Development of an Arm Rehabilitation System with Different Control Approaches

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Abstract—**Stroke rehabilitation plays a vital role for people with limb disability because of stroke attack. Due to gradually increasing medical prices, the cost of rehabilitation devices existed in the hospital and rehab centre are simultaneously increased. These devices also lack the features that help to ease and increase the spirit of patients during the rehabilitation process. Thus, this paper aim to create an arm platform-based for upper limb rehabilitation, where the interactive game features also created by using Unity 2D software for the purpose of motivating patients during the rehabilitation process. The main target is to develop an arm platform, which is focused on proper controller design for the active exercises in early-stage therapy. The performance of the arm platform is examined in term of range of motion. Therefore, it will reduce patient's pressure during the exercise and gradually improve their agility. In the proper control of the muscle tension, the designed upper limb rehabilitation exoskeleton device will provide an improvement in muscle strength and proper posture for an arm.**

Index Terms—**Upper Limb Rehabilitation Platform; System Identification; PID Controller; Fuzzy Logic Controller; Biomedical Control Systems.**

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I. INTRODUCTION

Nowadays, rehabilitations become crucial and playing vital roles in human recovery because it provides rapid func¬tional recovery, self-reliance, and opportunity to improve the quality of life [1]. It also helps to restore the patient health, capability and wellness. The rehabilitation process is also widely utilized in many medical areas such as cardiac, pulmo-nary, cancer, musculoskeletal, and even in the neurological area [2].

Stroke is one of the major causes which affect the limb function that needs to undergo the rehabilitation therapy. Since the year 2000, each year recorded almost 15 million people suffer stroke attack around worldwide and about 5 million from that are permanently disabled [3]. Up to present, the developed countries stroke pattern is declining mostly of healthy lifestyle practices, but anyhow the factor of the ageing population kept the worldwide pattern of stroke remains high [4]. Since the increasing trend of the elderly society, the essentials of health care and rehabilitation must take into consideration.

In recent trend, the robotic devices are seemed to have a potential implication on this field [5]. The rehabilitation robotic is a combination of robotics with the rehabilitation field which contains a wide range of mechatronic tools for the conventional therapy complement. Rehabilitation robotics assists more possibilities in accurate movements and through specific type of guidance, which is hard to attain by the manual interaction between therapist and patient [6].

The upper limb rehabilitation robot provides several assistance types including active, passive, haptic and coaching [7]. Upper limb rehabilitation robot categories are including exoskeleton and end-effector-based systems and commonly used as an exoskeleton. An exoskeleton-based is designed especially for wearer independent control movement [8].

Majority of stroke patients pointed out that an upper extremity weakness is the most common impairment, occurring in 77% of patients with a first-ever stroke [9]. For the early-stage post-stroke patient, passive devices are problem and most of them can't pass the easy task required since there is not enough arm muscle strength. In the previous research works, robots are focused on the passive device, arm power, stability and functional capability measure [8-10]. This design leads to the potential of abnormal muscle tone because of no proper control applied to the muscle tension produced by the patient. In addition, most of the design lack of focus on the patient's arm posture and potentially cause the abnormal posture [11].

Therefore, this paper aims to create an arm platform-based for upper limb rehabilitation, where the interactive game features also created by using Unity 2D software for the purpose of motivating patients during the rehabilitation process. The main target of this study is to develop an arm platform, which is focused on proper controller design for the active exercises in early-stage therapy. Firstly, the angular movement of the platform will be analysed mathematically to ensure the platform is capable to follow rehab active exercise in serving a patient. LabVIEW and MATLAB will be used as a programming platform. Then, the arm platform performance will be translated into a simulation and a program, which will be later integrated into the upper limb hardware platform as depicted in Fig. 1.

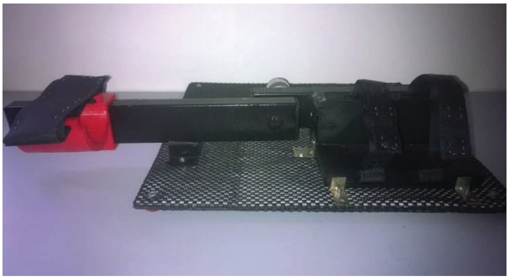

Fig. 1. Upper limb platform

II. DEVELOPMENT OF UPPER LIMB REHABILITATION PLATFORM

In this project, the general processes consist of hardware development of an upper limb rehabilitation active device, and also controller performance analysis implemented in this system. The MATLAB and LabVIEW software was used in simulation and real-time environment respectively. The crucial part of this project is to find out the transfer function for the desired motor movement, which was attached to the platform to generate a dynamic in the exercises of an upper limb rehabilitation. Then, the proposed controllers will be examined by implementing it to the obtained transfer function by using MATLAB/Simulink.

A. *Hardware Development*

The mechanical design was developed by using SolidWorks and focus on an arm platform, including arm, elbow, and forearm, which satisfy the motion in Single Degree of Freedom. Each part of the design was combined and printed by using a 3D printer. The purpose of the platform developments is to obtain the dynamic motion of the upper limb rehabilitation system, where the obtained data will be collected for the system identification process. Then, the transfer function of the upper limb platform will be generated from the system identification method through MATLAB software, where the transfer function obtained will be based on the desired movement of the motor.

All the equipment in this experimental setup is shown in Fig. 2, which consists of DC geared motor, motor driver, myRIO, upper limb platform and host PC with LabVIEW installed.

The motor movement is generating the voltage signal through a 12V adapter which is controlled by LabVIEW with the myRIO microprocessor. The function of the myRIO is to provide an output signal required by the motor and collect the dynamic data from the open loop system. The data are later transferred and stored in the MATLAB to generate the transfer function via system identification method.

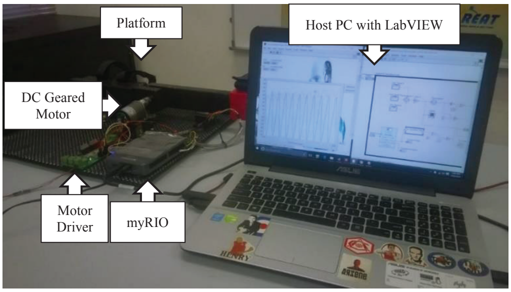

Fig. 2. Experimental Setup Equipment

B. Modelling of Open-Loop Upper Limb Rehabilitation Platform

Fig. 3. shows the block diagram model of open loop system development in LabVIEW. The modelled program is designed to satisfy the required motion control of (flexion/extension) movement for the upper limb. The output of the system considered as the performance of upper limb rehabilitation exercise in open loop. The system shows the block diagram model of open loop operation controlled by myRIO. This model receives a command created in LabVIEW to perform the motor operation. The myRIO acts as data acquisition, which has 10 analogue inputs, six analogue outputs and 40 digital inputs/outputs line. It is also has been integrated with LabVIEW to control the model for real-time modelling and simulation of the control system.

The multiple sine wave signals was used as the reference input signal for the system to generate motion forward and reverse for the motor. The signal generates are read by PWM and Digital output control and simulation block function. The PWM generated the total power delivered to the circuit to control the output of a motor based on the length and frequency of the pulses. Digital output basically used to draw the output desired of motion control. In this project, the digital output drew the motion forward and reverse of the motor. The motor operates based on the position receives by encoders. Data for this experimental setup are gathered from the input signal and the output position from the encoder. Data gathered from the experimental work was saved in Microsoft Excel file type for the system identification process.

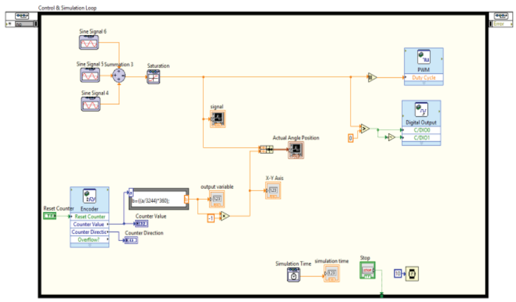

Fig. 3. Program for Open-Loop System

C. Open-Loop's System Identification

By using the estimation and validation of input and output signal, the value of poles and zeros can be determined by using a system identification toolbox. The value of poles is 3 and value of zeros is 2. The result of the estimation shows the best fit from this transfer function is 89.21%. Fig. 4. depicts the result of the measured and the simulated model output of the system.

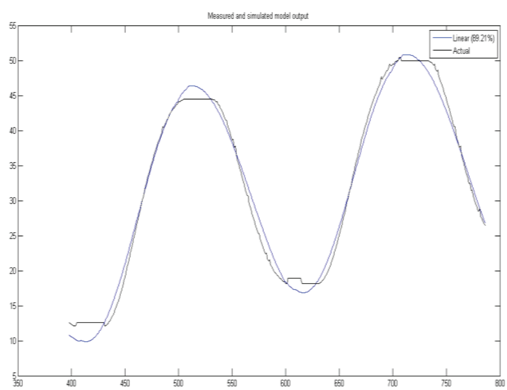

Fig. 4. Measured and Simulated Model Output

Through the system identification process, the transfer function is generated as:

$$tf = \frac{0.05315s^2 + 0.02571s + 8.829e-05}{s^3 + 1.225e-10s^2 + 0.0009805s + 4.472e-07} \quad (1)$$

Then, the transfer function obtains from the system identification was used for the controller design of the upper limb rehabilitation exercise. At this phase, several controller methods has been examined in order to fulfil the requirement of the system. In this paper, the PID controller and the Fuzzy logic controller were selected and examined. However, the topic regarding the PID and Fuzzy Controller is not discuss in this paper.

III. RESULTS AND DISCUSSION

Fig. 5. demonstrates the overall block diagram of the upper limb rehabilitation platform for the comparison purpose, which has been executed without the controller, with PID controller, and Fuzzy Logic controller.

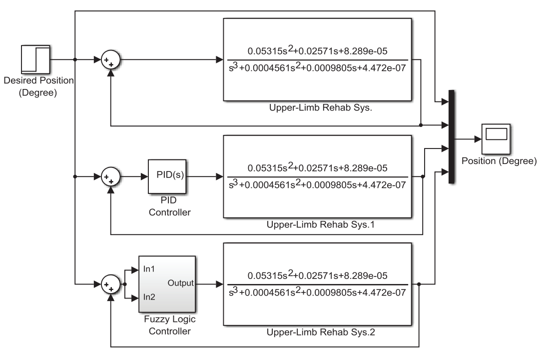

Fig. 5. Overall system in Simulink block diagram.

In the controller performance analysis, the upper limb rehabilitation platform has been applied to the PID and Fuzzy controllers to improve the output response of the system. The MATLAB/Simulink software has been chosen due to the simplicity in modelling and the implements of the PID tuning method and also the fuzzy logic tuning method for satisfying the criteria within the boundaries of the controller. The output response of the upper limb rehabilitation platform is demonstrated in Fig. 6.

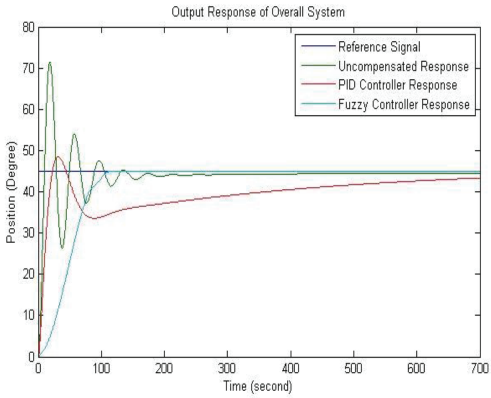

Fig. 6. Output Response of Overall System

As clearly demonstrated in Figure 6, through the auto-tuning process of PID controller, the gain Kp obtained is 0.1004, the gain Ki obtained is 7.9509 x 10-5, and the gain Kd obtained is 2.7862. The tuned response showing significant improvement in the rise time and settling time. While, the overshoot shows a better response decline from 59.7191% to 7.63% due to the transient response improvement by applying the required value of Kp, Ki, Kd. For the steady-state error, the response of the input reference and the output of a system after tuning shows the value of Ki eliminated the error become zero from the error value of 0.9876. The numerical analysis has been tabulated in Table 1.

TABLE I. THE VALUE OF TRANSIENT RESPONSE FOR OVERALL SYSTEM

Character	Closed-Loop	PID	Fuzzy Logic
OS (%)	59.7191	7.63	0.1469
T_s (sec)	200.3794	841	104.7493
T_r (sec)	6.6764	15.6	65.7942
e_{ss} (Degrees)	0.9876	0	0

IV. CONCLUSION

In this paper, the mechanical design and experimental setup for the upper limb rehabilitation control system have been presented. The design of a controller for the plant is presented based on simulation of the Upper Limb Rehabilitation system. The development of mechanical design is covered from upper arm to the forearm and focus on elbow joint that allows the movement in Single Degree of Freedom (1-DOF). The implementation of the controller on upper limb rehabilitation device will lead more advantages for patients who undergo an early stage of stroke therapy. The analysis shows that a significant improvement in terms of transient response, steady-state error, and root mean square error analysis has been achieved. As a result, it can be concluded that the fuzzy logic controller is more stable than PID controller since there is no overshoot reaction applied to the plant, which will cause the improper start that leads to the potential of abnormal muscle tone.

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