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Longitudinal vehicle dynamics control for improved vehicle safety

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Abstract

The aim is to investigate the improvements in vehicle safety that can be achieved by limiting the vehicle speed based on GPS path information. The control strategy is aimed at reducing vehicle speed before a potentially dangerous situation is reached, in contrast with widely used stability control systems that only react once loss of control by the driver is imminent. An MSC.ADAMS/View simulation model of an off-road test vehicle was developed and validated experimentally. A longitudinal speed control system was developed by generating a reference speed based on the path information. This reference speed was formulated by taking into account the vehicle's limits due to lateral acceleration, combined lateral and longitudinal acceleration and the vehicle's performance capabilities. The model was used to evaluate the performance of the control system on various tracks. The control system was implemented on the test vehicle and the performance was evaluated by conducting field tests. Results of the field tests indicated that the control system limited the acceleration vector of the vehicle's centre of gravity to prescribed limits, as predicted by the simulations, thereby decreasing the possibility of accidents caused by rollover or loss of directional control due to entering curves at inappropriately high speeds.
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1. Introduction

Applications of automation in vehicle engineering range from rain sensing windscreen wipers to climate control systems. More specific to the study of vehicle dynamics is the improvement achievable by implementing feedback control systems which influence the dynamic behaviour of the vehicle with regards to the six degrees of freedom, namely lateral, vertical and longitudinal translation as well as roll, pitch and yaw rotation. Application of automation to control these degrees of freedom may lead to the optimisation of vehicle utilisation.

1.1. Fully autonomous vehicles

One of the best examples of the application of automation in the modern engineering fraternity was during the 2005 DARPA Grand Challenge [1] and the 2007 DARPA Urban Challenge [2]. Both these Challenges required vehicles to negotiate terrains that represent everyday driving conditions (especially from a military point of view) and hence path planning played an important role in successfully completing these Challenges. The 2005 DARPA Grand Challenge was won by Stanford University's 'Stanley' [1] and the 2007 DARPA Urban Challenge was won by 'Boss', the entry from Carnegie Mellon University, General Motors, Caterpillar, Continental and Intel [2]. 'Stanley' managed an average speed of 30.7 km/h [1] and 'Boss' an average speed of 22.5 km/h [2]. Due to the fairly low speeds involved, most DARPA Challenge entries employed simple

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Nomenclature

Symbol	Description
A_{Brakes}	acceleration due to braking (m/s^2)
A_f	projected frontal area (m^2)
$A_{maxlong}$	maximum allowed longitudinal acceleration (m/s^2)
A_x	acceleration in the x-direction (longitudinal) (m/s^2)
A_y	acceleration in the y-direction (lateral) (m/s^2)
B_κ	linear coefficient matrix of quadratic cost function for minimum curvature formulation (Dimensionless)
C_D	coefficient of aerodynamic drag (Dimensionless)
c_i	constant term of straight line describing perpendicular bisector (m)
d_{prev}	preview distance (m)
e	velocity error (m/s)
F_D	demand force (N)
F_{Drag}	Force due to aerodynamic drag (N)
F_{rr}	force due to rolling resistance (N)
F_{incl}	force due to longitudinal road inclination (N)
g	gravitational acceleration (m/s^2)
h	centre of gravity height (m)
H_κ	hessian matrix of quadratic cost function for minimum curvature formulation (Dimensionless)
$\hat{\boldsymbol{i}}$	unit vector in x-direction (Dimensionless)
$\hat{\boldsymbol{j}}$	unit vector in y-direction (Dimensionless)
K_D	PID derivative gain (Dimensionless)
K_I	PID integral gain (Dimensionless)
K_P	PID proportional gain (Dimensionless)
M	vehicle mass (kg)
m_i	gradient of chord of ith segment of trajectory (Dimensionless)
$\boldsymbol{m}_i'$	gradient of perpendicular bisector of chord of ith segment of trajectory (Dimensionless)
n	engine speed (rpm)
P	position of vehicle on track (m)
P_{hyd}	hydraulic brake line pressure (MPa)
p_{00}–p_{40}	coefficients of 2D polynomial (Dimensionless)
R	radius of curve (m)
Δs_i	length of ith track segment (m)
t	time (s)
T	throttle position (%)
T_{EBT}	engine brake torque (N m)
T_{Engine}	engine torque (N m)
t_w	track width (m)
u	PID controller output (Dimensionless)
V	vehicle speed (m/s)
V_{ref}	reference speed (m/s)
x	coordinate x value (m)
x_l	left edge (bound) of road's x-coordinate (m)
$x_{q,}i$	X-coordinate of centre point of chord of ith segment of trajectory (m)
x_r	right edge (bound) of road's x-coordinate (m)
$x_{R,i}$	X-coordinate of centre point of arc of ith segment of trajectory (m)
ΔX_i	change in x-distance of ith track segment (m)
y	coordinate y value (m)
y_l	left edge (bound) of road's y-coordinate (m)
$y_{q,}i$	Y-coordinate of centre point of chord of ith segment of trajectory (m)
y_r	right edge (bound) of road's y-coordinate (m)
$y_{R,}i$	Y-coordinate of centre point of arc of ith segment of trajectory (m)
Δy_i	change in y-distance of ith track segment (m)
α	parameter identifying position of vehicle on the road (Dimensionless)
α_κ	parameter identifying position of vehicle on the road for minimum curvature formulation (Dimensionless)
θ	inclination angle (radians)
κ	curvature of trajectory (Dimensionless)
μ	tyre-road friction coefficient (Dimensionless)
μ_{rr}	coefficient of rolling resistance (Dimensionless)
ρ	density of air (kg/m^3)
τ	preview time (s)

linear vehicle models to control speed and steering. A possible area of improvement is thus to increase the speed these vehicles attained while competing in the various DARPA Challenges.

1.2. Driver assist systems

While the DARPA Challenges specifically aimed at developing fully autonomous vehicles (vehicles that drive with no human input), a more practical and feasible approach would be to develop a control system that can be used as a driver aid. By using sensor technology similar to that employed in the DARPA Challenges (such as numerous LIDARs, Differential GPS, radar and cameras), the vehicle can obtain preview information of its immediate surroundings that enables it to identify a suitable path to be followed. This is often referred to as path planning. This path information can subsequently be used for path following where decisions can be made that improve the vehicle's safety. Path planning using technology such as cameras, radar and LIDAR. has been extensively studied. This technology is well commercialised and many vehicles are now fitted with adaptive cruise control, traffic sign recognition, lane departure warning and satellite navigation. All these technologies rely on camera, GPS and radar sensors. In the present study, this is not the contribution to be made.

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