Development of Controller for Arm Exoskeleton

BY

MYSARA ABDELWAHAB IBRAHIM

14711

Dissertation submitted in partial fulfilment of

The requirement for the

Bachelor of Engineering (Hons)

Electrical and Electronics

May 2015

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Development of Controller for Arm Exoskeleton

By

MYSARA ABDELWAHAB IBRAHIM
14711

A project dissertation submitted to the
Electrical and Electronics Engineering
Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(ELECTRICAL AND ELECTRONICS)

Approved by,

____
(Dr. Irraivan Elamvazuthi)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MYSARA ABDELWAHAB IBRAHIM

ABSTRACT

The use of robotics in rehabilitation of stroke patients has not been extensively researched yet. Many studies were performed on the rehabilitation of the upper extremities using arm exoskeleton; the results shown by these studies show a positive effect in the rehabilitation of patients. This project is concerned with performing a study on two different controllers for the arm in order to provide an optimized controller for use in an arm exoskeleton as well as to study the most effective control technique. In the future, an exoskeleton arm can be built to be used in non-specialised or domestic settings for rehabilitation of stroke patients using the same control technique as the one chosen in this project as the better performing controller. PID, Fuzzy logic and Fuzzy PID controllers will be simulated on a DC motor model and the results will be compared and the better control technique will be recommended for future use in exoskeleton products.

ACKNOWLEDGEMENT

I would like to thank Dr. Irraivan Elamvazuthi for his continued support. I would also like to show gratitude to my family and friends for always being there when needed.

Table of Contents

CHAPTER 1: PROJECT BACKGROUND

1.1 BACKGROUND STUDY

Stroke is one of the main causes for morbidity and mortality and the most common cause for disability. It states that 85% of stroke patient suffer from acute arm impairment 40% are either chronically or permanently disabled [1]. In [2], the author was concerned with finding an optimum training program for chronic stroke patients with an arm exoskeleton.

The aim of this project is to develop a control system to be used in the future in an exoskeleton that is used for rehabilitation in a non-specialised or domestic setting. Robots have been shown to have a positive effect on limb rehabilitation and developing rehabilitation robots for use outside of specialist rehabilitation centres could be beneficial in terms of accessibility, intensity and cost of treatment.

Figure 1: Arm Exoskeleton

For the simulation of the controller and the exoskeleton arm, Matlab Simulink is used to simulate a model of the motor that fits the requirements to be used in the arm. The controller and the DC servo motor selected will then be simulated under different load conditions and the controller efficiency can be determined by the simulation results.

Two control systems will be used in this project and their results will be compared. The first system is the conventional PID control system which is more common and widely used with motors but has some drawbacks. The second control system is a Fuzzy logic control system which represents a completely different control technique.

The motor used in this project needs to be carefully selected to make sure that it can be used in an exoskeleton arm in order to increase the reliability of the results in actual use in an arm exoskeleton. The loads that need simulated must be close to the actual loads that the system is subjected to in actual implementation.

1.2 PROBLEM STATEMENT

Limb rehabilitation tends to be quite repetitive, with the subject repeating the same movements many times. Robots are ideal at performing intensive, repetitive activities, which first led to them being used in rehabilitation research. To date, research has shown that robots have potential in the effective rehabilitation of limb impairment. However, it is still not fully known if some approaches to controlling and administrating robot mediated therapy are more effective than others, or, if the specific benefits of the many approaches to robot rehabilitation are ultimately relatively insignificant compared to the effects of frequency, duration and intensity of treatment.

1.3 OBJECTIVES

The objectives of the project are:

1. To simulate various PID based control systems on a DC servo motor model and measure its efficiency
2. To simulate Fuzzy Logic based control system on a DC servo motor model and measure its efficiency
3. To determine which control system is more effective for future use in an arm exoskeleton

1.4 SCOPE OF STUDY

This project requires studies in control systems and their implementation on robotic arms as well as the study of the natural motion of human arm to deliver accurate results. This project also requires simulating a DC servo motor model under different loads with different control systems which requires studies in the use of Simulink simulator as well as study of PID and Fuzzy Logic control systems.

CHAPTER 2: LITERATURE REVIEW

2.1 ARM DYNAMICS

Study performed in [3] in order to study the kinematics and the dynamics of the human arm during daily activities, with the purpose of designing a seven degree of freedom powered exoskeleton. A motion capture system was used to capture a variety of activities and a seven degree of freedom model was used. The model was used with the help of the equations of motion to calculate the joint torques which will be of great help in this research.

”The human arm has seven DOF: Abduction/adduction and flexion/extension of the shoulder; rotation of the upper arm; flexion/extension of the elbow; rotation of the forearm; and radial/ulnar deviation and flexion/extension of the wrist” [4]. The exoskeleton should have torque abilities matching that of the arm. The study includes references for the values required to identify all the seven degrees of freedom of the arm that are shown in the table 1.

Table 1: Reference Arm angles and torques

Joint	Human Isometric Strength[1]	Human Joint Workspace Limits	Torque Specification	Workspace Specification	Peak Torque Output Capability	Workspace Capability
Elbow Flexion/Extension	72.5 Nm	Flexion: 146° Extension: 0°	6 Nm	Flexion: 120° Extension: 0°	5.46 Nm	Flexion: 90° Extension: 0°
Forearm Supination/Pronation	9.1 Nm	Supination: 86° Pronation: 71°	5 Nm	Supination: 90° Pronation: 90°	5.08 Nm	Supination: 90° Pronation: 90°
Wrist Palmar/Dorsal Flexion	19.8 Nm	Palmar Flexion: 73° Dorsiflexion: 71°	4 Nm	Palmar Flexion: 60° Dorsiflexion: 60°	$\approx$ 0.4 Nm @ $\alpha = 30°; \beta = 9°$	Palmar Flexion: 60° Dorsiflexion: $> 60°$
Wrist Abduction/Adduction	20.8 Nm	Adduction: 33° Abduction: 19°	4 Nm	Adduction: 30° Abduction: 30°	$\approx$ 0.4 Nm @ $\alpha = 21°; \beta = -11°$	Adduction: 30° Abduction: $> 30°$

2.2 REHABILITATION

The study in [5] showed the studies that were required to build a prototype exoskeleton arm with 7 degrees of freedom and it showed the improvements added to previous models and studies in the control part of the project. Project in study [6] also created a prototype but the model was a 5 degree of freedom arm and utilising a different control scheme.

2.3 Feedback Systems

There are many control schemes that can be used for controlling the motion of the arm exoskeleton. Study in [5] used an encoder feedback system that will ensure that the motors are working correctly. The control system is shown in figure 2. An accelerometer will also be place in the hand as extra feedback to ensure the required result.

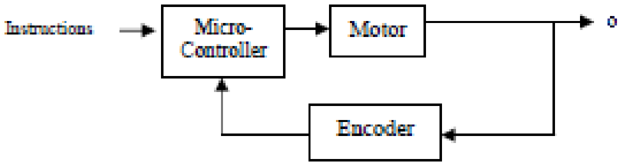

Figure 2: Feedback control of motors

The research conducted in [6] suggests that controlling the exoskeleton can be performed by the electromyography signals from the arm muscles and a controller to transform these signals into motion commands for the exoskeleton arm.

The researches in [1] and [7] employed a non-linear computed torque control and a linear PID control techniques. The study in [1] shows great stability of the control system and the calculated numbers were well within the acceptable range set by the author. Study [8] utilised a similar PID control technique with the addition of an embedded Harmonic drive transmission (HDT) and Elmo servo driver. The use of friction compensation and gravity compensation has positively affected the results of the controller. In [9], a brain computer interface is used in wirelessly controlling the arm exoskeleton for the stroke patient rehabilitation process.

2.4 PID versus Fuzzy logic

Paper [10] discussed the difference between the conventional PID controller and Fuzzy logic controller arguing that Fuzzy logic provides much better results than conventional PID systems under varying loads and disturbances. When using the PID system under different load conditions and noise, the system is not adaptive and the response is bad. On the other hand, the Fuzzy logic controller provides much better results than conventional PID systems.

Study in [10] also shows that in case of PI subsystem failure, conventional PID controller fails to handle this failure but Fuzzy controller can handle that failure well and can still perform well.

Table 2: Comparison between Conventional PID and Fuzzy PID

Control System	Advantages	Disadvantages
Conventional PID	- Depends on accurate calculation of parameters - Better overall system performance for simple systems	- Not very flexible in case of load disturbance and noise disturbance - Hard to tune for complex non-linear systems
Fuzzy Logic	- Easy to design - Intuitive	- High steady state error - Long settling time
Hybrid Fuzzy PID	- Better noise rejection - More flexible - Uses human knowledge, not accurate mathematical model - Less sensitive to inertia Variation	- Less accurate than calculated conventional PID parameters - Harder to design and simulate

Critical analysis

Most previous studies used a conventional PID controlling technique and considered it as the best technique that can be used for controlling the exoskeleton arm. The system is combined with various feedback systems such as encoder feedback and torque control systems. Conventional PID control is well established in text books and research and proven to play a major part in industry. On the other hand, Fuzzy logic controller is less common.

Conventional PID control has been used in papers [1], [7], [8], [17], [18], [22], [24] and [25] and these papers have shown commendable results. On the other hand, researches in [11], [14], [16], [19], [20], [21], [25], [26], [27] and [28] used Fuzzy control for the exoskeleton arm and got good results. The purpose of this paper is to determine the best control technique for the arm.

According to [12], conventional PID controller is simple, stable and easily adjustable. But in the case of parameter variability and uncertainty of the system, tuning the PID control parameters would be extremely difficult and would have poor robustness. On the other hand, Fuzzy PID control is a better method for controlling complex and unclear systems. Fuzzy PID has good adjustability to the system changes and noise. It has proven to be effective for imprecise processes which are difficult to control using conventional PID method. Results of [12], [14] and [26] show the superiority of Fuzzy PID over conventional PID in cases which conventional PID fails to adapt to the changes in the system and load.

The authors in [13], [14] and [26] also discussed the lack of flexibility of the conventional PID controller as opposed to Fuzzy PI controller type I and type II. The author compared the performance of type I and type II PI Fuzzy Logic controller and the results show that type II has better results than type I Fuzzy controller. The improvement was shown when dealing with load disturbance and noise added to the system.

Hybrid Fuzzy PID controller can be used in order to optimize the performance of the controller [23]. Hybrid Fuzzy PID controller was used in papers [13], [16], [25], [27] and [28] and their results show good system response and in [13] and [27] a comparison is held between Fuzzy and Hybrid Fuzzy and the results show that the system response is much better in the case of Hybrid Fuzzy PD controller.

CHAPTER 3: METHODOLOGY

3.1 RESEARCH METHODOLOGY

Figure 3 shows an overall view of the flow of work to be done in the project

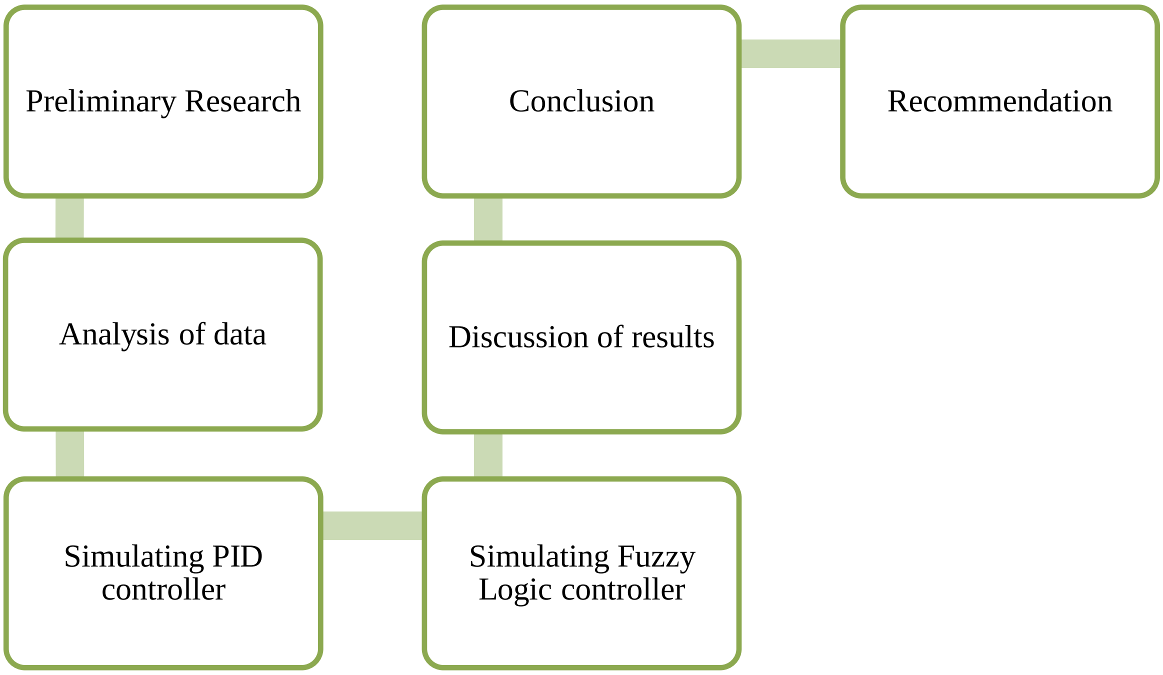

Figure 3: Overall process flow

3.2 PROJECT ACTIVITIES

Figure 4 shows the details of each step in the process flow.

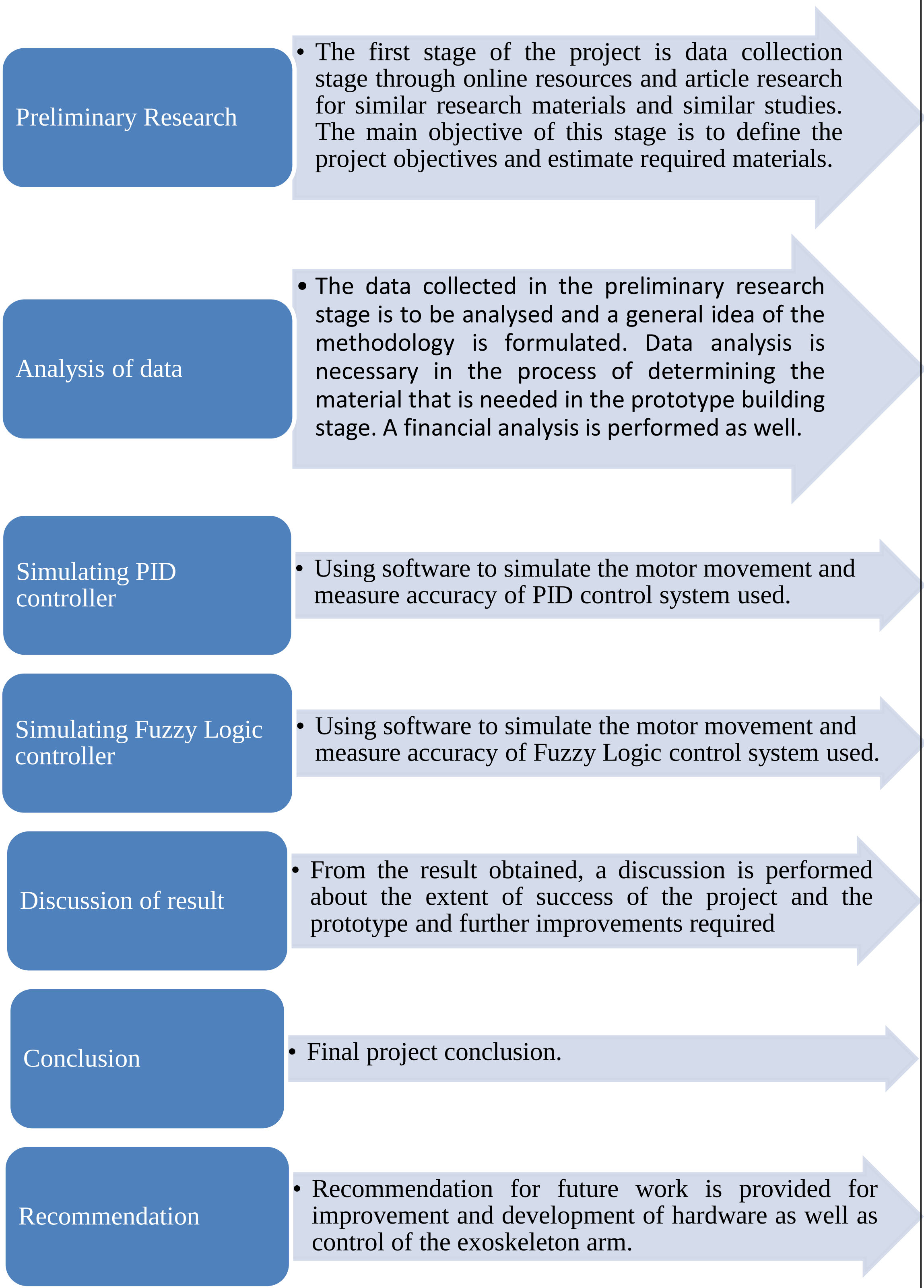

Figure 4: Detailed process flow

3.3 KEY MILESTONE

Table 3: Project milestones

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Simulation PID														
2	Simulation Fuzzy Logic														
3	Progress report														
4	Final Paper														
5	Technical Paper														
6	Project VIVA														

3.4 GANTT CHART

Table 4: Gantt chart

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Simulation PID														
2	Simulation Fuzzy Logic														
3	Data collection														
4	Final Paper														
5	Technical Paper														

3.5 TOOLS & SOFTWARE REQUIRED

Tools & software that will be used throughout the project are:

- Matlab
- Simulation tool (Simulink)

3.6 Project Methodology

Motor Selection

High torque, small size DC servo motor is selected for the motion of the robotic arm. A DC motor was selected as DC motors have better starting torque than AC motors.

Motor Modelling

Using previous motor models, a DC servo motor can be modelled using the following block diagram where the input is the voltage supplied to the motor and the output is the speed of the motor rotation. The load can be adjusted in the model to show the effect on the DC motor performance.

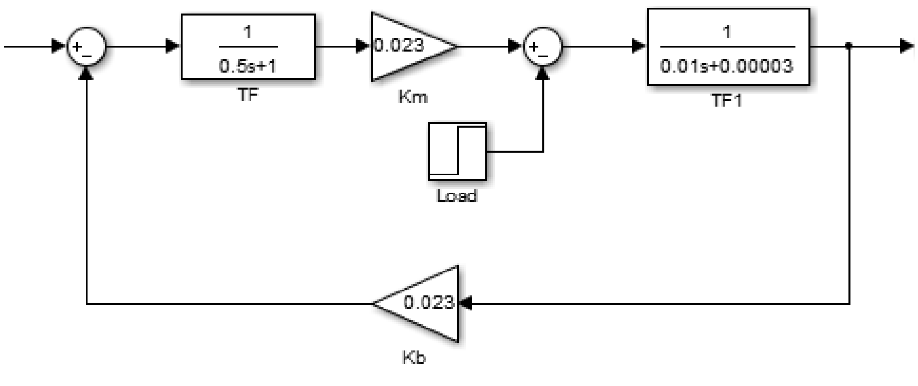

Figure 5: DC Motor Block Diagram

By reducing the block diagram model, the following second order transfer function can be reached between the input and the output.

$$G(s) = \frac{\omega(s)}{v(s)} = \frac{K_m}{[(R + Ls)(Js + b) + K^2]}$$

Figure 6: DC Motor Transfer Function

Where:

- w(s) is the motor angular speed
- v(s) is the voltage supplied to motor
- K_m is the motor constant
- R is the rotor armature resistance
- L is the armature inductance
- J and b are moments of inertia
- K is approximately the same as K_m

Using the motor specifications from the datasheet, the transfer function parameters of the motor can be specified and simulated using matlab.

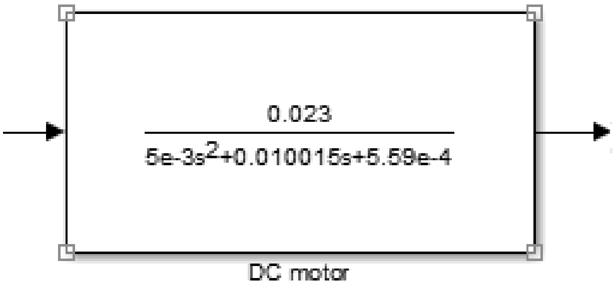

Figure 7: Transfer Function of Selected DC Motor

Conventional PID Controller Simulation

The transfer function is used in Simulink and PID controller is added to the motor while using unity negative feedback closed loop system. The response of the system is then measured under different load conditions to specify the efficiency of the controller. The PID toolbox is used as shown in figure 8.

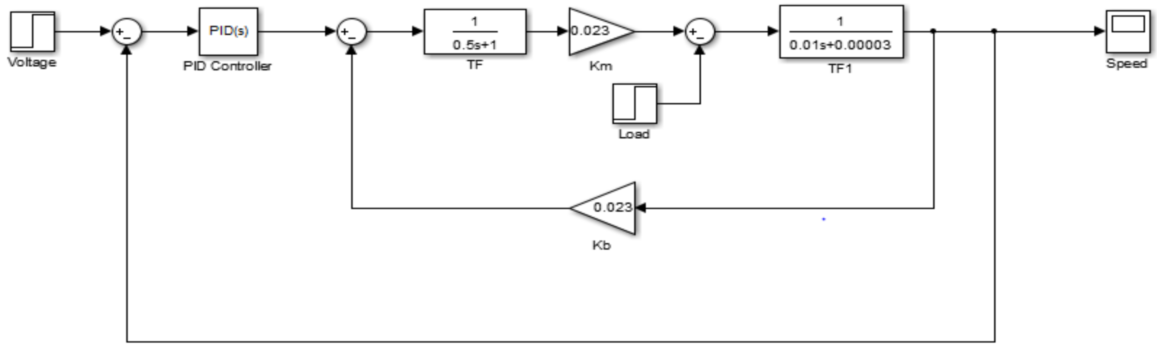

Figure 8: Simulink PID Block Diagram

Fuzzy Logic Controller Simulation

Fuzzy Logic toolbox is used to create a Fuzzy controller which is created by specifying inputs and the membership functions for each input. Next, a set of rules are created in order to specify the relationship between the inputs and the outputs. The most important point is to specify the type, number and overlap of the membership functions. In this project, a variation of 3, 5 and 7 membership functions will be used as Triangular membership functions. A balanced configuration will be used for all types of membership functions. Figures 9 to 11 show the selection of the type of the membership functions and their number.

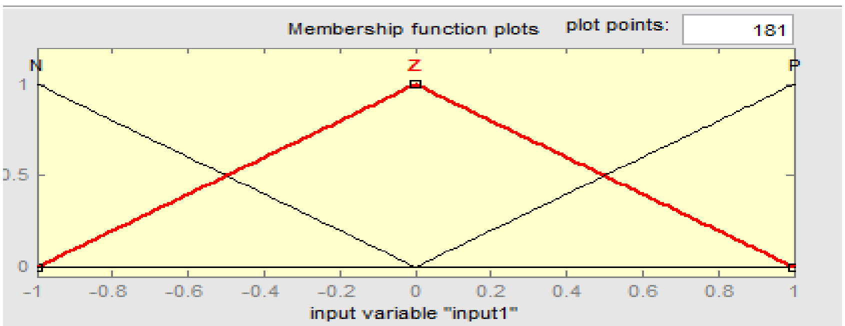

Figure 9: Three Triangular MFs

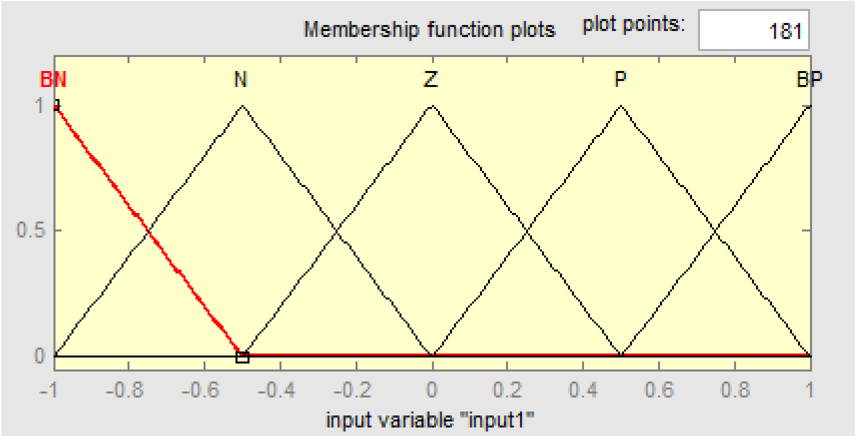

Figure 10: Five Triangular MFs

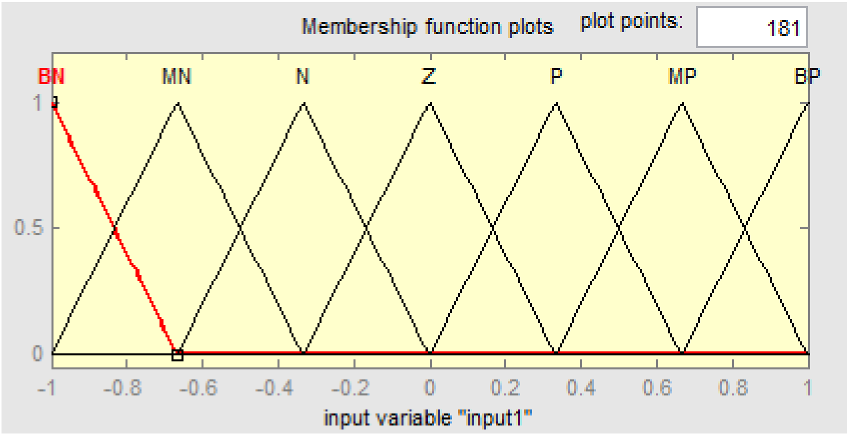

Figure 11: Seven Triangular MFs

After creating the Membership functions for all inputs and outputs, a set of rules are specified to define the relation between the inputs and the outputs. Shown in figure 12 is the set of rules used for three Triangular MFs.

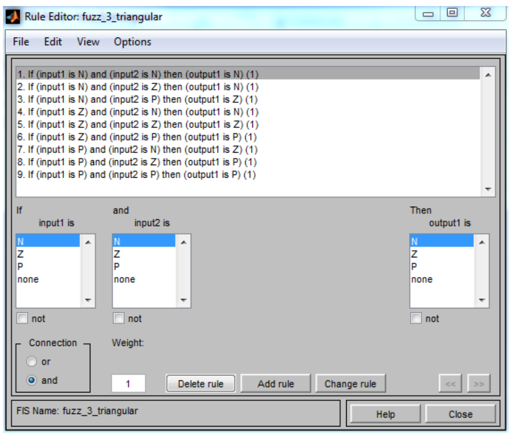

Figure 13: Rule set for three Triangular MFs

Finally, the Fuzzy block in Simulink is used and the motor model is added to it in order to perform the simulation. It is also possible to add different loads to test the controller performance under disturbances. Figure 14 shows the model that was used to simulate the Fuzzy controller.

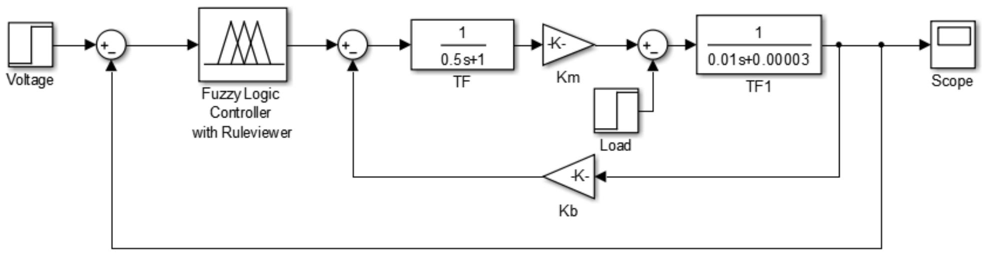

Figure 14: DC Motor Fuzzy Controller model

Hybrid Fuzzy PID Controller Simulation

Using the same Motor model and the Fuzzy controllers designed previously, a Hybrid PID Fuzzy controller can be used to control the DC motor and the system can be simulated as shown in figure 15.

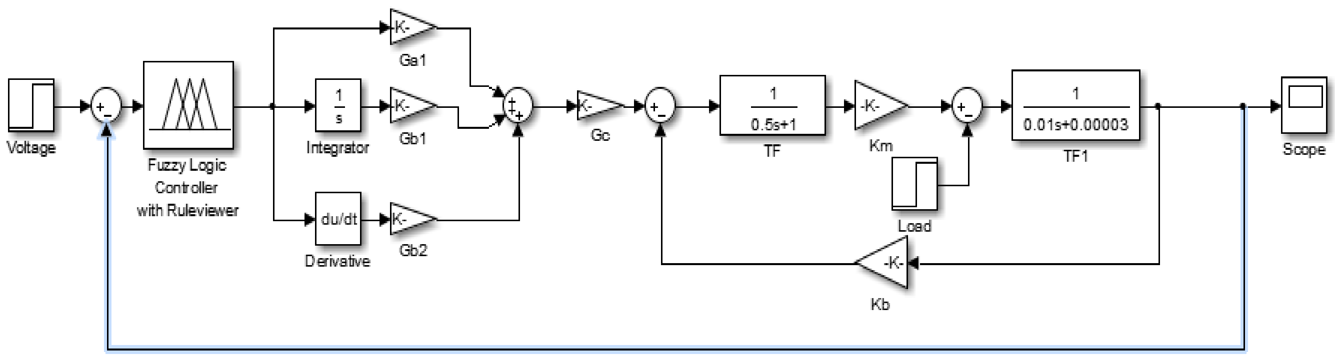

Figure 15: DC Motor Fuzzy Controller model

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

PID Controller

The DC Motor response to a step input with unity feedback and no controller can be seen in figure 16 and it is as expected having a steady state error and high settling time and overshoot.

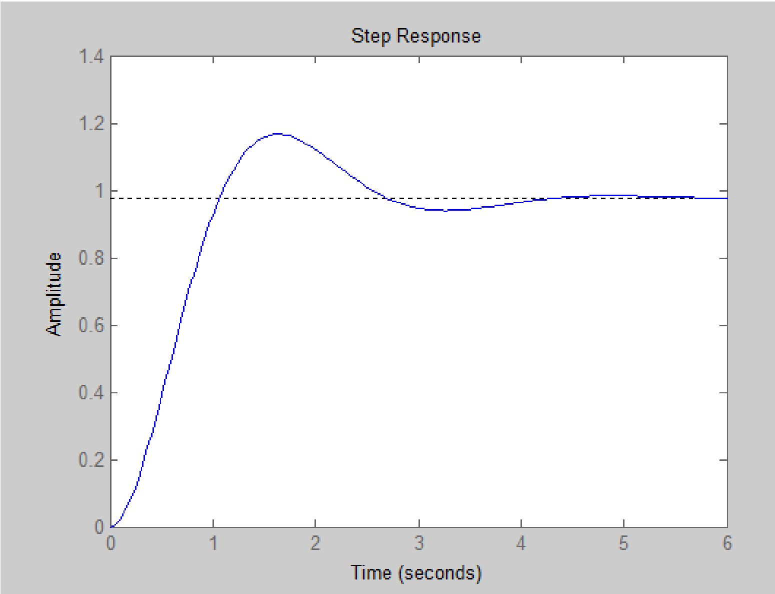

Figure 16: DC Motor with unity Feedback step response

After adding a P controller to with K_p specified by Simulink PID tuning tool, the response is as shown in figure 17.

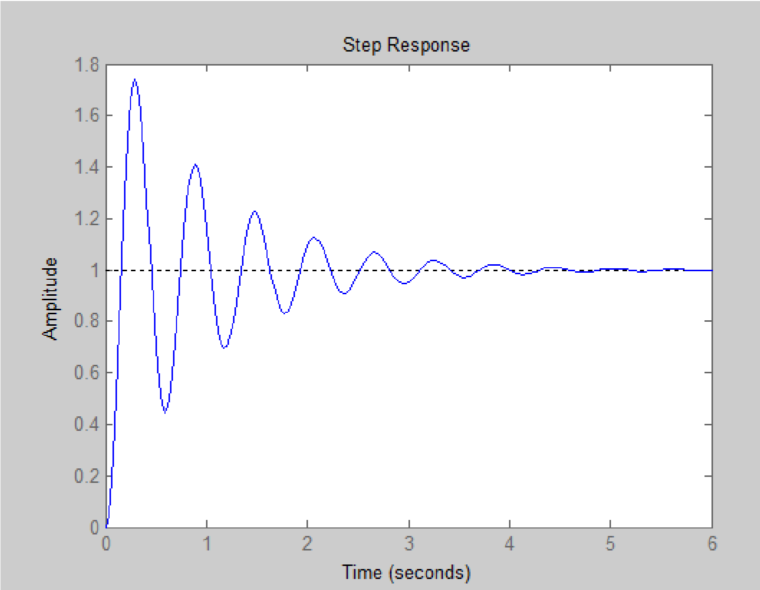

Figure 17: DC Motor with P controller step response

Next is adding a PD controller to with K_p and K_d specified by Simulink PID tuning tool, the response is as shown in figure 18.

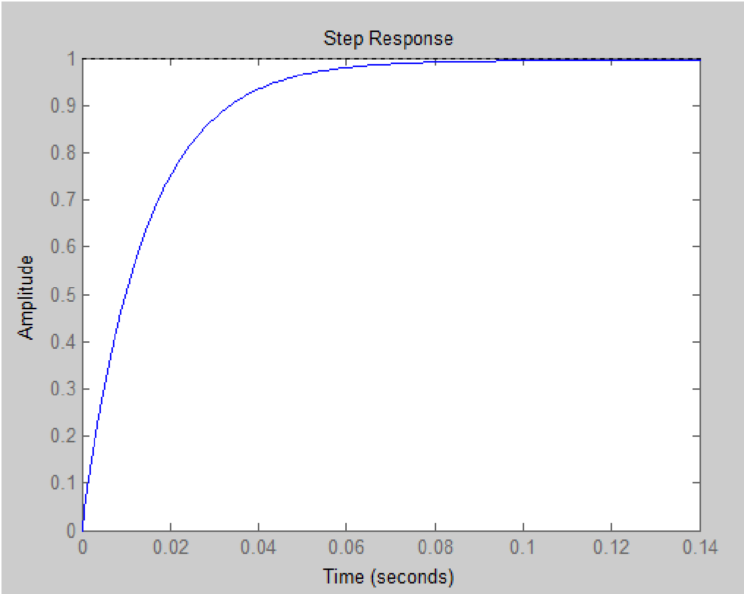

Figure 18: DC Motor with PD controller step response

Next is changing the controller to a PI controller to with K_p and K_i specified by Simulink PID tuning tool, the response is as shown in figure 19.

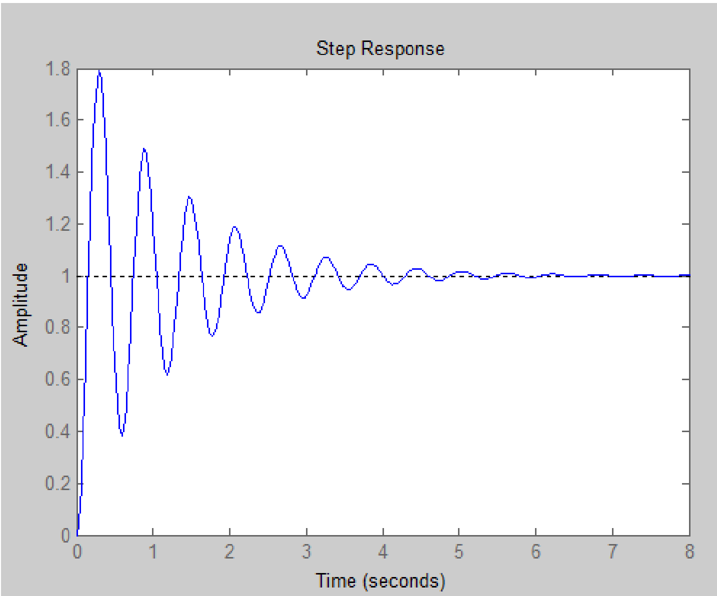

Figure 19: DC Motor with PI controller step response

Next, changing the controller to a PID controller to with K_p, K_i and K_d specified by Simulink PID tuning tool, the response is as shown in figure 20.

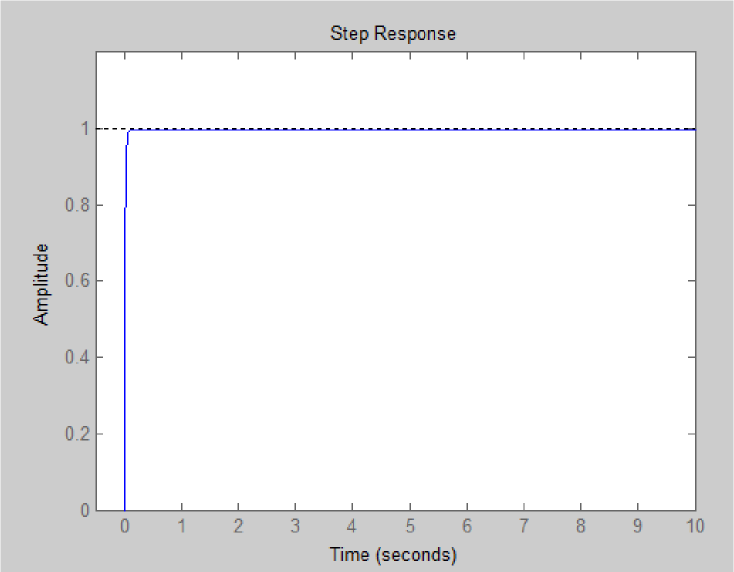

Figure 20: DC Motor with PID controller step response

Adding load 1 to the motor after 1 second, the step response is as shown in figure 21.

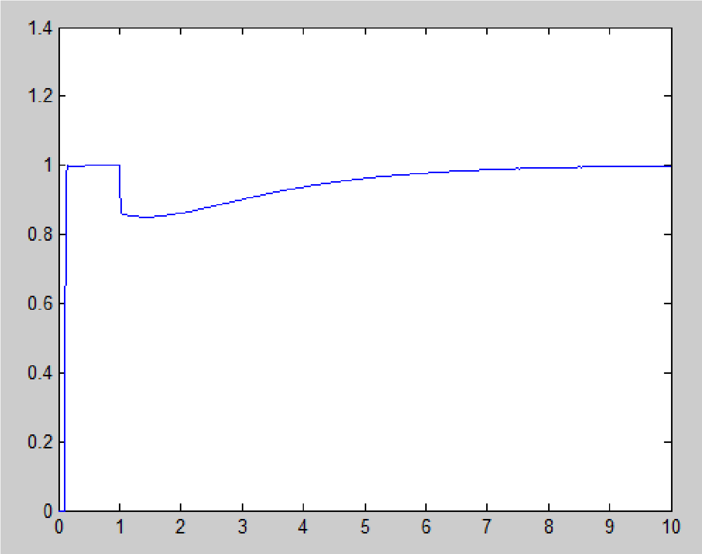

Figure 21: DC Motor with PID controller load 1 step response

Adding load 2 to the motor after 1 second, the step response is as shown in figure 22.

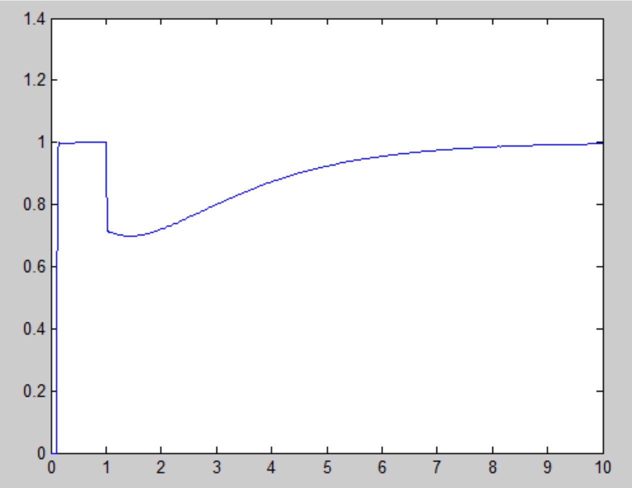

Figure 22: DC Motor with PID controller load 2 step response

Fuzzy Logic Controller

Simulating Fuzzy Logic controller using Simulink after creating the model is performed using the three controllers created with 3, 5 and 7 membership functions and using no load, load 1 and load 2 as load disturbance for the system. The results of the simulations can be seen in figures 23 to 31.

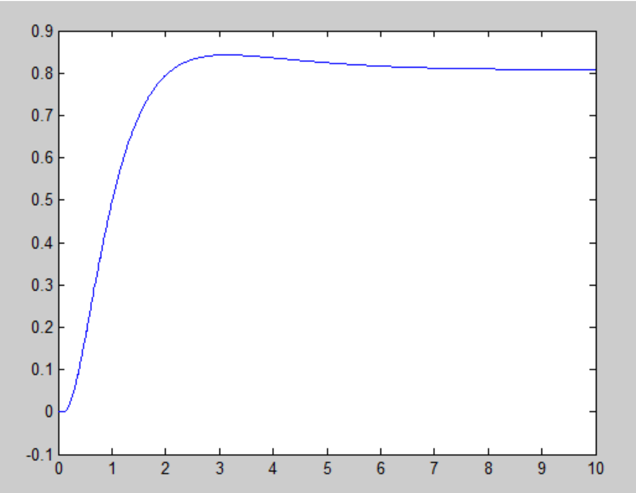

Figure 23: DC Motor with 3 triangular MFs Fuzzy controller (no load)

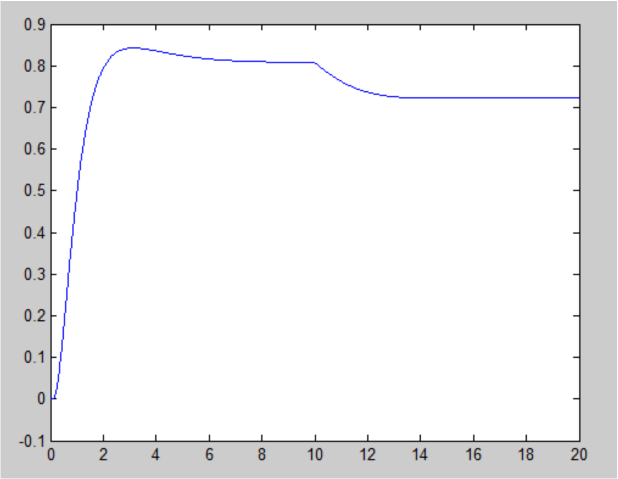

Figure 24: DC Motor with 3 triangular MFs Fuzzy controller (load 1)

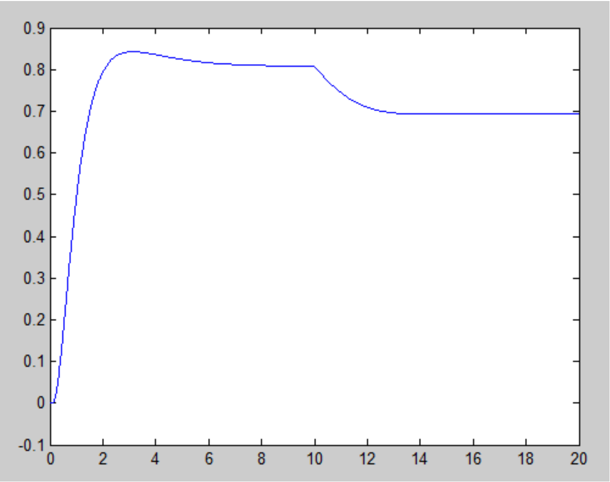

Figure 25: DC Motor with 3 triangular MFs Fuzzy controller (load 2)

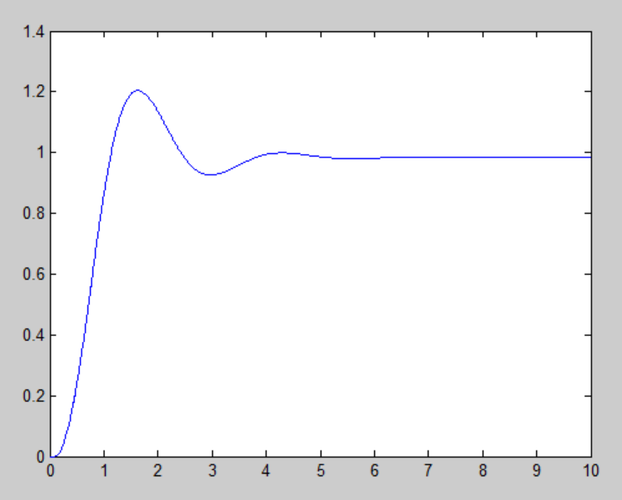

Figure 26: DC Motor with 5 triangular MFs Fuzzy controller (no load)

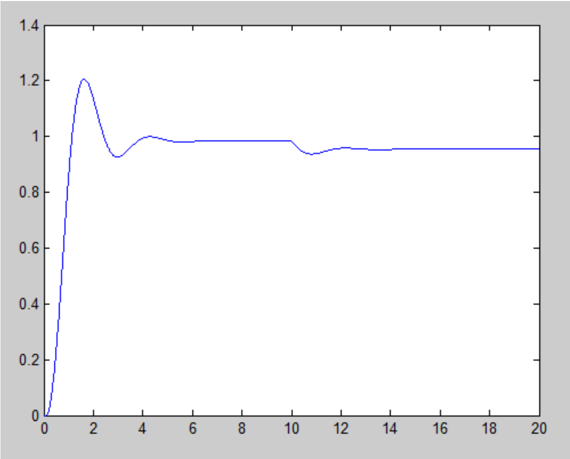

Figure 27: DC Motor with 5 triangular MFs Fuzzy controller (load 1)

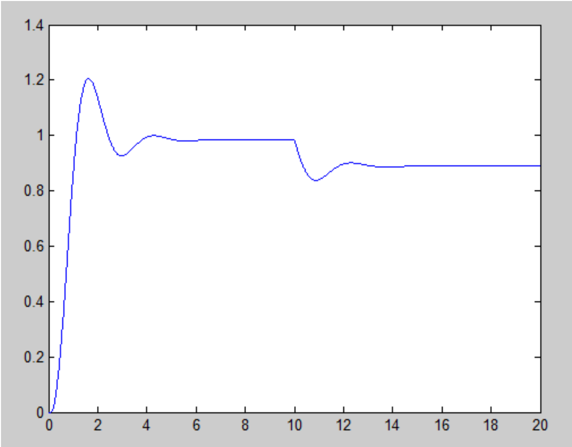

Figure 28: DC Motor with 5 triangular MFs Fuzzy controller (load 2)

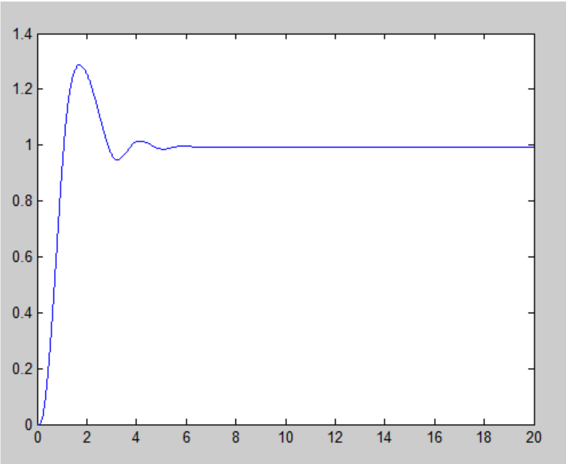

Figure 29: DC Motor with 7 triangular MFs Fuzzy controller (no load)

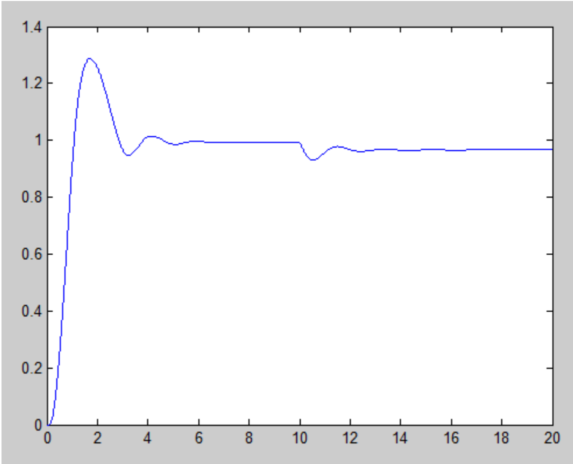

Figure 30: DC Motor with 7 triangular MFs Fuzzy controller (load 1)

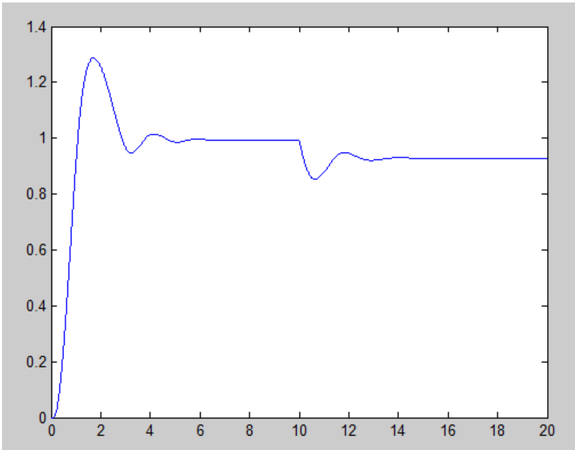

Figure 31: DC Motor with 7 triangular MFs Fuzzy controller (load 2)

Hybrid Fuzzy PID controller

Next is simulating the PID Fuzzy controller that is created in Simulink. Figure 32 to 40 show the step response of DC motor with different type of Fuzzy controller and with different loads.

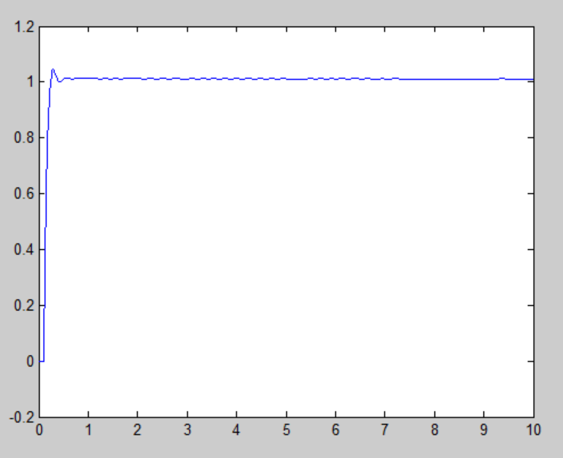

Figure 32: DC Motor with 3 triangular MFs Fuzzy controller (no load)

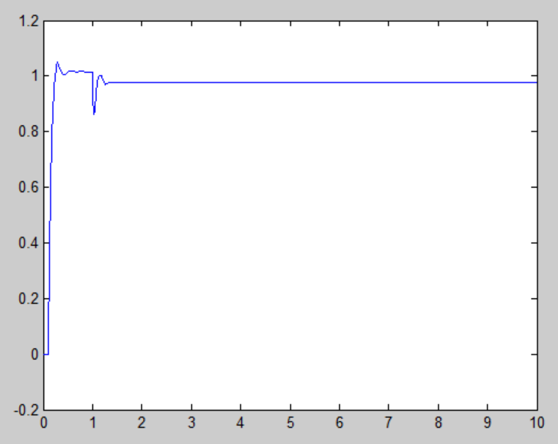

Figure 33: DC Motor with 3 triangular MFs Fuzzy controller (load 1)

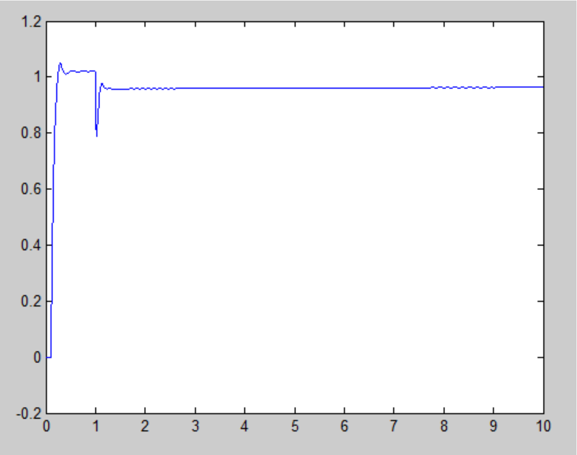

Figure 34: DC Motor with 3 triangular MFs Fuzzy controller (load 2)

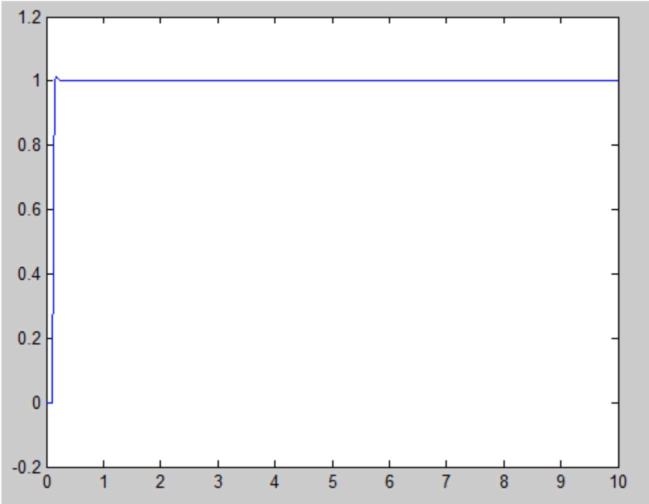

Figure 35: DC Motor with 5 triangular MFs Fuzzy controller (no load)

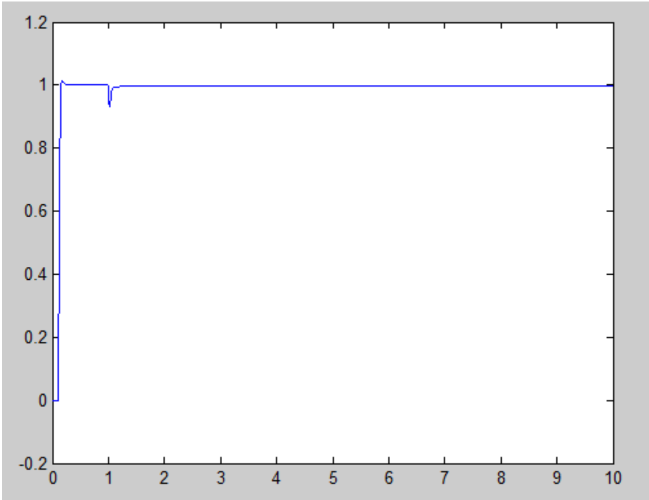

Figure 36: DC Motor with 5 triangular MFs Fuzzy controller (load 1)

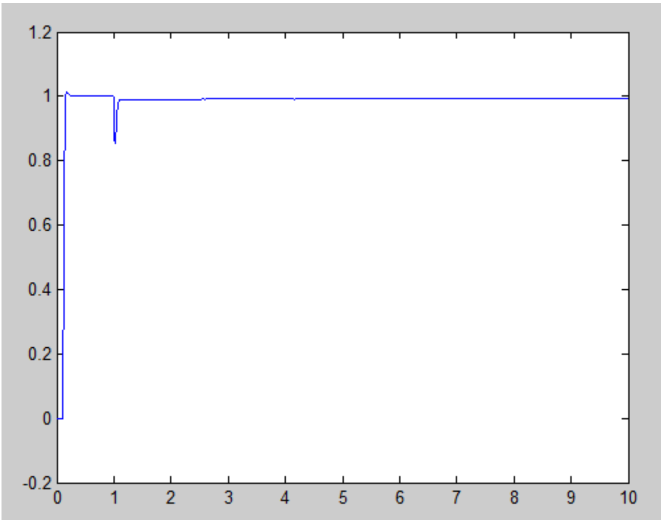

Figure 37: DC Motor with 5 triangular MFs Fuzzy controller (load 2)

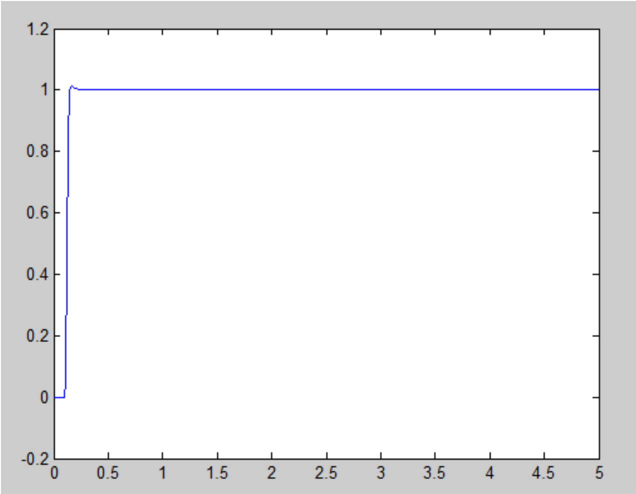

Figure 38: DC Motor with 7 triangular MFs Fuzzy controller (no load)

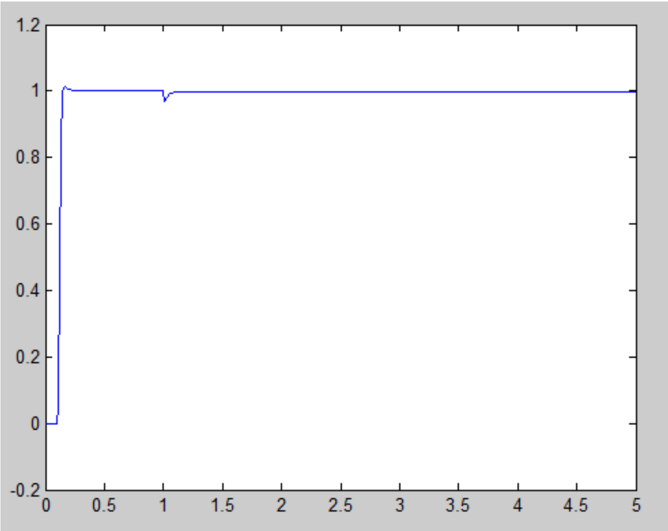

Figure 39: DC Motor with 7 triangular MFs Fuzzy controller (load 1)

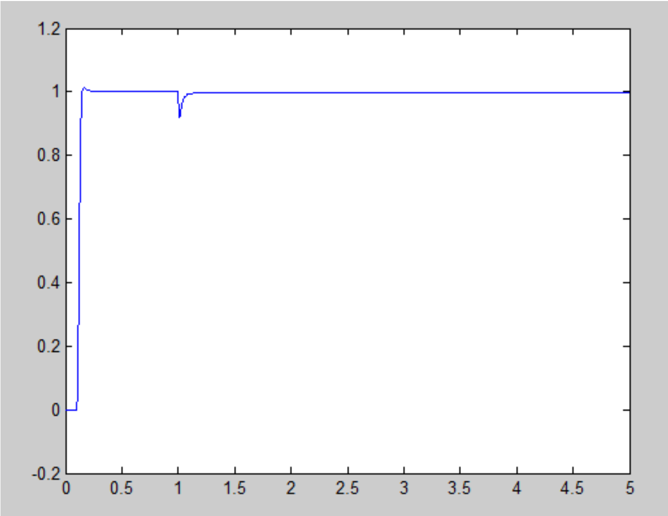

Figure 40: DC Motor with 7 triangular MFs Fuzzy controller (load 2)

4.2 Discussion

PID

Table 5 shows the results summary for the PID controller. As obvious from the numbers, the PID system is giving the best system response. Also as expected, the PID controller has good results when there is no load disturbance but as can be seen in figures 21 and 22.

Table 5: PID controller response summary

Controller	P (no load)	PI (no load)	PD (no load)	PID (no load)
Settling Time (seconds)	3.87	4.75	0.0598	0.0592
Steady State (volt)	0.999	1	0.999	1
Percentage Overshoot	74.40%	79.30%	0%	0%

After introducing load disturbance after one second, the system response is affected greatly and takes a lot of time to recover which is more obvious in the case of the higher load 2. Table 6 shows a comparison between PID with no load and PID with different loads showing the inefficiency of PID controller in handling load disturbance.

Table 6: PID controller response to load disturbance

Controller	PID (no load)	PID (load 1)	PD (load 2)
Recovery Time (seconds)	N/A	5.576	7.213
Steady State (volt)	1	0.98	0.963
Percentage Overshoot	0%	0%	0%

The results shown in table 5 and 6 are expected from the PID controller. At first, only a P controller is used which fails to improve the settling time and the overshoot of the response. The P controller only makes the rise time of the response much faster. After that, the PI controller is introduced which improves the steady state error but does not do much to improve the overshoot. Next, the PD controller is introduced which succeeds in reducing the overshoot to 0 which in turn decreases the settling time. Finally, the PID controller combines all the good pints of the previous controllers causing a good response as shown in figure 20 and from the results in table 5. After introducing loads, the system is very slow to react and recover to steady state which is obvious in figures 21 and 22.

Fuzzy Logic Controller

Using Fuzzy Logic Controller with 3, 5 and 7 membership functions and testing them with different loads shows the results that can be seen from figures 23 to 31. The results show that as the number of MFs increases, the response improves and the steady state error which is very high decreases. Table 7 shows a comparison between the efficiency of Fuzzy controllers versus the number of MFs.

Table 7: Fuzzy controllers with different number of MFs

Controller	Fuzzy 3 MFs	Fuzzy 5 MFs	Fuzzy 7 MFs
Settling Time (seconds)	6.23	4.566	4.531
Steady State (volt)	0.81	0.995	1
Percentage Overshoot	3.4%	20%	18%

Introducing loads after 10 seconds shows the effect of load disturbance on Fuzzy controllers and the result is as expected showing that Fuzzy controller with 7 MFs has the best recovery. It is also obvious from the simulation results that loads affect the steady state value of the response creating steady state error. Table 8 shows a comparison between different Fuzzy controllers with 2 different loads.

Table 8: Fuzzy controllers with different number of MFs load disturbance

Controller	Fuzzy 3 MFs (no load)	Fuzzy 3 MFs (load 1)	Fuzzy 3 MFs (load 2)	Fuzzy 5 MFs (no load)	Fuzzy 5 MFs (load 1)	Fuzzy 5 MFs (load 2)	Fuzzy 7 MFs (no load)	Fuzzy 7 MFs (load 1)	Fuzzy 7 MFs (load 2)
Recovery Time (seconds)	N/A	3	3.2	N/A	2	2.9	N/A	1.8	2.8
Steady State (volt)	0.81	0.72	0.698	0.995	0.98	0.95	1	0.99	0.97

Hybrid Fuzzy PID Controller

Using Fuzzy Logic Controller with 3, 5 and 7 membership functions mixed with PID controller in a Hybrid system and testing them with different loads shows the results that can be seen from figures 32 to 40. The results show that the Hybrid system is the best overall system in case of dealing with load disturbance and recovery time. Table 9 shows a comparison between the efficiency of Fuzzy PID controllers versus the number of MFs.

Table 9: Fuzzy controller response summary

Controller	Fuzzy PID 3 MFs	Fuzzy PID 5 MFs	Fuzzy PID 7 MFs
Settling Time (seconds)	0.277	0.055	0.052
Steady State (volt)	1	1	1
Percentage Overshoot	3.7%	1.4%	0.8%

Introducing loads after 1 second shows the effect of load disturbance on Hybrid Fuzzy PID controllers and the result is as expected showing that Fuzzy PID controller with 7 MFs has the best recovery. The load disturbance affects the steady state value of the response creating steady state error which is much smaller than that of Fuzzy controller. Table 10 shows a comparison between different Fuzzy PID controllers with 2 different loads.

Table 10: Fuzzy PID controllers with different number of MFs load disturbance

Controller	Fuzzy PID 3 MFs (no load)	Fuzzy PID 3 MFs (load 1)	Fuzzy PID 3 MFs (load 2)	Fuzzy PID 5 MFs (no load)	Fuzzy PID 5 MFs (load 1)	Fuzzy PID 5 MFs (load 2)	Fuzzy PID 7 MFs (no load)	Fuzzy PID 7 MFs (load 1)	Fuzzy PID 7 MFs (load 2)
Recovery Time (seconds)	N/A	0.23	0.26	N/A	0.18	0.22	N/A	0.15	0.19
Steady State (volt)	1	0.99	0.98	1	0.997	0.994	1	0.999	0.999

Table 11: overall system comparison (no load)

Controller	Fuzzy 3 MFs	Fuzzy 5 MFs	Fuzzy 7 MFs	Fuzzy PID 3 MFs	Fuzzy PID 5 MFs	Fuzzy PID 7 MFs	Conventional PID
Settling Time (seconds)	6.23	4.566	4.531	0.277	0.055	0.052	0.0592
Steady State (volt)	0.81	0.995	1	1	1	1	1
Percentag e Overshoot	3.4%	20%	18%	3.7%	1.4%	0.8%	0%

A comparison between the best controllers with no load is shown in table 11 and it shows that the Hybrid Fuzzy PID controller is the best overall system when considering settling time as well as recovery from load disturbance. On the other hand, conventional PID has the superiority in overshoot percentage. For the case of steady state error, both Fuzzy PID and conventional PID have the same accuracy. These results conform to the results from [12] and [13].

CHAPTER 5: CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

The focus of this project is developing the best control scheme for a functioning arm exoskeleton for rehabilitation of stroke patients who suffer from partial or permanent disability in their upper extremities. A comparison between the effectiveness of controllers (PID, Fuzzy logic and Fuzzy PID) is performed and the results show that for simple undisturbed systems, the PID controller provides a better response from the system and can be used for these applications. On the other hand, while dealing with complex systems that are subject to variable disturbances and noise like our system in the exoskeleton, the Fuzzy PID logic controller provides a better system response.

This project is expected to greatly impact the lives of patients who suffer from disabilities due to stroke of other reasons as well as a platform for developing full body exoskeleton for body enhancement and increasing strength.

5.2 FUTURE WORK

The next stage of this project is to build a functioning arm exoskeleton for actual use as a feasible product for stroke patients using the control system devised in this project. A feedback signal source for the motor controller can be generated using buttons as an initial stage and then developing into a signal generating from muscle sensors or an EEG.

REFERENCES

[1] Rahman, M. H., Saad, M., Kenne, J. P., & Archambault, P. S. (2009, December). Modeling and control of a 7DOF exoskeleton robot for arm movements. In Robotics and Biomimetics (ROBIO), 2009 IEEE International Conference on (pp. 245-250). IEEE.

[2] Frisoli, A., Sotgiu, E., Procopio, C., Bergamasco, M., Rossi, B., & Chisari, C. (2011, June). Design and implementation of a training strategy in chronic stroke with an arm robotic exoskeleton. In Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on (pp. 1-8). IEEE.

[3] Rosen, J., Perry, J. C., Manning, N., Burns, S., & Hannaford, B. (2005, July). The human arm kinematics and dynamics during daily activities-toward a 7 DOF upper limb powered exoskeleton. In Advanced Robotics, 2005. ICAR'05. Proceedings., 12th International Conference on (pp. 532-539). IEEE.

[4] Gupta, A., & O'Malley, M. K. (2006). Design of a haptic arm exoskeleton for training and rehabilitation. Mechatronics, IEEE/ASME Transactions on, 11(3), 280-289.

[5] Naidu, D., Stopforth, R., Bright, G., & Davrajh, S. (2011, September). A 7 DOF exoskeleton arm: shoulder, elbow, wrist and hand mechanism for assistance to upper limb disabled individuals. In AFRICON, 2011 (pp. 1-6). IEEE.

[6] Prasertsakul, T., Sookjit, T., & Charoensuk, W. (2011, December). Design of exoskeleton arm for enhancing human limb movement. In Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on (pp. 2199-2203). IEEE.

[7] Rahman, M. H., Saad, M., Kenne, J. P., & Archambault, P. S. (2011, December). Tele-operation of a robotic exoskeleton for rehabilitation and passive arm movement assistance. In Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on (pp. 443-448). IEEE.

[8] Liang, G., Ye, W., & Xie, Q. (2012, July). PID control for the robotic exoskeleton arm: Application to rehabilitation. In Control Conference (CCC), 2012 31st Chinese (pp. 4496-4501). IEEE.

[9] Webb, J., Xiao, Z. G., Aschenbrenner, K. P., Herrnstadt, G., & Menon, C. (2012, June). Towards a portable assistive arm exoskeleton for stroke patient rehabilitation controlled through a brain computer interface. In Biomedical Robotics and Biomechatronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on (pp. 1299-1304). IEEE.

[10] Sooraksa, P., & Chen, G. (2002). On comparison of a conventional proportional-integral plus derivative controller versus a fuzzy proportional-integral plus derivative controller: a case study of subsystem failure. In *Industrial Technology, 2002. IEEE ICIT'02. 2002 IEEE International Conference on* (Vol. 1, pp. 205-207). IEEE.

[11] Kiguchi, K., Esaki, R., Tsuruta, T., Watanabe, K., & Fukuda, T. (2003, October). An exoskeleton for human elbow and forearm motion assist. In Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on (Vol. 4, pp. 3600-3605). IEEE.

[12] Arulmozhiyal, R., & Kandiban, R. (2012, January). Design of fuzzy PID controller for brushless DC motor. In Computer Communication and Informatics (ICCCI), 2012 International Conference on (pp. 1-7). IEEE.

[13] Fayek, H. M., & Elamvazuthi, I. (2012). Type-2 Fuzzy Logic PI (T2FLPI) based DC servomotor control. Journal of Applied Sciences Research, 8(5), 2564-2574.

[14]Mehmet Akar and Ismail Temiz, 2007. Motion Controller Design for the Speed Control of DC Servo Motor, International Journal of applied Mathematics and Information.

[15]Nalunat Khongkoom, Attapol Kanchanathep, & Suthichai Nopnakeepong, 2000. Control of the position of DC Servo Motor by Fuzzy Logic, IEEE

[16]Oyas Wahyunggoro and Nordin Saad, 2008. Development of Fuzzy-logic-based Self Tuning PI Controller for Servomotor, Advanced Strategies for Robot Manipulators.

[17]K. Ang, G. Chong, and Y. Li, “PID control system analysis, design and technology,” IEEE Trans.Control System Technology, vol. 13, pp. 559-576, July 2005.

[18] Atef Saleh Othman Al-Mashakbeh,“ Proportional Integral and Derivative Control of Brushless DC Motor”, European Journal of Scientific Research 26-28 July 2009, vol. 35, pg 198-203.

[19] Chuen Chien Lee, “Fuzzy Logic in Control Systems:Fuzzy Logic controller–Part 1” 1990 IEEE

[20] Chuen Chien Lee, “Fuzzy Logic in Control Systems : Fuzzy Logic controller Part 2” 1990 IEEE .

[21] Zdenko Kovaccic and Stjepan Bogdan, “Fuzzy Controller design Theory and Applications”, © 2006 by Taylor & Francis Group. international, 2002.

[22]K. J. Astrom, and T. Hagglund, PID Controllers: Theory, Design, and Tuning, 2nd ed. Research Triangle Park, N.C., 1995

[23] R. C. Doff, Modern Control Systems. 9th ed. Prentice Hall, N. J., 2001.

[24]G. J. Silva, A. Datta, and S. P. Bhattachalyya, "New results on the synthesis of PID controllers," IEEE Transactions on Automatic Control, vo1.47, iss. 2, pp. 241-252,2002,

[25] A. Visioli, "Tuning of PID controllers with fuzzy logic," IEE Proc. Control Theory and Applications, vol. 148, iss l,pp. 1-8, 2001.

[26] M. I. Er and Y. L. Sun, "Hybrid fuzzy proportional integral plus conventional derivative control of linear and nonlinear systems," IEEE Trans. On Industrial Electronics, vol. 48, pp. 1109-1 117, 2001.

[27]M. Pamichkun, and C. Ngaecharoenkul, "Kinematics control of a pneumatic system by hybrid fuzzy PlD," Mechalronics, vol . 11, 2O00, pp. 1001-1023.

[28] D. Misir, H. A. Malki and G. Chen, "Design and analysis a fuzzy proportional derivative controller", Fuzzy Set and Systems, vol. 79, pp. 297-314, 1996.