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AUTOMATIC BRAKING SYSTEM CONTROL

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Abstract - The use of computer assisted systems is a major step towards improving the safety and performance of vehicles. This paper investigates one aspect of system design, the braking system. The design exercise is based upon a simulation of a cars braking system enables several alternative control strategies to be assessed. The findings illustrate the problems involved and the opportunities available for the application of an ‘intelligent’ control strategy.

Key Words: AUTOMATIC BRAKING SYSTEM, SAFETY, LASER, SENSOR, CAMERA.

1. INTRODUCTION

The recent developments in the new generation of sensor rich, distributed autonomous control technology has had a profound effect on the design of modern automotive vehicles. In particular, the intelligence afforded by robust embedded microelectronics throughout the vehicle together with the communications network topologies have resulted in control systems which greatly enhance the vehicle performance covering aspects such as safety, passenger comfort and environmental impact, to name but a few. In addition, an improved understanding of vehicle performance can be gained from the development of software simulation techniques which employ a range of system dynamic models, with the aim of achieving improved vehicle control strategies.

The following paper, investigates the performance of existing and potential strategies applicable to vehicle automatic braking system’s known as ABS. A system model developed using the MATLAB simulation environment is described, which is then implemented with a 'Bang-Bang' controller strategy to provide a benchmark for the evaluation of alternative control strategies. The main alternatives investigated were centred around PI and Fuzzy Logic based systems which take advantage of information received from the distributed sensors. One of the main aims was to improve the driver comfort when the ABS is activated whilst maintaining optimal system performance in terms of minimizing the vehicle stopping distance under emergency conditions. It is well known that the existing Bang-Bang control implementation is very severe in terms of the physical shock the driver experiences through brake pedal pulsations, when the system is activated.

The following sections evaluate possible alternatives and provide an indication of the level of system performance which could be achieved. The advantages of such intelligent control are that they can take full advantage of developments in Smart Tyre technology together with the increasing integrity of micro technology.

LITERATURE REVIEW

75 % of car accidents are at low speed, less than 32 kph. There are three main causes leading to car accidents:

(i) careless or fatigued drivers;
(ii) sudden change in road direction at “sharp blends and angles”;
(iii) bad weathers (heavy rain, dusty road, and dense fog), slippery roads, natural disasters (earthquake, tsunami).

The third cause contributes to about 19.42 % of car accidents.

Compensation for traffic accidents, including car accidents, is very costly in terms of traffic delay hours leading to increase of fuel waste and “congestion cost”: 4.2 billion hours, 2.9 billion gallons and $80 billion in US in 2007 respectively. Most of the accidents are caused by human errors such as less attention on road while driving, inefficient brake force creating not enough deceleration rate (21% has no deceleration, 73% decelerates less than 5 m/s2). Therefore ABS system needs to be developed to assist driver with braking maneuver to avoid collision, and reduce major and fatal injuries to passengers, collision aftereffect, and traffic congestion. Many automobile makers have introduced such systems to their high-end models since 2003 however the systems are not perfect and need further enhancement to be more effective.

2. System Development

The following model is part of a chassis simulation of a typical car which is currently under development to investigate the use of an overall distributed control system in vehicles.

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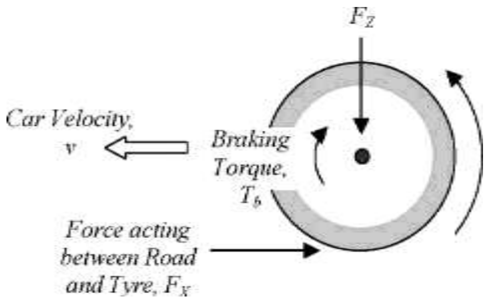
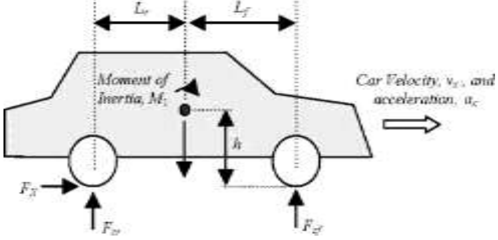


A. Wheel/Chassis Dynamics

For this paper a single wheel model [1] is employed as shown in Figure 1



Body Force acting on Wheel,

Wheel angular velocity, *m*

For the purposes of this paper the following assumptions are made:

- The overall braking force is distributed evenly around all four wheels.
- Each wheel experiences the same road conditions.
- The vehicles centre of gravity is mid-way between its wheelbase, that is $L_r = L\$$.
- The vehicle decelerates in a straight line from 100km/hr.

Under these conditions, the chassis will not experience pitch, roll and yaw forces.

B. Basic Component Of System

Fig -1: Forces acting upon a single and wheel

ABS system, commonly named as “automatic emergency braking system” or “autonomous emergency braking system”, consists of:

- a set of sensors installed on a host vehicle measuring: its velocity, acceleration, distances to other movable or stationary objects e.g. human, other vehicles, big rocks;
- a brake control mechanism: to control the vehicle’s brake automatically by electronic controller(s);
- controller(s): to process signals fed from the sensors, calculate and estimate potential of collision with the detected objects, provide warning signals to driver and assist driver in reducing vehicle’s speed to avoid collision or mitigate collision impact.

Controller is considered as the most important part and plays critical role in ABS system.

Different manufacturers develop different ABS systems and currently there is no common standard for ABS systems yet. Table 1 lists several ABS systems and Pre-AEB systems available in the market. The term “Pre-ABS systems” refers to the systems such as Lane Departure Warning System of Peugeot. It provides warning signals to driver when certain potential danger exists. This type of system could be expected to be further developed to become ABS system in the future.

Table-1: Several ABS Systems & Supplementary Technologies [8,9].

Brand	ABS Systems & Supplementary Technologies
Audi	Pre-Sense Basic Pre-Sense Front Pre-Sense Front Plus Adaptive Cruise Control (ACC) with Stop & Go function Audi Side Assist + Pre-Sense Rear Active Lane Assist Night Vision Assistant
BMW	iBrake 3 Driving Assistant + Lane Departure Warning & Collision Warning Active Protection
Ford	Active City Stop
	Forward Collision Warning with Brake Support
Mercedes-Benz	Pre-Safe Brake
	Collision Prevention Assist
	Distronic Plus
Peugeot	LDWS - Lane Departure Warning System
Toyota	Pre-Crash System
Volvo	City Safety
	CWAB-PD

C. Braking System Dynamics

A schematic of the hydraulic braking system used in the braking simulation [2]. Note that the applied braking force, F, is normalized for ease of application.

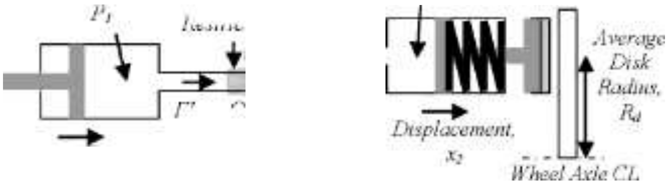


Fig -3: Hydraulic Brake Structure Schematic

The resulting brake subsystem model assumes non-laminar flow through the restriction,

$$Q=c_d.A^{\wedge}P\ (P_1\text{-}P2)$$

where Q is the restriction's discharge coefficient, *A* its cross-sectional area, and *p* the density of the brake fluid. Note that the increased use of servo-amplification has the following affects on the braking system model.

In braking terms, a slip of zero indicates the car is free-wheeling, and a value of unity increases
as in steady state = P_2.

i) Choking occurs in the restriction and
hence a longer time is required for the transference of to P_2.

ii) As the braking torque is simply a scaled version of the caliper pressure, P_2, then this behaviour transfers itself directly to the applied braking torque.

Note, that the model does not allow for variations in behaviour that arises due to temperature changes in the braking system, for example brake fade.

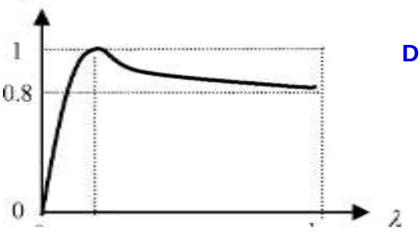


Fig -4: Road Friction/Slip Characteristic for a dry road and Normal road tyres

D. Tyre/Road Interaction

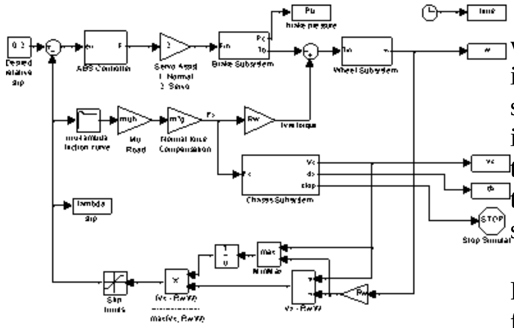


Fig-5: Simulink Simulation of the ABS

Under normal operating conditions the rotational velocity of the wheel, *co*, would match the forward velocity of the car, v_X (expressed in rotational terms), and any deviation of the two would indicate some problem with tyre grip. This difference is commonly defined in terms of wheel slip, *T*. which is evaluated via that the cars wheel is locked and it is skidding. Whereas for the traction control problem a negative slip of unity describes full wheel spin.

Friction between the tyre and road surface is described by the road friction coefficient, *p*. For dry road and normal road tyres this is of the form shown in Figure 4. Other road conditions are modelled usingzery different characteristics [1, 3].

Figure 5 shows the full Simulink Simulation of the ABS Control scheme described above.

3. System Design

The control scheme illustrated in figure 5 is designed to keep the slip at, or around, a value of 0.2 where figure 4 has shown the maximum tyre/road surface grip to occur. Using this scheme a logical relay (bangbang) control scheme was initially employed to provide a performance benchmark. Figure 6 shows the resulting servo-assisted braking performance which takes 3.61 seconds and 55m to come to a halt from 100km/hr.

The results of figure 6 show the braking scheme requirements. Namely, to brake as heavily as possible until the onset of slip and then control slip near to its maximum grip value. From a comfort point of view the pedal pulsations experienced by the driver can also be seen and from this, and from a performance point of view a controller capable of better maintaining slip at the desired level is established.

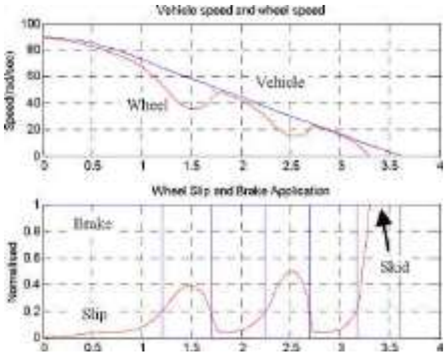


Chart -1: Bang-Bang ABS System

$$\frac{}{{}^{V}X \sim {}^{\circ} - {}^{R}W}$$

$\max(p_X\, O^{R}W$

Fig -6: Solution Space for the PI Controlled-ABS System

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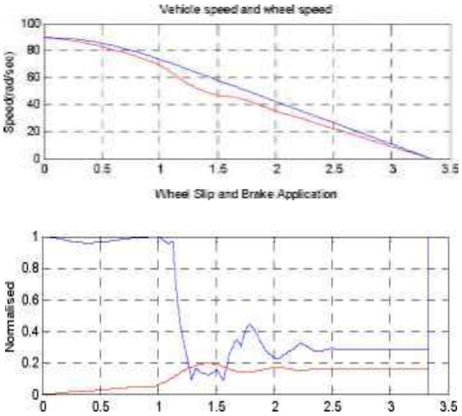
This was somewhat improved by the use of a single input-single output fuzzy controller to establish a small region, ± 0.15, of linear/non-linear proportional control around zero error conditions. Its performance is contrasted with the above bang-bang controller in table 1.

The use of classical PI control was then investigated using Genetic Algorithm [4] based tuning to determine the optimal controller settings in terms of minimum braking distance. Figure 7 shows the solution space and figure 8 the braking performance for the resulting settings of a proportional gain K_c of *5.1* and an integral time step *T* of % seconds. It can be seen to provide better regulation of the slip and therefore less significant changes in applied braking. An intelligent integration scheme [5] was employed to limit maximum integration levels in order to avoid any problems that may arise due to integrator saturation.
A Fuzzy Control strategy [6] based upon the available sensor measurements of slip and filtered rate of change of wheel velocity was developed using a Mamdani inference structure [7]. The initial results are shown in Figure 9 and Table 1.



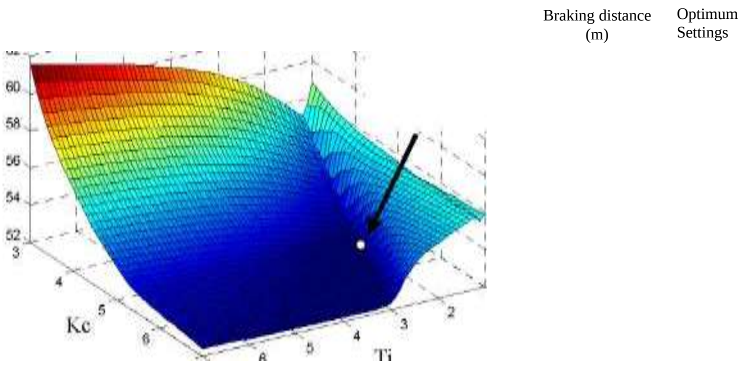
Hme(secs)

Chart -3: Fuzzy ABS Performance
{ Slip (k=0.925), dV_W (k=1/21) }

4. CONCLUSION

PI control has been shown to provide the best braking performance of the alternatives shown although it should be possible to equal or slightly better it by use of an equivalent surface from a suitably optimized fuzzy controller.

However, the effect of changing road conditions does have a considerable effect on controller performance as optimization of the PI controller for the reduced grip situation led to controller settings of Kc=4.2 and T_i =2.25 and a



stopping distance of 86.56m. That is a reduction of almost 4m in the best of the above. This will be further compounded if the shape of the characteristic differs, for instance when ice or gravel are encountered [1], as the maximum grip will no longer exist at a slip of 0.2.

In practice this would require some means of identifying the slip profile in order to brake at maximum potential. Some form of 'intelligent' pattern recognition of the initial braking profile for the onset of slip could be used in order to identify this parameter and select the most appropriate braking regime for that particular situation. Potentially this work could be directly applied to traction control system design.

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