Fault Tolerant Control of an Active Suspension system for Road Vehicles

ISSN (e) 2520-7393
ISSN (p) 2521-5027
Received on 29th May, 2018
Revised on 25th,June, 2018
www.estirj.com

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Abstract: In this paper a model-based approach is used in fault tolerant control (FTC) system to detect, identify and isolate the fault occur in an active suspension system of road vehiclesin order to maintain the ride comfort and vehicle performance in the presence of road disturbances. Quarter car active suspension system is considered in this research work and MATLAB/SIMULINK is used for simulations. In past, much research work has been done on actuator faults, however, this research focuses on the sensor fault occur in an active suspension system.Simulation results have shown the effectiveness and easy implementation of the applied approach to the active suspension system.

Keywords: *Quarter Car, Fault tolerant control system, Active suspension, FDI, FTC.*

1. Introduction

Today many road vehicles use active suspension system instead of semi active or passive suspension system due to the fact that active suspension gives better ride quality and comfort to the passengers. Active suspension system works according to the roads conditions, it add or dissipate the forces to accommodate the unevenness of the roads which results in smooth and comfortable ride. Active suspension system has sensors and actuators which usually gives reliable performance but in case of malfunctioning of sensors or actuators, vehicles gives worst performance in normal road conditions. To overcome this situation, we must have a fault tolerant control system which gives reliable and better performance during the malfunctioning of sensors and actuators. Many researchers focus on the fault tolerant control system for actuators malfunctioning but, in this research,we consider the case of sensor malfunction of active suspension system. Quarter car active suspension system model is used to design the fault tolerant control system for road vehicles. design of the fault tolerant control system is based on the model-based approach in which a system model and a mathematical model compares to make a residual signal, the magnitude of the residual signal gives the identification of the fault occur in system. The next stage of the fault tolerant control system is to locate the origin of the fault, in our case sensor of the active suspension is the origin of the fault. After identification and location of fault, last step is to eliminate the fault from the system. For eliminating the fault, system activate the faulty mode controller to give optimal ride comfort as well as road holding to the road vehicles while sensor malfunctioning.

This paper organized as the next section describe the dynamics and mathematical modeling of the system, then defines the proposed methodology of the fault tolerant control system and by using this methodology, strategy design and implementation of the FTC system in MATLAB/SIMULINK environment described. Finally, discussed the simulation results with conclusions and future work.

2.Mathematical model for an active suspension system.

Mathematical modeling of an active suspension system derives from the basic equations of the spring mass and damper system, Fig. 1 shows the quarter car active suspension system.

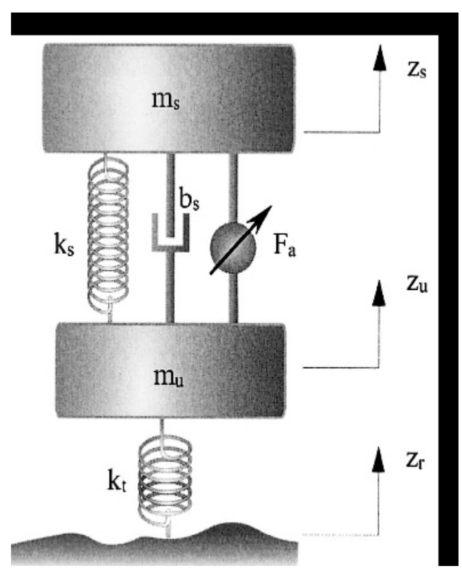

Fig. 1 Quarter Car Active Suspension Model

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The following are the equation of motion of the quarter car active suspension system.

$$m_s \ddot{z}_s + b_s(\dot{z}_s - \dot{z}_u) + k_s(z_s - z_u) = F_a \quad (1)$$
$$m_u\ddot{z}_u + k_t(z_u - z_r) - b_s(\dot{z}_s - \dot{z}_u) - k_s(z_s - z_u) = -F_a \quad (2)$$

Where m_s and m_u are the sprung mass and unsprung mass, F_a is the active suspension actuator force,b_s is the suspension damping, k_s and k_t are the suspension stiffness and tire stiffness, z_s, z_u *and* z_r are the sprung mass displacement, unsprung mass displacement and road profile input respectively.
The state space model of the quarter car active suspension system can be written as.

$$\dot{x} = Ax + BF_a + L\dot{z}_r \quad (3)$$

Where

$$x = [x_1x_2x_3x_4]^T \quad (4)$$

Rattle space or suspension deflection

$$x_1 = z_s - z_u \quad (5)$$

Sprung mass absolute velocity

$$x_2 = \dot{z}_s \quad (6)$$

Deflection of tire

$$x_3 = z_u - z_r \quad (7)$$

Unsprang mass absolute velocity

$$x_4 = \dot{z}_u \quad (8)$$

Below is the standard matrix form representation of the quarter car active suspension system state space model.

$$A = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -\frac{k_s}{m_s} & -\frac{b_s}{m_s} & 0 & \frac{b_s}{m_s} \\ 0 & 0 & 0 & 1 \\ \frac{k_s}{m_u} & \frac{b_s}{m_u} & -\frac{k_t}{m_u} & -\frac{(b_s+b_t)}{m_u} \end{bmatrix},$$

$$B = \begin{Bmatrix} 0 \\ 1/m_s \\ 0 \\ -1/m_u \end{Bmatrix} \quad \text{and} \quad L = \begin{Bmatrix} 0 \\ 0 \\ -1 \\ 0 \end{Bmatrix} \quad (9)$$

3. Methodology of FTC (Fault tolerant control) system.

Fault tolerant control system consist ofmajor three steps in which first step is to detect the fault in a system then second step is to identify the location or origin of the fault which occur in a system then third step is to isolate the fault from the system and give optimal result. In this research work, authors implement FTC (fault tolerant control) system on a quarter car active suspension system to detect, identify and eliminate the fault which occur during normal ride of the car in order to give smooth and better ride quality, this research focuses on the fault occur in sensor which gives signals to the controller in active suspension system. If the sensor malfunctioning then controller add or dissipate false force to the system hence our suspension gives jerk effect even on smooth road, to overcome this problem authors use this FTC system. Figure 2 shows the flow chart of the FTC system.

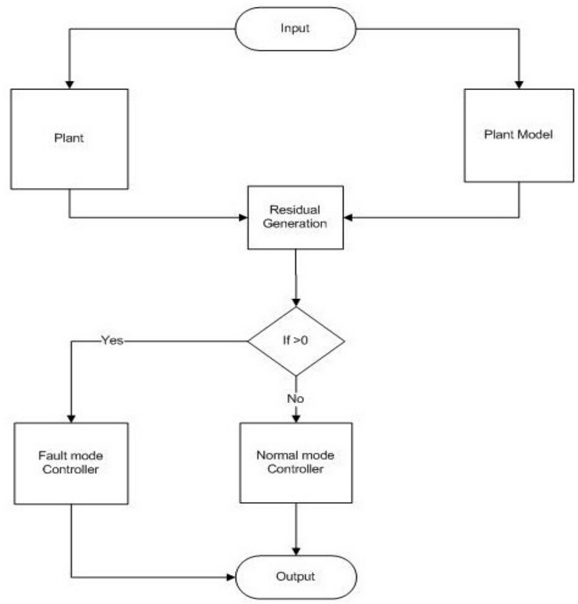

Fig. 2 Flowchart of the FTC system.

From Fig. 2, methodology of the FTC system defines as authors use model base approach to detect or identify the fault in system by using the mathematical model data and compare it with real time data to generate the residual, if residual is greater than zero then fault mode controller activated which gives optimal result while in normal conditions normal mode controller is activate which gives output according to the road profile.

4. Strategy of FTC (Fault tolerant control) system.

This research work is based on the simulation, for this purpose authors use the MATLAB/SIMULINK software to design the strategy of the FTC system. For designing of FTC system of quarter car active suspension system in SIMULINK authors use separate blocks for each operation of the system. Figure 3 shows the SIMULINK model of the FTC system for quarter car active suspension system.

Design of FTC system consist of various block in SIMULINK in which authors use road profile as an input function to the real-time block of active suspension system with or without FTC system and to the model-based block of active suspension system which use for the residual generation. Road profile consist of two road bumps with different time interval, active suspension system with FTC block gives the simulation with optimal result while system is in faulty state as compare to the block of active suspension system without FTC. The other main block is the reconfiguration of the controller to accommodate fault, it gives input to the system which makes our system stable during malfunctioning of the sensor and gives better and smooth ride while system runs in a faulty state.

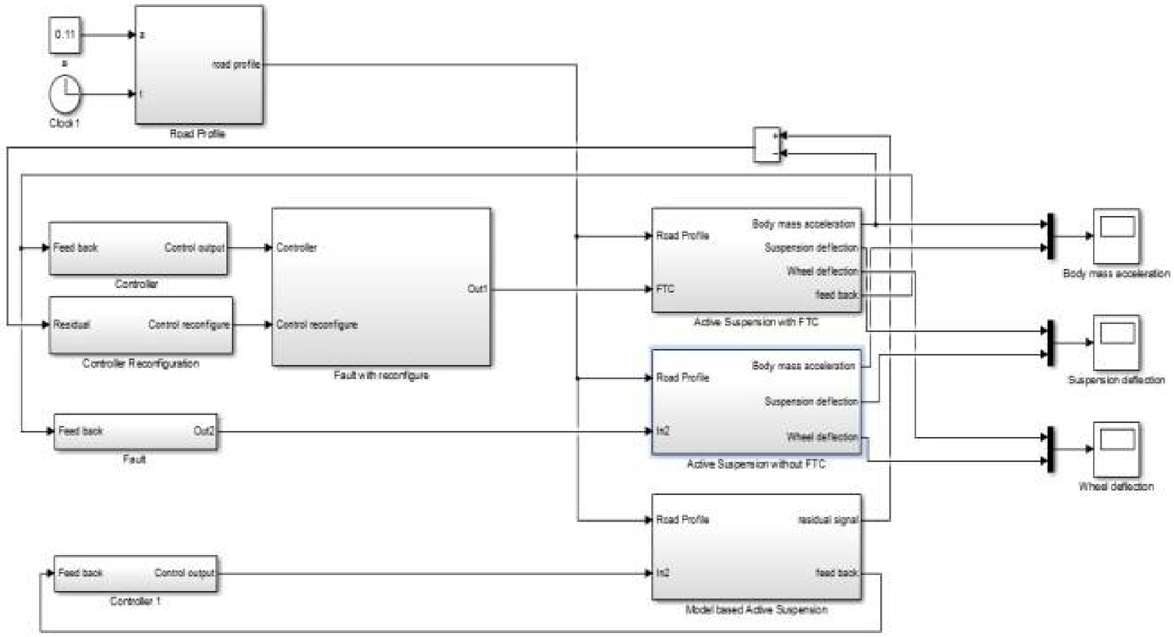

Fig. 3 SIMULINK model of FTC system.

5. Simulation Results and Discussion.

Fig. 4,5 and 6 shows the simulation results, in Fig. 4, the graph represents the body mass acceleration of the quarter of vehicle, the blue line represents the system when FTC mode is activated while red lines in graph shows the system without the FTC, during sensor malfunctioning. After 04 Sec of simulation run our proposed FTC system gives smooth and better result as compare to the system without FTC system. In Fig. 5, the graph represents the wheel deflection of the quarter of vehicle, blue line in the graph show the wheel deflection with FTC system and red line show the wheel deflection without FTC system while sensor malfunctioning. The graph clearly show that the wheel deflection is under control with FTC system and in the last Fig. 6, the graph represents the suspension deflection of the quarter of vehicle, again the blue line represents the suspension deflection with FTC and red line show the suspensiondeflection without FTC, better and smooth result achieve by using our proposed fault tolerant control system. Table 1 shows the parameters of quarter car model for simple passenger car for our simulation

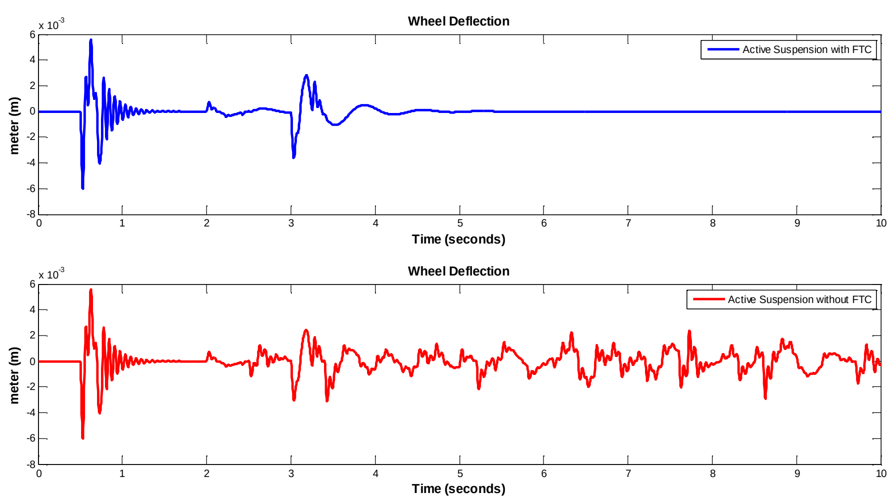

Fig. 5 Wheel deflections with and without FTC system

Table. 1 Quarter Car Model Parameters

S. No	Parameter	Value	Unit
01	m_u	60	Kg
02	m_s	285	Kg
03	k_s	600000	N/m
04	k_t	25400	N/m
05	b_s	1300	N-s/m

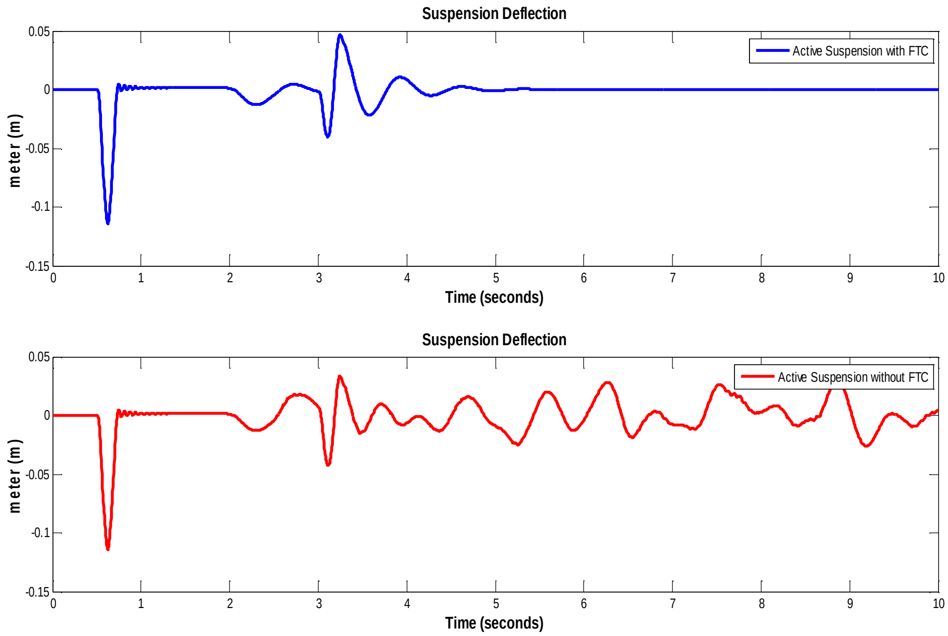

Fig. 6 Suspension deflection with and without FTC system.

6. Conclusions

Simulation results show that by using our proposed fault tolerant control strategy, we achieve good ride quality and better road holding while our active suspension system sensor malfunctioning. The proposed fault tolerant control system has following key benefit.

- The strategy based on the analytical redundancy.
- It reduces the usage of extra hardware due to analytical redundant system.
- It effects on the overall weight of the system.
- Cost effective.
- Easy to implement.

In future we will consider more typical sensor fault and implement our strategy to full car model in order to realize real time challenges and modify our strategy to accommodate these changes.

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