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PROOF

Intelligent Active Control System Design For Improving Vehicle Performance And Safety

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Abstract
Active control system has an indispensable effect on vehicle stability, performance and safety.So, design and implementation of control systemsis one of the most effective methods, which could considerably enhance the vehicle stability and controllability.Motion control, stability maintenance and ride comfort improvement are fundamental issues in design of active control systems. In this paper, intelligent vehicle systems are introduced and in order to optimize the vehicle safety smart control systems such as smart airbag by GPS, electronic stability program (ESP), Traction control system (TCS) and active suspension systems are developed for passenger vehicles. Also advanced smart highways technologies with communication systems are presented. These control systems used path, steering angle and throttle as a input to control vehicle velocity, acceleration and yaw rate to improve vehicle safety in sever manouvers and situations. Application of these systems results in improving safety, traffic flow and contrallability of vehicle. Simulation results demonstrate the effectivness of developed active control systems in vehicle safety and crash aviodance.

Keywords: Active control system, intelligent transportation system, safty, ESP, smart airbag, vehicle longtudinal, lateral and vertical dynamic

Introduction
With the recent increase in automotive safety consciousness, driver and passenger seats with seatbelt pretentioners have become standard equipment in virtually all vehicles in conjunction with improvements in collision safety technology and awareness of the importance of fastening seatbelts.
Further, in China, where the number of vehicles sold has rapidly increased, traffic accident fatalities are increasing yearly, exceeding 100,000 people since FY 2001 [1]. As in Europe, the Chinese government is pursuing the application of head-on collision standards, and the introduction of European side collision standards is under discussion.
In terms of measures by automobile manufacturers in this situation regarding collision safety, system standardization is progressing, including multi-stage control airbags for reducing damage from airbag systems, as well as side collision and head protection, provided in some vehicle types.
Active saftey and control systems of vehicles are one of the most important factors in decision making in intelligent transportation systems and are divided into three control groups: longtudinal, latera and vertical dynamics. During the previous decade, active safety technology (AST) developed to assist the driver to prevent accidents and decrease dangers. These technologies are used when the driver makes a wrong reaction or is not able to control the vehicle, suitably. In order to simulate active safety technologies, driver model is needed to model driver behaviors. This model is designed based on inherent driver and vehicle limitations [2, 3].
Active steering systems in front (AFS) or both in front and rear (4WS) can effectively improve the steerability performance in the linear region of the tyre [4]. In critical high lateral acceleration situations that the tyre cornering force varies in the saturation region, however, a direct yaw moment control (DYC) system can make the vehicle stable [5]. Although the concepts are now dated, nonetheless, new research work are still trying to enhance the system performance using different control schemes3 or using integrated AFS and DYC controls [6]. Abe [7] used a sliding mode controller for DYC and showed that change in chassis control from 4WS to

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DYC inevitably improves handling performance and active safety in vehicle motion with larger slip angles and/or higher lateral accelerations. Also in previous researches smart airbag [8, 9] and body structure can effectively reduce transmitted acceleration to occupant. Heredia and Ollero [10] present a method to analyse the stability of an autonomous vehicle path following algorithm takingexplicitly into account the computation and communication delays due to position estimation in the control loop.Another area of work in vehicle safety is active or semi active suspention system which uses magneto reoligical dampers as damping fluid [11, 12] to isolate the vibration and improve vehicle ride and handling properties. Also, active traction control systems [13]with controlling vehicle longtudinal dynamic maintain safety distance and velocity between vehicles.
In the current research, active safety systems integrated with a vehicle model are developed aiming to imrpve vehicle safety and stability properties. In this way, to improve vehicle path following and stability condition the integration of the AFS/DYC controller, with the consideration of smart airnag and active suspension system is proposed. The main contribution is an intelligent active controller for improving vehicle safety and decresing crash possibility. Furtheremore smart chassis structures and passive safety sytems are presented and effect of them are evaluted in various driving conditions.

2. Smart passive system

Passive safetysystems act afteran accidentto protect the occupant andstability ofthe vehicle. Some of these smart technologies are smart airbag with GPS, modoular and smart structure and suspended seats.

2-1 smart air bag

Traditional airbagsystems as shown in figure (1),consist of three basic components: crash sensors, an igniter, and an inflatable bag. The operation of these legacy systems is also relatively straightforward. If one of the sensors is tripped by a sufficient force, the ignitor goes off, which causes the bag to rapidly inflate. It's a one size fits all solution for a significantly more complex problem.

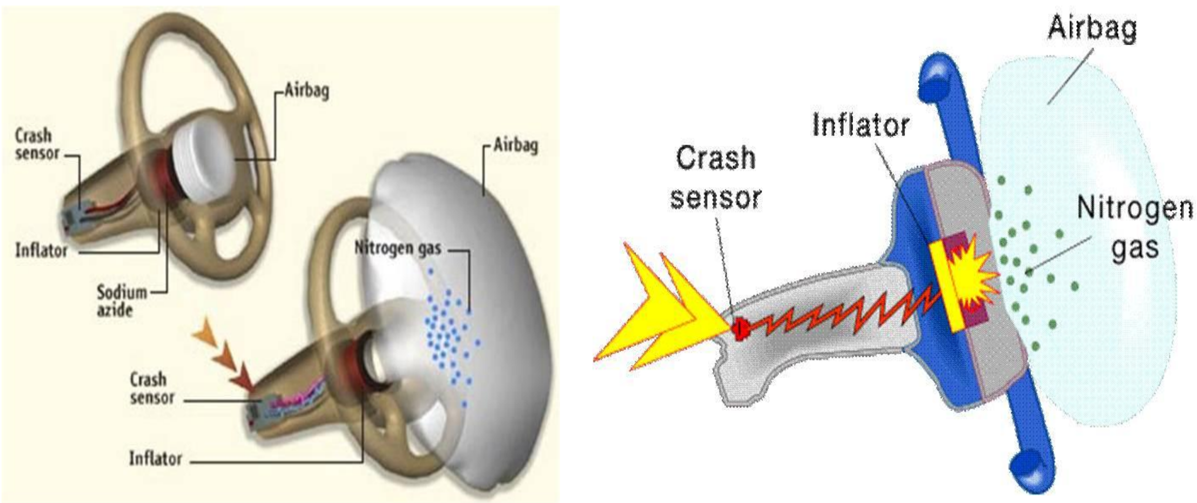

Figure 1: airbag structure and performance

Smart airbags make use of a variety of additional sensors to determine whether the system should deploy.The most basic form of smart airbag simply has an embedded weight sensor in the front passenger seat. If the passenger is below a certain threshold, the airbag system will shut off. This is sometimes referred to as a seat occupancy detector, and the same type of system can be used to trip a seat belt warning indicator or alarm.
More complicated smart airbag systems also include other sensors. Some of these systems can determine the position of the passenger on the seat with ultrasonic sensors (figure 2), which can allow the system to shut down if the passenger is too close to the dash. Other systems are capable of determining whether there is a car seat present, which will then prevent the airbag from deploying.
Other smart airbags are capable of modulating the force that they use to deploy depending on the weight and position of the passenger.
Another type of smart airbags which is developed in this paper, are equipped with GPS system. In this system, after acting the air bag for higher lateral accelration, airbag system send signal to GPS system to report the accident location to relief center.

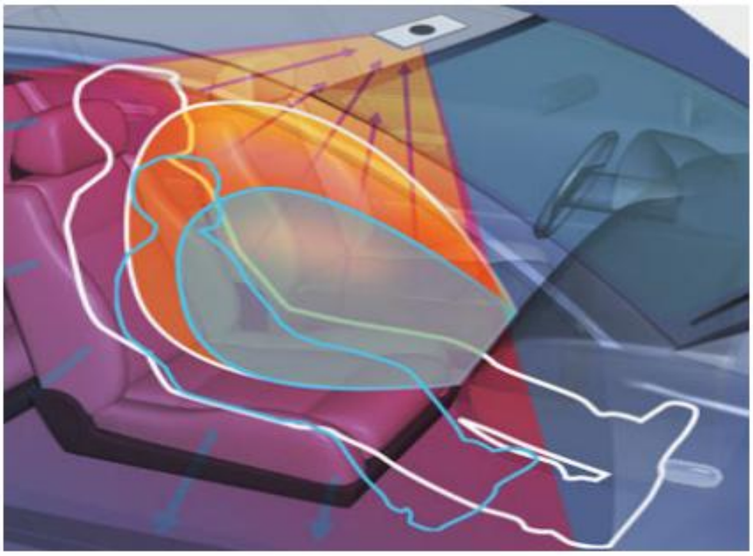

Figure 2: smart air bag performance

In severe accident, electrical system and battery may be in trouble, so auxiliary battery is considered in developed sytem to supply power to send a signal to ACU and process system. The proposed elecrtrical circuit and shemathic of system are illustrated in figures 3 and 4 respectively.

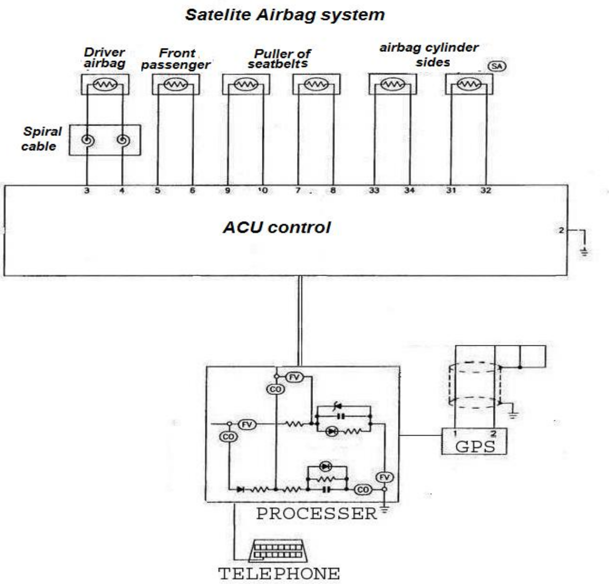

Figure 3:electrical circuit of smart air bag

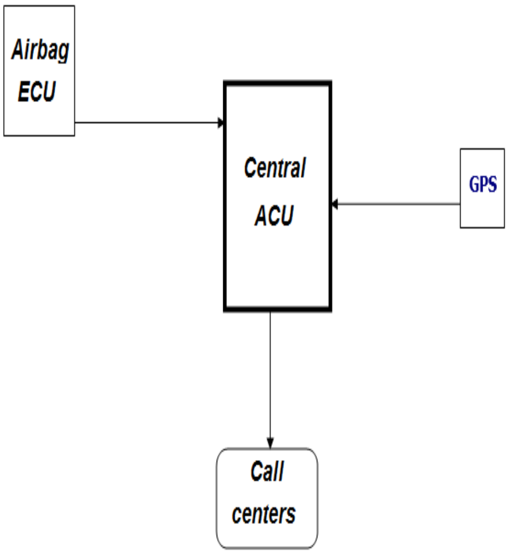

Figure 4: Schematic of smart air bag structure

2-2 Suspended seat

Seats should reduces the trasmitted accelartaion, impact and displacement to driver and passengers and have ability to resist agains tension and pressure forces over sever manouvers. As shown in figure 5, seats according instalation can be divided to three category include: floor, ceiling and wall mounted.

Another technolgy for suspended seats is using MR damper fluids to damp vibration according displacement magnitude. These suspension systems utilize semi active control to regulate the damping coeffiecient by applying electrical current. They demonstrate the rapid response and wasting more energy than the conventional dampers. In order to simulate the vertical dynamic of vehicle, 10 dof vehicle model with considring tire, suspension, seat and driver model is used which is shown in figure 6.

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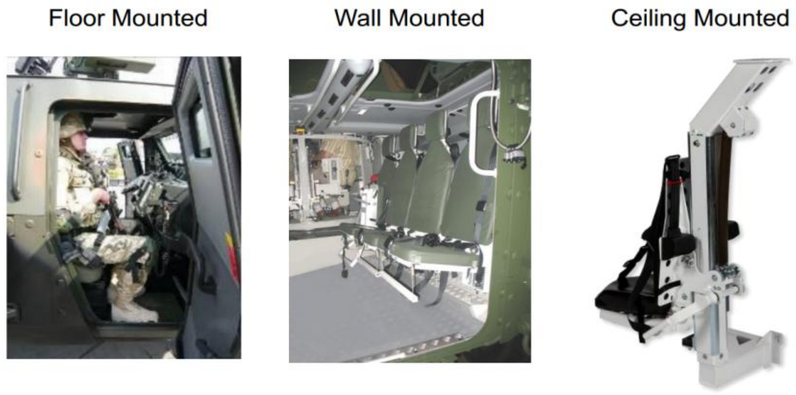

Figure 5: suspended seat conections

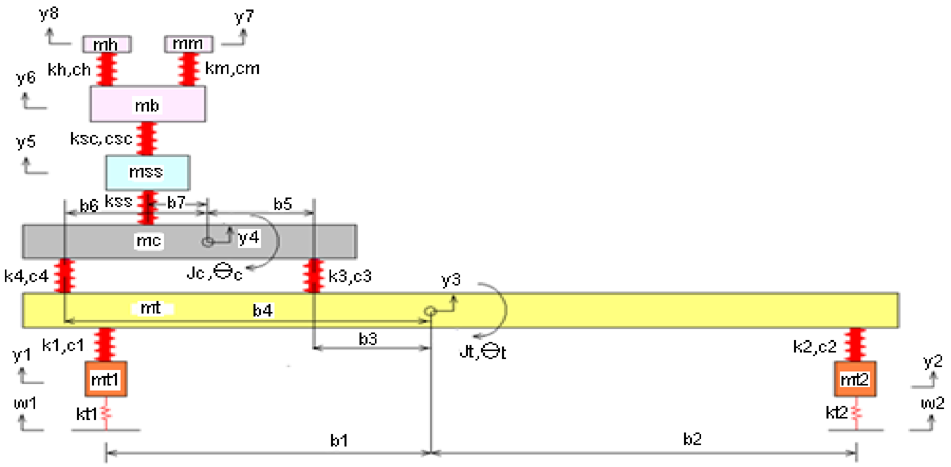

Figure 6: 10 dof vehicle vertical model

2-3 Modular body structure

In order to improve the safety of vehicle, modular and honeycomb structure of vehicle is utilized in vehicle body and chassis. These structures absorbs crashes energy and prevent thetransfer of energytotheoccupants.Some of them are illustrated in figure 7.

Figure 7: modular structure

2-4 smar seatbelt

The main passive safety system to reduce injuries and deaths caused by accidents and transmitted acceleration to passengers is seatbelt. In this paper conceptual design of smart seatbelt developed. In this intelligent system, if the passengers do not fast the seatbelt properly, vehicle fuel and speed limited to decrease risk. For this purpose sensors installed on belt buckle and belt tension to send a signal to ECU to control vehicle speed and fuel rate if it is not fasten correctly. If passengers do not install the safety belt buckle or pull the seat belt is not enough, sensors send data to the ECU to reduce fuel injection to keep the vehicle speed under80 km/hr. its procedure is shown in figure 8.

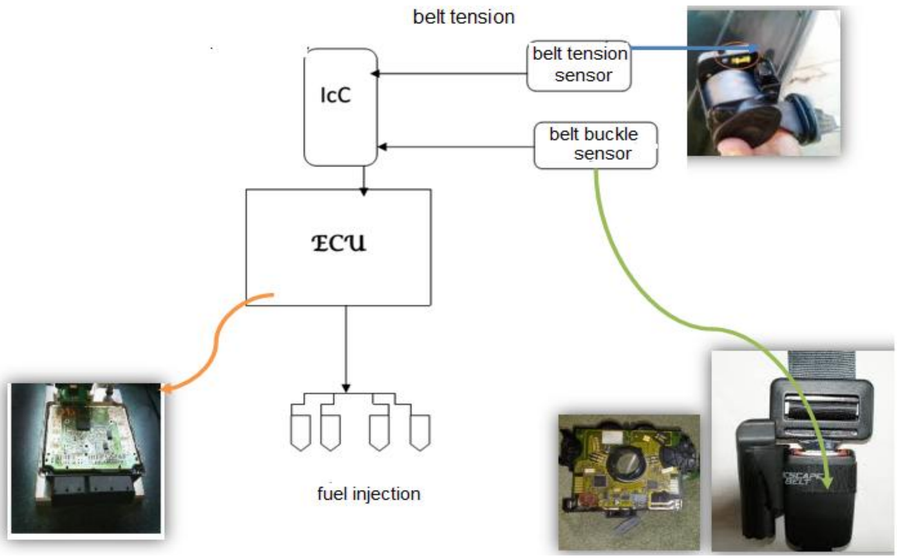

Figure 8: Smart seatbelt procedure

3.Smart road

Intelligent transportation systems usually refers to the use of information and communication technologies in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. Automated highway systems are efforts in building safe roads which keep vehicles' motion between lines and on the road center with the use of proper road infrastructures to prevent accidents and sudden deviations of vehicles on the road to improve and manage better the traffic.

Dynamic highway is one the inteligent road systems to adjustes guide rails positions and continious or dotted lines to mange the traffic according its flow. Dynamic traffic control, adjustable depending on the situation. Dynamic highway systems contribute to capacity management. Figure 9 demonstrate the comparisopn the traffic folw in various road types.

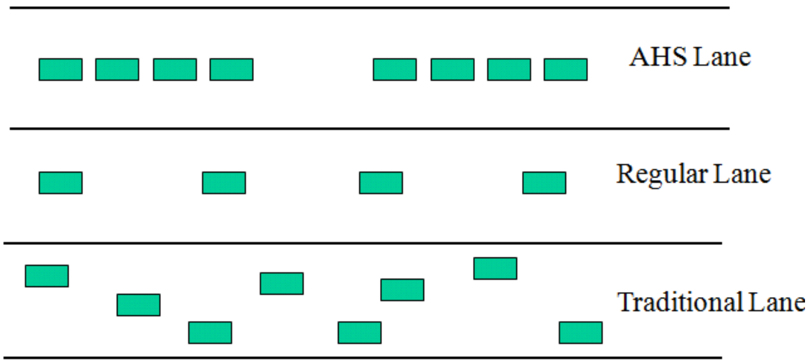

Figure 9: smart, regular and traditional road teraffics

The smart road system enables cars to exchange information about traffic situations, driver behavior and external factors. Vehicle-to-vehicle and vehicle-to-infrastructure communication (car-to-x technology) creates better situational awareness to help drivers navigate traffic more safely and efficiently with using GPS system.

4. Active control systems

Intelligent Vehicles (IVs) are equipped with control systems that can sense the environment around the vehicle and that result in a more efficient vehicle operation by assistingthe driver or by taking partial or complete control of the vehicle. There are several IV technologies that support and improve the platooning concept by allowing vehicle-vehicle and vehicle-roadside coordination [14, 15]:

Longtudinal dynamics, lateral dynamics and vertical dynamics. Some of these systems are illustrated in figure (10).

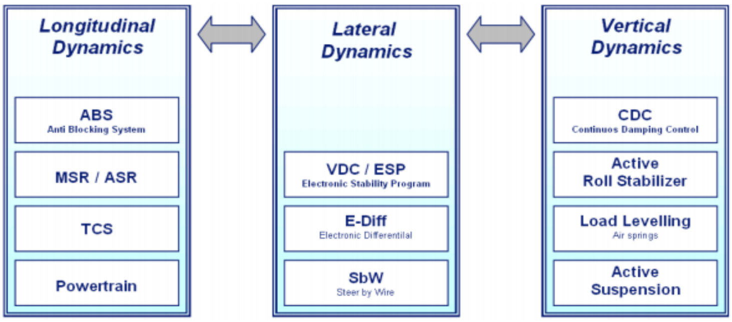

Figure 10: active control system category

4-1 Longtudinal dynamic

Traction control and adaptive crouse control systems are common and pratical longtidinal active systems. Traction control helps limit tire slip in acceleration on slippery surfaces. Many of today's vehicles employ electronic controls to limit power delivery for the driver, eliminating wheel slip and helping the driver accelerate under control.TCS sensors measure differences in rotational speed to determine if the wheels that are receiving power have lost traction. When the traction-control system determines that one wheel is spinning more quickly than the others, it automatically "pumps" the brake to that wheel to reduce its speed and lessen wheel slip. In most cases, individual wheel braking is enough to control wheel slip. However, some traction-control systems also reduce engine power to the slipping wheels.

Conventional cruise control systems simply maintain a preset speed. The driver presses a button to set the speed, and a servo or actuator on the throttle linkage maintains that speed until the driver steps on the brake, changes the speed setting up or down, or disengages the cruise control. An ACC system is a radar-based system that extends conventional cruise control andthat is designed to monitor the immediate predecessor vehicle in the same lane, and toautomatically adjust the speed of the equipped vehicle to match the speed of the preceding vehicle and to maintain a safe intervehicle distance. Cooperative ACCis a further enhancement of ACC systems that uses wirelesscommunication technologies to obtain real-time information about the speed, acceleration, etc. of the precedingvehicle. Vehicles equipped with cooperative ACC can exchange the information muchquicker and allow to set the safe minimum time headway as small as 0.5 s. Hence, withreduced headways between vehicles, the maximal traffic flow can be augmented evenfurther these systems usally apply fuzzy control method [16] for control strategy system.

Adaptive cruise control (figure 11), by comparison, is a “smart” system that actively maintains a preset distance between vehicles rather than a preset speed. A laser or radar range finder sensor in the front of the vehicle measures the distance to the vehicle ahead. The driver then selects a distance that suits the driving conditions, and the system automatically maintains that distance as traffic speeds up and slows down. This makes adaptive cruise control much better than conventional cruise control for driving in heavy traffic, and it reduces the risk of rear ending another vehicle if the driver isn’t paying attention.

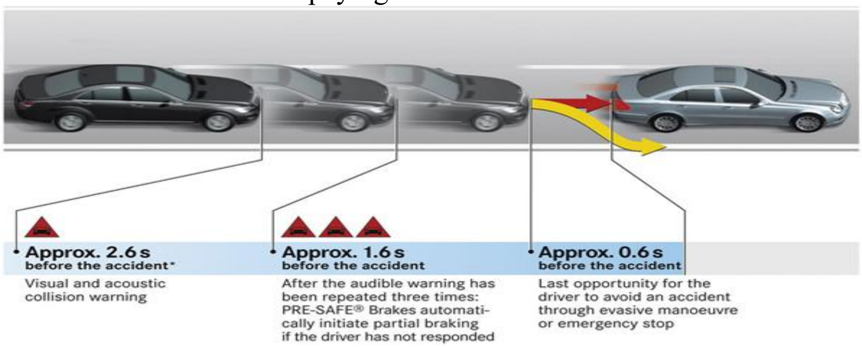

Figure 11: adaptive crouse control system

4-2. Lateral Dynamic

The main lateral dynamic control systems which are popular are ESP, AFS and ABS which are used in passenger cars. In this paper integrated AFS/ESP system is utilized to improve vehicle performance.Electronic stability program combines the capability of ABS and TCS with a lateral stability control feautures. While ABS and traction control system improve the longtudinal staility of the vehicle by limiting wheel slip, ESP primary function is to enhance vehicle control during cornering. Schematic ESP function is illustrated in figure 12.

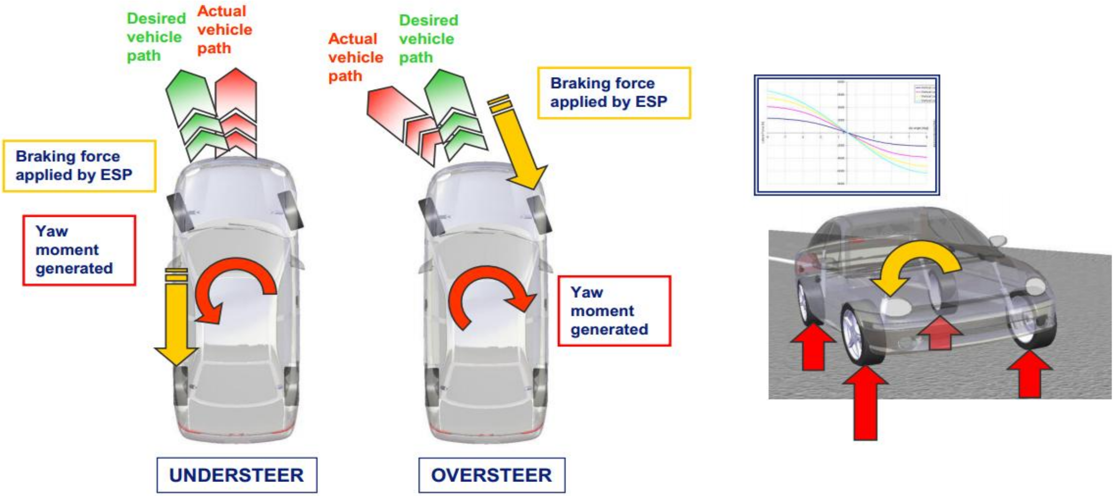

Figure 12: ESP performance

AFS describes a steering system for a vehicle in which the relationship between the driver's steer inputs and the angle of the steered road wheels may be continuously and intelligently altered to imrpve vehicle steerability in linear region. This system as shown in figure (13) according manouver and vehicle variables regulates the steering angle of driver and reduces control effort of driver.

4-3 Vertical dynamic

In this type of system, the conventional spring element is retained, but the damper is replaced with a controllable damper. Whereas an active suspension system requires an external energy source to power an actuator that controls the vehicle, a semiactive system uses external power only to adjust the damping levels, and operate an embedded controller and a set of sensors. The controller determines the level of damping based on a control strategy, and automatically adjusts the damper to achieve that damping. Various suspension system performnce and components are compared in figure 14.

Figure 13: Comparision of driver performance with and without AFS [17]

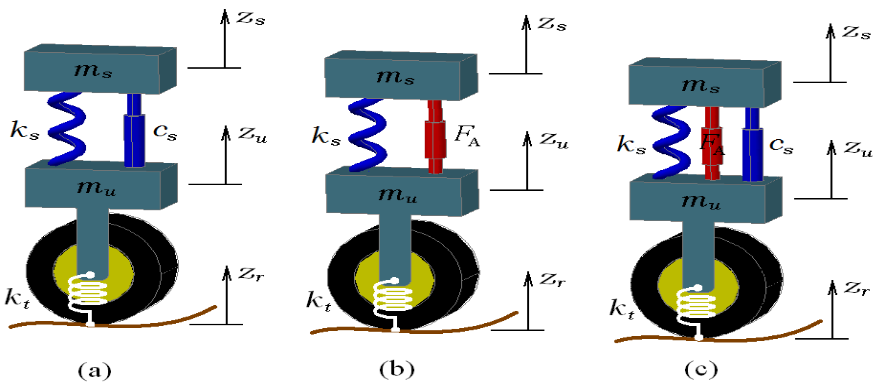

Figure 14: Quarter-car suspension systems: (a) Passive Suspension System, (b) Active Electromagnetic Suspension System and (c) Active Hydraulic Suspension System [18, 19]

5. Results

In this section, the proposed suspension damping model and exprimental results are compared to verify the proposed MR damper. As shown in figure (15) there is a sufficient aggrement between exprimental and simulation results.

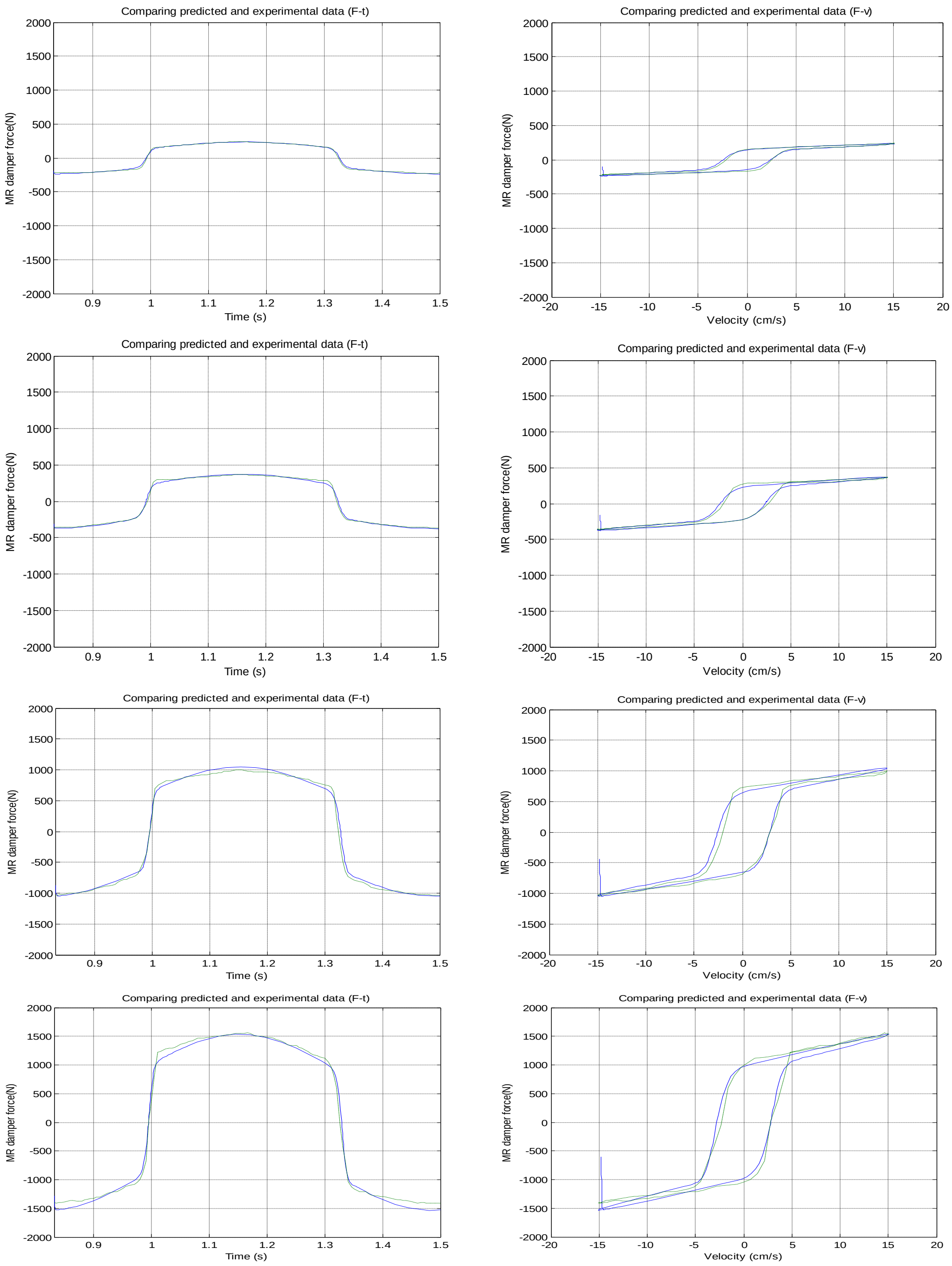

Figure 15: force-speed and force time graphs of MR damper - - - experimental _____ simulation model

In the next step, simulation results of proposed vehicle model with integrated ESP-AFS system, only ESP and without controller cases are compared for j-turn manouver. Vehicle path, lateral deviation, lateral velocity and acceleration are illustrated in figur (16) – (19) respectively.

Vehicle path and lateral deviation demonstrate that integrated ESP-AFS control system follow desied path vith minimoum deviation. Also lateral acceleration and velocity over j-turn manouver indicate that vehicle with integrated controller is more stable than only ESP case. Whilst without active control system vehicle is not able to follow desired path and losses its stability.

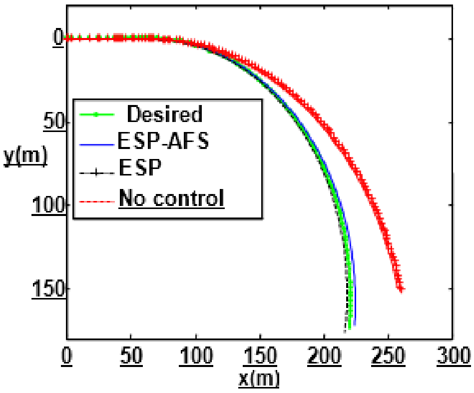

Figure 16: vehicle J-turn path

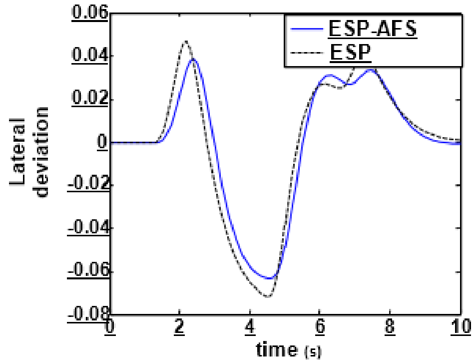

Figure 17; Lateral deviation

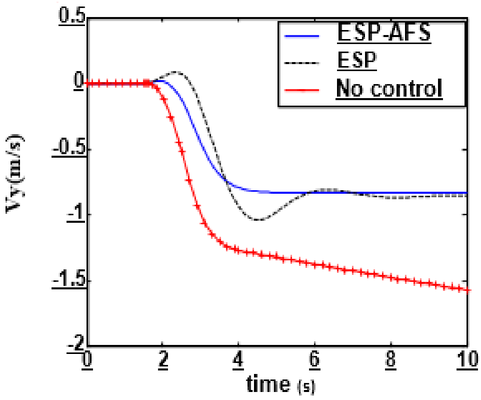

Figure 18: lateral velocity

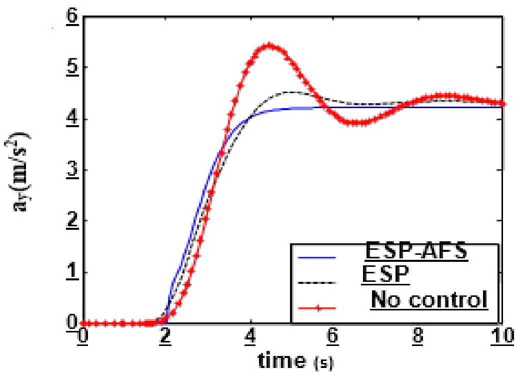

Figure 19: lateral acceleration

Conclousion

In the last decadeintelligentcontrol andprotection systemisapplied tovehicles as aneffectivewayto increasesafety, performance andthe protectionlevel.In this regard,the most recenttechnologiesandsafetyprotection of vehicle active and passivecontrol systems, are provided and the effects of these systems on vehicle safety and performance are evaluated. These systems in various driving condition prevent vehicle crash, reduces damages and improve traffic flow.In this study, the effectiveness of a active control systems for vehicle safety was evaluated in various critical situations. The proposed control law is developed based on yaw moment and active front steering as well as minimizing the lateral deviation and heading error in relation to a given path and driver's inputs. The main advantiges of active and smart safety systems of vehicle are:

1- Accordingtotheroad networkandgeographical position, vehiclesposition identified in sever conditions and also are guided in theoptimal routes.

2- Vehicle speed and path are regulated in optimal way.

3- traffic flow is improved by considring lateral and longtudinal velocity and distance.

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