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Intelligent Vehicle Control System

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Abstract – *This paper proposes a novel method of haptic shared control system using steering mechanism and braking system. Haptic shared control achieves smooth collaboration between humans and vehicles by facilitating mutual communication and enhances drivers' safety during manual driving. The method proposed in the paper is a simple one that aims to reduce car crashes and accidents by giving feedback to the human driver in the form of sense of touch. Various existing driver assistance systems have also been discussed.*

Key Words: Haptic Control, Advanced Driver Assistance System, Advanced Emergency Braking System, Lane Departure Warning System, Parking Assistance System, Cooperative States, Steering

1. INTRODUCTION

India is expected to emerge as the world's third largest passenger vehicle market by 2021. Currently, the automotive sector contributes more than 7 percent to India's GDP and the Automotive Mission Plan 2016–26 has set an aspiration to increase this contribution to 12 percent. However, there were about 500 thousands road accidents in 2015. Majority of these (more than 70 percent) were caused due to the driver's fault. This includes over speeding, driving under the influence of alcohol etc. The rate of rise in vehicles' population has far exceeded the rate of expansion of road network in past few decades, creating a massive pressure on the roads. This necessitates frequent steering and application of brakes. Such frequent steering and braking reduce the average speed at which vehicles ply on the roads, raising cost per kilometer and increasing carbon emissions. Therefore India is in dire need of safe driver assistance systems designed to prevent road accidents. Congestion prevention cannot be merely achieved by the construction of new roadways but through the control of vehicles and traffic flow to increase the practical capacity of the roads.

Driver assistance systems have been developed to warn drivers of the impending dangers so that he/she may take necessary action in time to prevent major accidents and casualties. A variety of approaches, ranging from fully autonomous systems to the ones using shared control, have been adopted. However, a system which is fully autonomous has not proved very effective, as evidenced by the crash of autonomous cars in countries like US. It is due to limitations and idiosyncrasies of existent technologies like LiDAR based vision and GPS. Hence, humans with their superior senses of vision and information processing capability can in collaboration with autonomous systems fill in for the gaps in technology. Humans are generally better than machines in taking decisions in dynamic environment. Such a dynamic environment is often encountered in driving. However, the ability to act upon those decisions may be limited by whether or not the human driver is fully awake or alert or whether he/she possesses the required physical strength. This is where the shared control of vehicle between the humans and autonomous control systems comes into picture.

Haptic Control involves using sense of touch as an indicator and input to control some mechanism. This control is of utmost importance in road vehicles, especially cars, buses and other public transport means which are controlled using steering wheels. On these steering wheels, a force is felt by the driver every time he/she negotiates a turn. The force on the steering wheel varies with different parameters such as current speed, angle of turn, banking of the road, height of centre of gravity of the vehicle etc. In order to be able to steer properly, there must be some mechanism or a control system that works alongside humans in collaboration.

In this paper we have first introduced the systems that have been launched in the market worldwide for the safety of car drivers. We then propose a novel control system of the vehicle based on the intelligent control of steering and braking systems.

2. ADVANCED DRIVER ASSISTANCE SYSTEM

Driver assistance system is an umbrella term used for all the technologies employed for assisting the driver in danger recognition, decision making and operation. These systems use technologies that alert the drivers about potential problems to avoid the accidents and collisions. The various driver assistance systems that are available in the market include adaptive cruise control, lane departure warning system, forward collision warning system, emergency brake assist system and parking assistance system.

2.1 Adaptive Cruise Control

This advanced driver assistance technology is especially useful on the highway, where a vehicle automatically slows down or speeds up in response to the actions of the vehicle in front of it in order to maintain safe distance from it. This greatly improves driver safety and convenience as well as increases capacity of roads by maintaining optimal separation between vehicles and reducing driver errors. Inter-vehicle distance is often measured by using lidar.

However it fails to measure the distance accurately in adverse weather condition or when the leading vehicle is dirty. Radar based systems have slightly lower directional resolution than lidar but they can be used in adverse weather conditions.

2.2 Lane Departure Warning System

Lane departure warning system is a mechanism designed to prevent the driver from moving out of its lane. These systems address the main causes of collisions: driver error, distractions and drowsiness. There are three types of systems:

- Lane Departure Warning, LDW: Systems which warn the driver if the vehicle is departing from its lane. The driver is then responsible for taking corrective actions.
- Lane Keeping Assist, LKA/LKS: Systems which warn the driver and, with no response, automatically applies torque on the steering wheel to ensure the vehicle stays in its lane.
- Lane Centering Assist, LCA: The most invasive technology which keeps the car centered in the lane.

2.3 Forward Collision Warning System

Forward collision warning system warns the drivers in the event of an imminent frontal crash. When the vehicle comes too close to another vehicle in front of it, a visual, audible, and/or tactile signal occurs to alert the driver of the situation. The system uses sensors to detect slower-moving or stationary vehicles. When the distance becomes so short that a crash is imminent, a signal alerts the driver so that he can apply the brakes or take evasive action, such as steering, to prevent a potential crash.

2.4 Emergency Brake Assist System

Emergency brake assist system is designed to provide additional braking force to a drive in case of an emergency situation. It falls into two main categories: electronic and mechanical.

Electronic brake assist systems use an electronic control unit to compare instances of braking to pre-set threshold limit. If a driver has pushed down the brake hard enough and fast enough to surpass this threshold, the control unit will see it as an emergency situation and boost braking power. These systems are adaptable and they compile information on braking style and change the thresholds to ensure the highest accuracy in an emergency situation.

Mechanical systems also use pre-set thresholds, but these are set mechanically which means that they are not adaptable to individual drivers. These systems include a locking mechanism that gets activated when the brake pedal is pushed beyond a critical point. Once this threshold is passed, the locking mechanism switches the source of braking power from the brake piston valve to the brake booster, which supplies the braking assistance.

2.5 Parking Assistance System

Parking assistance system refers to an automated parking aid which utilizes radar technology, cameras and sensors. It allows the car to do most of the work itself when parking into a spot. The system informs the driver if it detects a suitable parallel or perpendicular parking space. When activated, the system calculates the best way of approaching the gap, the steering maneuvers required and the number of moves involved.

3. PROPOSED MODEL

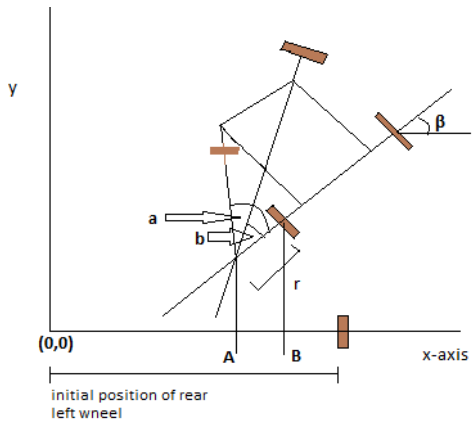


Figure 1: Instantaneous position of various variables

In the diagram, let **a** and **b** be the angles that front wheels make with respect to the line joining the hinges of the wheels. As can be seen, there is an instantaneous centre of rotation formed by the intersection of the lines perpendicular to all the four wheels. The x-coordinate of this centre is shown as A. Let $\mathbf{x_{ot}}$ be the x-coordinate of instantaneous centre of rotation at any instant of time. There is also a radius of curvature, **r**, as the distance between the instantaneous center and the midpoint of the width of rear left tyre. It is assumed that the vehicle is moving at the constant velocity, **v**, while making the turn. Let $\mathbf{x_t}$ be the x-coordinate of the midpoint of rear left wheel. This serves as the good indicator of vehicle's position in the x-y plane.

For setting the origin of the coordinate-system, the left limit of the lane will always be chosen by the autonomous system as shown in the diagram. At all times, it is assumed that perfect steering takes place and that there is no slipping of the tyres at any instant. For a perfect steering, the following relationship must always be satisfied:

$$\cot(b)-\cot(a)=w/l$$

where **w**=width of chassis, and **l**=length between centres of corresponding front and rear wheels.

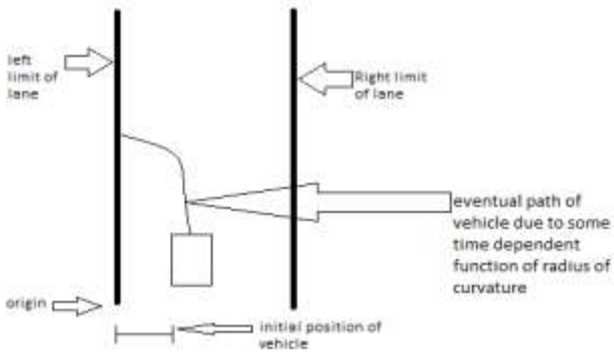


Figure 2: Schematic Diagram of lane and vehicle

Now **b** and **a**, and hence, **r** depend upon angle **Θ** given to the steering wheel mechanism. Now, **Θ** could be any function of time,**t**. Thus, **r**, in turn, is a function of time. **β** is the angle turned by the vehicle with respect to the horizontal about its centre of mass at any instant of time. **β** is also a function of time.

Mathematically,

$$r= n(t);$$
$$\Theta=g(t);$$
$$\beta=m(t);$$

Let at any instant of time **t**, radius be **r** and angle of rotation about centre of mass be **β**. Then in infinitesimal time **dt**, the change **dβ** would be related by the following equation:
$vdt= r\, d\beta$;

Integrating both sides,
$\int_0^t v/r\,dt= \int_0^\beta d\beta$; This gives, $\beta= \int_0^t v/n(t)dt=m(t)$; **(1)**

Similarly, let x_{ot} be the x-coordinate of instantaneous centre at instant **t** and x_t be the position of vehicle. Then for infinitesimal change dt, we have:

$x_t +d\, x_t= x_{ot} + r\cos(\beta+ d\beta)$; **(2)**

Simplifying,

$x_t +d\, x_t = x_{ot} +r(\cos(\beta).\cos(d\beta) - \sin(d\beta).\sin(\beta))$;

for $d\beta$, $\cos(d\beta) =1$ and $\sin(d\beta)= d\beta$;

$x_t +d\, x_t = x_{ot} +r(\cos(\beta) - d\beta.\sin(\beta))$; **(3)**

$((r-(r+dr))(x_t +d\, x_t)+(r+dr)x_{ot})/r = x_{ot} + d\, x_{ot}$; **(4)**

Simplifying and neglecting product of small quantities like $dr.dx_t$, we get:

$(x_{ot} - x_t)dr/r= dx_{ot}$ **(5)**

Solving **(4)** and **(5)** equations and using them, we get – $\cos(\beta)dr=dx_{ot}$

Or, $-\cos(m(t)).n'(t)dt=dx_{ot}$.

Now, integrating both sides again within the correspoding limits,

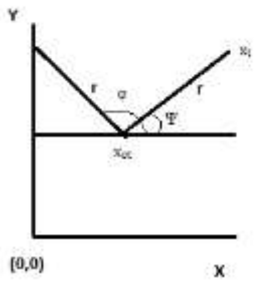
$-\int_0^t \cos(m(t)).n'(t)dt= x_{ot} -(x_{ti} - r_i)$;

where x_{ti} is the initial vehicle position and r_i is the initial radius of curvature at time, **t=0**; Thus, $x_{ot}= F(t)$; **(6)**

Then, x_t is given by the relation, $x_t = n(t).\cos(m(t)) + F(t)= G(t)$; **(7)**

Let Δt_u be the constant time interval after which the electronic system takes the update of the state of the vehicle(basically, x_t and **Θ**). Also, let Δt_{smin} be the minimum stopping time required for the vehicle to come to halt if it is moving at speed **v** without jeopardising its stabilty.

It is proposed that the onboard computer calculate the actual time to collision at any instant **t** using the vehicle's current position, x_t, current radius of curvature, **r**, instantaneous centre of rotation, x_{ot} and initial vehicle position, x_{ti} using the following formula that follows directly from the acoompanying figure:



$x_t=x_{ot} + r\cos(\Psi)$, which gives $\Psi= \cos^{-1}((x_t-x_{ot})/r)$; **(8)**

and

$0= x_{ot} + r\cos(\varphi)$, which gives $\varphi= \cos^{-1}(-x_{ot}/r)$; **(9)**

$\Psi - \varphi$ = angle to be turned at current radius of curvature for collision.

If $\Delta t_{sactual}$ is the actual time to collision from current instant of time, then it is given by the following relationship:

$$\Delta t_{sactual} = (\Psi - \varphi).r/v \qquad (10)$$

Now, if $\Delta t_{sactual} > \Delta t_{smin}$, then their difference is the leeway available with the driver. He/she may rotate the steering wheel in any direction. However, as the wheel is rotated, there would be a change in the value of Θ. Such a value change would be updated in the system and new $\Delta t_{sactual}$ would be computed. For effective updation of the changes of values , Δt_u should be sufficiently small.

If in any case, $\Delta t_{sactual} = \Delta t_{smin}$, brakes should be applied immediately. In no case should $\Delta t_{sactual}$ decrease below the level of Δt_{smin}.

Now, the driver should also be warned of the impending dangers and must be assisted in decision-making regarding the direction and magnitude of angle Θ_{human} by which he/she turns the steering wheel. One way of doing this is by communicating to the driver by means of torque applied on the steering wheel by the electronic system. This is the concept of haptic control wherein by means of sense of touch,the information is being conveyed to the human driver regarding the magnitude and direction in which the correct input has to be given. This system of haptic control should be intuitive in order to enable the driver to be able to manipulate the wheel effectively.

The information in the form of torque on the steering wheel can be passed on to the human driver in an intuitive manner if there is increase in the torque on the wheel with the increase in magnitude of error. Let Θcorrect be the correct angle calculated by the autonomous system at any given instant of time based on speed v, current x-coordinate,xt and Δtsmin. The torque applied on steering wheel could be $T_{sw} = k. (\Theta_{human} - \Theta_{correct})$; a '-'ve torque would mean it opposes the direction of Θ and a positive torque means it supports the direction of Θ. 'k' is a positive constant.

Hence by selecting suitable values of **k**, Δt_{smin} and Δt_u, the model can be made to work.

4. CONCLUSIONS

From the above discussion it is clear that a system in which there are various modes of communication between man and machine leads to better management and efficient outcomes. It is expected that the proposed method of control would result in the decrease of severe accidents and fatalities. Also the cost of implementation of the system is expected not to be too high. The approach of integrating haptic control system with advanced braking system is expected to be superior to the extant systems in which a haptic control and advanced braking are considered as separate. As the future work, we wish to implement an internet of cars in which systems mounted on different vehicles act as a single unit and coordinate each other's activities so that fatalities could be further reduced.

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