International Journal of Control Science and Engineering 2017, 7(2): 32-43
DOI: 10.5923/j.control.20170702.02

Comparative Study between Intelligent Algorithms for Active Force Control of Side Car Mirror Vibration

Mohammad Gohari[1,*], Mona Tahmasebi[2]

[1]Faculty of Mechanical Engineering, Arak University of Technology, Arak, Iran
[2]Agricultural Engineering Research Department, Markazi Agricultural and Natural Resources Research and Education Center Agricultural Research, Education and Extension Organization (AREEO), Arak, Iran

Abstract Side and internal mirrors are used widely in vehicles to have better vision of road, and they play important role in driving controls. Whereas vehicles are exposed to vibration permanently due to road profile, generated vibration in mirrors produces image blurring. Thus maybe driver vision is affected by this issue and unwanted crashes are occurred. Some active vibration controllers were developed based on PID scheme, but this vibration is happen with high speed and conventional controllers cannot attenuate oscillation superiorly. Active force control (AFC) by providing extra feedback can enhance performance of controller in vibration cancelling when high speed disturbances are exciting. In this paper, AFC hybridized to iterative learning algorithm (IL) and neural network (NN). These two schemes were simulated and compared together to find best intelligent method for this purpose. Various disturbances were exerted to the systems, and accuracy and stability of controllers were reached. The results show that AFC-IL has better potential in noise termination compared to AFC-NN in car side mirror vibration reduction.

Keywords Active force control, Side car mirror vibration, Iterative learning, Neural network

1. Introduction

One of the negative effects of vehicle vibration is oscillation of internal and external car mirror. This vibration is results of transmitted vibration from chassis generated by road roughness and induced vibration by wind. The reflected image is blurred by side car mirror vibration, and it is not tolerable by drivers. Some times, blurring image in mirror reduces vision of driver, and this is serious problem in terms of safety. To diminish mirror vibration as problem, mechanical structures of side car mirrors were optimized and mass of those were reduced, but vibration problem still remained. Some passive isolators and active vibration controllers were employed to avoid resonating of mirror. The earlier study on car mirror vibration was done by O'Grady et al., via finite element modeling (FEM) [1]. In another research, the geometry of mirror and stiffness of that was optimized by FEM [2]. Furthermore, induced vibration generated in side car mirror was modeled by Homsi *et al.*, employing computational fluid dynamics (CFD) software and structure of that modified to minimize the unwanted vibration [3]. Additionally, two US patents were submitted which related to vibration reduction side car mirror (US Patent No.5, 818,650 and No.5, 327,288). These inventions use the passive suspension to isolate mirror from car body vibrations. Next, the primary work suggested to use active mirror vibration control were presented [4]. The studies declare that human perception was the mainly affected by frequencies in the range of [0,40Hz]. The aerodynamics of automotive is the main origin of vibrations higher than 20Hz. Frequencies lower than 20Hz are generally attributed to the vehicle body vibration [5, 6]. The control system ought to react to all frequencies in the range [0-120Hz] with particular importance on the resonant modes. Traditional control technique which is simple and stable could just works at a very low speed effectively [7]. In active control, new techniques such as fuzzy, neural network and adaptive controls are established to enhance the robustness and accuracy of controllers.

One of the novel methods in control is active force control (AFC) which is focused by researchers, which is discussed subsequent, because of its high efficiency, rationally simplicity, and accuracy. A whole package of the AFC system was recommended by Hewit and Burdess to control a robot manipulator [8]. AFC has been suggested to be effective in remove noises and disturbances for physical systems. The AFC method was initially utilized for vibration control by Hewit et al. to control a flexible robot arm motion [9]. Furthermore, the AFC integrated with conventional controller was employed in active suspension systems of vehicles [10, 11]. Besides, it has been employed to roll vibration attenuating of a spray boom [12-15]. Additionally, AFC was applied in trajectory control of mobile robot [16].

* Corresponding author:
moh-gohari@arakut.ac.ir (Mohammad Gohari)
Published online at http://journal.sapub.org/control

The consequences of these studies performed the AFC technique is more successful in rejecting disturbances of undesired oscillation of the systems. The outcomes of these investigation declared that the AFC approach is more efficient in suppression the magnitude of unwanted vibrations of the system. as the most vital computational unit in AFC is the estimate of the estimated mass or moment of inertia of system dynamics, the employ of artificial intelligence (AI) technique for instance artificial neural network (ANN) and iterative learning (IL) to find out this parameter has been commenced by Mailah [7]. Next, other types of AI method entrenched into the AFC method has been suggested such as fuzzy logic (FL) [17, 18, 9], neural network [19, 10, 20], and iterative learning [21-23] techniques had been extensively utilized by investigators.

As implied, vibration reduction in side car mirror is so crucial, and disturbance rejection is main function of controller. Due to this issue, current paper tries to enhance performance of active mirror vibration control system (AMVS) by employing active force control (AFC). To approximate estimated mass inertia, two schemes were evaluated: artificial neural network (NN) and iterative learning (IL). The possibility of vibration suppression by these two techniques was evaluated by simulations.

2. Methodology

First of all, dynamic modeling of AMVS is discussed in this part. Then, the designed PID controller was hybridized to AFC scheme. Approximation of estimated mass inertia is done by NN and IL. The performance of AMVS integrated by AFC will be simulated by Simulink/MATLAB and will be compared together.

2.1. Side Car Mirror Suspension Model

Though road roughness and wind typically leads to vibration in the side car mirror, canceling these unwanted vibrations is vital to increase driver vision accuracy on the reflected image. The major advantage of performing active suspension method is the potential of the system in which the suspension parameters can be adaptively adjusted through the action.

As roll vibration is major type of generated vibration in side car mirror [24], control system was designed to attenuate that. The mirror jam used in this research is considered as rigid plate pivoted to a mirror frame and a solenoid with metal core is engaged as the actuator. A schematic illustration of the mirror suspension system is exemplified in Fig. 1.

The essential torque is wanted on the mirror screen is calculated by the general equation of motion for rotating systems as follows [25] (Craig, 2005):

$$\tau = H(\theta)\ddot{\theta} + h(\theta,\dot{\theta}) + G(\theta) + \tau_e \quad (1a)$$

Where
τ : Actuated torque
θ : Mirror screen angle
$\ddot{\theta}$: Mirror screen angular acceleration
H: Inertia matrix of system
h: Centripetal and Coriolis torque vector
G: Gravitational torque vector
τ_e : External disturbance

The mirror frame is excited to different internal and external disturbances which some of them comes from road profile and engine vibration trough working and some of them generated by wind. So, the simplified Equation 1a can be stated as bellow:

$$\tau = I\ddot{\theta} + C\dot{\theta} + K\theta \quad (1b)$$

Where
I: mirror screen mass moment of inertia
C: Rotational Damper constant of mirror
K: Rotational spring constant of mirror

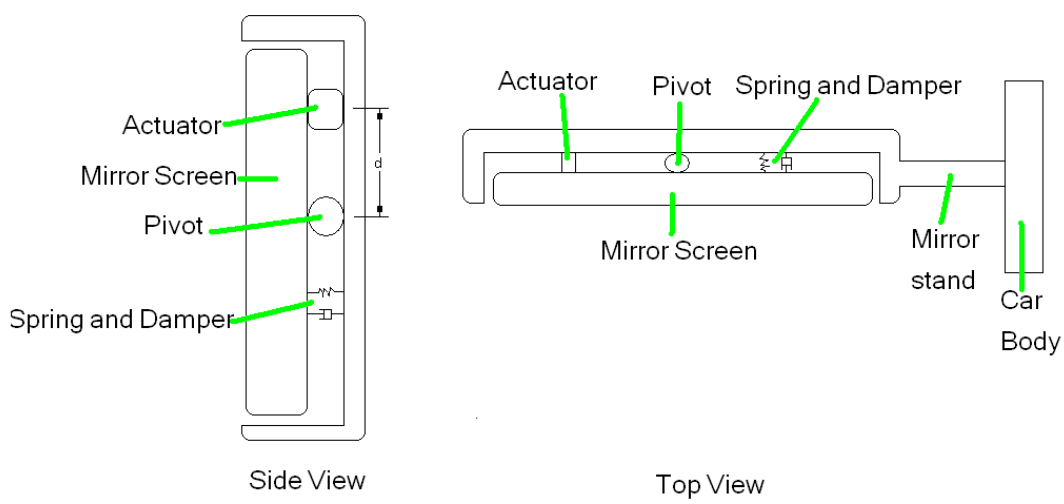


Figure 1. A schematic diagram of Side Car Mirror Vibration

2.2. Active Force Control

Hewit and Burdess firstly presented the AFC which established on Newton's second law of movement [8]. In this control strategy, the actuated force/torque is measured by sensor or other techniques. Also, the desired torque/force calculated from acceleration of output by multiplying to estimated mass/inertia. The difference between these two torques/forces is delivered to the actuator to compensate. Thus, enough torque/force is generated by actuator which adjusted by controller. In fact, this difference is estimated disturbance which it should be compensated and can be mentioned as bellow:

$$Q' = T' - I'\alpha' \tag{2}$$

Where Q', I ', and T 'are estimated disturbances torque, estimated inertia, and actuated torque, correspondingly [7]. If disturbance torque can be predicted precisely, it can be applied to decouple the performed torque from the actual disturbances torque. This aids the system to stay stable in attendance of external instabilities generators. As torque of actuator is considered as a linear magnetic actuator which has distance to pivot point to produce required torque in this project, Equation (2) can be represented in the subsequent appearance [26, 27]:

$$Q' = F_{magnet} d - I'\alpha' \tag{3}$$

Where

$$T' = F_{magnet} d \tag{4}$$

Where as F_{magnet} (force) can be applied by magnetic intensity (B), magnetic flow (L), n is number of wire cycles and electrical current (i) according to bellow:

$$F = nBLi \tag{5}$$

The electromagnetic force (F_{magnet}) is proportional to the current (i) according to [26, 27]:

Then, by substitution equation 5 in equation 4, following equation was reached:

$$T' = BLdi \tag{6}$$

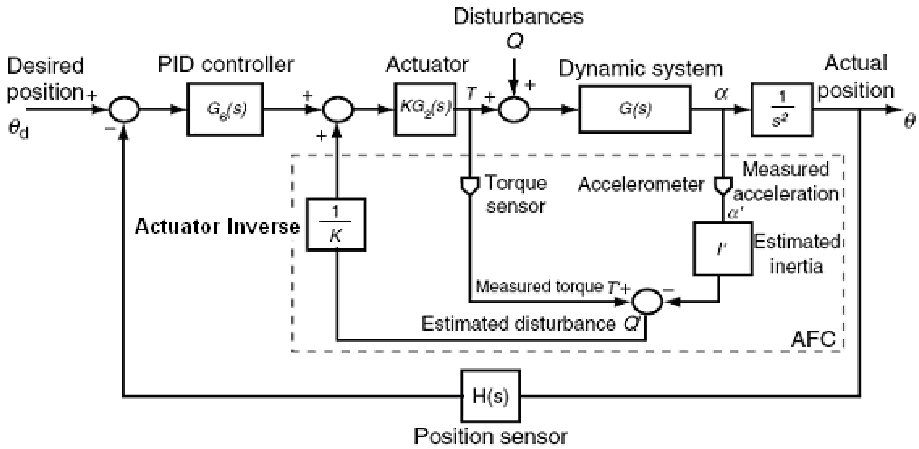


Figure 2. The block diagram of applied AFC to AMVS

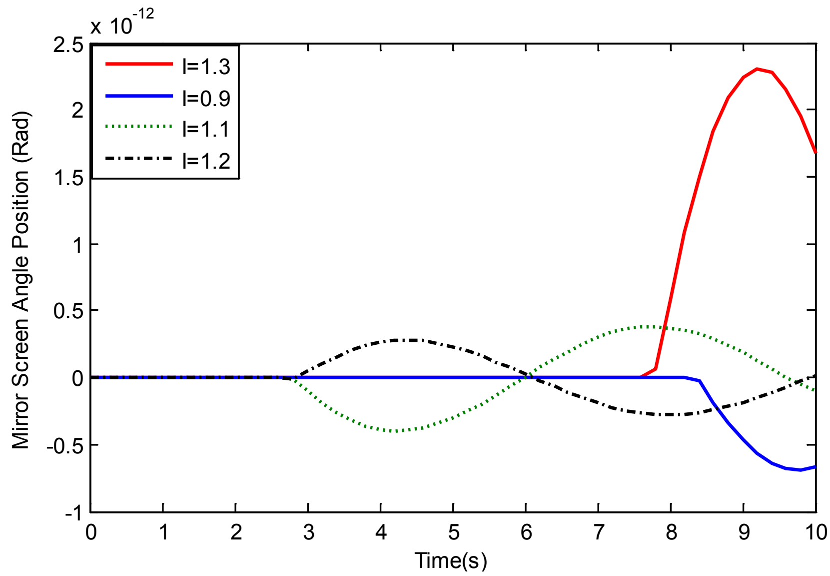


Figure 3. Performance of AVSM in reducing mirror screen motion for different values of mass moment of inertia

By simplification the constant coefficients (BLd) was considered as K:

$$K = BLd \Rightarrow T' = Ki \quad (7)$$

The "i" is the solenoid electrical current, and "K" is the solenoid torque constant. Also, "d" is distance between pivot point and linear magnetic actuator, and "B" is magnetic intensity. In addition, to measure actuated torque, the consumed current is multiplied to magnetic solenoid constant.

The performance of AFC related on method of calculation of the mirror screen estimated inertia. The schematic diagram of the AFC-PID approach employed to AMVS is depicted in Fig.2. In this paper, the techniques to attain the estimated inertia are iterative learning (IL) and neural network (NN). The best performance of AFC-PID control system was acquired by I'=0.115 via crude method. Various estimated inertia values produce various response of system where as large value of I' generates instability in the system. Fig.3 illustrates effect of I' on the performance of AMVS responses.

2.3. AFC-NN Developed Technique for AMVS

The earlier studies on the theory of artificial neural network (ANN) initiated in the 1980's [28-31]. A classic ANN multilayer feed forward topology includes of a number of neurons as input, hidden and output layers. They are interconnected through weights updated as the training process. Threshold or activation functions are typically non-linear functions which are applied at the output. The mainly ordinary equation that expressed the input/output relationship of a neuron is as bellows:

$$y = f\left(\sum_{i=1}^{m} w_i I_i + b\right) \quad (8)$$

Where $\{x_j\}$ is the set of inputs, w_{ij} is the synaptic weight connecting the j_{th} input to the i_{th} neuron, b_i is a bias, $\varphi_i(\ )$ is the activation function, and y_i is the output of the ith neuron considered. The back propagation error algorithm is commonly used as training algorithm. This algorithm adjusts the weights and biases through learning process via input-target pairs by minimizing the error between target and network output as bellow [32]:

$$e^2(n) = (y_d(n) - y_a(n))^T (y_d(n) - y_a(n)) \quad (9)$$

Where e is error, and y_a, yd are network output and target, respectively. Also, Levenberg-Marquardt (LM) algorithm is utilized as training function [33]:

$$W_{ij}(n+1) = W_{ij}(n) + \Delta W_{ij}(n) \quad (10)$$

$$\Delta W_{ij}(n) = \frac{1}{J^T(W_{ij}(n))J(W_{ij}(n)) + \mu I} J(W_{ij}(n)) e(W_{ij}(n)) \quad (11)$$

Where W_{ij} is the weight, μ is referring to the learning rate; I and J are identity matrixes and Jacobin, respectively.

The AFC is equipped by NN to forecast estimated inertia online. The NN topology, training and adaptation were done offline. In proposed NN, input is error signal and output is estimated inertia. The NN includes 2 hidden layers and 5 neurons in each layer. Fig.4 shows the AFC for AMVS which is implemented to NN. In this architecture, NN can predict estimated mass moment of inertia from error signal. To find best topology of NN, crude method was performed. The NN error minimization was employed to update the weights and biases via LM algorithm.

The controller system was simulated by MATLAB/Simulink Software and exemplified in Fig.5. To be sure about controller performance, various disturbances were tested by simulation as continue:

- Sinusoidal wave of amplitude, am = 5 cm and frequency, f = 4.4 Hz
- Sinusoidal wave of amplitude, am = 5 cm and frequency, f = 2.2 Hz

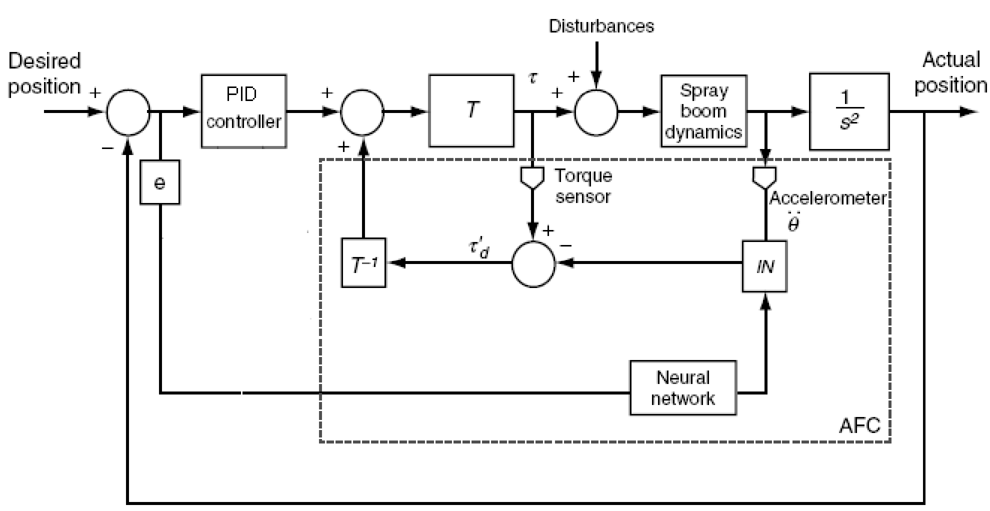


Figure 4. Schematic diagram of AFC-NN

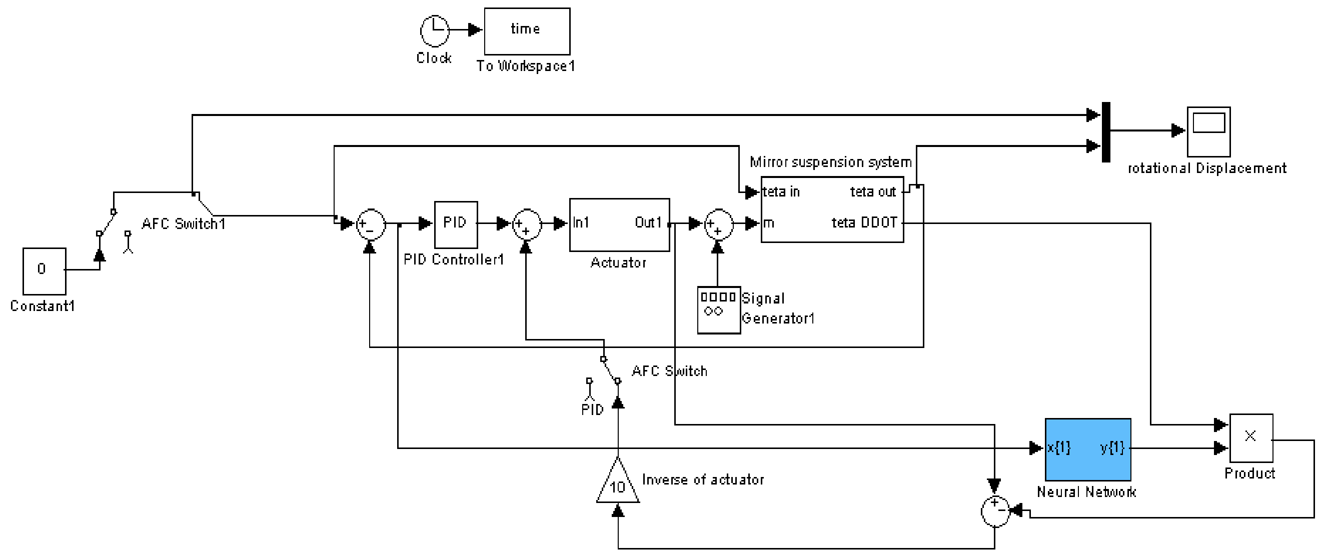


Figure 5. The simulated AFC-NN by MATLAB/Simulink Software

The amplitudes and frequencies of sinusoidal wave functions were chosen refers to study by Priyandoko et al., for vehicle systems [10]. The result of AFC-NN was studied and discussed in later sections. The mechanical properties of side car mirror and tuned PID controller coefficients are listed in Table 1. The mirror constant was acquired from Irankhodro Company for SAMAND sedan car. Tuning of PID was done by trail and error technique.

Table 1. Side Car Mirror Parameters and PID controller coefficients

Mass of mirror screen	0.35 Kg
Mirror screen Mass moment of inertia	0.00358 Kg.m^2
Rotational Spring constant	26.9 Nm/rad
Rotational Damper constant	0.1 Nms/rad
PID parameters:	
Proportional coefficient (Kp)	10
Integrative coefficient (Ki)	1.1
Derivative coefficient (Kd)	3

2.4. Iterative Learning Scheme

The iterative learning algorithm (ILA) is an intelligent approach during the performance of a dynamical system be enhanced and enhanced as time increases based on minimizing the error. The fundamental concept of the ILA was first time established by Uchiyama [34]. Later on, Arimoto et al. afford an adequately analysis of the convergence, stability and robustness of the ILA [35 and 36]. Fig.6 shows a schematic of the proportional-Integral-Derivative type (PID-type) of ILA.

The input signal u_k and the current output signal y_k are saved in memory each time of processing. The system error, $e_k = y_d - y_k$, is evaluated by the learning algorithm where y_d is the preferred output of the system. Then algorithm calculates a new input signal u_{k+1} based on this error signal, which is stored for next iteration. The subsequently input command is chosen where as it leads to the performance error to be diminished on the next iteration. To have better convergence and stability in algorithm output, integrator and derivative elements were added to ILA which is called PID-ILA. The equations described PID-ILA is declared following:

$$u_{k+1} = u_k + (\Phi + \Gamma \frac{d}{dt}) e_k \quad (12)$$

$$u_{k+1} = u_k + (\Phi + \Psi \int dt) e_k \quad (13)$$

$$u_{k+1} = u_k + \Phi e_k + \Gamma \frac{de_k(t)}{dt} + \Psi \int e_k(\tau) d\tau \quad (14)$$

Where Φ is proportional learning parameter, Γ and Ψ are derivative and integral learning parameters, respectively. Fig.7 shows the PID-IL applied in AFC. The coefficients of ILA "Φ , Γ , and Ψ" were tuned as 0.0001 by Heuristic method.

The simulated AFC-IL is shown in Fig. 8, and results of that is discussed and compared to AFC-NN and PID in next section.

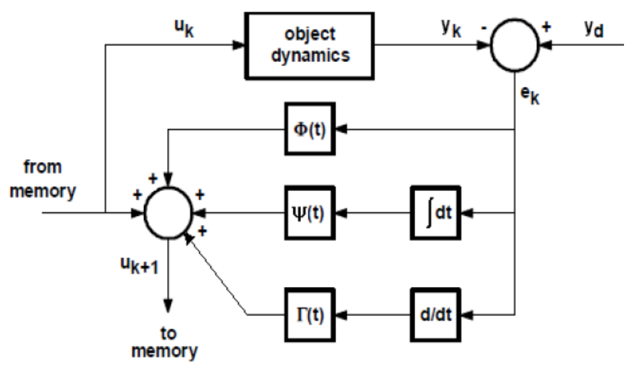


Figure 6. Schematic diagram of the PID-type of ILA

3. Result and Discussion

Fig.9 illustrates the time responses of mirror angular position for conventional PID, AFC-NN, and AFC-IL strategies when exposed to disturbance which is described before. The results unveil that the performance of PID is not good as much as AFC-IL and AFC-NN. Also, the response of PID is not stable compared to AFC-IL and AFC-NN. It means that potential of PID in canceling of vibration is very lower than other intelligent AFC schemes. In addition, AFC-NN variation is lower than AFC-IL which is obvious in shown close up view of Fig. 9. The root means square values (RMS) were computed to measure closeness of responses to desired value. The RMS values were reached as 9.23*10^-15, 0.11*10^-15, and 0.0004 for AFC-IL, AFC-NN, and PID, respectively.

Furthermore, the responses of three schemes were obtained in frequency domain by Fast Fourier Transformation (FFT) which is depicted in Fig.10 and 11. As can be seen in Fig. 10, the peaks of magnitude of PID acquired around 0.15 while in AFC-IL and AFC-NN are around 2.5*10^-12. Although first peak of AFC-NN and AFC-IL are same, between 10 to 100 Hz, the magnitudes of NN are lower than IL.

Also, the responses of controllers were reached when square disturbance applied. As can be seen in Fig.12, PID controller can not attenuate the vibration as well as AFC-NN and AFC-IL which exemplified in Fig.13. The comparison between PID, AFC-NN and AFC-IL in frequency domain were shown in Fig.14 and Fig.15. The peaks of magnitude of PID attained around 0.65 while in AFC-IL and AFC-NN are around 2*10^-9 and1.5*10^-7, respectively.

In addition to previous disturbances, system was subjected to White Noise Random, and results of various schemes were unveiled in Fig.16 and Fig.17, in time and frequency domain, respectively. Again, in both domains, AFC-NN and AFC-IL show better performance compared to PID controller. Subsequently, for better comparison, the results of AFC-IL and AFC-NN were demonstrated separately in Fig.18 and Fig.19, respectively.

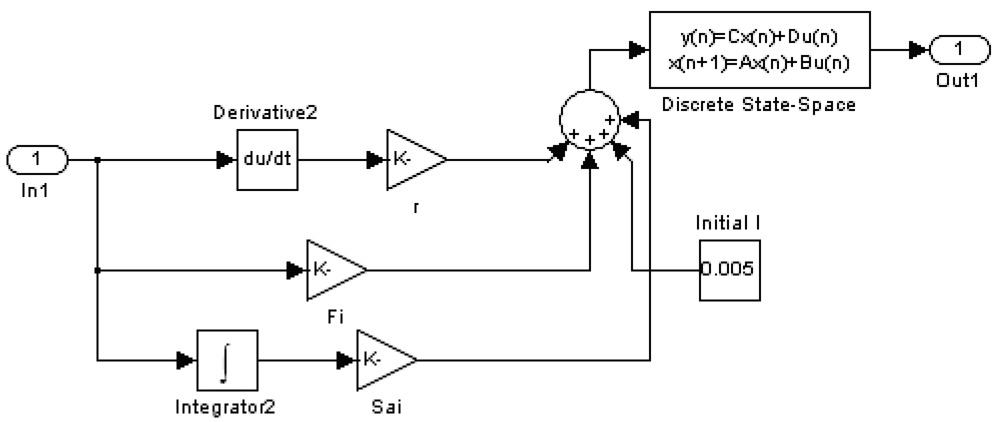


Figure 7. Applied PID-IL in AFC

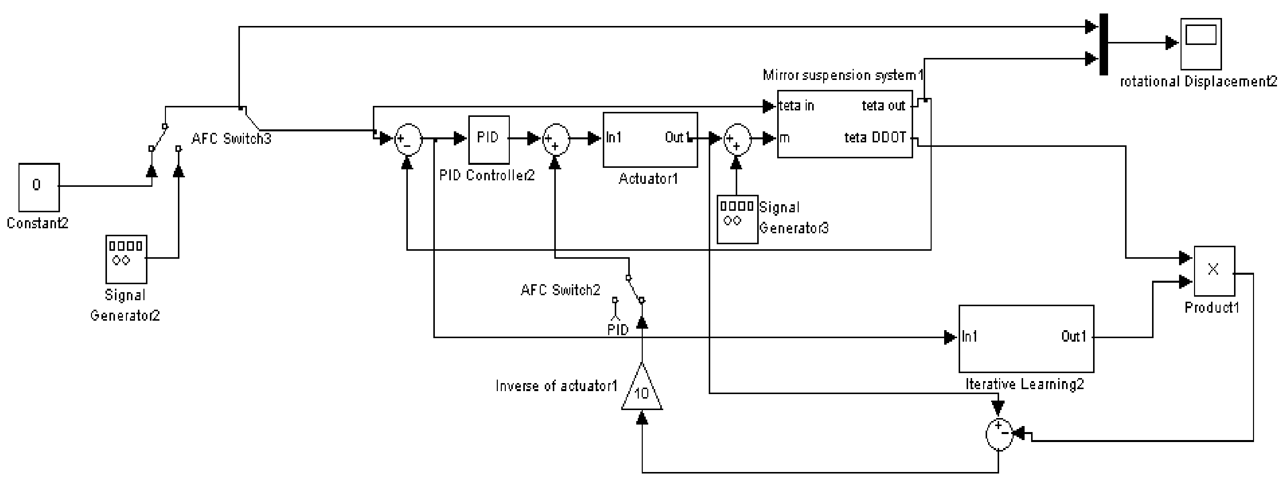
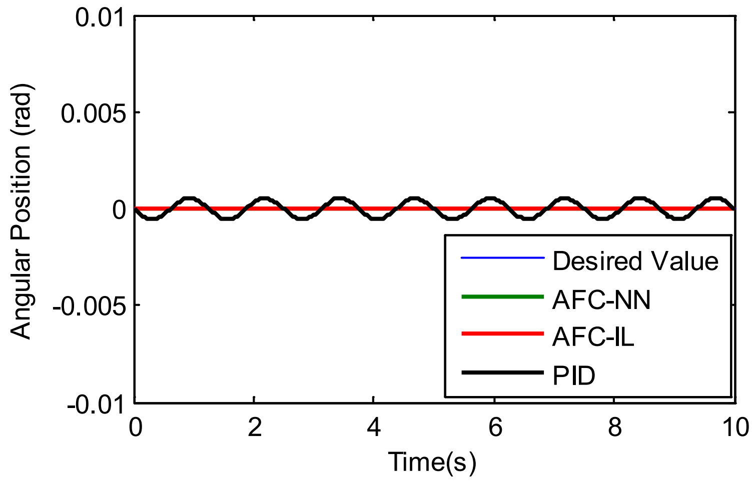
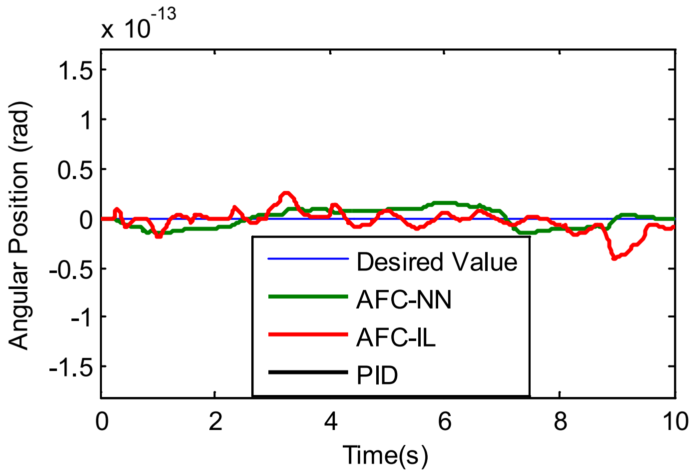


Figure 8. The simulated AFC-IL for AMVS



(a)



(b)

Figure 9. (a) The time response of all the control schemes with Sinusoidal disturbance, (b) the close up view of responses

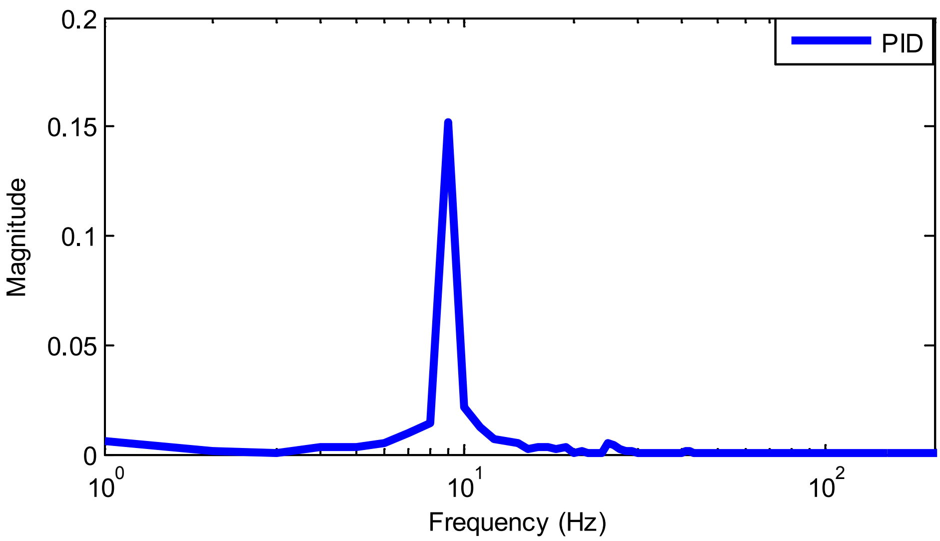


Figure 10. The frequency domain response of PID controller subjected to sinusoidal disturbances

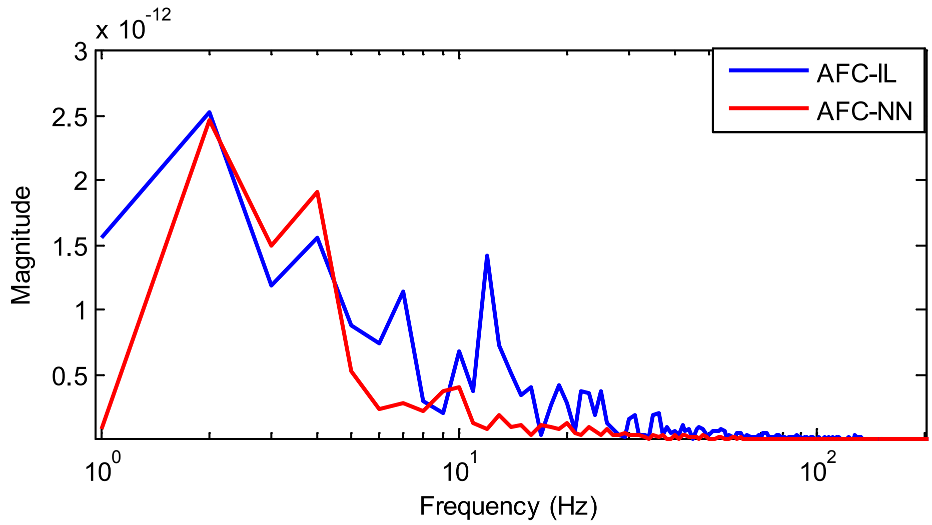


Figure 11. The frequency domain response of AFC-IL and AFC-NN schemes subjected to sinusoidal

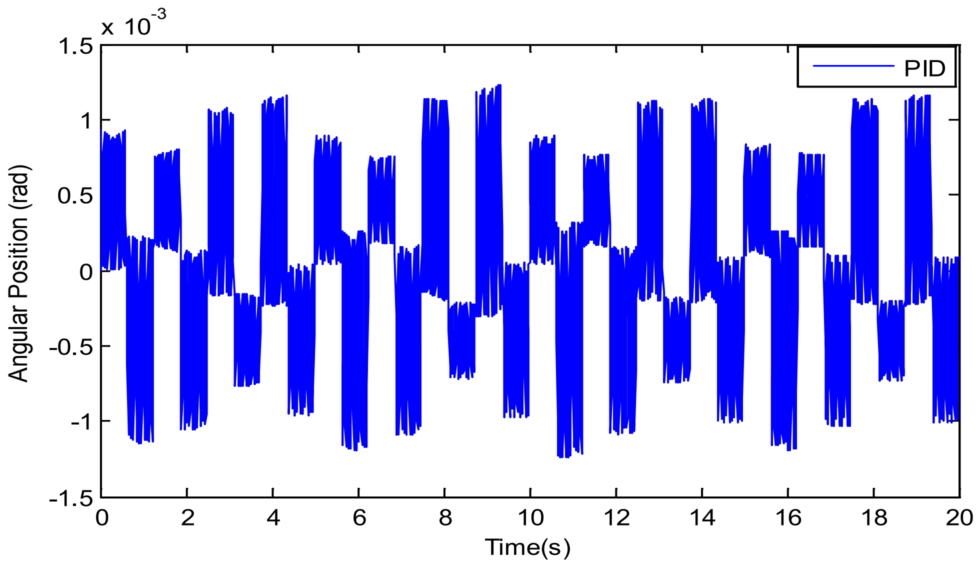


Figure 12. The time domain response of PID controller subjected to square disturbances

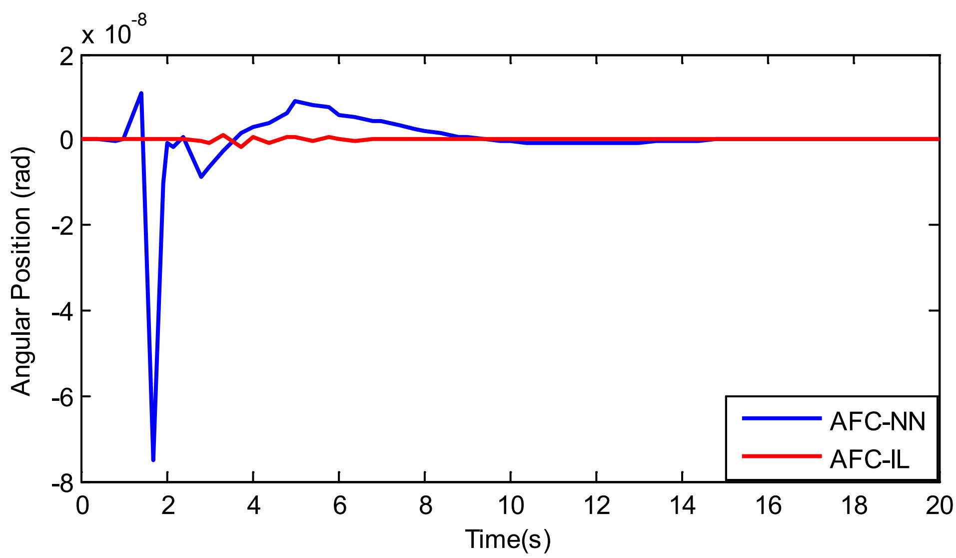


Figure 13. The frequency domain response of AFC-IL and AFC-NN controllers subjected to square disturbances

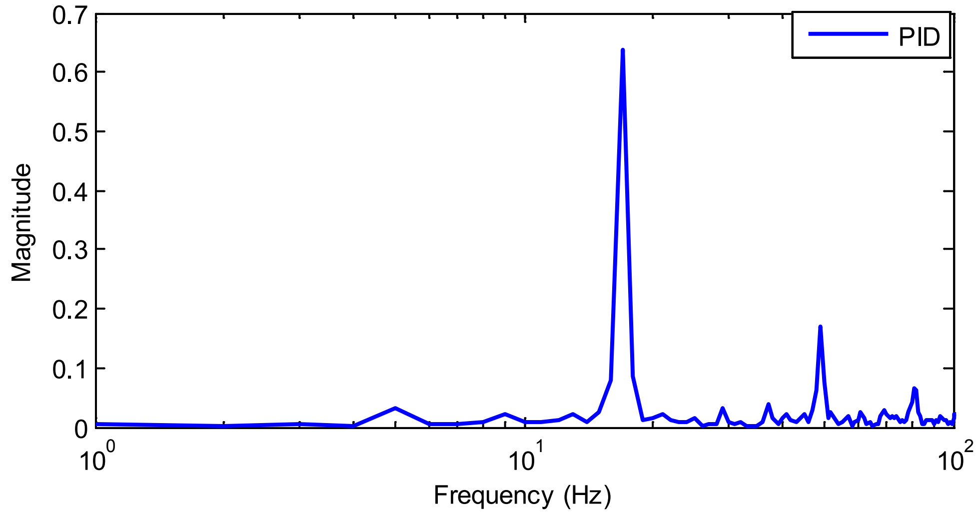


Figure 14. The frequency domain response of PID controller subjected to square disturbances

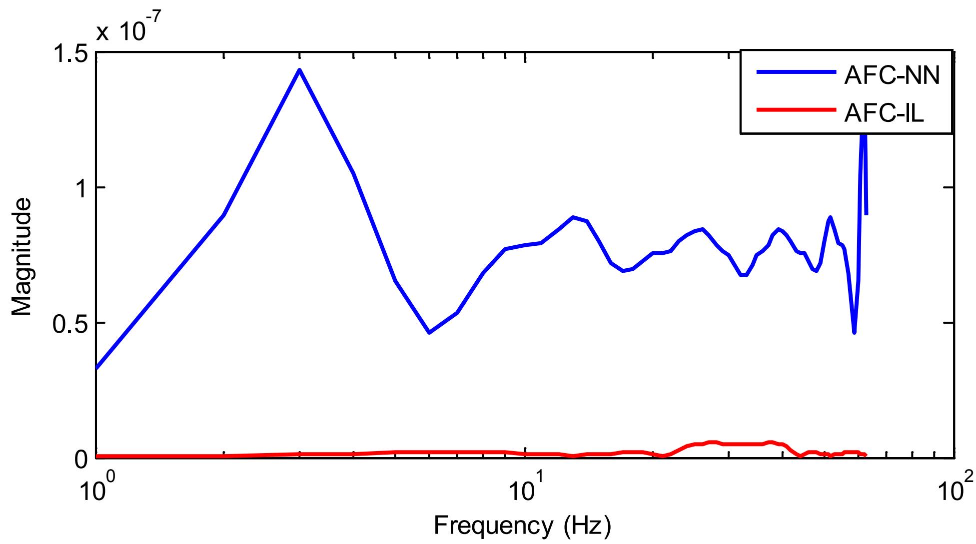


Figure 15. The frequency domain response of AFC-IL and AFC-NN schemes subjected to square disturbance

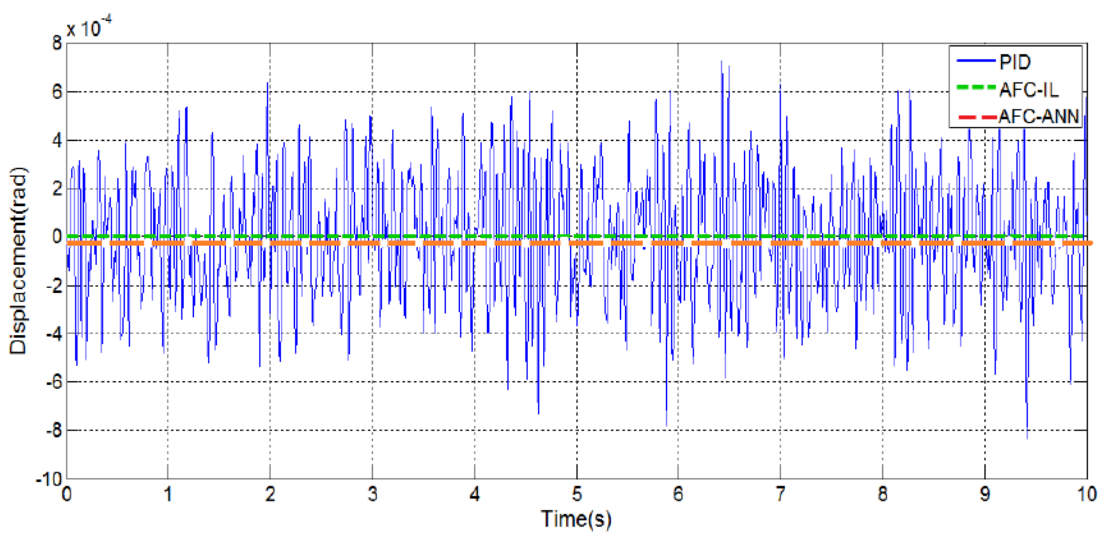


Figure 16. The time response of all the control schemes with White Noise Random

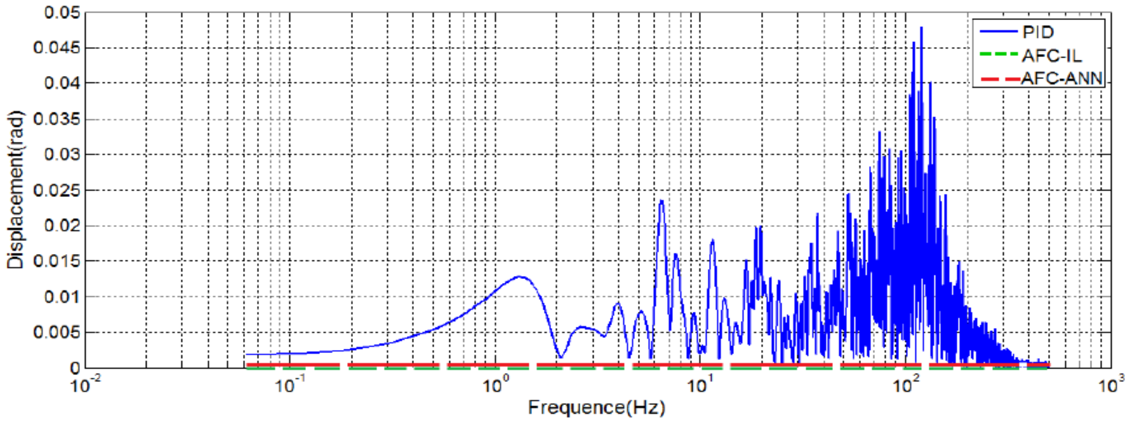


Figure 17. The frequency domain response of PID, AFC-IL and AFC-NN schemes subjected to White Noise Random

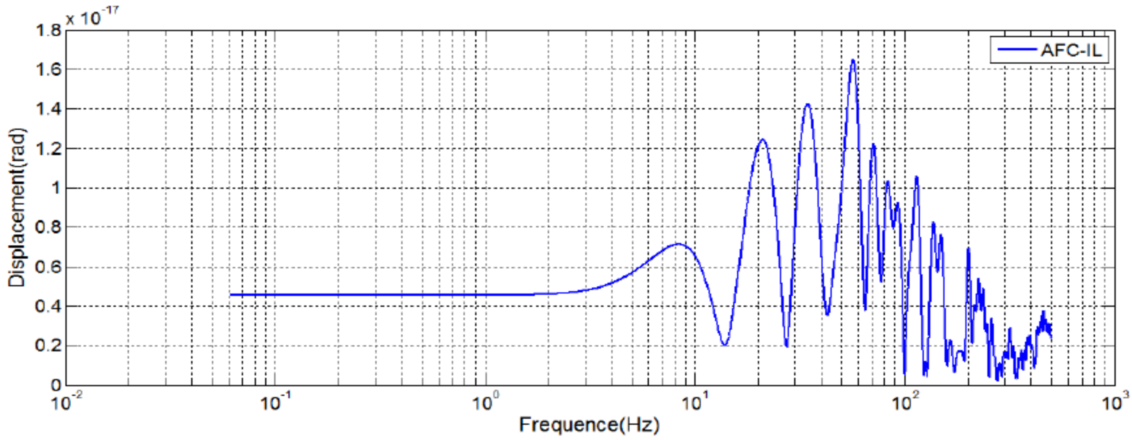


Figure 18. The frequency domain response of AFC-IL scheme subjected to White Noise Random

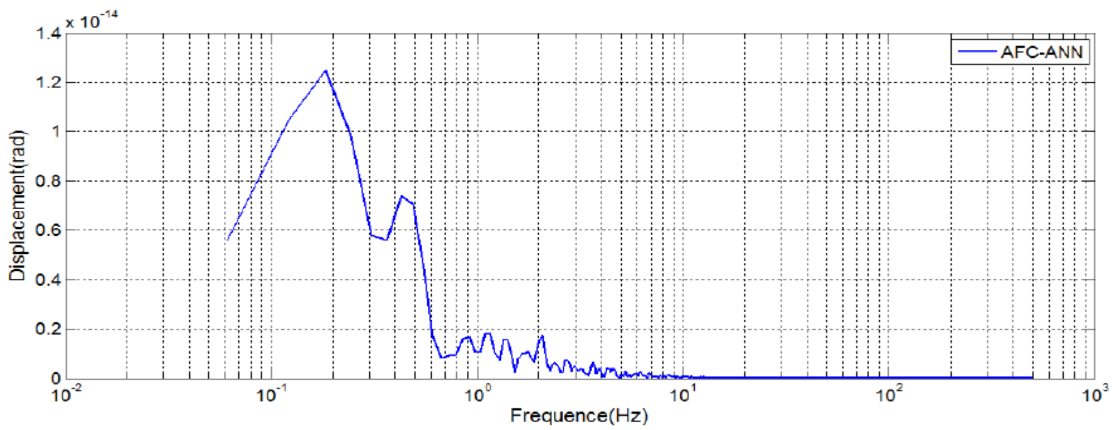


Figure 19. The frequency domain response of AFC-NN scheme subjected to White Noise Random

Table 2. Comparison between AFC-IL and AFC-NN

	PID	AFC-IL	AFC-NN
The RMS values (Sinusoidal disturbance)	0.0004	9.23*10^-15	0.11*10^-15
The first peak of magnitude in frequency domain (Sinusoidal disturbance)	0.15	2.5*10^-12	2.5*10^-12
The RMS values (White Noise Random)	0.006	14*10^-18	15*10^-18
The first peak of magnitude in frequency domain (White Noise Random)	0.012	0.7*10^-17	1.2*10^-14
The RMS values (Square disturbance)	0.005	3*10^-10	9*10^-10
The first peak of magnitude in frequency domain (Square disturbance)	0.65	2*10^-9	1.5*10^-7

4. Conclusions

A new controller occupied the active force control for vibration control of vehicle side mirror. This AFC were hybridized to artificial neural network and iterative learning algorithm called AFC-NN and AFC-IL, respectively. The designed controllers were simulated for the suppression of a roll motion of a side car mirror suspension system. The AFC-based scheme is found to be simple in terms of computation and make it proper for real time usage. Also AFC is efficient and create robust and accurate still in the attendance of diverse disturbances. Besides, the simulation results demonstrate that for known parameters and situations, the proposed AFC-NN and AFC-IL schemes performances improved compared to the conventional PID controller. Additionally, AFC-IL in comparison to AFC-NN shows better response in frequency domain and time domain. The results as well express that the AFC-based strategy as intelligent control method is able to reject the disturbances efficiently for the side car mirror suspension. However, supplementary trail should be conducted to investigate the effects of other forms of disturbances, uncertainties and parametric changes in real condition such as road tests. A continuing research through the development of a full working test rig equipped to the proposed control strategy is in progress to practically assess and evaluate the simulation findings related to the parameters of concern.

REFERENCES

[1] O'Grady M., McCarthy B., Vibration in an automobile internal rear-view mirror, Mechanical & Corrosion Properties, Series a (Key Engineering Materials) (1996), Vol.118-119, pp.35-42.

[2] Song F., Ayorinde E. O., Vibration characteristics of the automotive rearview mirror, American Society of Mechanical Engineers (ASME)- Noise Control & Acoustics Division (1999), Vol. 26, pp.247-251.

[3] Homsi E., Weir S., Reinhardt L, Minimization of flow induced vibration on thermoplastic automotive side-view mirror, Special Areas Annual Technical Conference – ANTEC (1998), Conference Proceedings, Vol. 3, pp. 2628-2634.

[4] Moo A., Huynh T. S., Active Mirror Control, (2002), Adelaide University.

[5] Watkins S., Oswald G., The flow field of automobile add-ons — with particular reference to the vibration of external mirrors, Journal of Wind Engineering and Industrial Aerodynamics (1999), Vol. 83, pp. 541-554.

[6] Lee K., Barbaro M, Watkins S., Vehicle & Industrial Aerodynamics group, Data of on road vibration measurements of a side-view mirror.

[7] Mailah, M., Intelligent Active Force Control of a Rigid Robot Arm Using Neural Network and Iterative Learning Algorithms (1998), University of Dundee, UK: Ph.D Thesis.

[8] Hewit, J. R. and Burdess, J. S., Fast Dynamic Decoupled Control for Robotics using Active Force Control. Trans. Mechanism and Machine Theory (1981), 16(5), 535-542.

[9] Hewit, J. R. and Morris, J. R., Disturbance observer control with estimation of the inertia matrix, Proc. of IEEE/ASME International Conference on Advanced Intelligent Mechatronics (1999), 753-757.

[10] Priyandoko, G. Mailah, M., Jamaluddin, H., Vehicle active suspension system using skyhook adaptive neuro active force control. Journal of Mechanical Systems and Signal Processing (2009), 23, 855–868.

[11] Rajeswari, K., Lakshmi, P. Simulation of suspension system with intelligent active force control. Proceeding of International Conference on Advanced in Recent Technologies in Communication and Computing (2010), 271–277.

[12] Tahmasebi, M., Rahman, R.A., Mailah, M., and Gohari, M. (2012). Sprayer Boom Active Suspension using Intelligent Active Force Control. Journal of World Academy of Science, Engineering and Technology, 68, 1277-1281.

[13] Tahmasebi, M., Rahman, R.A., Mailah, M., and Gohari, M. (2013a). Active Force Control Applied to Spray Boom Structure. Applied Mechanics and Materials Journal (In press).

[14] Tahmasebi, M., Rahman, R.A., Mailah, M., and Gohari, M. (2013b). Roll Movement Control of a Spray Boom Structure using Active Force Control with Artificial Neural Network Strategy. Journal of low frequency noise, vibration and active control, 32(3), 189-202.

[15] Tahmasebi, M., Gohari, M., Rahman, R.A., and Mailah, M. (2013c). Self-Tuning PD Controller of a Sprayer Boom Structure Using Neural Network. 4th IGCESH 2013. Universiti Teknologi Malaysia

[16] Gohari, M., Tahmasebi, M., and Nozari, A., Application of machine learning for NonHolonomic mobile robot trajectory controlling, 4th International eConference on Computer and Knowledge Engineering (2014), pp. 42-46.

[17] Mailah, M. and Rahim, N. I. A., Intelligent Active Force Control of a Robot Arm Using Fuzzy Logic. IEEE International Conference on Intelligent Systems and Technologies TENCON (2000). 24-27 September. Kuala Lumpur, 291-296.

[18] Jahanabadi, H., Mailah, M., Md Zain, M. Z., and Hooi, H. M., Active Force with Fuzzy Logic Control of a Two-Link Arm Driven by Pneumatic Artificial Muscles. Journal of Bionic Engineering (2011), 8, 474-484.

[19] Hussein, S. B., Jamaluddin, H., Mailah M. and Zalzala, A., A Hybrid Intelligent Active Force Controller for Robot Arm using Evolutionary Neural Networks. Proceedings International Conference on Evolutionary Computation (2000), San Diego, USA. 117-124.

[20] RA Rahman, M Tahmasebi, M Gohari, Design and Simulation of a Passive Vertical Suspension System for Spray Boom Structure, Journal of Mechanics Engineering and Automation (2011), Vol.1(6), 420-424.

[21] Kwek, L. C., Wong, E. K., Loo, C. K. and Rao, M. V. C., Application of Active Force Control and Iterative Learning in a 5-Link Biped Robot. Journal of Intelligent and Robotic

Systems (2003), 37: 143–162.

[22] Mailah, M., Hooi, H. M., Kazi, S., and Jahanabadi, H., Practical Active Force Control with Iterative Learning Scheme Applied to A Pneumatic Artificial Muscle Actuated Robotic Arm. International Journal of Mechanics (2012), 1(6), 88-96.

[23] Noshadi, A., Zolfagharian, A., & Mailah, M., Performance analysis of the computed torque based active force control for a planar parallel manipulator. Applied Mechanics and Materials (2012), 110, 4932-4940.

[24] Grasas, C., & García, J. J. (2001). Measurement of in-service vibration of interior mirrors using virtual laser technique. ATZ worldwide, 103(10), 12-15.

[25] Larchez, A., & Naghdy, F. (2005). Real time prediction of vehicle mirror vibration.

[26] Kerber, F., Hurlebaus, S., Beadle, B. M. and Stobener, U., Control concepts for an active vibration isolation system. J. Mechanical System and Signal Processing (2007), Vol. 21, pp. 3042-3059.

[27] Chen, K. T., Chou, C. H., Chang, S. H. and Liu, Y. H., Intelligent active vibration control in an isolation platform. J. Applied Acoustics (2008), Vol.69, pp. 1063-1084.

[28] RP Lippmann, Pattern classification using neural networks, IEEE communications magazine 27 (11), 47-50.

[29] Lippmann, An Introduction to Computing with Neural Nets., IEEE ASSP Magazine(1987), pp. 4–22.

[30] Hecht-Nielsen, Neurocomputing: Picking The Human Brain, IEEE Spectrum (1988), 25(3), pp. 36–41.

[31] Wasserman, Philip D., Neural Computing: Theory and Practice (1989), Van Nostrand Reinhold.

[32] Wilamowski, B.M., Iplikci, S., Kaynak, O., and Efe, M.O., An algorithm for fast convergence in training neural networks. Proceedings of the International Joint Conference on Neural Networks (2001), Washington, DC, USA, Vol. 3, pp. 1778–1782.

[33] Hagan, M.T., and Menhaj, M.B., Training feed forward networks with the Marquardt algorithm, IEEE Transactions on Neural Network (1994), 5 (6), 989–993.

[34] Moore, K. L., Iterative Learning Control for Deterministic Systems. Springer-Verlag (1993), London Limited.

[35] Arimoto, S., Kawamura, S. and Miyazaki, F., Bettering operation of robots by learning, J. Robotic Syst (1984), Vol.1, pp. 123140.

[36] Arimoto, S., Kawamura, S. and Miyazaki, F., Applications of Learning Method for Dynamic Control of Robot Manipulators. Proc. of 24th Conf. on Decision and Control. Ft. Lauderdale (1985), 1381-1386.