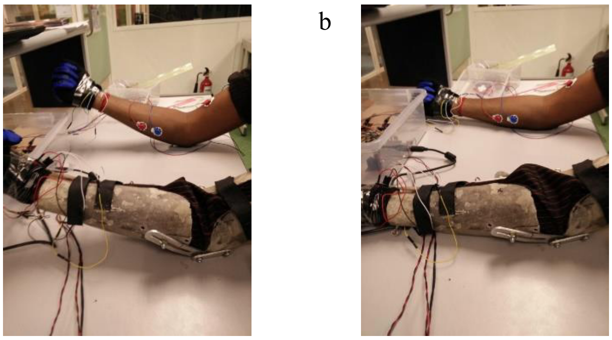

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Fig. 3. Initial Position (a); (b) fully stretched Position

3.1 Data Collection

As for the data collection terminology, the angles of the deflection will be calculated from the initial position of the arm which is to be 85° upon the connections of the exoskeleton as shown in Figure 3. Therefore, the systems performance will be calculated using the formulae 1. The formula compares the initial starting angle of 85° with the end position angle:

$$System\ Performance = \frac{Deflected\ Angle}{Initial\ Angle} x\ 100\% \quad (1)$$

The calculated formulae will be tabulated in the Table 1.

Table 1. Data Collection of System testing

Subjects	Gender	Age (Years)	Maximum Muscle Contraction (Voltage)		Angle of end position	System Performance
			FDS	Bicep - Branchii		
1	Male	24	2.25	5.71	61°	71.76%
2	Male	23	2.49	3.54	60°	71%
3	Male	23	2.50	2.89	48°	56.4%
4	Male	23	4.04	7.60	68°	80%
5	Male	27	3.56	5.02	70°	82.35%
6	Male	28	2.43	3.45	55°	65%

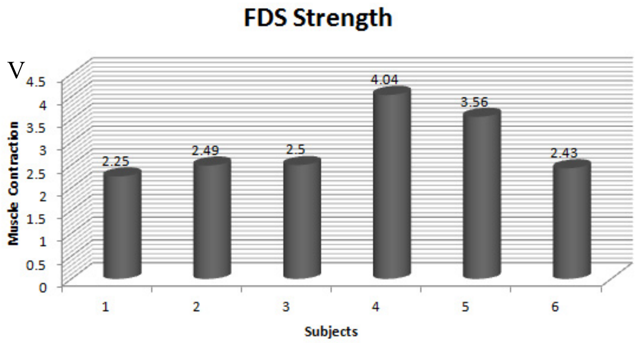

Fig. 4. FDS Strength Chart

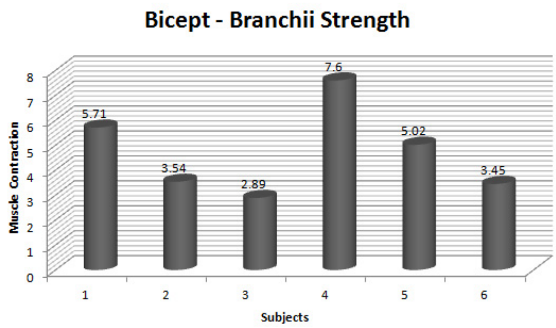

Fig. 5. Bicep – Branchii Strength

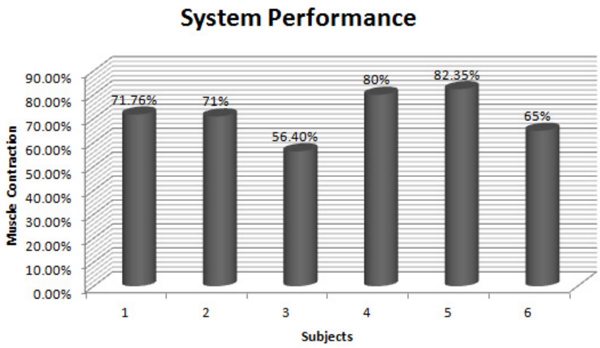

Fig. 6. System Performance chart

As per observed from the result tabulation, it can be interpreted as the range of muscular strength does not match all the subject evenly as shown in Figure 4, 5 and 6. The test subjects are tested for their strength using the methodology proposed in the previous test results and methodologies. The data also can be interpreted by referring to the weight, size, body type and also the daily routine of the subject rather than using age factor as the age is not a necessary form of subjective for the testing expect for the classification of the group age. Besides, the performance of the strength result can be said to contribute to the system's performance as the level of system performance percentage can be seen is directly proportional to the person who has the most force exert.

The suitability of the system performance can be determined using the performance of the system whereby the highest ratio of the system's performance had been rated up to 82% with the lowest 56% from Figure 6. The adaptability of the system; meet by the standard of the working principal has to achieve at least 50% of the system's performance. Hence the exoskeleton system able to adapt to the user as the performance rating is not lower that 50%.

In short, the system which had been implemented has no major difference in term of the functionality as the only adaptability of the design is it can be used clinically compare to any other mechanism. Besides, the designation had been done in much low cost mechanism as per compare to other mechanism in the existing system. However, the overall performance is slightly adaptable to the existing system as the suitability of the mechanism does not differentiate much compare to other designs.

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