AVEC'22

Autonomous Path Following and Emergency Braking Control for Intelligent Vehicles Using Low Cost Devices

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The novelty of this paper is an Event-Triggered LPV Output-Feedback H∞ controller that generates a steering control signal to follow the road, an acoustic sensor based AEB-P system which avoids vehicle collision with pedestrians and a speed controller based on the curvature of the path. The validation of the proposed system is done through simulation tests with CarSim®.

- Autonomous Driving Systems
- Advanced Driver Assistance Systems
- Sensors and Actuators

1. INTRODUCTION

Autonomous driving is one of the most promising research topics in road transport and is set to solve many problems related to traffic efficiency, accessibility and safety. Although years of research still lie ahead to achieve the full replacement of human drivers, new approaches to autonomous driving strategy are being developed to improve road safety and human confidence in autonomous driving.

An autonomous vehicle gathers sensors and actuators, all connected through a communication network, in order to drive autonomously. Path generation and path-following control are the basis of automated driving systems. When the path can be known in advance and only a path-following algorithm is needed, the problem is known as path-tracking, which is easier to compute; whereas when the trajectory has to be calculated, the problem has to include a path-planning algorithm and is known as path-planning. After the desired paths are obtained by path-generation algorithms, a path-following method can be defined to track the generated paths.

Obstacle detection technologies are a key development point in autonomous vehicles. Together with automatic emergency braking (AEB) systems, reliability of autonomous vehicles and safety of vulnerable road users, such as pedestrians, can be improved. Although systems like these are already being integrated in commercial vehicles, high technology costs are still a problem to address in order to achieve a large fleet of vehicles at an affordable price with advanced safety systems.

The novelty of this work is the development of a LMI-Based H∞ output-feedback path-following controller that keeps the vehicle on a previously known path, and an AEB-P, which avoids vehicle collision with pedestrians. This control system is presented for automotive use under low-cost or already built in systems. The algorithm is validated through a simulation using the software CarSim®, which is one of the preferred programs for studying vehicle dynamics among automotive researchers.

2. H∞ OUTPUT-FEEDBACK PATH-FOLLOWING CONTROLLER

The robust event-triggered LPV output-feedback path following controller design is presented through this section.

2.1 Vehicle model

The mathematical model followed for this work is described on [1] and depicted in Figure 1

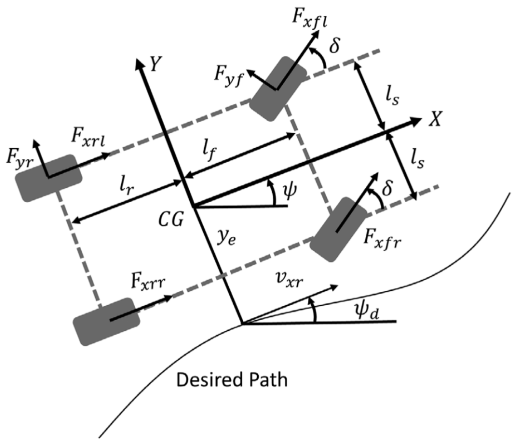

Fig. 1. Yaw motion model [1]

AVEC'22

Vehicle planar motion is assumed as the road condition studied for this work has neglectable height differences along the path. The ground vehicle is modeled as a rigid body with longitudinal motion, lateral motion and yaw motion. The Pitch and roll motion are ignored.

2.2 H∞ Controller design

For the design of the proposed H∞ output-feedback path-following controller, the control input is defined as

$$u(t) = K(\rho)\tilde{y}(t) \quad (1)$$

where $K(\rho)$ is the control gain matrix to be designed, which is dependent to the linear time varying parameter vector $\rho = [v_x \; 1/v_x]$; $\tilde{y}(t)$ is the delayed plant measurement, which is sent by an event triggering mechanism every time the observed measurement from the plant changes notoriously; this reduces the network usage and lowers the amount of resources involved in the communication process [2]. Taking the definition in (1), the mathematical model of the closed-loop system is expressed as

$$\dot{x}(t) = A(\rho)x(t) + B_u K(\rho)\tilde{y}(t) + B_d \omega(t)$$

$$y(t) = C_1 x(t);\; z(t) = C_2 x(t) \quad (2)$$

where y(t) is the plant measurement and z(t) is the controlled output.

The closed-loop system in eq. (2) has an H∞ performance level γ under zero initial condition if the following inequality is satisfied

$$||\, z^T(t)z(t)||_2 < \gamma||\omega^T(t)\omega(t)||_2 \quad (3)$$

In order to ensure system stability, a Lyapunov-Krasovskii functional is chosen as in [3], where high order functionals are considered to analyze how the system is affected by event delays.

After the restrictions of the system are set, the controller gain matrix is designed under a Linear Matrix Inequality optimization problem. For this issue, the Matlab® Robust Control Toolbox is employed due to its simplicity; however, non-commercial software such as Yalmip can be considered as an alternative.

3. AEB-P CONTROL SYSTEM WITH ACOUSTIC SENSORS

This section presents the proposed three-stage cascade braking AEB-P control algorithm.

3.1 Multiple beam acoustic sensor array

Pedestrian detection is achieved through a 7-beam acoustic sensor system that can detect pedestrians up to 20 meters ahead of the vehicle within the normal width of a road [4].

The use of acoustic technology for pedestrian detection improves the probability of detection in poor visibility conditions compared to other technologies based on light propagation, such as LIDAR or RADAR systems, and also costs are reduced.

3.2 AEB-P control algorithm

The designed AEB-P control system is based on the TTC (Time To Collision) calculation , which represents the remaining time until a collision between the vehicle and an object (pedestrian) occurs if both the heading and the relative speed between them remain constant. TTC is calculated as follows:

$$TTC = \frac{d_r}{v_r},$$

where d_r and v_r are the relative distance and velocity between the vehicle and the nearest pedestrian. The TTC value is compared with the stopping times that determine the activation of one of the two stages of partial braking or full braking, as shown in Figure 2. The stopping time is the travel time elapsed since a deceleration a_{brake} is applied until the vehicle, with initial velocity v_x, comes to a complete stop:

$$\tau_{stop} = \frac{v_x}{a_{brake}}$$

For each of the braking stages, a different deceleration reference is used for the automatic brake control. The values are shown in Table 1.

Deceleration reference	Value (m/s^2)
a_{b1}	3.8
a_{b2}	5.3
a_{bfull}	9.8

Table 1. Deceleration reference values

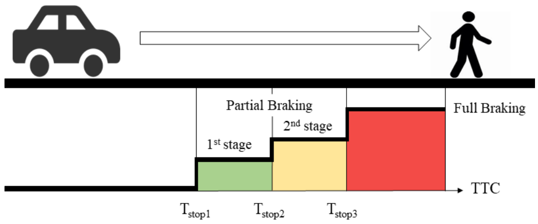

Fig. 2. Operating representation of AEB-P system

4. RESULTS

The path defined for this test is presented in Figure 3. Since the test path is known in advance, vehicle speed is controlled depending on the path curvature as done in previous works [5].

The results of the vehicle lateral error to path with the speed and steering controller are depicted in Figure 4. The maximum lateral error to the path appears on the sharpest turn.

AVEC’22

Once a pedestrian is detected, AEB-P system triggers to avoid collision with the pedestrian by diminishing vehicle speed. Figure 5 illustrates the longitudinal dynamics of the vehicle in more detail when the AEB system is triggered by pedestrian detection. In this particular case, the pedestrian is detected at a distance of 20 meters from the front of the vehicle by sensor number 3 and, eventually, by sensor number 2. Given the velocity of the vehicle and the relative distance to the pedestrian, the AEB controller decides to apply the second stage of partial braking to finally stop the vehicle before a collision occurs.

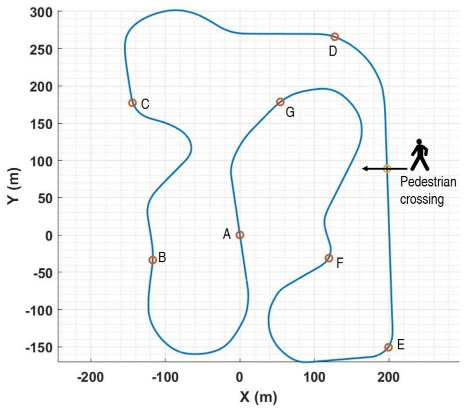

Fig. 3. Test path

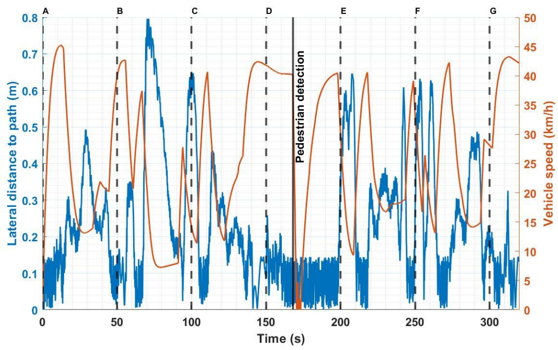

Fig. 4. Lateral error to path and vehicle speed

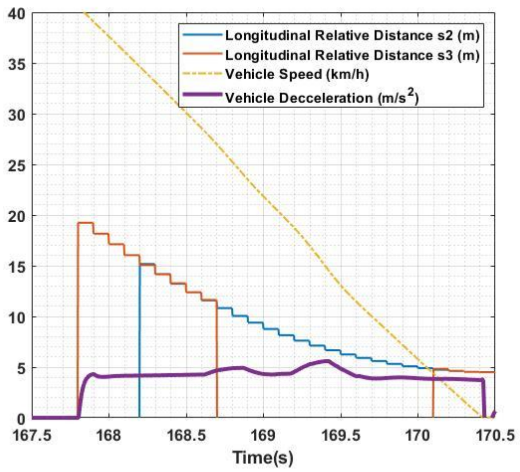

Fig. 5. Vehicle speed, deceleration and relative distance with nearest pedestrian in an AEB activation

5. CONCLUSION

This paper presents a control system for autonomous vehicles in which the designed path-following algorithm can track any path while the proposed AEB-P detects and avoids possible collisions with pedestrians under a low cost architecture.

For the path-following problem, a discrete event-triggered mechanism has been defined to determine when the measurements from the plant should be transmitted over the network in order to reduce the Transmission Rate. A Lyapunov–Krasovskii functional analyzes the stability criterion for the closed-loop system, taking into account the existence of network delays. LMI based conditions have been presented in order to find a feasible controller, which guarantees that the closed-loop presents an asymptotically stable behavior with a prescribed $H\infty$ disturbance attenuation level. The performance of the proposed controller has been tested with CarSim®, which works with high-order non-linear vehicle models in order to have a more reliable approach to a real system.

The AEB-P control algorithm analyzes whether a collision may occur and computes a deceleration value in order to reduce the vehicle speed and stop the car before reaching any possible obstacle while maintaining good levels of comfort. It is worth mentioning that the process behind the detections of the multiple beam acoustic sensor array has been neglected as the objective in this work is to study the performance of the AEB-P algorithm in different detection scenarios. Work is in progress and tests with the real sensor array mounted in a vehicle are being made in order to evaluate the real performance of the controller and make the necessary adaptations to deal with the noise, uncertainties and possible false detections of the acoustic system.

Future works may include path-generation algorithms to consider performing an emergency maneuver whenever the vehicle approaches an obstacle on more complex road conditions. In addition to this, it is desirable to analyze system failures during the controller design process to achieve a more robust solution. The ultimate goal of this project is to evaluate the performance of the proposed system on a real vehicle.

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AVEC'22

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