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Simulation of Driver Model for Traffic Safety Considering Road Conditions

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Abstract
With the increase of traffic and considering optimal management of traffic flow and safety, it is required to simulate intelligent transportation systems (ITS). In this paper, intelligent transportation systems are introduced at first and in order to control the vehicle optimally in a traffic condition, a driver model is designed based on vehicle specifications. Automatic lane keeping system of the driver model receives vehicle's desired path as input of control system considering traffic conditions by using mounted cameras on the vehicle and causes the vehicle to move intelligently on the desired path with simultaneous change and control of steering angle (lateral dynamics) and throttle (longitudinal dynamics). The performance of the presented driver model was satisfactory in performing automatically different manoeuvres (lane change, overtaking and cornering). Application of this driver model results in improvement of safety and traffic flow and decrease of fuel consumption and emissions.

Keywords: Traffic Safety, Driver Model, Traffic Model, Optimal Control of Vehicle

1. Introduction
With the increase of vehicles usage in human societies, vehicle motion control is of great importance in the field of traffic management. Considering the importance of traffic and its effect on human life and also the progress of electric and control industries, intelligent transportation systems are used as a solution to improve traffic conditions and to enhance efficiency of transportation systems. Furthermore, it is aimed to increase safety and traffic flow, decrease traffic congestion, fuel consumption and emissions.

Modern control systems are of the most important factors in decision making in intelligent transportation systems and are divided into three control groups: road, vehicle and driver. 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 behaviours. This model is designed based on inherent driver and vehicle limitations. One of the intelligent systems which is used to track vehicle's optimal path is the comprehensive driver model (longitudinal and lateral) design which is of the most modern vehicle technologies. At present, extensive researches [1-3] are being done on this system in vehicle manufacturing companies. An important issue for the chassis control systems is to control the lateral vehicle motion variables such as the yaw rate and side-slip angle by controlling the vehicle yaw moment. Active steering systems in front (AFS) [4] or both in front and rear (4WS) [5] can effectively improve the steer ability performance in the linear region of the tyre [6]. A mathematical model for the steering control of an automobile is described by Sharp et al [7], also, Mahmoodi-k et al. [3] investigated the robust design optimization process of suspension system for improving vehicle dynamic performance (ride comfort, handling stability)using the Genetic algorithm.

Design of driver model to move the vehicle on the desired path is one of the vehicle's intelligent path tracking systems in order to enhance safety, reduce fuel consumption and emission, improve traffic conditions and passengers comfort. This paper investigates application of vehicle comprehensive model in combination with driver model with focus on desired path tracking for kinds of arbitrary paths. Automatic lane keeping system, receives the target path as control system inputs via cameras and sensors mounted on the vehicle. The simplest method to model driver behaviour laterally is by feedback control which is shown in Fig (1). In feedback control theory, it is assumed that the driver has a desired path (y_d); then, feedback control is applied to make the output (y) track the desire path. Fig (1) demonstrates schematically the vehicle motion on the optimal path on the road.

2. Traffic Model

It is needed to simulate intelligent transportation systems with the increase of vehicles to improve and manage traffic safety. In order to do so, a traffic model must be available to identify traffic problems and their solution. Speed, congestion and traffic flow are the three principle variables which are estimated by traffic models. The speed of traffic flow based on the travelled distance of vehicles is assessed in time unit and the congestion is defined as the number of present vehicles in a range of the road. Traffic flow illustrates the number of passing vehicles in a reference point in time unit which is usually measured every one hour.

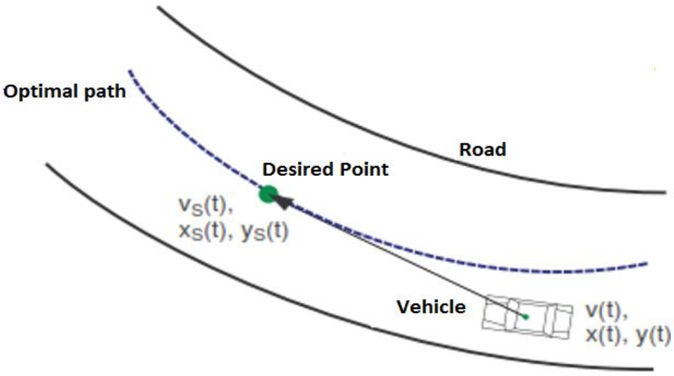

Figure 1: track and estimation of vehicle's optimal path by the driver model

Traffic models, based on modelling of traffic details are divided to three classes: macroscopic model, microscopic model and mesoscopic model. Macroscopic model deals with average of traffic variables like speed average, average traffic congestion and flow. This model simulates a part of the highways macroscopically and it is used mostly to analyse traffic flow condition in a determined range. Traffic microscopic model, unlike the macroscopic model, considers the behaviours and state variables of each of the vehicles in traffic flow and simulates vehicle behaviour like speed, acceleration and path change. Mesoscopic model, which combines the characteristics of the previous models, simulates every vehicle's behaviour in a specific part of a macroscopic model. In this paper, with driver model design, microscopic traffic model is taken into account which ultimately results in the macroscopic model improvement.

Using traffic models with sensors and cameras mounted on the vehicle, the optimal path is sent to the vehicle's control centre considering traffic conditions; then the vehicle moves on the determined path, utilizing throttle and brake control (vehicle longitudinal dynamics) as well as steering angle and lateral velocity control (vehicle lateral dynamics), with minimum deviation.

3. Intelligent Control Systems and Their Aim

Using modern electric systems and organizing intelligent transportation systems affect greatly on management and improvement of traffic conditions. Intelligent transportation systems include automatic, computer and communication control systems which are in relation with the vehicle in traffic systems and results in improvement of traffic flow and traffic safety.

Intelligent transportation as well as common methods (highways construction, widening and improving roads conditions and etc.) cause the increase of effective capacity and improvement of facilities efficiency and is an impressive step in development of technology and communication which increases safety. Intelligent transportation system with triple intelligent focus of road, vehicle and driver helps the problems of traffic in different fields such as advanced navigation, traffic management improvement, safe driving and improvement of vehicle performance to reduce fuel consumption and environmental pollution. In this paper, it is more focused on the vehicle and the driver in intelligent systems.

3.1. Intelligent Road

Automated highway systems are efforts in building safe roads which keep vehicles' motion between lines and on the road centre 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. One of the most modern methods in this field is placing magnets beneath the road which keeps vehicles between the lines and prevents them from spiral motions and sudden deviations on highways. In fact, vehicles can move on a determined path like monorails. When entering or exiting from these intelligent roads, the vehicle is controlled automatically with acceleration or deceleration.
Another example of these intelligent roads is using communication facilities like GPS which helps the driver to determine the proper path by receiving information of road traffic conditions. Fig (2) illustrates an instance of this kind of communication system and data transmitting to the vehicles. As it is clear, knowing the road conditions and the road being closed in red line path due to the accident, the driver changes the path and drives on the optimal path which is determined by the GPS. To use this intelligent road system, it is required to equip the vehicles with modern electric systems and upgrade the roads.

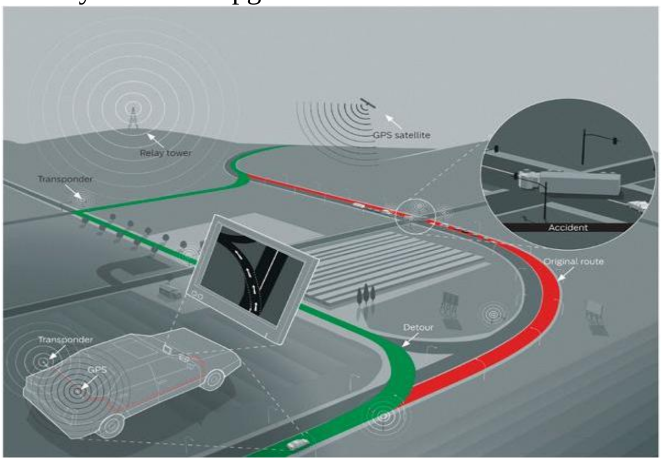

Figure2: an example of intelligent road

3.2. Intelligent Vehicles
Vehicle safety systems are generally divided to two categories of passive safety systems which can be safety belts, airbags and etc., and active safety systems which include modern systems of control and electronics in vehicles. In this paper, an example of active traffic safety systems is simulated which consists of design of a driver to control vehicle path considering the traffic model. Fig (3) shows the advancing process of vehicle safety systems in recent years. In this figure, active safety systems are shown by blue line and the passive safety systems are demonstrated by red line.

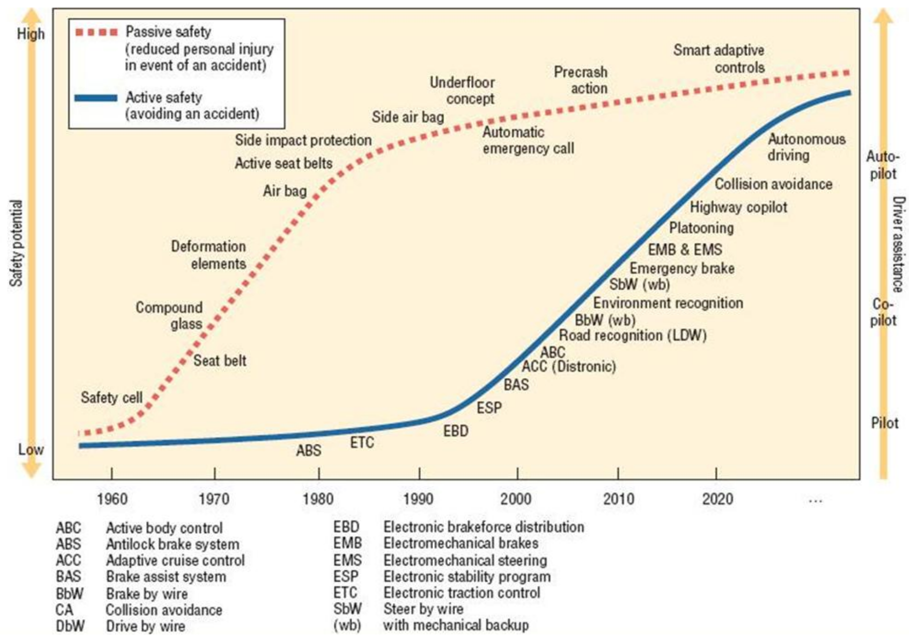

Figure 3: advance of vehicle safety systems

Modern control systems are set on the vehicle and can be used as driver assistant systems in critical situations or can improve passengers' safety and comfort with the help of vehicles' intelligent control and guidance system.
Antilock brake system (ABS) and electronic brake force distribution (EBD) are of active safety systems which improve braking and stability with the increase of handling and optimal distribution of brake force. A more recent kind one of these systems is electronic stability program (ESP) which has a great effect on vehicle stability and control. This system maintains vehicle stability in critical conditions by applying braking on the wheel which is slipping.

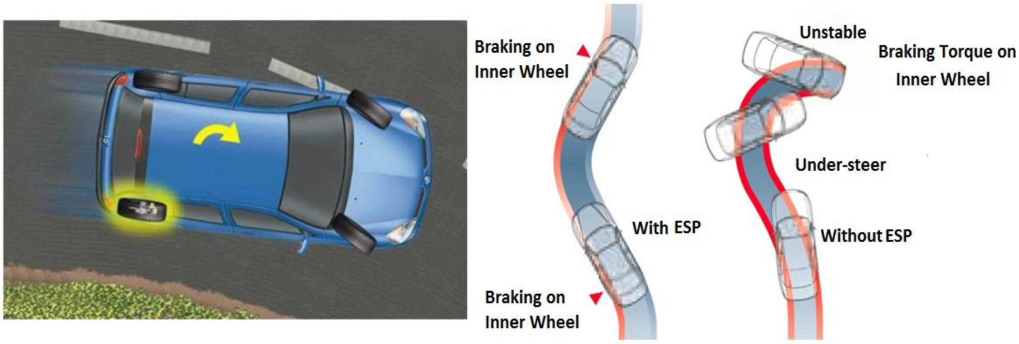

Figure4: performance of vehicle stability control system

Collision warning device/algorithms (CWA) are of driver assistant systems which were first introduced by Gibson [8]. These systems identify vehicle safe distance from the obstacle with respect to vehicle state variables (longitudinal and lateral velocity, yaw rate, longitudinal and lateral acceleration and etc.) and the driver's delayed reaction time and warn in the case of critical conditions.
Another type of these systems is lane departure warning (LDW) which in fact is an active safety system that assists the driver by informing him/her of path deviation through identifying road range via determination of side and centre lines. Fig (5) exhibits the performance of this system in two cases of normal and warning.
These systems can be very effective to prevent accident or path deviation by warning the driver during drowsiness and distraction.

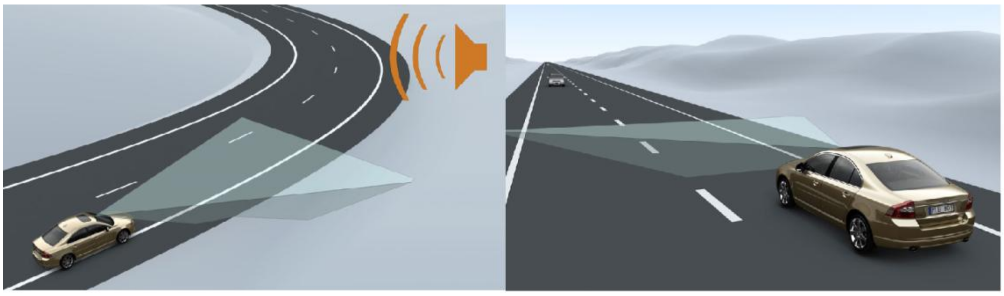

Figure5: performance of vehicle stability system

3.3. Intelligent Driver

As was shown in Fig (2), the newest active safety technologies in vehicles are completely intelligent systems of driver model which are being used with the aim of optimal tracking. The simplest type of active driver systems with numerous applications is the longitudinal driver model which is also known as adaptive cruise control. This system can control vehicle distance and longitudinal speed via throttle and brake control. Adaptive cruise control is applied in higher highway speeds over 40 km/hr while in low speeds (0-30 km/hr), stop & go system is utilized and the previous speed is kept between these two speeds. This longitudinal dynamic control system has a radar placed in front of the vehicle which receives the information based on vehicles' and obstacles' distance and speed and sends the relevant signal to the electronic control unit of the vehicle which in turn regulates vehicle speed by throttle and brake control. Fig (6) shows the performance of adaptive cruise control system. At the first stage, the vehicle moves with constant speed on its path. At the second stage, the obstacle (front vehicle) is identified by the radar which is placed at the front bumper and finally at the third stage, vehicle speed is reduced proportional to the front car's speed and the longitudinal distance is kept safe and standard. In result, the probability of accident is reduced and the traffic flow is improved by maintaining longitudinal distance and proper speed.

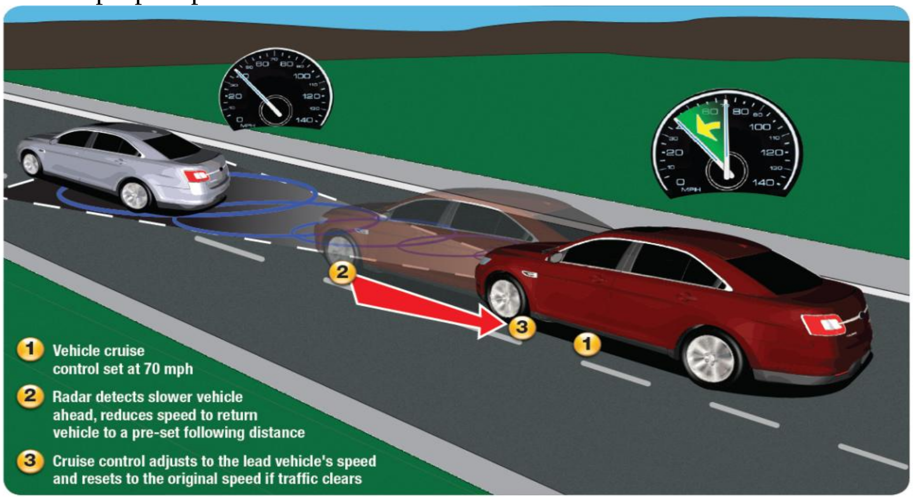

Figure6: performance of adaptive cruise control

However, the newest technology in intelligent driver systems is the design of automatic driver model longitudinally and laterally which considers lateral conditions as well as control of speed and longitudinal distance (adaptive cruise control) and performs the best driver reaction in different driving conditions. Performance of complete driver model is illustrated schematically in Fig (7).

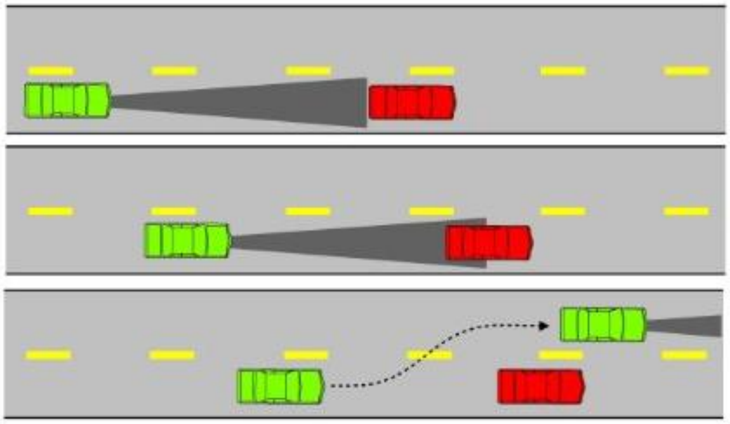

Figure7: performance of driver model in lane change

Later in this article, the design of vehicle longitudinal and lateral driver model and its performance accuracy for different roads and manoeuvres are being presented.

4. Driver Model Design

Driver behaviour and human/vehicle relationship is an important issue in the field of vehicles and transportation. The response that a driver gives to his/her surrounding traffic affects road design, traffic regulations and human-vehicle relationship. As an example, neglect (impatience) or driver's little attention are the reason of 65-75% of the accidents reported by the police and careless drivers are subject to accidents 3 to 6 times more than careful drivers [9]. During the previous decade, human driver model (HMD) is developed to assist drivers to prevent accidents and reduce danger. These technologies are applied when the driver makes a wrong reaction or is not able to control the critical condition. Driver model which models driver's behaviour is required to simulate active safety technologies effects on vehicle performance.

Driver limitations can be physical and spiritual. Driver (human) does not recognize frequencies under 15 rad/sec naturally [10]. The main reason of driving accidents is driving mistakes which can be due to driver's neglect and impatience (cell talking, eating and etc.), hurry in arriving to destination (high speed and critical manoeuvres), delayed reaction to condition changes and lack of enough driving information.

Driver behaviour can be considered with automatic control theory as the vehicle controller. The common method to design driver controller is analysing human's control behaviour as a linear continuous feedback control function and presenting it as a transfer function. The transfer function of the driver model, used in this paper, is the improved driver model which is presented in [11] and is as follows:

$$H(s) = h(\tau_D S + 1 + \frac{1}{\tau_I S})e^{-\tau_L S} \qquad (1)$$

Human operator has a time delay to take the vehicle under control of the input (actuation) which is expressed by the term $e^{-\tau_L S}$, where τ_L is the time delay parameter. The least control action that the driver operator performs is to change the output with regard to the input. In other words, the operator is proportional and the parameter h presents a proportional constant. Furthermore, human operator can control the optimal path with anticipating system input change (actuations). Here, the output signal of the driver model is normally proportional to the input change rate or the measure of differential input. Namely, it is called differential control operator which is expressed by the time differential parameter τ_D. Driver controller can also do the integral control operation which is the output signal proportional to the integral of the input signal. This integral operator presents the fact that when the vehicle deviates from its main path, the driver is able to take it back to the aimed path which is determined by the integral time τ_I.

In driver model controller design, driver's view and anticipation from the road is simulated in the open loop model, then in the closed loop model, compensatory control is being used. With simultaneous change and control of throttle and brake (longitudinal dynamics), the vehicle moves intelligently on the desired path. In the design process, a comprehensive vehicle model is simulated in MATLAB software (Simulink). Then, based on various control theories, vehicle parameters (steering angle, longitudinal and lateral velocity, yaw rate), regarding their feedbacks, are controlled such that the vehicle moves on the desired path with minimum error. Different strategies are being used during recent years. In the driver model presented in [12], yaw rate and lateral distance from the target path are as index parameters and considering the steering input, the error between desired and anticipated variables is calculated. Based on this simplifying assumption in which the steering input is constant, the simulation is performed.

In this paper, it is aimed to use a model with higher degrees of freedom as well as optimal control theory in driver model design considering simultaneously longitudinal and lateral vehicle models. To do this, the comprehensive model of [13] is utilized first and then a two layer control system is applied. In the first layer, vehicle longitudinal dynamics is controlled through throttle and brake control. In the second layer, vehicle lateral dynamics is controlled using steering angle and yaw rate control. Control model is shown in Fig (8).

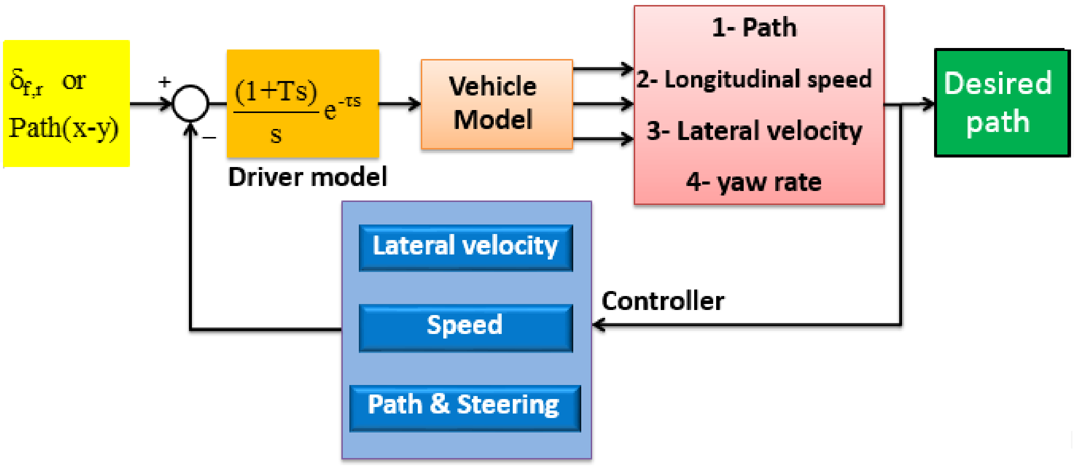

Figure8: driver model control system

5. Driver Model Simulation

Nonlinear comprehensive vehicle model and driver model controller which were presented in previous sections, are simulated in MATLAB/Simulink software for a car with specifications near SAMAND vehicle on dry road. In analysing the performance of designed driver model with optimal controller, the simulation is done for the following steering inputs: step function, ramp (lane change) and double lane change (overtaking).

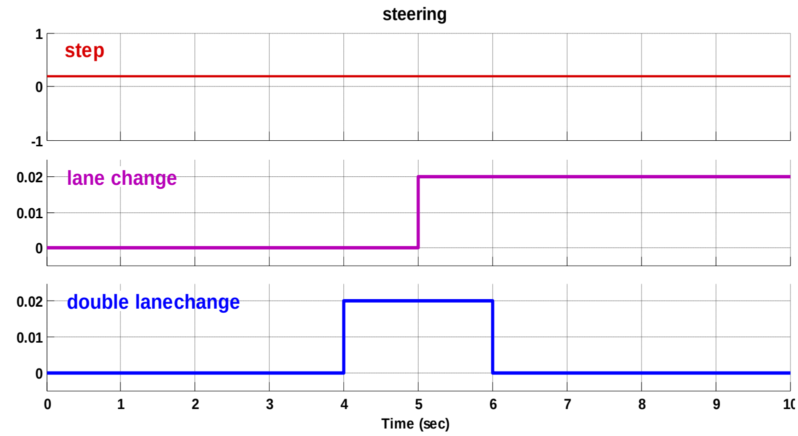

Figure 9: steering inputs

Simulation results are presented for four cases: without controller (black), steering and lateral velocity control (red), lateral velocity and yaw rate control (blue) and simultaneous lateral and longitudinal control (blue) for manoeuvres of lane change and double lane change which are being shown in Fig (10) and Fig (11). In Fig (12) and Fig (13) the accuracy of driver model performance with optimal controller, when moving on the desired path $y = x^2 / 200$ and cornering, are illustrated.

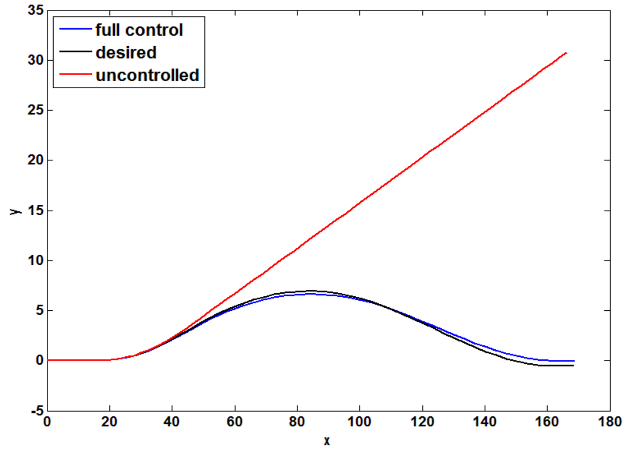

Figure 10: double lane change path control using throttle control (longitudinal velocity) and steering control (lateral) with optimal controller

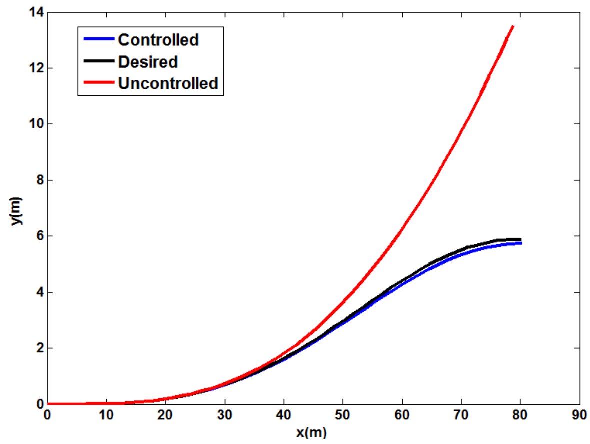

Figure 11: vehicle path deviations with different controllers with optimal controller for lane change manoeuvre

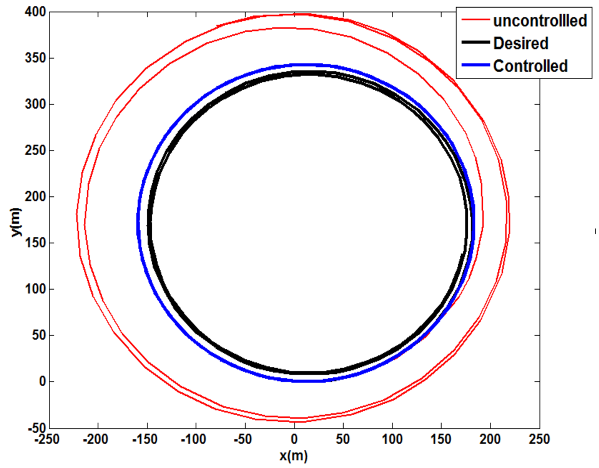

Figure12: turning path control using throttle control (longitudinal velocity) and steering control (lateral) with optimal controller

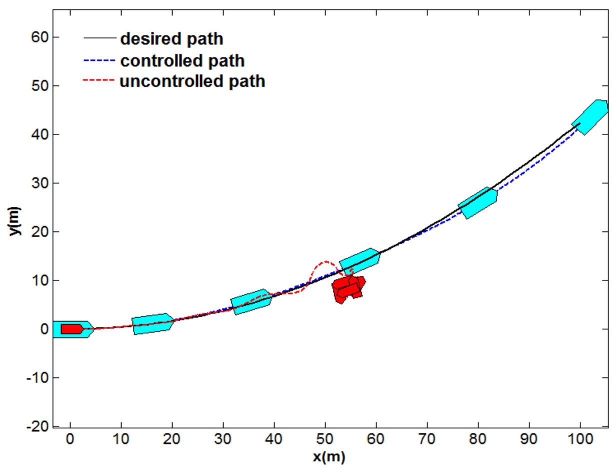

Figure 13: vehicle path deviations with optimal control for arbitrary desired path

Conclusion

Intelligent transportation systems are used in recent decade as an effective solution to increase traffic safety and flow which improves traffic management, safe driving, and passengers comfort and reduces adverse environmental effects, fuel consumption and costs.

Therefore, vehicle longitudinal and lateral drivel model was simulated as intelligent active safety system. This model can prevent accidents due to driver mistake with safe and proper performance in different conditions. Also, considering optimal path choosing and the road situations, this model improves the traffic and reduces vehicle high acceleration manoeuvres, which in result decreases fuel consumption and emissions.

Automatic driver model system, as the newest active safety system, is an effort to eliminate driving mistakes, which are the main reason of traffic accidents and problems. Generally, the advantages of intelligent systems are:

1. Considering the path of highways network, the vehicles are guided on the optimal path.
2. Path and speed changes are regulated based on the traffic flow.
3. Maintaining standard longitudinal and lateral distances in the traffic, the motion of more vehicles is possible on a determined path.
4. Sudden and incorrect driver actions which are due to neglect and tiredness are prevented.
5. Increases traffic capacity of highways and improves traffic safety.

Vehicle stability and safety studies needs close loop system simulation which is done by modelling and controller design of driver/vehicle and the performance accuracy is shown in various manoeuvres.

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