ENHANCING TRAVEL COMFORT OF QUARTER CAR WITH DRIVER MODEL USING FRACTIONAL ORDER TERMINAL SLIDING MODE CONTROLLER WITH DUAL ACTUATOR

S. RAJENDIRAN1, P. LAKSHMI2

1Department of Electrical and Electronics Engineering, College of Engineering Guindy, Chennai, India, 994398249
2pecraja@gmail.com, p_lakshmi@annauniv.edu

B.Rajkumar
Department of Electrical and Electronics Engineering, College of Engineering Guindy, Chennai, India
brajkmarei@gmail.com

Abstract: The ride quality and travel comfort of the passenger is based on the type of the suspension system used in the vehicle. The active suspension system is one of the good choice to reduce the vibration and enhance the travel comfort. In this paper, a quarter car with driver model and dual actuator is considered for analysis. To reduce the vibration and increase the travel comfort, different types of Sliding Mode Controllers (SMC) such as Terminal SMC (TSMC), Fractional Order SMC (FOSMC) and Fractional order Fuzzy SMC (FOTSMC) are designed and simulated in the active suspension system of the quarter car with driver model. Different kinds of road disturbances are given to the system to stimulate the vibration in the system. The responses of the controllers with the quarter car system is compared with the passive system. The results shows that the FOTSMC performs better than TSMC and FOSMC.

Key words: Actuators, Fractional Order Terminal Sliding Mode Controller, Sliding mode control, Vibration control.

1. Introduction

Suspension system in a vehicle is used to enhance the travel comfort and ride quality. In the vehicle suspension system passive, semi active and active suspension are the three types used to reduce the vibration. Different kinds of springs are used in passive suspension system. In semi active suspension the spring and damper parameters are changed with respect to the road condition during the run time. Hence vibration reduces to a particular level and it requires minimum power to perform. In case of Active Suspension System (ASS) an external control force is applied to the opposite direction of the vibration. Therefore it reduces the vibration better than semi active and passive suspension systems. The active and semi active suspension systems are used in addition to the passive suspension system in the vehicles.

While travelling in a car, comfort of the passenger will be more when there is a minimum vibration. Since the road surfaces are not smooth, the vehicle experience the vibrations. These vibrations affects the health of the passengers and the life of the vehicle. The wear and tear of the vehicle will also increase. Therefore the ASS is designed to handle these vibrations. Different kinds of algorithms are used to produce the control force in the ASS. The control force should be as minimum as possible and should change rapidly with respect to the changes in the road disturbances.

Considering the one fourth of the vehicle for the analysis of the vibration control is a common practice among the researchers [1 &2]. These type of quarter car model has two masses namely sprung mass and unsprung mass [3]. On top of the sprung mass an integrated Seat suspension [4] with Chassis suspension and Driver body model (SCD) have been considered for vibration control in [5]. The driver body model can be considered either as a single mass [5] or four masses as discussed in [6 &7]. The concept of active seat suspension which acting as a secondary controller is discussed in [7] along with the main car suspension is available. The control strategies for the quarter car is reviewed in [8].

The control strategies for the quarter car with driver model are discussed in the following papers. A semi-active suspension controller using Sliding Mode Control (SMC) for SCD [9], design of the optimal seat suspension using Genetic algorithm [10], state feedback
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and static output feedback controllers [7] are designed for an 8 Degree Of Freedom (DOF) quarter car model. The driver’s bio mechanical effects [11] are considered for analysis of vibration control. As for as the SMC is concern, Grey Fuzzy SMC [12], type-2 FLC based SMC [13], Robust Fuzzy based SMC [14], model-free adaptive SMC [15] are designed to enhance the performance of the quarter car model. In [16] SMC is used to estimate the car body mass of the quarter car. Fractional Order SMC (FOSMC) [17-20] and Terminal SMC (TSMC) [21-23] are used in various applications to improve the performances of the system. Fractional Order Terminal SMC (FOTSMC) is designed for a dynamical systems with uncertainty in [24].

In this paper, FOTSMC is proposed to enhance the travel comfort of the Quarter Car with integrated Seat suspension and Driver model (QCSD) with Dual Actuator (DA). The performances of the controller is compared with FOSMC, TSMC and the passive suspension system. Three types of road profiles are considered to test the performance of the controller. Finally, results and conclusions are summarized in Section 5.

2. Quarter car with Driver Model

The QCSD has 8 DOF. In general a quarter car model has 2 DOF with its sprung mass (m_s) and unprung mass (m_u). It is described by Equation (1.1) and (1.2), along with this an integrated seat suspension components includes another 2 DOF (Equation (1.3) and (1.4)) and a driver human body model adds another 4 DOF Equation (2.1) to (1.8). The QCSD is shown in Figure 1. The dynamic vertical motion Equations for the QCSD with Single Actuator (SA) are as follows.

\[ m_s \dddot{y_s} = -k_s (y_s - y_u) - c_s (\dot{y}_s - \dot{y}_u) + k_s (y_s - y_e) + c_s (\dot{y}_s - \dot{y}_e) - f_s \]  
(1.1)

\[ m_s \dddot{y_u} = -k_s (y_s - y_u) - c_s (\dot{y}_s - \dot{y}_u) + k_s (y_s - y_e) + c_s (\dot{y}_s - \dot{y}_e) + f_s \]  
(1.2)

\[ m_s \dddot{y_f} = -k_s (y_f - y_e) - c_s (\dot{y}_f - \dot{y}_e) + k_s (y_s - y_e) + c_s (\dot{y}_s - \dot{y}_e) \]  
(1.3)

This QCSD has dual actuators. The first actuator is mounted in between the sprung mass and unprung mass. This actuator with the suspension system is called as the car suspension. The second is mounted in between the...
sprung mass and the frame. This actuator with the suspension system is called as the seat suspension. A linear electromagnetic actuator can be used to produce the control force. Since the performance of the QCSD with SA is compared against QCSD with DA, the controllers for the QCSD with DA is designed based on the modified Equations. In the presence of the seat suspension system Equation (2.2) and (2.3) will be modified as follows

\[ m\ddot{y}_s = -k_s(y_s - y'_s) - c_s(y_s - y'_s) + k_m(y_r - y'_s) + c_m(y_r - y'_s) + f_s \]  

(2.9)

\[ m\ddot{y}_c = -k_c(y_c - y'_c) - c_c(y_c - y'_c) + k_m(y_s - y'_c) + c_m(y_s - y'_c) + f_c \]  

(2.10)

where

- \( m \) - mass,
- \( y \) - displacement,
- \( c \) - damping constants,
- \( k \) - the spring constant
- \( y_r \) - the road displacement input.
- \( f_c \) - actuator force by the seat suspension.
- \( f_s \) - actuator force by the car suspension.

The subscripts t, s, ss, u, f and c are representing tyre, sprung, seat suspension, unsprung, frame and cushion of seat. The driver mass consists of four parts such as thighs, lower torso, upper torso and head, the same are represented in subscripts from 1 to 4 respectively.

3. Design of controllers

3.1 Design of Fractional order Sliding Mode Controller

To control the vibration in the vehicle, SMC is one of the good choice because of the uncertainties in the road disturbance and it is also one of the simple and effective robust control. SMC produces the control signal in presence of disturbance and it is also one of the simplification techniques. The existence of the sliding mode is possible when the sliding surface converges to zero in finite time. The necessary condition [25] to drive the state trajectory toward the sliding surface is

\[ \dot{s}(x,t) = 0 \]  

(2.6)

The fractional order sliding surface is,

\[ s = D^\alpha x_i + cx_i \]  

(2.7)

where \( c \) is a sliding surface gain, taking derivative on both sides

\[ \dot{s} = D^{\alpha-1} x_i + cx_i \]  

(2.8)

By substituting the state variables and simplification, the equivalent control force is

\[ f_s = k_c(y_s - y'_s) + c_c(y_s - y'_s) - k_m(y_r - y'_s) - c_m(y_r - y'_s) \]  

(2.9)

Hence the desired control force is,

\[ f_d = k_c(y_s - y'_s) + c_c(y_s - y'_s) - k_m(y_r - y'_s) - c_m(y_r - y'_s) - k_m \text{ sign}(s) \]  

(2.10)

where \( k, m \) and \( \text{ sign}(s) \) is the switching control, which satisfies the desired criteria as per the Equation (2.3) and brings the system into the sliding surface and converges to zero in finite time. \( k = n + f_s \) and \( n \) is a positive constant

\[ f_i = -\frac{k}{m_r}(y_r - y'_r) - \frac{c}{m_r}(y_r - y'_r) \]  

(2.11)
In case of the QCSD with DA the Equation (2.10) is modified as
\[
f_a = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e)
\]  
(2.12)

To design the integrated seat suspension active force \( f_a \) the state variables are as follows,
\[
x_1 = y_s - y_e \quad \text{(2.13) and } x_2 = \dot{y}_e
\]

the sliding surface is chosen as per the Equation (2.7). By substituting the state variables and simplification, the equivalent control force is,
\[
f_{a\text{-equiv}} = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e) - cm_1 \frac{q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.15)

Hence the desired control force is,
\[
f_s = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e)
\]  
(2.16)

where \( k_s = \text{sign}(s) \).

\[
f_s = \frac{k_s}{m_f} (y_s - y_e) - \frac{c_s}{m_f} (\dot{y}_e - \dot{y}_s) + \frac{k_m}{m_f} (\ddot{y}_s - \ddot{y}_e) + \frac{cm_1 q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.17)

3.2 Design of Terminal Sliding Mode Control

To design TSMC for the QCSD with SA, the state variables are chosen as shown in Equation (2.4) and (2.5). The terminal sliding surface S becomes
\[
S = \left(\dot{x}_1\right)^p + cX_1
\]  
(2.18)

where \( p \) and \( q \) are integers which satisfy the condition \( p < q < 2p \).

Taking derivative of Equation (2.18)
\[
\dot{S} = \frac{p}{q} \left(\frac{\dot{x}_1}{x_1}\right)^{p-1} \dot{x}_2 + c\dot{x}_1
\]  
(2.19)

As per the Equation (2.6)
\[
\dot{x}_2 = \frac{p}{q} \left(\frac{\dot{x}_1}{x_1}\right)^{p-1} x_2 + c\dot{x}_1
\]  
(2.20)

By substituting the state variables in the above equation, the \( f_a \) becomes \( f_{a\text{-equiv}} \) and it is shown as follows
\[
f_{a\text{-equiv}} = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e) - cm_1 \frac{q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.21)

Hence the desired control force \( u_s = f_{a\text{-equiv}} - k_m \text{sign}(s) \)

\[
f_s = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e)
\]  
(2.22)

3.3 Design of Fractional order Terminal Sliding Mode Control

To design FOTSMC for the QCSD with SA, the fractional order terminal sliding surface is chosen as follows,
\[
S = (D^\alpha \dot{x}_1)^p + c\dot{x}_1
\]  
(2.23)

where \( D^\alpha \) is the fractional calculus with \( 0 < \alpha < 1 \) Taking derivative of Equation (2.28)
\[
\dot{S} = \frac{p}{q} \left(\frac{\dot{x}_1}{x_1}\right)^{p-1} \ddot{x}_2 + c\ddot{x}_1
\]  
(2.29)

As per the equation (3.6)
\[
\ddot{x}_2 = \frac{p}{q} \left(\frac{\dot{x}_1}{x_1}\right)^{p-1} x_2 + c\ddot{x}_1
\]  
(2.30)

The state variables are chosen as per the Equation (2.4) and (2.5). By substituting the state variables and simplification the equivalent control force is,
\[
f_{a\text{-equiv}} = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e) - cm_1 \frac{q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.24)

In case of the QCSD with DA the Equation (2.24) is modified as
\[
f_s = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e)
\]  
(2.25)

Hence the desired control force is,
\[
f_s = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e) - cm_1 \frac{q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.26)

To design the integrated seat suspension active force \( u_s \), the state variables are as per the Equation (2.13) and (2.14). The terminal sliding surface is chosen as per the equation (2.18) and the state variables are substituted. The equivalent control force derived from above equation is,
\[
f_{a\text{-equiv}} = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e) - cm_1 \frac{q}{p} (\dot{y}_e - \dot{y}_s) \frac{s^\alpha}{\Gamma(1+\alpha)} - k_m \text{sign}(s)
\]  
(2.27)

The desired control force is,
\[
f_s = f_{a\text{-equiv}} - k_m \text{sign}(s)
\]  
(2.28)

Hence the desired control force is,
\[
f_s = k_s (y_s - y_e) + c_s (\dot{y}_e - \dot{y}_s) - k_m (\ddot{y}_s - \ddot{y}_e)
\]  
(2.29)
\[ f_{s, eq} = k_s (y_s - y_r^2) + c_s (\dot{y}_s - \dot{y}_r) - k_u (y_f - y_r) - c_u (\dot{y}_f - \dot{y}_r) \] (2.31)

Hence the desired control force is,
\[ f_s = k_s (y_s - y_r) + c_s (\dot{y}_s - \dot{y}_r) - k_u (y_f - y_r) - c_u (\dot{y}_f - \dot{y}_r) \] (2.32)

In case of the QCSD with DA the Equation (2.32) is modified as
\[ f_s = k_s (y_s - y_r) + c_s (\dot{y}_s - \dot{y}_r) - k_u (y_f - y_r) - c_u (\dot{y}_f - \dot{y}_r) \] (2.33)

\[ x_1 \text{ and } x_2 \text{ are chosen as shown in the Equation (2.13) and (2.14), and the sliding surface is as per Equation (2.28) By substituting the state variables and simplification, the equivalent control force is} \]
\[ f_{s, eq} = k_s (y_s - y_r) + c_s (\dot{y}_s - \dot{y}_r) - k_u (y_f - y_r) - c_u (\dot{y}_f - \dot{y}_r) \] (2.34)

\[ f_s = k_s (y_s - y_r) + c_s (\dot{y}_s - \dot{y}_r) - k_u (y_f - y_r) - c_u (\dot{y}_f - \dot{y}_r) \] (2.35)

4. Numerical simulation and results

The QCSD with SA and QCSD with DA are simulated separately in SIMULINK blocks of MATLAB R2012b. The QCSD parameters used in this work are from [7] and summarized in the Table I. While testing the performances of the QCSD, the system is subjected to three types of road inputs. All the three controllers are designed with the single bump [7] as the road input, then tested with other two types of road inputs without any modification in the controllers. The second type of road profile chosen for analysis is the sinusoidal road and the third type is the random road profile [13]. The road profiles are shown in Figure 2 and simulation are performed for the period of 2 seconds for all the cases.

While designing the SMC, \( \lambda \) is chosen as 2.5, \( \alpha \) is chosen as 0.85 and \( n=0.00001 \), \( p=23 \) and \( q=23.23 \) to obtain the desired response. The same SMC parameters are used for all cases.

The Head Acceleration (HA) of the driver is the final control element considered for analysis. The performance of the controllers are compared in two different cases. The first one is the QCSD with SA and the second one is the QCSD with DA. Initially the controllers are designed and tested for the QCSD with SA and single bump road input. The Figure 3 shows that the passive response of HA of QCSD with SA. The time response of the HA is plotted for controllers with single bump input (Figure 4). The force produced by the SA is shown in Figure 5.

<table>
<thead>
<tr>
<th>Mass (Kg)</th>
<th>Damping coefficient (Ns/m)</th>
<th>Spring stiffness (N/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_d</td>
<td>20</td>
<td>c_1</td>
</tr>
<tr>
<td>m_c</td>
<td>300</td>
<td>c_1</td>
</tr>
<tr>
<td>m_h</td>
<td>15</td>
<td>c_w</td>
</tr>
<tr>
<td>m_r</td>
<td>1</td>
<td>c_2</td>
</tr>
<tr>
<td>m_s</td>
<td>12.78</td>
<td>c_3</td>
</tr>
<tr>
<td>m_t</td>
<td>8.62</td>
<td>c_4</td>
</tr>
<tr>
<td>m_u</td>
<td>28.49</td>
<td>c_5</td>
</tr>
<tr>
<td>m_m</td>
<td>5.31</td>
<td>c_6</td>
</tr>
</tbody>
</table>

Table 1. Parameters used for quarter car with driver model

Figure 2. Road Profiles

Figure 3. Passive response of the HA for single bump
The performance of the QCSD with DA is analyzed for the single bump input. The Figure 6 shows the time response of HA for single bump input for the QCSD with DA. The force produced by the active seat and active car suspension are shown in Figure 7 and Figure 8 respectively. From the RMS values (shown in Table II) of the time response of the HA, the FOSMC reduces the HA of the QCSD with DA by 16.47% better than the QCSD with SA. Similarly the TSMC and FOTSMC reduces the HA of the QCSD with DA by 23.69% and 15.24% better than the QCSD with SA respectively.

In DA the car suspension system has the saturation level of 1500 N [7]. This saturation level is not considered in SA and the force produced by the controller is more and the performances are less compared with the DA. In DA the control force is distributed in car suspension as well as in the seat suspension. The car suspension takes the primary control action up to its maximum limits and the remaining control force is supplied from the seat suspension. Therefore the control action in DA is better than SA.

When the performance of the controllers are compared with each other the FOTSMC reduces HA by 93.41% in QCSD with DA and 76.71% in QCSD with SA, which is better than FOSMC (93.18% and 76.71%) and TSMC (91.47% and 67.79%) in QCSD with DA and QCSD with SA respectively. Since the performance of the FOTSMC is better than the other controllers, the Figure 9 compares the performance of the FOTSMC in DA and SA.

<table>
<thead>
<tr>
<th>Types of Road inputs</th>
<th>RMS values (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bump</td>
<td>Sinusoidal</td>
</tr>
<tr>
<td>Passive</td>
<td>2.957</td>
</tr>
<tr>
<td>FOSMC</td>
<td>0.6887</td>
</tr>
<tr>
<td>TSMC</td>
<td>0.9528</td>
</tr>
<tr>
<td>FOTSMC</td>
<td><strong>0.6453</strong></td>
</tr>
<tr>
<td>DA</td>
<td>FOSMC</td>
</tr>
<tr>
<td></td>
<td>0.2016</td>
</tr>
<tr>
<td></td>
<td>TSMC</td>
</tr>
<tr>
<td></td>
<td>FOTSMC</td>
</tr>
</tbody>
</table>
In a road surfaces the speed breakers are placed to force the vehicle to reduce the speed. These speed breakers are modeled as the sinusoidal road input and the performance of the controller are tested.

Figure 7. Force $u_r$ produced for single bump road input

Figure 8. Force $u_r$ produced for single bump road input

Figure 9. Performance of FOTSVM for single bump

Figure 10. Passive response of the HA for sinusoidal road input

Figure 11. Time response of the HA for sinusoidal road input in QCSD with SA

Figure 12. Force produced for sinusoidal road in QCSD with SA
In this case the road input has the positive and negative magnitudes therefore the passive response (shown in Figure 10) of the QCSD and the time response with the controllers for QCSD with SA (shown in Figure 11) has high in magnitude with respect to single bump. The force produced by the controllers (shown in Figure 12) are also high compared with the single bump input. Similar to the single bump road input, the performances of the controllers in DA is better than the SA for sinusoidal road input. From the RMS values, the FOSMC reduces the HA of the QCSD with DA by 8.16% better than the QCSD with SA. Similarly the TSMC (by 11.91%) and FOTSMC (7.65%) reduces the HA of the QCSD with DA than the QCSD with SA.

When the performance of the controllers are compared with each other the FOTSMC reduces HA by 90.53% in QCSD with DA and 82.88% in QCSD with SA, which is better than FOSMC (90.14% and 81.98%) and TSMC (87.31% and 75.4%) in QCSD with DA and QCSD with SA respectively.

Figure 13, Figure 14 and Figure 15 shows the time response of the HA for QCSD with DA and sinusoidal input, the active control force produced by the seat suspension and car suspension respectively.

The Figure 16 compares the performance of the FOTSMC in DA and SA for the sinusoidal road input and shows the effectiveness of the DA.

As the road surfaces are not uniform, any kind of disturbances are expected from the road. Therefore it
is necessary to consider the random road profiles and test the performance of the controllers. As the road inputs are randomly changing in 0.1 seconds, the control action should be quick enough to handle the changes and hence it requires higher magnitude of the force. As the road disturbance is random in nature the passive response of the QCSD is also random in nature as shown in Figure 20.

![Figure 20. Passive response of the HA for random road](image)

![Figure 17. Force produced for random road in QCSD with SA](image)

![Figure 18. Time response of the HA for random road input in QCSD with DA](image)

![Figure 19. Force u produced for random road input](image)
Similar to the other two road profiles considered so far, the performances of the controllers in DA is better than the SA for random road input. From the RMS values of the time response of the HA, the FOSMC reduces the HA of the QCSD with DA by 11.14% better than the QCSD with SA (Figure 21). Similarly the TSMC (by 17.15%) and FOTSMC (9.92%) reduces the HA of the QCSD with DA than the QCSD with SA. Figure 17 shows the force produced by the SA for random road input.

Figure 18, Figure 19 and Figure 22 shows the time response of the HA for QCSD with DA for random road input, the active control force produced by the seat suspension and car suspension respectively. While comparing the performance of the controllers with each other, the FOTSMC reduced HA by 89.74% in QCSD with DA and 79.83% in QCSD with SA, which is better than TSMC (88.87% and 71.51%) and FOSMC (89.71% and 78.58%) in QCSD with DA and QCSD with SA respectively.

Figure 23 compares the performance of the FOTSMC in QCSD with DA and SA for the random road profile. From the response, it is inferred as the DA controller HA better than the SA for the random road profiles.

The vehicle ride quality is analyzed with respect to Power Spectrum Density (PSD) and plotted for the HA in QCSD with DA (Figure 24 to Figure 26) as a function of frequency for all three types of road profiles. FOTSMC reduced HA effectively in the human sensitive frequency range [2] of 4 to 8 Hz for all the road profiles.

Figure 22. Force $u_t$ produced for random road input

Figure 23. Performance of FOTSMC for random road

Figure 24. PSD of HA in single bump in QCSD with DA

Figure 25. PSD of HA in sinusoidal road input in QCSD with DA
5. Conclusion

The vibration control strategies for the QCSD with SA and DA are designed and simulated for FOTSMC. The performances of the FOTSMC are compared against the TSMC, FOSMC and passive system. The results are analyzed in terms of RMS and PSD. When the DA and SA are compared, the FOSMC for QCSD with DA reduces the HA by 11.92% then QCSD with SA. Similarly the TSMC and FOTSMC in QCSD with DA reduces the HA by 17.58% and 10.94 % respectively. Therefore the QCSD with DA performs better than the QCSD with SA. While the performance of the controllers in QCSD with DA are compared, the FOTSMC is 4.95 % better than the FOSMC and 0.84% better than TSMC. In the case of QCSD with SA, the FOTSMC reduces the HA by 1.21% better than the FOSMC and by 8.73% better than the TSMC. FOTSMC outperforms the other controllers in all the road inputs.

The driver or passenger mass can be considered as the variable mass and this condition is called as the perturbed condition. These SMCs and other types of advanced SMCs such as Fuzzy based SMC and integral SMCs can be designed for the system with perturbed condition and further analysis is possible.

6. References


