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Suppression of Hand Tremor Using Active Force Control and Fuzzy Logic Controller

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Abstract

This study aimed to investigate the combination among proportional–integral–derivative, (PID) controller, fuzzy logic controller, (FLC) and active force control, (AFC) implemented in model 4-Degree of-Freedoms (4-DOFs) biodynamic hand model. Simulation and comparative studies using MATLAB Simulink involve these models have been successfully implemented with the aid Check Step Response Characteristics, (CSRC) Toolbox Simulink block, to obtain the values of constraints and estimated mass, (EM) for each of the proposed controller model. The comparison results show that hybrid system model PID-AFC is a highly superior and extremely robust for 4-DOFs biodynamic hand which managed to reduce the displacement amplitude of tremor as much as 99.594% and tremor acceleration signal by 98.535%. However, hybrid model adaptive intelligent system, PIDFLC-AFC managed to reduce displacement amplitude tremor signal as much as 99.113% and 97.826% reduction at tremor acceleration signal. Meanwhile proposed model PIDFLC-AFCFLC is demonstrated, the best result of adaptive intelligence models for PSD of displacement and acceleration signal frequency. Both of these models might be the most robust system model for auto-tuning controller and different external disturbances introduced in the system.

Key-word: - active tremor control, fuzzy logic, AFC, PID controller, tremor.

1. Introduction

Hand tremor commonly referred to as shaking hands and not dangerous for life, but it can be embarrassing or delaying daily tasks [1-2]. This is an early sign of Parkinson's disease. Essential tremor is the most common neurological diseases that happen to adults, disruption of normal brain function by the cerebellum and the degenerative process [2]. Shaking is most commonly in the hands, arms, head, and the vocal cords, and not be controlled [1]. This tremor is more evident when you try to use muscle. When the muscles are relaxed, shaking will not likely happen or will become lighter.

In comparison, patient with Parkinson's disease often suffer from hand tremors when resting the muscles and see a decrease in muscle tremors when being used. Among the reasons for hand tremor are convulsions, overactive of thyroid, disease of cerebellar, Huntington's disease, side effects of medications, excessive caffeine, alcohol abuse or addiction, stress or anxiety, and low blood sugar [3]. Although there is no cure for most tremors, but reducing intake of caffeine, alcohol, or other stimulants can reduce your concussion [2]. However, there is no medication for hand tremor caused by Essential tremor. The problem will be worsened if the age is increasing. The type of treatment depends on the severity of the tremor and the side effects on patients. However, not all hand tremors need a treatment.

In addition to medications, surgery may be a treatment option that is usually is intended for people with severe disabilities tremor. Deep Brain Stimulation (DBS) is a surgical method used for the treatment of tremor [4-6]. Thalamotomy is also another surgical option that, through this method, your surgeon will cut through small cuts in the thalamus of the brain. Among the methods of therapy that is recommended by the doctor is to change your lifestyle as a way of helping ease Essential tremor [5]. Gamma Knife (GK) Thalamotomy is a very appropriate choice for patients who do not fit for DBS [5].

These include using heavier objects or add weights on hand can control the movements properly. The use of equipment specifically designed for hand tremor disease can also help people who have problems of grip and control. Even so, all of treatment of PD patients, will suffer from side effects, addiction and withdrawal symptoms in the long term as well, will cost involved quite expensive, for surgical treatment. Consequently, as example of the use of electronic devices that use sensors that can stop the effects of vibration on hand, next it can improve the quality of life, and can overcome the problem that adversely affected daily routines, by PD patient. Accordingly, this study was developed to optimize the tremor absorption ability, by the devices on the hands of PD patients. With referring to the 4-DOFs hand biodynamic model that has been developed by earlier studies [7-8], a few model controller systems that are intelligent and effective in meeting the objectives developed for this study. In addition, the results from this study may also indicate which the controller is effective for reducing the tremors.

2. Modelling and Simulation of PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC Controller Systems

In order to complete this simulation hand model biodynamic 4-DOFs are required to perform the simulation process. All models of these controller system consist of a spring-mass-damper 4-degree of freedom (4-DOFs) to represent a human arm [7-8]. Thus this study was extended by the findings from As'arry [7]. Modelling systems for suspension tremor hand as a whole is made up of various essential components that are represented by a block diagram. Amongst important components involved are controllers (PID, PIDFLC, AFC and AFCFLC) [7][9-10], actuator (voice coil drive components, linear) [11], 4-DOFs model state spaces, scope (displacement and acceleration graph) and function block parameters (memory, saturation, zero order hold and product). These blocks represent all equations required for 4-DOFs system.

Proposed system control scheme that can be described as follows:

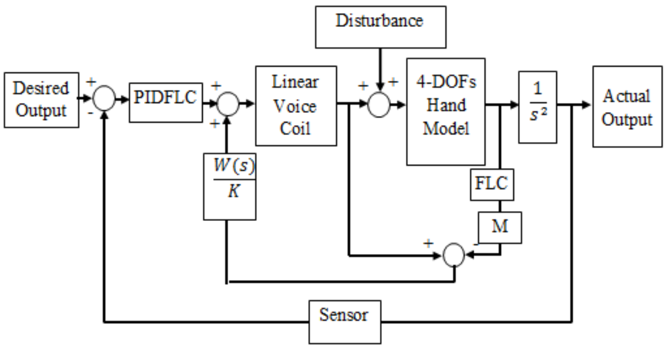

Figure 1 Schematic diagram of proposed control scheme

Table 1 shows the active tremors controller using other methods of controller and model by previous researchers (Simulation).

Table 1 Various active tremor control using other method control by other researchers [17]

Researcher	Method Control	Device/ Actuator	Displacement of Hand Tremor Reduced	Result (% of Tremor Reduction)
Dimgguo Zhang, Wei Tech Ang	FLC, PDC& Compensator	FES	±1mm	60%
Sri Sitaram Chowdary Lavu, Abhijit Gupta	PID Controller	Piezo-electric	±0.02mm	55%
A. As'aary, M.Z. Md. Zain, M. Mailah, M. Hussein, Z.M. Yusop	PD Controller & AFC	Linear Electro-magnet	±2mm	80%
Jamaluddin, H. A. As'aary, M.Z.	PID FLC Controller	Linear voice coil actuator	±2mm	80%

At first, the system model 4-DOFs without any controller need to be built and be run simulations to obtain an uncontrolled system represent as actual tremor vibration signal and facilitate the comparative study conducted. For this study, two FLC models [12-16] have been developed which are the FLC model for proportional, P and FLC model for AFC, M. The simulation is conducted with a 4-DOFs hand model and running within 10 seconds of the simulation time.

However, as previously reported researchers dealing with, problems value EM are the main problem to obtain the desired output and more optimal [13-14][17-20]. Amongst the values of constraints and EM involved in this model are PID gains (kP, kI and kD), AFC gain (M), FLC error input gain (kin1and kin2), and FLC output, (kout1and kout2). Based on earlier studies, various numerical suitable for input and output variables used in the FLC obtained based on experience [13-14][17-20]. Therefore, selections of the appropriate numerical range are a very important step in this scheme. In this case, only a FLC error derivative gain alone, using heuristic methods which, based on values of FLC input gain error, kin1 which is obtained from auto tuning CSRC block optimization. The parameter to be estimated it must be able to control values of input gain error, kin1 that not too large and complicated. In this study, a value of FLC error derivative is set as 0.001. However, heuristic methods remain to be done, in some parts of the setup process before the auto-tuning optimization method using block CSRC is executed.

Modelling of Fuzzy Logic Controller

The first step to construct FLC, FLC's toolbox is called in command window. As with other FLC models, FLC design for this research, have two inputs (error and derivative error) and one output. The error was defined as the difference between the output of the controller and the reference value or designated point. Meanwhile, the derivative error was defined as the difference among the error at time t and (t-1) [18]. Method of fuzzy logic applied to this system is a method of Mamdani. Defuzzyfication used for fuzzy logic controller is the centroid.

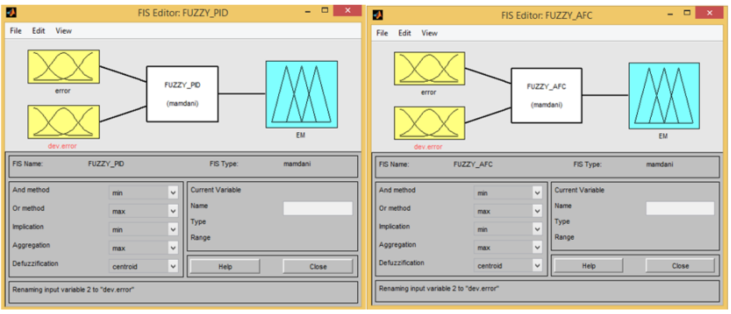

Figure 2 Fuzzy Logic toolbox command window with two inputs and one output for PID and AFC controller.

In this case, FLC attached to the PID controller and controller AFC to estimate the EM of the PID and AFC. Whereby the output of the FLC, respectively, will produce the EM on each controller attached. Therefore, the desired output variables which are EM proportional gain for PID controller and the AFC loop, the desired output variables, EM is to estimate the value of M. Input for the FLC which are error and derivative error is used to generate EM. Figure 2 shows editor fuzzy inference system (FIS) of the input and output for FLC dynamic suspension system human hand tremor. The first step for opening the FLC is fuzzification input controller which is a reference to the design of the input membership function. According to the human hand tremor dynamic system, error massive displacement has been selected as two of input PID and AFC loop FLC, which fuzzified using a triangle-shaped membership function, as shown in Figure 3 to Figure 5

Two input and output implemented in Fuzzy logic toolbox has seven membership functions each with the name of the variable linguistic such as Negative Big (NL), Medium Negative (NM), Negative Small (NM), Zero Error (Z), Positive Small (PS), Positive Medium (PM) and Positive Big (PL). For output fuzzy logic controller, it has the same membership function such as Fuzzy logic controller input. Through this study, the membership function of each input and output can be made by setting the values of parameters and the type of membership function. Type of membership functions and parameters, is by using, the heuristic method. If the system indicates unsatisfactory results, parameters and types of membership functions able to be changed continuously so that the system generates the appropriate output.

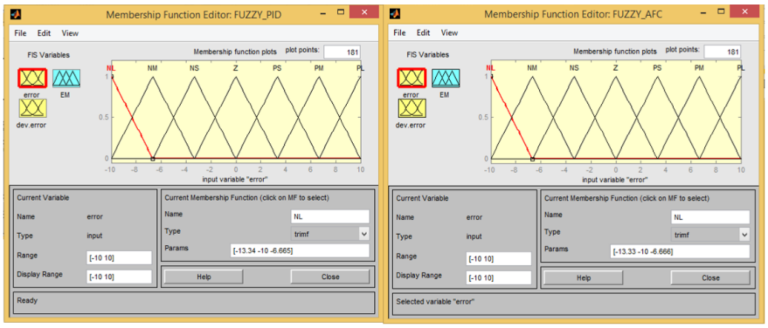

Figure 3 Triangle shaped membership functions command window of error input for PID and AFC controller (range in [-10 10])

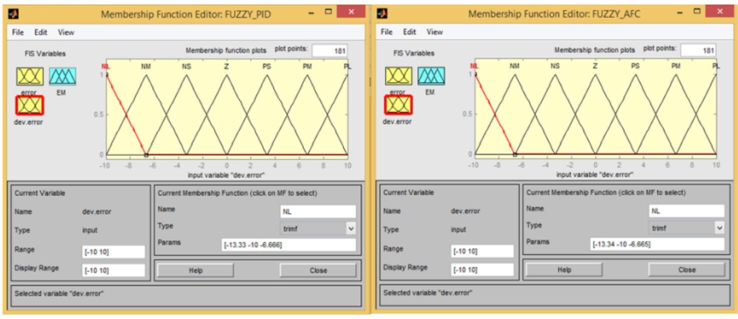

Figure 4 Triangle shaped membership functions command window of derivative error for PID and AFC controller (range in [-10 10]

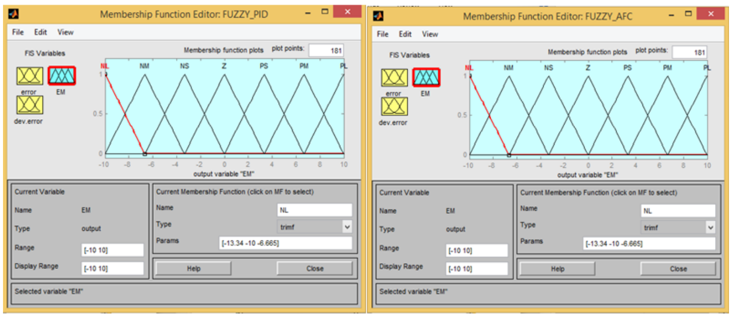

Figure 5 Triangle shaped membership functions command window of output, EM for PID and AFC controller (range in [-10 10]

As mentioned earlier, the parameters for the FLC particularly the range of these parameters are through heuristic methods. Based on all of the models that have been developed, the range of -10 to 10 as shown in Figure 3 to Figure 5, was chosen as it is appropriate for all models to produce a more optimal results. In this case, the use of 49 methods is best for the system, it has been proved by the researchers earlier [17], if compared to the rules of linguistics. The advantage of this method is that it will not have a negative result as shown in Table 2 and FL command window as shown in Figure 6 below:

Table 2 Matrix Whelan Mc Vicar Regulation 49 Schedule

e/de	**NL**	**NM**	**NS**	**Z**	**PS**	**PM**	**PL**
NL	NL	NL	NL	NL	NS	NS	Z
NM	NL	NM	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PM	PM	PL
PL	Z	PS	PS	PM	PL	PL	PL

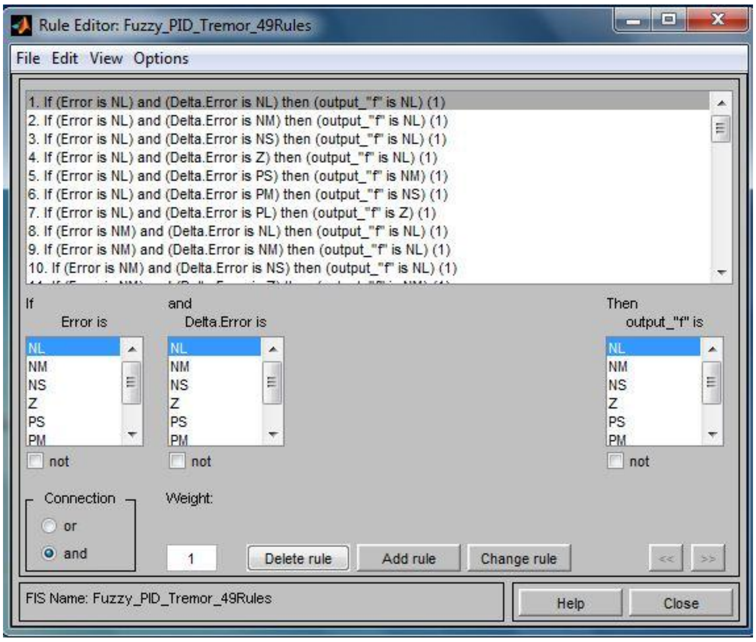

Figure 6 Fuzzy Logic rules command window with 49 rules

Proposed PIDFLC Controller System

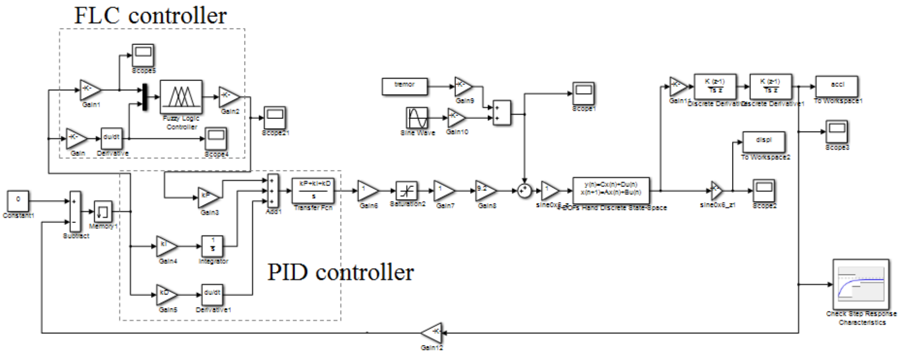

Figure 7 4-DOFs Simulink modelling controller system using adaptive PIDFLC

PIDFLC Simulink model developed from earlier studies [17]. Figure 7 show that sub-system FLC has two inputs and one output. Error and derivative error are two inputs used to produce EM as output. Initially, the simulation of PIDFLC is carried out in advance to see the reliability of the model simulation output, compared with actual hand tremor signal. Simulation process is executed a number of times so that the values obtained constraints (kin1 and kout1) and EM (kP, kI and kD) is more realistic. For this model, the value of this parameter gain must be changed a number of times in order to avoid unrealistic parameter value is the derivative error gain of FLC. Hence, the parameter gain which compliant is 0.001. Performance and robustness of the system by acceleration and displacement of this model can get through the scope that has been connected to model Simulink and be compared to actual tremor signal of PD patient.

Proposed PID-AFC Controller System

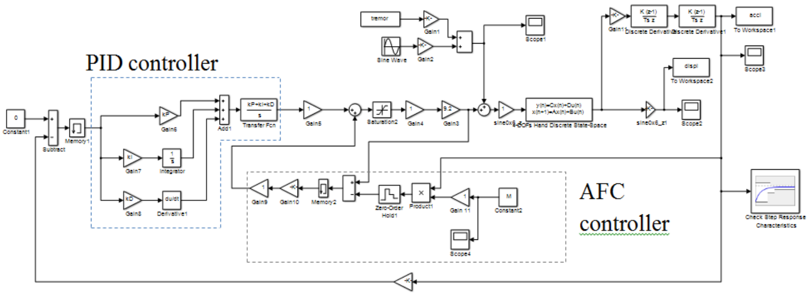

Figure 8 4-DOFs Simulink modelling controller system using hybrid PID-AFC

Next, the simulation process also been conducted on the proposed hybrid model, PID-AFC as shown in Figure 8. Since this model does not have the FLC, hence all of the EM (kP, kI, kD and M) obtained via optimize block SCRC. After the optimization process completed, results that obtained be compared to actual tremor signal of PD patient.

Proposed PID-AFCFLC Controller System

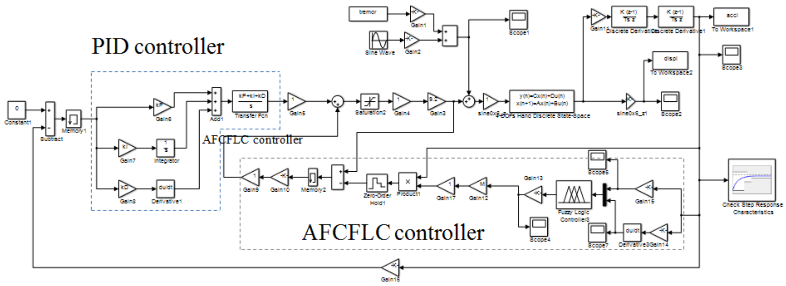

Figure 9 4-DOFs Simulink modelling system using adaptive hybrid PID-AFCFLC

Model systems for PID-AFCFLC and PIDFLC-AFC, as shown in Figure 9 and Figure 10 respectively are obtained from the model AFCFLC-PIDFLC as in Figure 11, by issuing block FLC from AFCFLC-PIDFLC system model. However, for FLC modelling, are the same for all models of systems, which are developed. In this simulation process, to avoid unrealistic values obtained via optimize SCRC block Simulink toolbox, parameter gain of FLC derivative error at AFC controller, which also compliant of 0.001. For this model, the constraint and EM involved are kin2, kout2, kP, kI, kD and M. After the optimization process completed, results that obtained be compared to actual tremor signal of PD patient.

Proposed PIDFLC-AFC Controller System

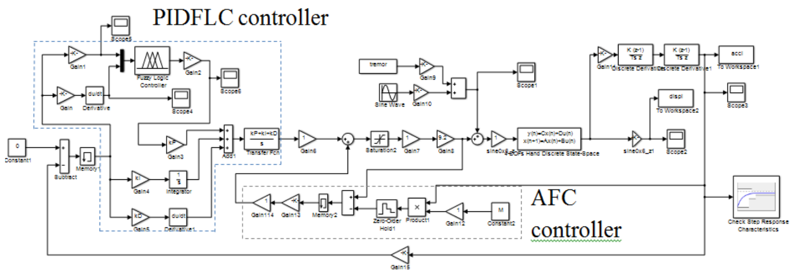

Figure 10 4-DOFs Simulink modelling controller system using adaptive hybrid PIDFLC-AFC

Subsequently, the model PIDFLC-AFC, as shown in Figure 10, the simulation process is similar to previous models. The values of constrains and EM that need to acquire in order to optimize suppression signal amplitude are kin1, kout1, kP, kI, kD and M. Results of simulation obtained be compared to actual tremor signal of PD patient.

Proposed PIDFLC-AFCFLC Controller System

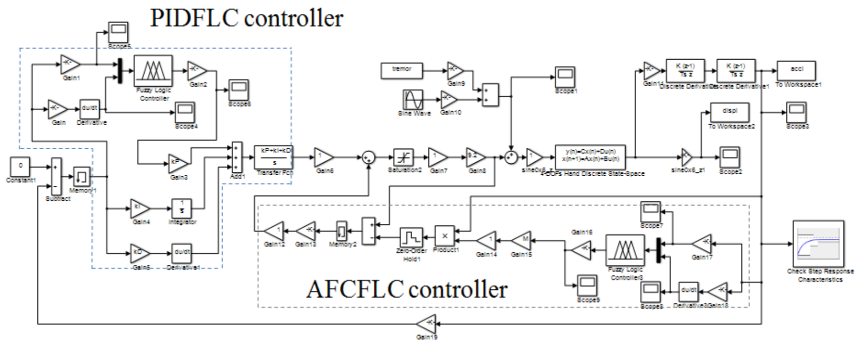

Figure 11 4-DOFs Simulink modelling controller system using adaptive hybrid PIDFLC-AFCFLC

Finally, the simulation process is performed on adaptive hybrid PIDFLC-AFCFLC model as in Figure 11 that combine all controllers, to demonstrate the ability of a combination adaptive intelligent controller, in terms of robustness performance in suppression amplitude tremor signal of PD patient. Derivative error gain parameter for PIDFLC and AFCFLC controller is same as previous proposed Simulink models, which is only appropriate with the value of 0.001. The values of constrains and EM that require to obtain from the optimize CSRC block Simulink block are kin1, kin2, kout1, kout2, kP, kI, kD and M. Results of simulation obtained be compared to all proposed Simulink models and actual tremor signal of PD patient.

Optimization Process

Basically, this model 4-DOFs optimization studies, uses Check Step Response Characteristics, (CSRC) block that conducted automatically by MATLAB / CSRC Toolbox®, to produce a more optimal output value of EM. The CSRC block able to applied in simulation mode to monitor signal but only in normal mode or accelerator simulation, for optimization of reaction. Block CSRS works by checking whether the received signal step response meets or fulfil the required limit during the simulation process occurs.

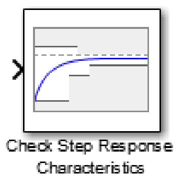

Figure 12 Check Step Response Characteristics (CSRC) block from matlab library pane Toolbox

Simulink Design Optimization offer functions, interactive tools and a block to analysing and tuning model parameters. The use of CSRC block is one method that can be considered the best method for determining the value of constraints or EM contained in any simulation model. This is because this method is more simple and easy as well not require the complicated knowledge of mathematical models of plants to tune it to meet requirements. With just couple of clicks away and the values of the parameters and constraints required in each Simulink models can be obtained automatically.

The method not only help in improve the accuracy of the model, but can acquire the model parameters or EM automatically with the value of most optimal and will be more time saving, if the addition of check or specified settings are appropriate and applicable. Next, the EM parameters or constraints can be tuned to fulfil the time-domain and frequency domain requirements, such as custom needs and the phase margin and overshoot. For the study of model 4-DOFs hand tremor, the selection step response in the assertion model, such as the characteristics of step time (seconds), initial value, final value, rise time (seconds), % rise, settling time (seconds), % settling, % overshoot and % undershoot, is based on heuristic approach method. Through this research, the first step to start the auto tuning optimization using CSRC block, is to define PID gains (kP, kI and kD), FLC input error gain (kin1 and kin2), FLC output (kout1 and kout2) and AFC gain (M) initially and optimization toolbox will provide optimal value. For the initial setting, the values of these constraints can be set as 1, and then model process simulation is executed.

The next step, characterized in assertion selection step response model, designated in accordance with requirements heuristic methods by open selection block parameters dialog. After the determination of the characteristics of is done, click on the option open response optimization design tool and select the variable set in response optimization. Then, create a new set of design variables and add the variables that need to be tuned for more optimal. In this case, the limit is a minimum value designated as 0 and the maximum as infinity, while scale is set as 1. After that select workspace design optimization, so that the values of design variables will be sent to the workspace. Finally, click on optimized button to start the optimization process. The optimization process is iterating in order to meet the requirements. After the process is done, the new optimized values will be appeared. The above steps are repeated until the values of the selected variable design complied with the requirements of this model referring to the optimization progress.

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3. Results and Discussion

Five models of adaptive intelligent hybrid that have been proposed and developed to meet the objectives of this study which are PID-AFC, PIDFLC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC. Lists of the constraints and EM values as in Table 3, which contained in each of the proposed suppression hand tremor Simulink models that were obtained from optimize CSRC block, are listed as follows:

Table 3 Constraints and EM values obtained by using CSRC block Simulink toolbox

No.	Estimated Mass/Model Constraints	PID-AFC Model	PIDFLC Model	PIDFLC-AFC Model	PID-AFCFLC Model	PIDFLC-AFCFLC Model
1	kP	37.675	1.4441	0.6359	5.4177	4.0771
2	kI	9.9028	9.6635	0.8125	2.5683	1.6914
3	kD	0.0486	1.3035	0.6218	4.0454	2.6096
4	kin1	-	30.5834	0.7484	-	4.0767
5	kout1	-	11.3033	0.7603	-	4.0129
6	kin2	-	-	-	0.2776	4.0771
7	kout2	-	-	-	1.0921	0.3576
8	M	1.312	-	2.321	1.0921	0.3576

The real tremor displacement PD patients were an average of ± 10mm [21-22]. Based on graphs comparison as in Figures 13 and 14, clearly shows the five models are capable of reducing the value of the actual displacement tremor hands of PD patients however, referring to the close-up view in Figure 14, the signal of the PID-AFC system model controller is the best if compared in terms of tremor displacement. Table 4 below shows the average values, the maximum amplitude displacements (mm) and percentage of reduction tremor after using proposed controller models.

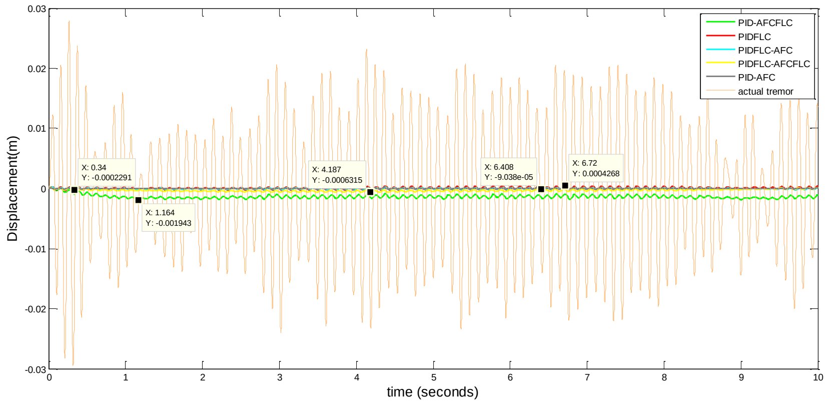

Figure 13 Comparison between five proposed controller models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC, PIDFLC-AFCFLC), and actual displacement of PD patients.

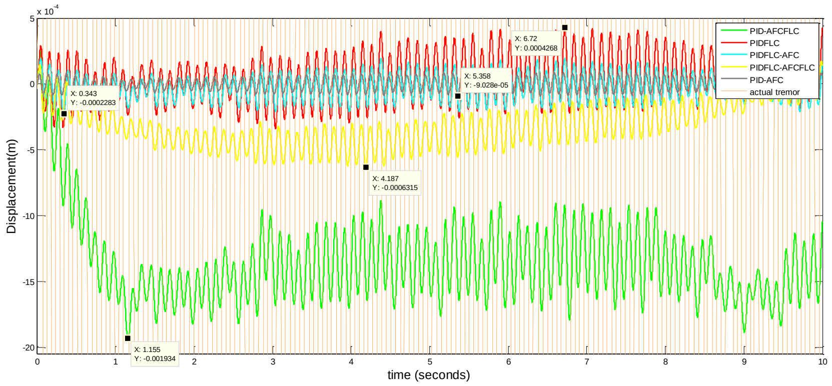

Figure 14 Comparison between five proposed control models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC, PIDFLC-AFCFLC), and actual displacement of PD patients. (Zoom Mode)

Table 4 Comparison between the average values, maximum amplitude displacements (mm) and percentages of reduction tremor after using the proposed models controller and the actual tremor of PD patient.

No	Proposed Controller Models	Average Amplitude Displacement (mm)	Maximum Amplitude Displacement (mm)	Percentage of Reduction Tremor (%)
1	Actual Tremor	± 10	-2.928E+-01	-
2	PIDFLC	± 1.535E-01	4.268E-01	98.465
3	**PID-AFC**	**± 4.064E-02**	**-9.028E-02**	**99.594**
4	PIDFLC-AFC	± 8.870E-02	-2.283E-01	99.113
5	PID-AFCFLC	-1.360E-00	-1.934E-00	86.4
6	PIDFLC-AFCFLC	-3.120E-01	-6.315E-01	96.88

Referring to the Table 4, has listed more clearly comparative values between the average and maximum displacement amplitude values and the percentage reduction in tremor after applying the five models that have been proposed and compared with the actual hand tremors displacement at ± 10 mm. It was found that the best proposed controller model is PID-AFC system at average ±0.0406 mm with maximum displacement amplitude -0.0902 mm and managed to reduce the tremor as much as 99.594 %, virtually eliminating all tremors that exist. The next best of proposed model controller is PIDFLC-AFC at average 0.0887 mm and -0.2283 mm maximum displacement amplitude. Meanwhile, a total of 99.113 % been shown too significantly of this controller model successful in reducing vibration at tremor patients.

It is followed by another proposed controller models, such as PIDLFC, PIDFLC-AFCFLC and PID-AFCFLC with values of average, and maximum amplitude displacements as well as the percentages reduction in tremors at the hand of PD patients shown in Table 4.

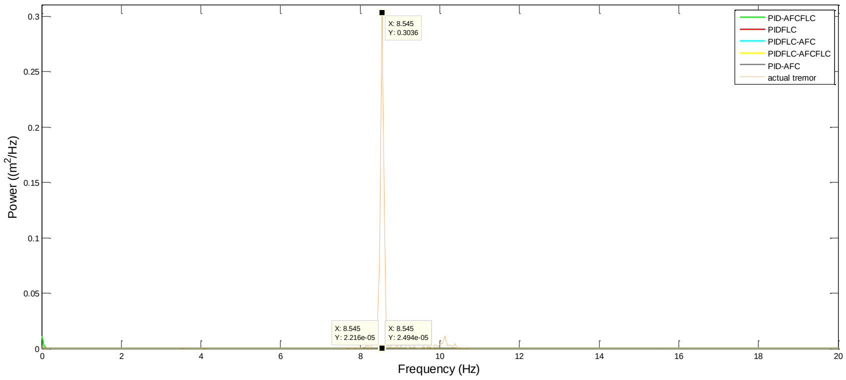

Figure 15 Comparison the PSD ((m / s^2) ^{2} / Hz) against displacement frequency (Hz) between five control models, (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual displacement of PD patients.

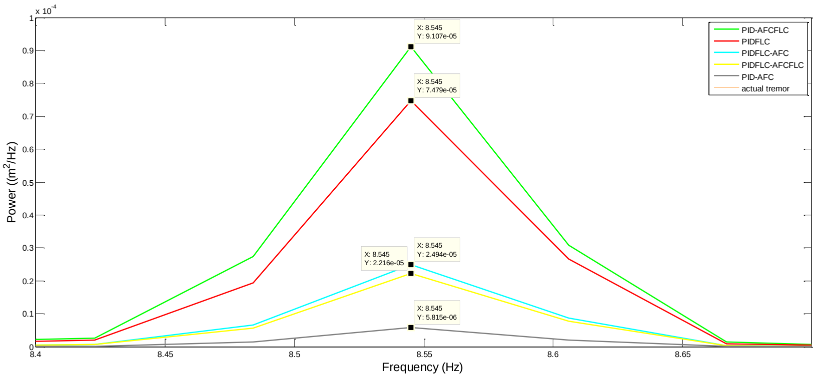

Figure 16 Comparison the PSD ((m / s^2) ^{2} / Hz) against displacement frequency (Hz) between the five control models, (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual displacement of PD patients. (Zoom mode)

The graph above indicates, the Power Spectrum Density, PSD tremor displacement of the five models including the actual PSD tremor displacement for PD patients against frequency. From Figure 15, it can be seen that the maximum amplitude of actual tremors hands frequency displacement, is 0.3036 ((m^2) / Hz) with a frequency at 8.545 Hz. Meanwhile, Table V below shows the average value, the maximum amplitude of frequency displacement (mm) and percentage of reduction of tremor after using proposed models controller.

Table 5 Comparison between the five proposed model and the actual tremor of PD patients of maximum amplitude displacement frequency at 8.845 Hz, ((m^2)/Hz).

No	Proposed Controller Models	Maximum Amplitude Displacement Frequency , ((m^2)/Hz)
1	Actual Tremor	3.036E-01 (@ 8.545Hz)
2	PIDFLC	7.479E-05 (@8.545Hz)
3	**PID-AFC**	**5.815E-06 (@ 8.545Hz)**
4	PIDFLC-AFC	2.494E-05 (@ 8.545Hz)
5	PID-AFCFLC	9.107E-05 (@ 0Hz)
6	PIDFLC-AFCFLC	2.216E-05 (@ 0Hz)

Based on the Figure 16 and Table 5 above, the proposed control model PID-AFC, is indicating the lowest value of maximum amplitude of the displacement, which 5.815E-06 ((m^2)/Hz) and the frequency at 8.545 Hz. Followed and the proposed model control PIDFLC-AFCFLC by the value of maximum amplitude displacement, 2.216E-05 ((m^2)/Hz) and the frequency at 8,545 Hz.

The third best of proposed control model is PIDFLC-AFC with the value of maximum amplitude displacement, 2.494E-05 ((m^2)/Hz) and the frequency at 8.545 Hz. For the proposed controller model PIDFLC and PID-AFCFLC, values of maximum amplitude displacement, as shown in Table 5 with the frequency of 8.545 Hz. From these two displacements and frequency graphs analysis, the application of intelligent adaptive, FLC to PID and AFC controller is not help to provide robustness and performance in reducing vibration compared to hybrid PID-AFC controller for this study. However, the percentage reduction in tremor, as a whole remained at a relatively high level.

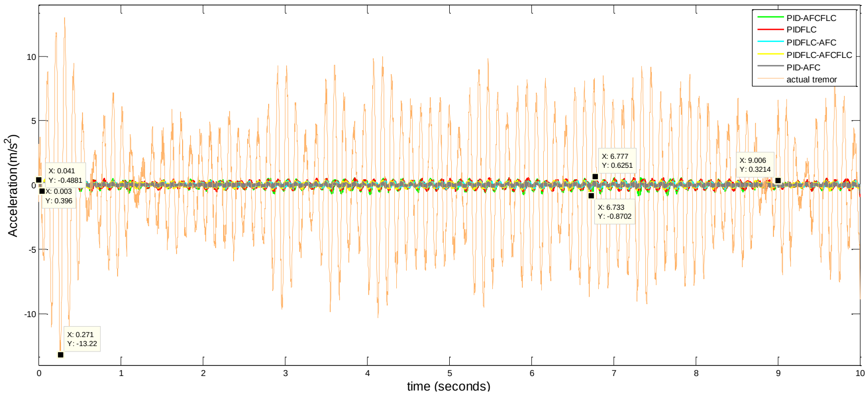

Figure 17 Comparison between five proposed controller models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual acceleration of PD patients

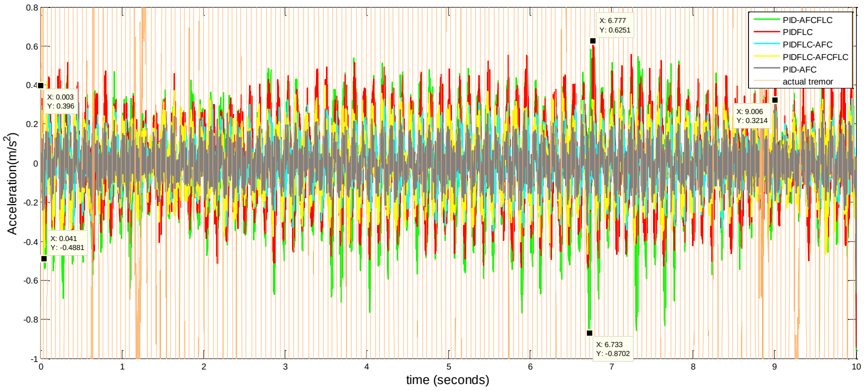

Figure 18 Comparison between five proposed control models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual acceleration of PD patients. (Zoom Mode)

The real tremor acceleration of PD patients is with an average of ±4-6 m/s^2 [21-22]. As a result of the shape of graphs comparison, for Figures 17 and 18 above, clearly shows the five models are capable of reducing the value of the actual acceleration tremor hands PD patients however, referring to the close-up view in Figure 18, the signal of the PID-AFC system model controller is the best if compared in terms of tremor acceleration. Table 6 shows the average value, the maximum amplitude acceleration (m/s^2) and percentage of reduction tremor after using proposed controller models.

Table 6 Comparison between the average values, maximum amplitude accelerations (m/s^2) and percentages of reduction tremor after using the proposed controller models and the actual tremor

No	Proposed Model Controllers	Average Amplitude Acceleration (m/s^2)	Maximum Amplitude Acceleration (m/s^2)	Percentage of Reduction Tremor (%)
1	Actual Tremor	± 4.6	-1.322E+01	-
2	PIDFLC	± 1.730E-01	6.251E-01	96.239
3	**PID-AFC**	**± 6.740E-02**	**3.214E-01**	**98.535**
4	PIDFLC-AFC	± 1.000E-01	3.960E-01	97.826
5	PID-AFCFLC	± 1.930E-01	-8.702E-01	95.804
6	PIDFLC-AFCFLC	± 1.162E-01	-4.881E-01	97.474

As shown in Figure 17 and Figure 18, it can be viewed or observed that, the actual tremors acceleration PD patients, is average at ±4-6 m/s^2. Accordingly, it is next compared with the five proposed controller models with the values of average and maximum amplitude displacement values as well as the percentage reduction in tremor acceleration. Results from the analysis and findings from graph of acceleration that has been plotted shown, model controller of PID-AFC still remained stability and robustness in reducing tremor, at an average value of ±0.0674 m/s^2 and maximum amplitude acceleration at 0.3214 m/s^2, The percentage reduction in tremor acceleration PD patients have been successfully be mitigated by 98.535 %.

Followed by the proposed control model PIDFLC-AFC with the average value of ±0.1 m/s^2 and maximum amplitude acceleration at 0.396 m/s^2 and successful in reducing tremor acceleration as much as 97.826 % of PD patients. In contrast to the analysis displacement and frequency displacement, proposed control model PIDFLC-AFCFLC is better than the proposed control model PIDFLC, with the average value ±0.1162 m/s^2 and maximum amplitude acceleration 0.4881 m/s^2 and successful in reducing the acceleration of tremors tremor PD patients about 97.474 %. While average amplitude acceleration value, for the proposed control model PIDFLC is about ±0.173 m/s^2 and 0.6251 m/s^2 of maximum amplitude acceleration as well as successful in reducing tremors acceleration about 96.239 %. PID-AFCFLC proposed control model is indicated the lowest result in terms of tremor reduction by about 95.804 % and the highest in amplitude acceleration signal by ±0.1930 m/s^2 compared to other proposed controller models.

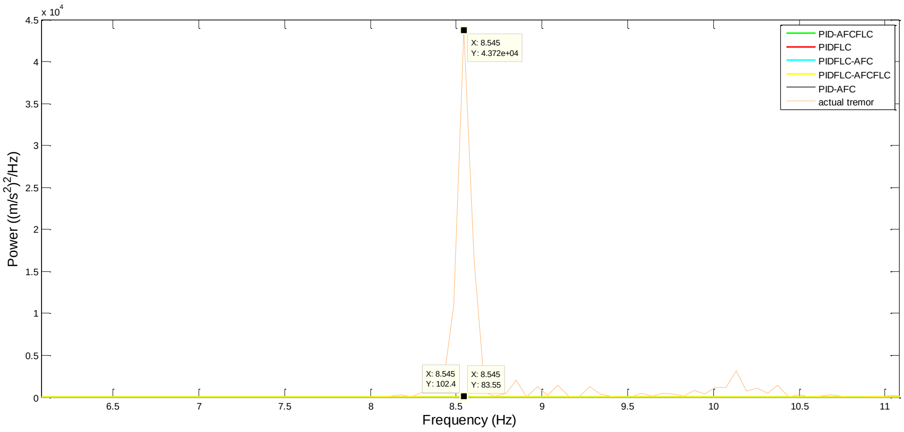

Figure 19 Comparison the PSD ((m / s^2) ^{2} / Hz) against acceleration frequency (Hz) between five control models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual acceleration of PD patients.

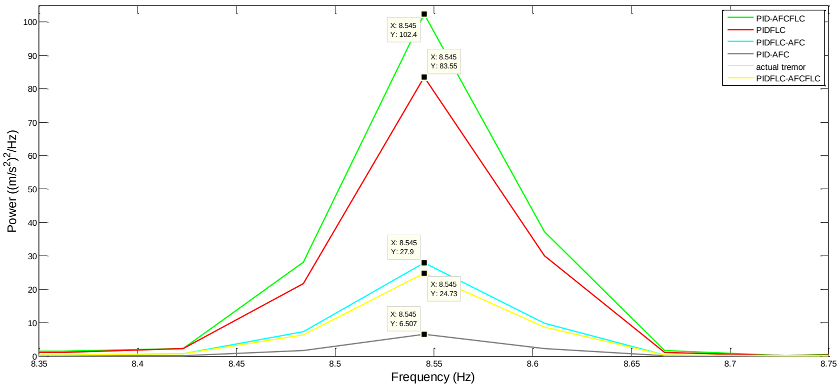

Figure 20 Comparison between the PSD ((m / s^2)^2 / Hz) against acceleration frequency (Hz) for five control models (PIDFLC, PID-AFC, PIDFLC-AFC, PID-AFCFLC and PIDFLC-AFCFLC) and actual acceleration of PD patients. (Zoom mode)

The graph above indicates, the Power Spectrum Density, PSD tremor acceleration of the five models including and the actual PSD tremor acceleration for PD patients against frequency. From Figure 19, it can be seen that the maximum amplitude of actual tremors hand frequency displacement is 43720 ((m/s^2)^2/Hz) with the frequency at 8.545 Hz. Table 7 below shows the average value, the maximum amplitude of frequency displacement (mm) and percentage of reduction of tremor after using proposed controller models.

Table 7 Comparison between the five proposed model and the actual tremor of PD patients of maximum amplitude acceleration frequency at 8.845 Hz, (((m/s^2)^2)/Hz).

No	Proposed Controllers Models	Maximum Amplitude Acceleration Frequency at 8.845Hz , (((m/s^2)^2)/Hz)
1	Actual Tremor	4.372E+04
2	PIDFLC	8.355E+01
3	**PID-AFC**	**6.507E+00**
4	PIDFLC-AFC	2.790E+01
5	PID-AFCFLC	1.024E+02
6	PIDFLC-AFCFLC	2.473E+01

Based on the Figure 20 and Table 7 above, the proposed control model PID-AFC controller is demonstrated the lowest value of maximum amplitude acceleration with 6507 ((m/s^2)^2/Hz) and the frequency at 8.545 Hz. Followed with the PIDFLC-AFCFLC proposed control model with the value of maximum amplitude displacement at 24.73 ((m/s^2)^2/Hz) and the frequency at 8.545 Hz. The third best proposed controller model is PIDFLC-AFC with the value of maximum amplitude displacement, 27.9 ((m/s^2)^2/Hz and the frequency at 8.545 Hz. For the PIDFLC and PID-AFCFLC proposed control model, value of maximum amplitude displacement is as shown in Table 7 with the frequency of 8.545 Hz. Out of both acceleration and frequency graph analyses, it was found that the application of adaptive intelligent, FLC to the AFC and PID controller is viewed appear to about the same in terms of providing robustness and ability of vibration reduction for this study. However, the percentage reduction in tremor, as a whole remained at a relatively high level. All results of this study are an important finding and serve as the initial process that may help other researchers for designing, developing and fabricating equipment or machinery to deal with tremor of PD patients.

4. Conclusion

The comparison results show that the hybrid system model PID-AFC is a highly superior and extremely robust for 4-DOFs biodynamic hand. However, the hybrid model PID-AFC system may not be suitable if there are some external disturbances introduced and the EM obtained from these simulations are not fully effective because the AFC has to adapt to new external disturbances, with some wave signal range. The proposed controller model which combines artificial intelligence methods (FLC), PIDFLC-AFC and PIDFLC-AFCFLC are be found performing more robust dedicated to this case in which, the adaptive method will be able to block the external disturbances or new errors, within the specified range which is [-10, 10] for this study as summaries as Table 8.

Table 8 Summaries of simulation analysis result

No	Type of Controller	Proposed Controller Models	Features
1	Hybrid	PID-AFC	The best model in all analysis results. Appropriate for manual tuning controller [19].
2	Hybrid Artificial Intelligent	PIDFLC-AFC	The best AI model in terms of tremor signal of displacement and acceleration. Appropriate for auto tuning controller [19].
3		PIDFLC-AFCFLC	The best AI model in terms of PSD of displacement and acceleration signal frequency. Appropriate for auto tuning controller [19].

Apart from that, the use of Simulink block CSRC Toolbox is an extremely simple and effective method to get the values of constraint and EM, which is a major problem for designers of models system controller since over the years. In addition, the findings from this study seen have managed to reduce costs in the development of hand tremor suspension system, which does not need to add FLC controller designed into the system especially for PID-AFC proposed model. However, the proposed controller models which are added to AILFC, viewed not be able to compete greatness of proposed hybrid model, PID-AFC controller due to inaccuracies in estimating the gain at FLC derivative input error. This gain is determined by heuristic method, in order to control the FLC input gain error. Next, value an excessively large by gain error input, derived from CSRC block optimizing process can be avoided.

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