# GA TUNED DISTANCE BASED FUZZY SLIDING MODE CONTROLLER FOR VEHICLE SUSPENSION SYSTEMS

K.Rajeswari[1] and P.Lakshmi[2]
[1]Research scholar, [2]Assistant Professor,
Department of Electrical Engineering, College of Engineering, Guindy, Anna University, Chennai, India.
Email: rajeswariarul@gmail.com

## *ABSTRACT*

*This paper presents the design of Genetic Algorithm tuned Distance based Fuzzy Sliding Mode Controller (GA+DFSMC) applied to vehicle suspension system of a quarter car model. DFSMC has only one-dimensional rule table and the generation of fuzzy rules becomes easier. Genetic Algorithm (GA) is proposed to tune the gain parameters to increase the speed of system response and to reduce the chattering in the sliding phase so that a better performance can be achieved. The objective of this work is to design, simulate and compare the performance of the GA+DFSMC with various controllers. Simulation is carried out using MATLAB and SIMULINK. Simulation results indicate that the proposed vehicle suspension system proves to be effective in the vibration isolation of the vehicle body.*

*Keywords: vehicle suspension, quarter car model, fuzzy sliding mode, genetic algorithm, chattering*

## INTRODUCTION

The vehicle suspension system is currently of great interest both academically and in the automobile industry worldwide. Increased competition in the automotive market has forced industries to research on alternative strategies to the classical passive suspension systems. In order to improve the handling and comfort performance, instead of a conventional static spring and damper system, semi-active and active systems are being developed. A semi-active suspension involves the use of dampers with variable gain. An active suspension involves the passive components augmented by actuators that supply additional forces. Alternatively, an active suspension system possesses the ability to reduce the acceleration of sprung mass continuously as well as to minimize suspension deflection which results in the improvement of tyre grip with the road surface [1].

Various control strategies have been proposed in past four decades to control the vehicle suspension system. Optimal control has been used in active suspension system since 1960s [2]. Fuzzy Logic Controller (FLC) has emerged as another method for design of an automotive active suspension system [3-7]. FLC scheme needs a trial and error method to design the rule table and the control parameters. Sliding Mode Control (SMC) of an active suspension has been reported by many researchers [8, 9]. The sliding mode control has relatively simple structure and it guarantees the system stability. Due to the discontinuous control component in the control law, there exists chattering in the control output. To overcome the above shortcomings, Fuzzy Sliding Mode Controller (FSMC) was proposed [10, 11]. Recently, the adaptive fuzzy sliding mode controller is reported to suppress the sprung mass position oscillation due to road surface variation in an active suspension system [12-15]. This intelligent control strategy combines adaptive rule with fuzzy and sliding mode control algorithms.

In this paper, Genetic Algorithm (GA) applied to Distance based Fuzzy Sliding Mode Controller (DFSMC) has been developed for an active vehicle suspension system. In the process of designing the proposed controller, a new variable called the signed distance is introduced which is the distance between the actual state and the sliding line $S$ in the $x-\dot{x}$ plane. The signed distance is used as the single input variable instead of error and change in error to represent the contents for rule antecedent. This simple but powerful FSMC design method is called the DFSMC. Both the number of fuzzy rules and the complexity in the DFSMC are greatly reduced compared to those of in the conventional FSMC. Lyapunov analysis is employed to investigate the stability property of the proposed controller. Genetic algorithm is employed to tune the gain parameters so that the controlled system can achieve a better performance in the SMC design**.**

Organization of the paper is as follows. Quarter-car model is briefly explained in the next section. Sliding mode control and the Distance based fuzzy sliding mode controller are then discussed in succession. Next, the mechanism of GA is presented. Simulation results are discussed and presented in the later part of the paper. Finally, the last section concludes the paper.

## ACTIVE SUSPENSION MODEL

A two degree of freedom “quarter-car” automotive suspension system is shown in Figure 1. It represents the automotive system at each wheel i.e. the motion of the axle and of the vehicle body at any one of the four wheels of the vehicle. Quarter car model is considered because it is simple and one can observe the basic features of the active suspension system such as a sprung and unsprung mass, suspension deflection and tyre deflection [16]. The suspension is shown to consist of a spring $k_s$, a damper $b_s$ and an active force actuator $F_a$. The active force can be set to zero in a passive suspension. The sprung mass $m_s$ represents the quarter car equivalent of the vehicle body mass. An unsprung mass $m_u$ represents the equivalent mass due to axle and tyre. The vertical stiffness of the tyre is represented by the spring $k_t$. The variables $z_s$, $z_u$ and $z_r$ represent the vertical displacements from static equilibrium of the sprung mass, unsprung mass and the road respectively. Equations of motion of the two degree of freedom quarter car suspension is given by

$$m_s Z_s = F_a - k_s(Z_s - Z_u) - b_s(Z_s - Z_u)$$

$$m_u Z_u = k_s(Z_s - Z_u) + b_s(Z_s - Z_u) + k_t(Z_r - Z_u) - F_a \tag{1}$$

It is assumed that the suspension spring stiffness and tyre stiffness are linear in their operating ranges and that tyre does not leave the ground.

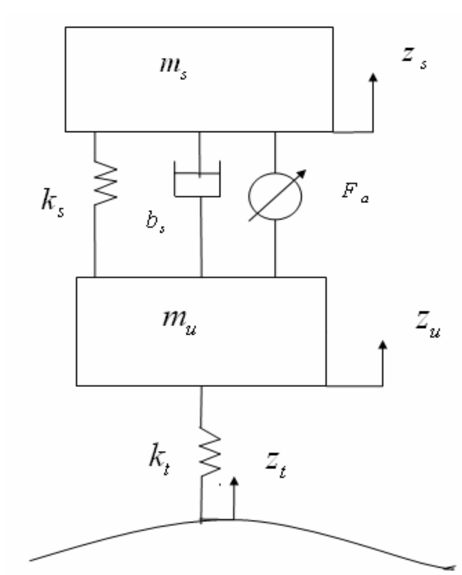



*Figure 1: Quarter car model*

## SLIDING MODE CONTROLLER

SMC has been applied to non-linear systems. It is a variable structure control and was first used by Utkin [17]. The main idea is to bring the error on sliding surface. When the system is on sliding surface it is insensitive to the disturbances and parameter changes. Consider the state model of an active suspension system is of the form

$$\dot{x} = Ax(t) + Bu(t) + f(t) \tag{2}$$

where $x \in R^n$ - system state,

$u \in R^m$ - system input,

$A \in R^{n*n}$ - system matrix,

$B \in R^{n*m}$ - control vector and

$f(t)$ - road disturbance.

Let the time varying switching surface, $S(x,t) = 0$ in the state space $R^n$ be defined by the scalar equation

$$S(x,t) = Cx \tag{3}$$

where $C = [c_1, c_2, \ldots\ldots, c_{n-1}, 1]$ is a strictly positive real constant and

$$S = c_1 x_1(t) + c_2 x_2(t) + \ldots.. + c_{n-1} x_{n-1}(t) + x_n(t) = 0\,. \tag{4}$$

Lyapunov function $V = \frac{1}{2}S^2$ where $V$ is a positive real constant and from the Lyapunov theorem, if the condition $\dot{V} < 0$ is satisfied, then the state trajectory of the system will be forced to approach the sliding surface. The necessary condition for the state trajectory to stay on the sliding surface is [18],

$$\dot{S}(x,t) = 0. \tag{5}$$

The control law that satisfies the sliding mode condition is obtained as,

$$u = u_{eq} - k\,\mathrm{sgn}(S) \tag{6}$$

where $'k'$ is a constant representing the maximum controller output.

$$\mathrm{sgn}(S) = \begin{cases} 1 & for \quad S > 0 \\ -1 & for \quad S < 0 \end{cases} \tag{7}$$

and $u_{eq}$ is the equivalent control when the system is in sliding mode and is obtained from (5).

$$\dot{S}(x,t) = C\dot{x} = 0 \tag{8}$$

$$u_{eq} = -(CB)^{-1}[CAx(t) + Cf(t)] \tag{9}$$

Although the control law (6) can force the state to the sliding surface, a chattering phenomenon will occur due to the discontinuous control signal generation. It is a drawback in the control behaviour and it can be avoided by introducing a boundary layer of width $\Phi$ neighbouring the switching surface and using a continuous function to smooth out the control discontinuity [19]. Thus replacing $\mathrm{sgn}$ function in (6) with $sat(S/\Phi)$, modified sliding mode control behaviour is described as

$$u = u_{eq} - ksat(S/\Phi) \tag{10}$$

where
$$sat(S/\Phi)=\begin{cases}(S/\Phi) & if \quad |S/\Phi|<1\\ \operatorname{sgn}(S/\Phi) & if \quad |S/\Phi|\geq 1\end{cases} \tag{11}$$

## DISTANCE BASED FUZZY SLIDING MODE CONTROLLER

In this section, fuzzy variable called signed distance ($d_s$) is introduced to develop SMC. It decides the magnitude of control signal for a given error $(e)$ and change in error $(ce)$. The expression $-ksat(S/\Phi)$ is replaced by an inference fuzzy system to eliminate the chattering phenomenon. DFSMC is a powerful fuzzy logic controller based on single input variable instead of the system state variables or error and its derivatives to represent n-dimensional rule table as in the case of FLC. Also the tuning of scaling factors and the generation of fuzzy rules becomes easier.

Let $M(x,\dot{x})$ be the intersection point of the switching line and the line perpendicular to the switching line from an operation point $N(x,\dot{x})$, as illustrated in Figure 2. The distance between $M(x,\dot{x})$ and $N(x,\dot{x})$ can be given by the following expression

$$d=\left[(x-x_1)^2+(\dot{x}-\dot{x}_1)^2\right]^{1/2}=\frac{|\dot{x}+cx|}{\sqrt{1+c^2}} \tag{12}$$

where and 'c' is the positive constant.

The signed distance $d_s$ is defined for an arbitrary point $N(x,\dot{x})$ as [20]

$$d_s=\operatorname{sgn}(S)\frac{|\dot{x}+cx|}{\sqrt{1+c^2}} \tag{13}$$

where

$$\operatorname{sgn}(S)=\begin{cases}1 & for \quad S>0\\ -1 & for \quad S<0\end{cases} \tag{14}$$

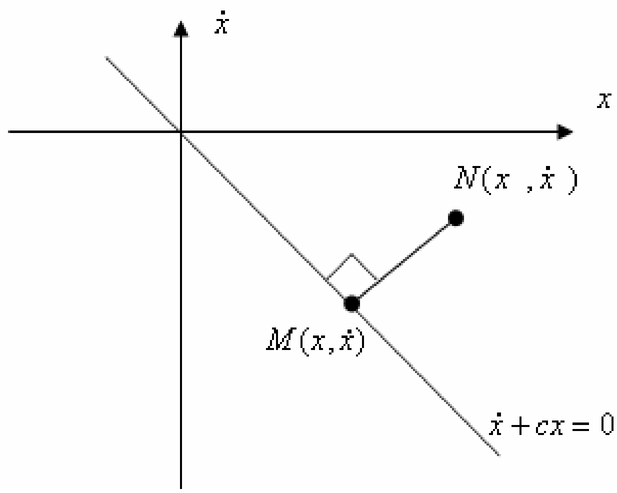



*Figure 2: Plot showing calculation of signed distance*

$$S = \dot{x} + cx \tag{15}$$

Consider the following Lyapunov function

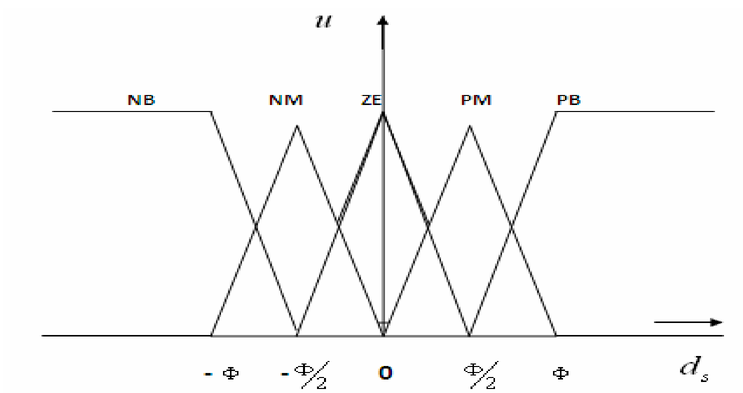
$$V = \frac{1}{2} d_s^2 \tag{16}$$

and

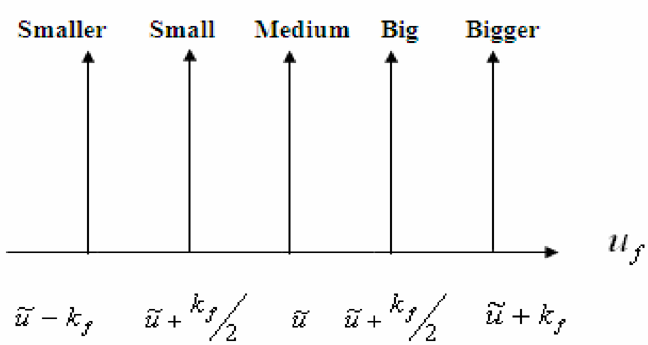
$$\dot{V} = d_s \dot{d}_s = \frac{S\dot{S}}{1+c^2} \tag{17}$$

The sufficient condition for Lyapunov stability is that $V$ is positive definite and $\dot{V} < 0$ i.e. $\dot{V}$ is a negative definite scalar function. From (16) and (17), it is observed that if $S > 0$, then $d_s > 0$, decreasing $u$ will make $d_s \dot{d}_s$ to decrease, so that $\dot{V} < 0$ and that if $S < 0$, then $d_s < 0$, increasing $u$ will make $d_s \dot{d}_s$ to decrease, so that $\dot{V} < 0$. From the above relation control law of DFSMC becomes [20]

$$u \propto -d_s \tag{18}$$




(a)




(b)

*Figure 3: (a) Fuzzy input membership functions (b) Fuzzy output membership functions*

To design a DFSMC, $d_s$ and $u$ are defined as the input and output variables respectively. The numbers of fuzzy control rules are equal to the number of linguistic levels of its input variable $d_s$. Hence the number of fuzzy control rules in the DFSMC is greatly reduced compared to that of FLC. The membership values are shown in Figure 3. If-Then rules of DFSMC can be described as [21],

$R^1$ : If $d_s$ is NB then $u$ is BIGGER

$R^1$ : If $d_s$ is NM then $u$ is BIG

$R^1$ : If $d_s$ is ZE then $u$ is MEDIUM

$R^1$ : If $d_s$ is PM then $u$ is SMALL

$R^1$ : If $d_s$ is PB then $u$ is SMALLER

where NB, NS, ZE, PS, PB are the linguistic terms of antecedent fuzzy set and they mean Negative Big, Negative Small, Zero, Positive Small, and Positive Big respectively. The general form of the fuzzy rules is given by

$$R^i = \text{If } d_s \text{ is } A_i \text{ then } u \text{ is } B_i,\ i = 1,\cdots,5 \tag{19}$$

where $A_i$ is a triangle-shaped fuzzy member and $B_i$ is a fuzzy singleton. *Sup-min* compositional rule of inference is used. Figure 4 shows the result of a defuzzified output $u$ of fuzzy input $d_s$. The following equation describes the relation between $u$ and $d_s$ [21]

$$u = \tilde{u} - k_f\, sig\left(d_s/\Phi\right) \tag{20}$$

where

$$sig(a) = \begin{cases} 1 & if \quad a \geq 1 \\ a & if \quad -1 < a < 1 \\ -1 & if \quad a \leq 1 \end{cases} \tag{21}$$

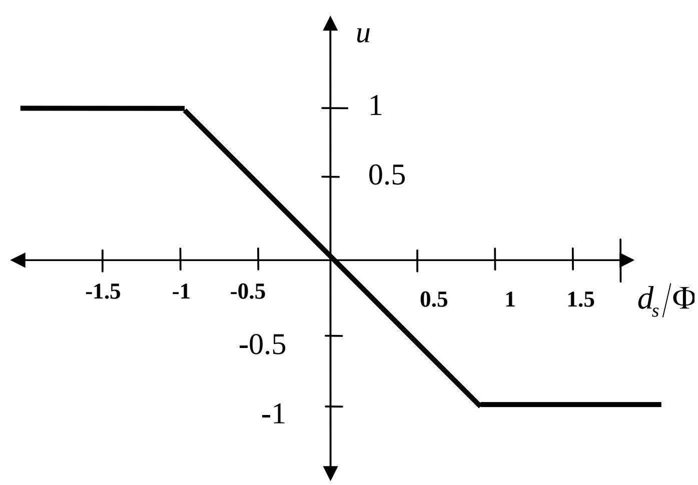



*Figure 4: Control signal of DFSMC*

From (20) and (10), it is observed that control signal in DFSMC and the modified sliding mode control are similar. To design a DFSMC, the membership function of the input and output variable can be obtained from the modified sliding mode controller. The centre of the output fuzzy set $\tilde{u}$ can be substituted by $u_{eq}$ in the SMC and the span of fuzzy set $k_f$ can be substituted by $k$ in the modified sliding mode controller.

## GENETIC ALGORITHM APPLIED TO DFSMC DESIGN

GA are search algorithms that use operations found in natural genetic to guide through a search space. GA use a direct analogy of behaviour. They work with a population of chromosomes, each one representing a possible solution to a given problem. Each chromosome has assigned a fitness score according to how good solution to the problem it is. GA are theoretically and empirically proven to provide robust search in complex spaces, giving a valid approach to problem requiring efficient and effective searching [22].

The performance of sliding mode controller is influenced by two important factors: chattering phenomenon and hitting time. The chattering phenomenon of sliding mode controller usually occurs when the system state gets close to the sliding surface and it will affect the stability of the controlled system. If the time taken for the state to hit the sliding surface is shortened, the system with the desired dynamic character will be faster and it can also decrease the uncertainty of the system. In order to improve the performance of sliding mode controller, the parameters $\Phi$ and $k$ in the equation of the control law are adjusted. The width $\Phi$ of boundary layer will influence the chattering magnitude of sliding mode controller and $k$ will influence how soon the state reaches the sliding surface. GA is used to search the appropriate values of these two parameters and regard $\Phi$ and $k$ as a parameter set

$$R_i = (\Phi, k) \tag{24}$$

that is going to form the chromosome in GA. The hitting time and chattering of the controlled system are used as the performance index of fitness function. The definition of the fitness function is defined as follows [21]

$$f(R_i) = g_1(HT(R_i)) \times g_2(CH(R_i)) \tag{25}$$

where $HT(R_i)$ is the value of the hitting time. It is obtained by calculating the time that the state first hits the sliding surface and when the state reaches $S(X, HT) = 0$. $CH(R_i)$ is the chattering quantity defined by $CH(R_i) = \int_{t \geq HT} |S(X,t)| dt$ . The definitions of $g_1$ and $g_2$ are

$$g_1(HT(R_i)) = e^{-\left(HT/W_1\right)^2} \tag{26}$$

$$g_2(CH(R_i)) = e^{-\left(CH/W_2\right)^2} \tag{27}$$

where $w_1$ and $w_2$ are weight factors that control the value of the hitting time and chattering quantity. From the definition of fitness function, the smaller chattering quantity and the shorter hitting time will make $f(R_i)$ a larger value and it means that the performance of the controlled system with the selected parameter set will be better.

In GA, parameters need to be selected, such as generations, population size, crossover rate, mutation rate, coding length of chromosome [21, 23] and then the searching algorithm will search out a parameter set to satisfy the designer's specification or the system requirement. In GA parameter setting, $w_1 = 1$ and $w_2 = 5$.

Parameters for the GA simulation are set as follows

i. Initial population size: 50
ii. Maximum number of generation: 100
iii. Crossover: Uniform crossover with probability 0.8
iv. Mutation probability: 0.01.
v. Upper and lower bounds of $\Phi$ and $k$: $\Phi \in [0,20]$ , $k \in [0,20]$

## RESULTS AND DISCUSSION

The parameters of the quarter car model are obtained from [1] and listed as follows

| | |
|---|---|
| Sprung Mass ( $m_s$ ) | 240 kg |
| Unsprung Mass ( $m_u$ ) | 36 kg |
| Damper coefficient ( $b_s$ ) | 980 Ns/m |
| Suspension Stiffness ( $k_s$ ) | 16,000 N/m |
| Tyre Stiffness ( $k_t$ ) | 160,000 N/m |

Simulations are performed using MATLAB and Simulink. The system has two inputs and four outputs. Inputs being the road disturbance and control force. Outputs are the body displacement, suspension deflection, body acceleration and tyre displacement whose responses are analysed for sinusoidal road input conditions. The road profile is a 3-Hz sinusoidal function. Simulations are conducted for open loop passive, active suspension with SMC, active suspension with DFSMC and active suspension with GA+DFSMC to evaluate their performances. All the relevant parameters and conditions are maintained the same for all the schemes to ensure a realistic and a fair one-to-one comparison.

Figure 5a-d show the simulation results of a suspension system using the conventional passive and the SMC. Figure 5a and 5c clearly indicate that the SMC reduces the body displacement and body acceleration by one-third which guarantee better ride comfort. Figure 5b and 5d show that the suspension deflection and tyre deflection are of the same magnitude.

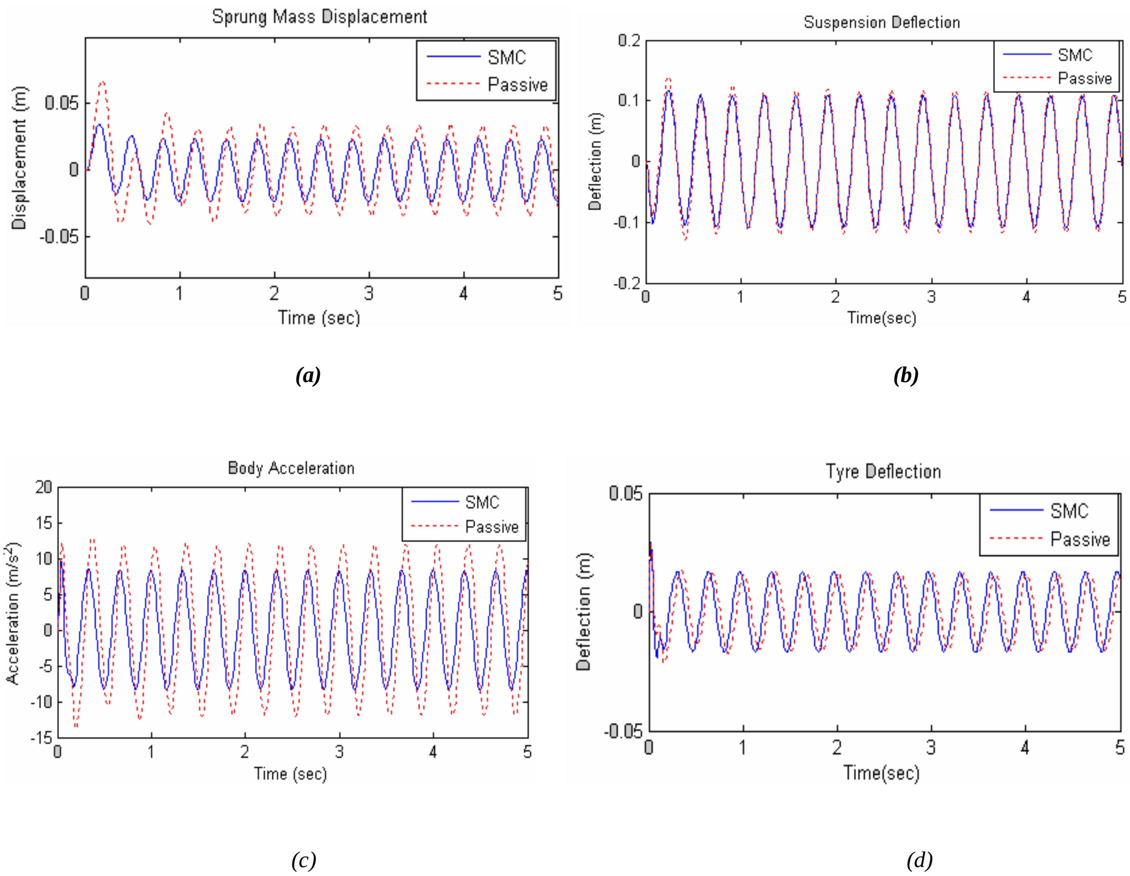
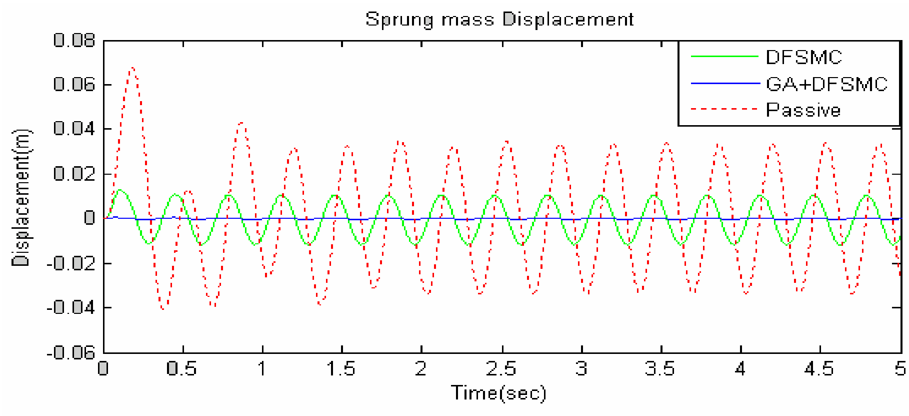


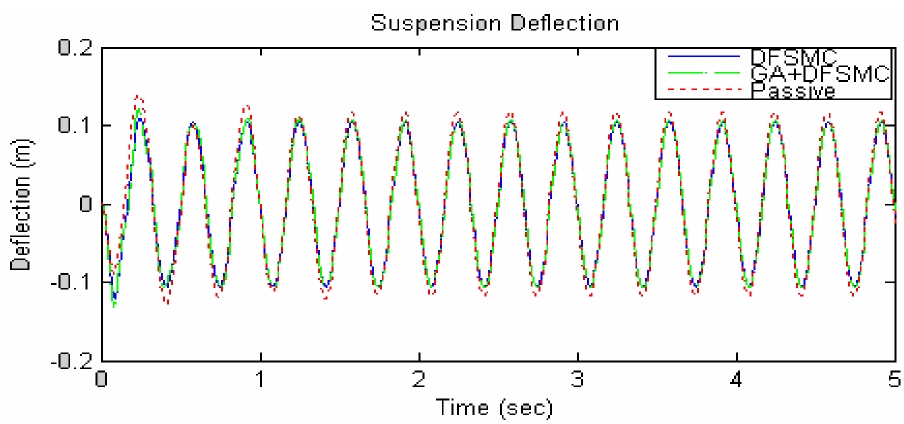

*Figure 5: Sprung mass displacement (a) and Suspension deflection (b) and Body acceleration(c) and Tyre deflection (d) for sinusoidal input road profile with SMC*

ISSN 1823-1039 ©2008 FEIIC

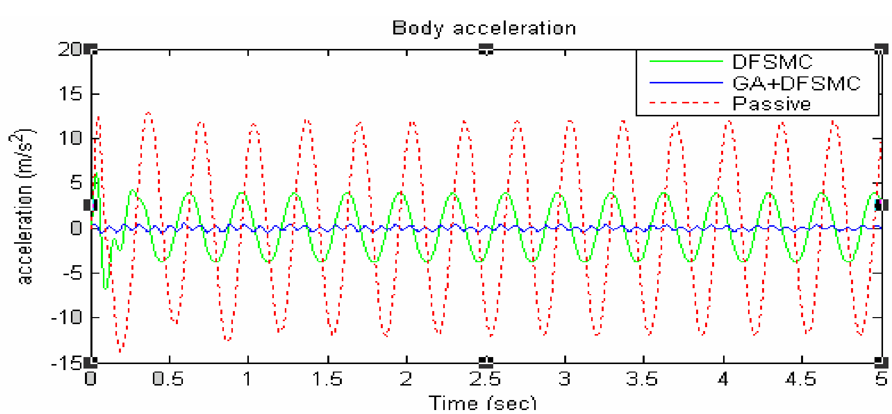
Figure 6a-d show the simulation results using DFSMC and the proposed GA+DFSMC control schemes. Figure 6a shows the sprung mass displacement very much reduced by GA+DFSMC. Figure 6b indicates that the suspension deflection controlled by GA+DFSMC is smaller than that of passive but larger than that of DFSMC. Figure 6c shows that the GA+DFSMC achieve the best performance of sprung mass acceleration. Figure 6d illustrates the road holding ability maintained by the GA+DFSMC is superior to that of others. The performance of the tyre deflection of the proposed controller has some oscillations at the beginning. The performance of the system clearly indicates the superiority of the active suspension with GA+DFSMC over its counterparts. The controller output for the actuator of the active suspension system is shown in Figure 7a and 7b.



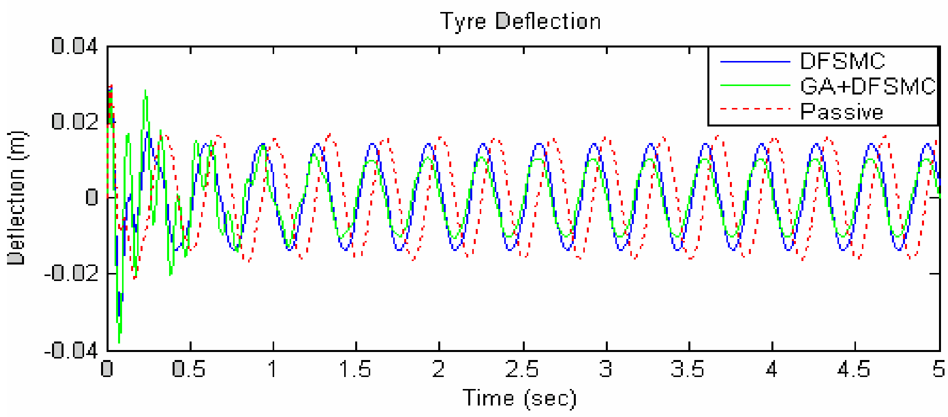

*(a)*




*(b)*

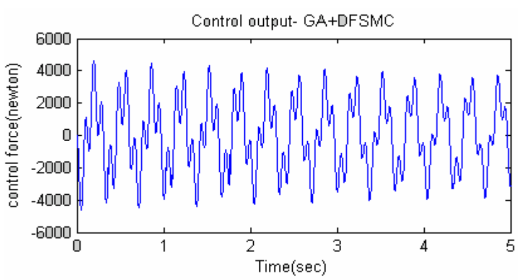



*(c)*

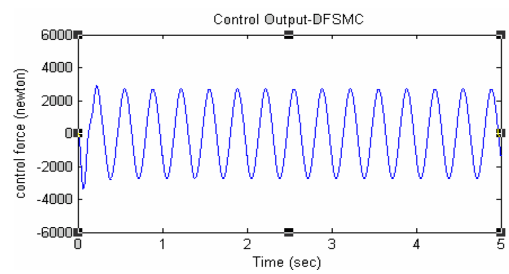



***(d)***

*Figure 6: Sprung mass displacement (a) and Suspension deflection (b) and Body Acceleration(c) and Tyre deflection (d) for sinusoidal road profile with DFSMC and GA+DFSMC*




(a)




(b)

*Figure 7: Control output (a) GA+DFSMC and (b) DFSMC*

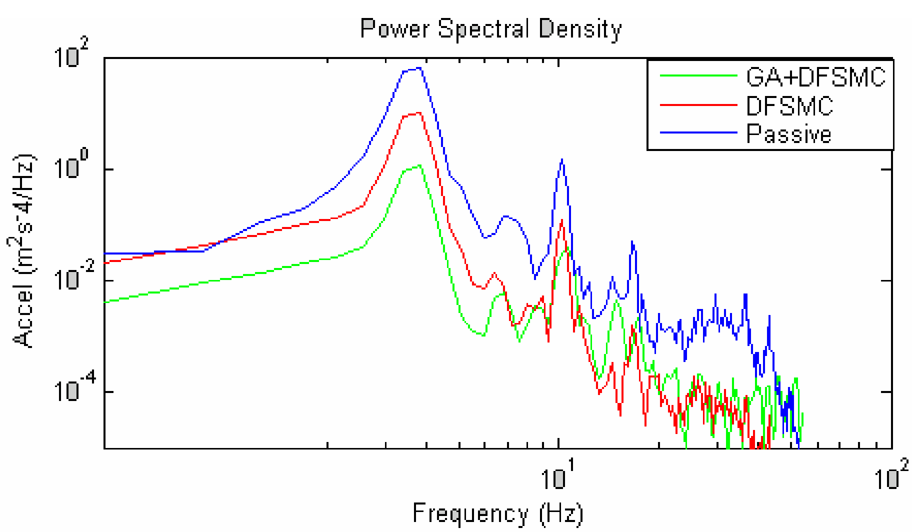



*Figure 8: PSD of Sprung mass acceleration*

*Table 1: R.M.S. values of the time responses of the Quarter car model*

| Input | Controller | Sprung Mass Displacement (m) | Suspension Deflection (m) | Body Acceleration ($m^2/s$) | Tyre deflection (m) |
|---|---|---|---|---|---|
| Sinusoidal Road profile | Passive | 0.0247 | 0.08305 | 8.459 | 0.01151 |
| | SMC | 0.01673 | 0.07642 | 5.896 | 0.01196 |
| | DFSMC | 0.007933 | 0.07441 | 2.841 | 0.01020 |
| | GA+DFSMC | 0.0002926 | 0.07598 | 0.2393 | 0.008232 |

The comparison of all three controllers is presented in Table-1, which shows the Root Mean Squares (RMS) of the body acceleration, suspension deflection, body displacement and tyre deflection. GA+DFSMC reduce the body displacement and body acceleration by almost 90% compared to that of the conventional SMC. Tyre deflection of GA+DFSMC is reduced by 32% to that of SMC. Suspension deflection of DFSMC is better than the proposed controller. This is because the proposed controller uses the suspension deflection to keep superior ride quality under the constraint of tyre deflection. The results show that GA+DFSMC scheme outperforms the conventional passive, SMC and DFSMC in providing desired ride comfort and handling qualities.

In the evaluation of vehicle ride quality, the Power Spectral Density (PSD) for the acceleration of the sprung mass as a function of frequency is of prime interest and is shown in Figure. 8. The proposed method has significantly suppressed the acceleration of sprung mass effectively in the low frequency band. It can be observed from the PSD plot that the acceleration has been brought down within the frequency between 0.4 Hz to 7.5 Hz by the proposed control scheme. The ride comfort of vehicle system is obviously improved in the sensitive frequency range. Thus the active suspension with GA+DFSMC could greatly contribute to the improvement of the vehicle ride comfort.

## CONCLUSION

In this paper, GA+DFSMC is designed for the quarter car model based active suspension system which calculates the desired force signal. GA+DFSMC simplifies the implementation of a fuzzy controller. Only five rules are required for each dynamic operation instead of two-dimensional rule bank. The proposed technique is used to conquer the difficulty that how to simultaneously consider the hitting time and the chattering quantity of SMC in the selection of the gain parameters. Simulation results indicate that the proposed approach can achieve the performance requirements effectively. It is also proved from the RMS values of sprung mass displacement, body acceleration, suspension deflection and tyre deflection that the GA+DFSMC based active suspension provides higher ride comfort and road handling qualities when compared to existing passive and SMC. The proposed control method guarantees the system robustness in presence of uncertainties of suspension parameters.

**REFERENCES**


[1] Seok_il Son. (1996) Fuzzy Logic Controller for an Automotive Active Suspension system. Master's Thesis, Syracuse University.

[2] D.Hrovart. (1993) Application of optimal control to Dynamic advanced automotive suspension design. Transactions of ACME, Journal of Dyamic System, Measurement and Control, **115**: 328-342.

[3] Mehdi Farahmand, Caro Lucas. (2003) Design of Fuzzy Logic and optimal control to an Automotive Active Suspension system. Proceedings, International Conference on Control and Automation, pp. 688-692.

[4] F.J.D'Amato and D.E.Viasallo. (2000) Fuzzy Control for Active Suspensions. Mechatronics, **10**: 897-920.

[5] M.V.C.Rao and V.Prahlad. (1997) A tunable fuzzy logic controller for vehicle-active suspension systems. Elsevier, Fuzzy sets and systems, **85**(1): 11-21.

[6] Andrew J.Barr,Dr.Jeffrey L.Ray. (1996) Control of an Active suspension using Fuzzy Logic. Proceedings, International Conference on Control and Automation, pp. 42-48.

[7] Dae sung Joo, Nizar Al-Holou (1995) Development and Evaluation of Fuzzy Logic Controller for Vehicle Suspension Systems. Proceedings, South eastern symposium on system theory, pp. 295-298.

[8] Yahaya Md. Sam, Johari H.S.Osman and M.R.A.Ghani. (2004) A class of proportional –Integral sliding mode control with application to Active suspension. Elsevier, Systems & control letters, **51**: 217-223.

[9] T. Yoshimura, A. Kume, M. Kurimoto and J.Hino (2001) Construction of an Active suspension system of a Quarter car model using the concept of Sliding mode control. Journal of Sound and Vibration **239**(2): 187-199.

[10] F. Qiao. Q. M. Zhu , A. Winfield and C. Melhuish (2003) Fuzzy sliding mode control for discrete nonlinear systems. Transactions of China Automation Society **22**(2): 311-315.

[11] I. Eksin, M. Guzelkaya, S. Tokat. (2002) Sliding Surface slope Adjustment in Fuzzy Sliding mode controllers. Proceedings, $10^{th}$ Mediterranean Conference on Control and Automation - MED2002 Lisbon, Portugal.

[12] Shiuh-Jer Huang , Hung-Yi Chen (2006) Adaptive sliding controller with self-tuning fuzzy compensation for vehicle suspension control. Elsevier, Mechatronics **16**: 607–622.

[13] Jianmin Sun and Yi Sun. (2007) A Fuzzy Method Improving Vehicle Ride Comfort and Road Holding Capability. Proceedings, Second IEEE Conference on Industrial Electronics and Applications, pp. 1361-64.

[14] Shiuh-Jer Huang and Wei-Cheng Lin (2003) Adaptive Fuzzy Controller With Sliding Surface for Vehicle Suspension Control. IEEE transactions on fuzzy systems, **11**(4): 550-559.

[15] Zhen Liu, Cheng Luo. (2006) Road Adaptive Active Suspension Control Design. Proceedings, IMACS Multiconference on "Computational Engineering in Systems Applications"(CESA), Beijing, China. pp. 1347-50.

[16] A.G.Ulsoy,D.Hrovart and T. Tseng (1994) Stability robustness of LQ and LQG active suspension. Transactions of ASME, Journal of Dynamic systems, Measurement and control, **116**: 123-131.

[17] Utkin.V.I. (1978) Sliding modes and their applications in variable structure systems, Mir. Moscow.

[18] U. Itkis, (1976) Control System of Variable Structure, Wiley, New York.

[19] Lee, C. C. (1990), Fuzzy logic in control systems: fuzzy logic controller—Part I. IEEE Transactions on Systems, Man and Cybernetics, **20**: 404–418.

[20] L.C.Hung, H.P.Lin and H.Y.Chung (2007) Design of self tuning fuzzy sliding mode control for TORA system. Elsevier, Expert system with applications, **32**: 201-212.

[21] Ching-Chang Wong, Bing-Chyi Huang and Hung-Ren Lai (2001) Genetic-based Sliding Mode Fuzzy Controller Design. Tamkang Journal of Science and Engineering, **4**(3): 165-172.

[22] J. R. Velasco and L. Magedalena. (1995) Genetic Algorithm in Fuzzy Control Systems. J. Periaux and G.Winter. (Eds.), Genetic algorithms in engineering and computer science, John Wiley and Sons.

[23] Ching-Chang Wong and Shih-Yu Chang (1998) Parameter Selection in the Sliding Mode Control Design Using Genetic Algorithms. Tamkang Journal of Science and Engineering, **1**(2): 115-122.