ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

SYSTEM IDENTIFICATION MODELING OF ARM REHABILITATION DEVICES

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ABSTRACT

In this paper, modeling of the arm rehabilitation device using system identification technique is presented. Patients who have post-stroke may lose control of their upper limb. If they are treated with effective rehabilitation training, the patients can restore their upper limb motion functions and working abilities. These rehabilitation devices are used to recover the movement of arm after stroke. Robot assisted therapy systems need three elements which are algorithms, robot hardware and computer system. An accurate system modelling is crucially important to represent the system well. Inaccurate model could diminish the overall control system later on. The objective of this work is to development mathematical modeling of the arm rehabilitation device by using System Identification from experimental data. Several transfer functions are evaluated in order to choose the best performances that represent the system. It must show a good criteria based on the best fitness percentage, stability of the location of poles and zero and also the frequency response characteristics. The derived model is validated via simulation for stability analysis. It is expected that a stable model with an acceptable level of accuracy would be developed for further control system design.

Keywords: *Post-stroke, Rehabilitation, Transfer function, System identification, Robot assisted*

1. INTRODUCTION

Stroke is the third largest cause of death in Malaysia. Ever year estimated about 40,000 people in Malaysia suffer from stroke and it is examined to be the single typical cause of severe disability [1]. In 2010, American Heart Association identified the robot assisted therapy as a method of rehabilitation which can provide resistance or assistance of movement, accurate feedback, and also as a method to provide rehabilitation to the patient with less assistance from the therapist. Furthermore, it also mentions that "Current robots tend to exercise only the proximal arm, and then improve motor skills at the shoulder and elbow but not those of wrist and hand; consequently, robots that only train the shoulder and elbow are limited in their ability to improve completion of Activities of Daily Living (ADL) [2]". Robotic exercises devices are extensively used in rehabilitation training for the improvement of the patient's upper-limb. To automate therapy for the arm, wrist and hand following stroke, the rehabilitation robotic devices and system are being developed. As shown in Figure 1 the upper limb has several DOFs and it is very difficult to doing the rehabilitation as it really is [3]. The control parameter of the device is the arm's angle position as shown in Figure 1.

This work will only developed mathematical modeling for the arm rehabilitation devices by finding the transfer function from the experimental data which is Voltage(V) for input and Position (radian) for the output using system identification toolbox in Matlab software [4]. It will not showing the mathematical derivation of the model. It also contributed to the further research on control system design for arm rehabilitation devices.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

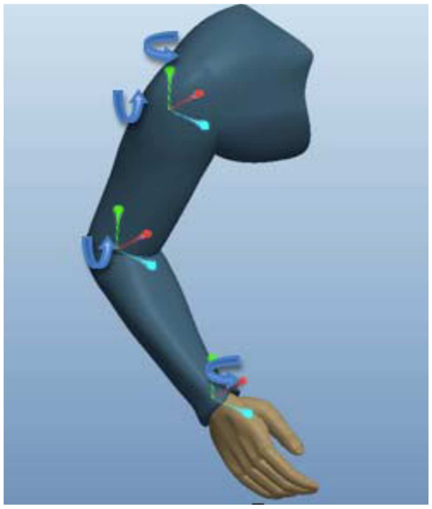

Figure 1: Human Arm Structure

2. METHODOLOGY

Based on Figure 2, it show that the overall process of this work. Started with study on some previous research and then continued with input and output data collection of the arm rehabilitation system. After data has been collected, the system's transfer function is determined using System Identification technique and proceed with model validation.

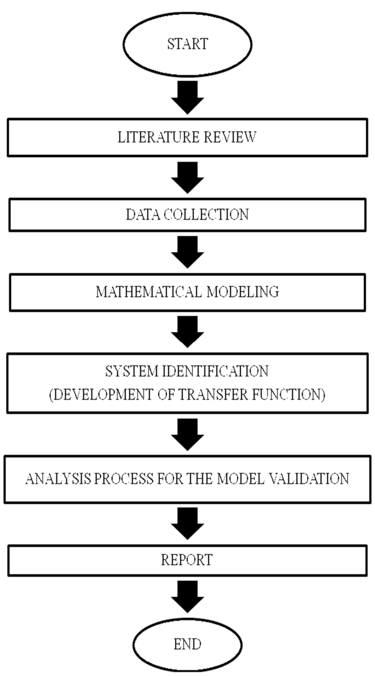

Figure 2: Flowchart Of The Work.

A. Experimental Data

Firstly, a portable reconfigurable I/O (RIO) device which is The National Instruments myRIO-1900 is used to design control system. Before that, the NI myRIO-1900 is connected to the host computer by using USB and also to the adapter that supplies voltage, the NI myRIO-1900 led will blinking. After that, the connecting wire is used to connect to the 4 Channel Motor Driver and NI myRIO-1900's user manual is referred for info regarding the connector pin outs.

Then, the DC Motor that applied to the arm prosthesis model is connected towards the 4 Channel Motor Driver as shown in Figure 3. The block diagram is designed where there are three input of sine wave signal to the system and the data is collected as the encoder moves clockwise and anticlockwise for several times [5][6]. While collecting the position data, EMG data is also collected at the muscle of the arm. During the data collection, the sampling time is set to 0.001.

B. System Identification

The steps of developing or improving the mathematical description of a physical system using experimental data are called System Identification. To discover a mathematical model of a dynamic or physical system from observed data is the main purposes of System Identification. Step function, ARMA sequences, sum of sinusoids and pseudo random binary sequence (PRBS) are the standard input signals in system identification. It is mathematically randomized bit stream so that it will become neutralized and balanced data [7].

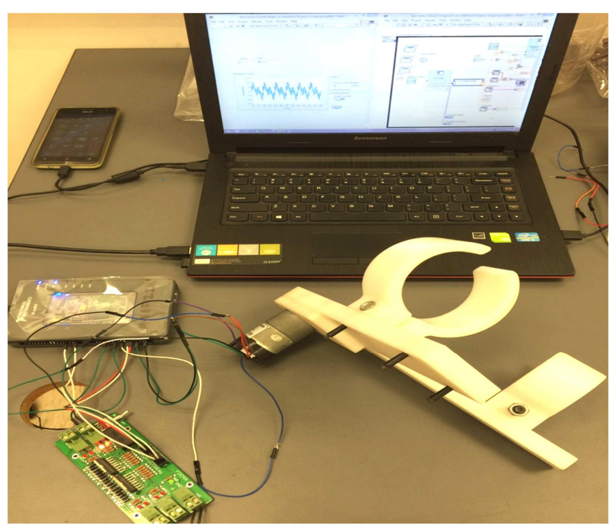

Figure 3: The Experimental Setup

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3. RESULT AND DISCUSSION

The data obtained from experiment is used to build transfer function that suitable for the system. By using system identification the transfer function is build by estimating the number of orders of the system and then it is verified by comparing the model output, transient response, frequency response and stability of the zero and pole. The voltage is the input and motor position (radian) as the output as in Figure 4.

A. Model Output Percentage

For the first transfer function, the pole is 2 and zeros is 1. The model output for the measured and simulated is compared as shown in Figure 5 and this transfer function got its best fits percentage which is 79.75%. Whereas for the second transfer function, the pole is 2 and zeros 2 and the best fits percentage is 56.92%. While the third transfer function has pole 3 and zeros 0 and the percentage is 38.59% and lastly the pole is 3 and zero is 1 with its best percentage 48.04%. The equation for each transfer function is in the Table 1;

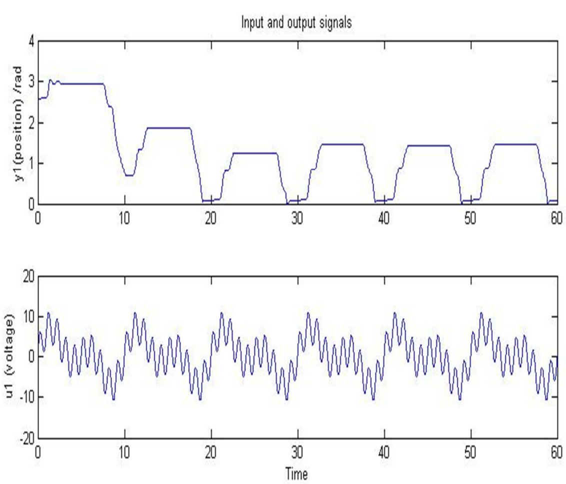

Figure 4: Signal Of Input Is Voltage (U1) And Output Is Position (Y1)

Table 1: Transfer Function Block Parameter

Label	Transfer Function
TF 1(blue)	$\frac{0.1052s + 0.02344}{s^2 + 0.1124s + 0.002552}$
TF (green)	$\frac{-0.016s^2 + 0.08733s - 0.00183}{s^2 + 0.04416s + 1.27e - 19}$
TF 3 (red)	$\frac{-0.003343}{s^3 + 0.03264s^2 + 0.396s + 0.0}$
TF4 (light blue)	$\frac{2.465s + 0.1089}{s^3 + 24.6\ ^2 + 2.659s + 0.06956}$

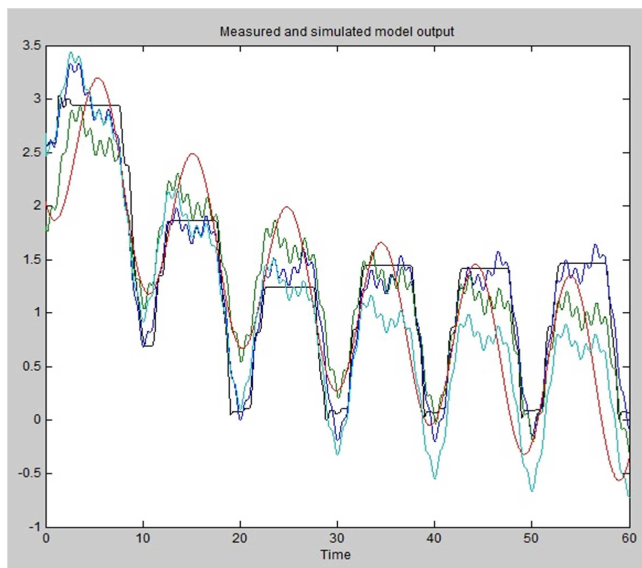

Figure 5: Best Fit Percentage Validation

From Figure 5 it shows that between all the transfer function, transfer function 1 has the best fits percentage which is 79.75% (rounding to 80%) based on modeling rule of thumb at least 80% best fits percentage considered model acceptable. Therefore it can be conclude that the transfer function of the arm rehabilitation device is the 2nd order system similar to the DC motor system. The linkage and bearing of the device does not affect much the motor characteristic.

B. Stability of Poles and Zeros

Stability can be determined directly from its transfer function where the poles should be in the negative real parts (left side) to be stable. The

Journal of Theoretical and Applied Information Technology
30th November 2015. Vol.81. No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

system becomes less stable when the poles get closer to the boundary. Whereas for the unstable pole, it lying in the right hand side of the s- plane. When added poles to the transfer function, it makes the root locus pulled to the right hence the system becomes less stable while addition of zeros makes the root locus pulled to the left and thus the system becomes more stable. The location of poles and zeros are as below in Figure 6.

For the transfer function 1, the poles both on the left sides and zeros too. While, transfer function 2, the poles are nearly to the origin and there is one zero at the right half-plane indicating that the response starts off at negative direction thus the increase in the magnitude of the derivative leads an increase in the magnitude of the undershoot. Transfer function 3 is marginally stable because it has 2 distinct poles at the imaginary axis and the remaining one pole at negative real part and it has no zero. The forth transfer function, all three poles and one zero are at the left side. So, from the observation, transfer function 1 is more stable compared to the other three because the poles is both on negative sides and there is a 1 zeros added which can increase the stability of the system.

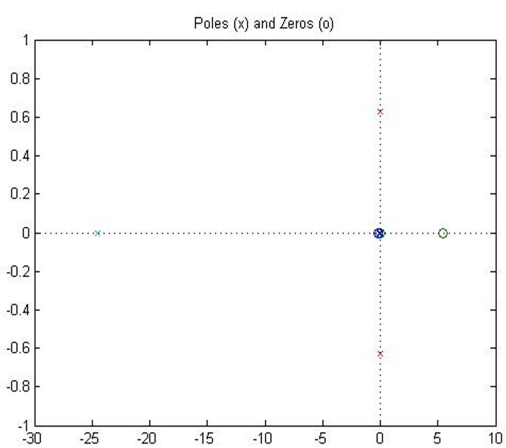

Figure 6: Poles And Zeros Of Transfer Function

C. Frequency Response from the Bode Plot Diagram.

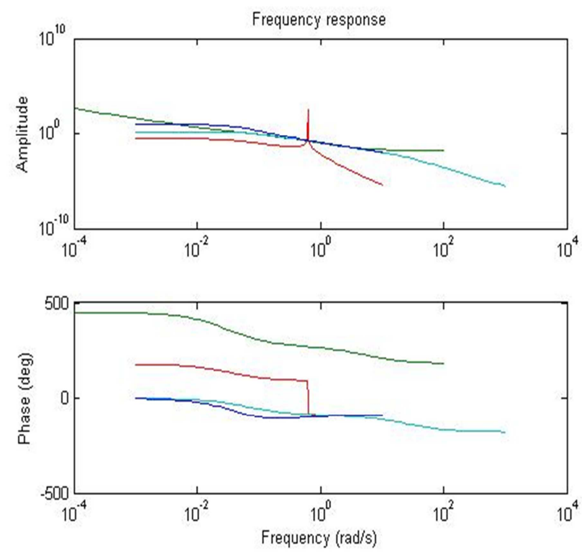

Figure 7: Frequency Response Of The Transfer Functions

Based on Figure 7, the frequency response of transfer function 1 at frequency less than 100 rad/s is close to 0dB which means the output of the motor will look like the motor's input. If 0.01 Hz input position command, the motor with this control system can go along with close to identical amplitude. The output will not lag behind the input as observed in the same frequency range; it shows that the phase is at 0 degrees. Between the input and output of the system, 0dB at 0 degrees indicates perfect agreement. Figure 7 shows that the transfer function 1 gives a better frequency response compared to the other transfer function where the system move too far from identical amplitude.

4. CONCLUSION

In this work, in order to develop the transfer function the experimental setup is done by collecting the encoder data which is observing arm's position when flexion and extension of the 1 DOF (Degree Of Freedom) of DC Motor shield. The arm rehabilitation device is modeled by using System Identification and the transfer function validation is analyzed for stability analysis. The data is used to develop a transfer function and represent the best performance for the controller. Based on the verification, the transfer function 1 gives the best performance compared to the other

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

transfer function because its best fits percentage of measured value and simulated value is the highest which 79.75%. It is also more stable between the other three transfer function based on the poles and zeros position in s-plane. The characteristic of the frequency response also shows a good criterion.

ACKNOWLEDGMENTS

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education for financial support through research grant no. RAGS/2013/FKE/TK02/04//B00027.

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