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Navigation as a Virtual Sensor for Enhanced Lighting Preview Control

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Abstract— **The principal interest of currently available bending light systems using vehicle information (vehicle speed, steering wheel angle) is to adjust the beam orientation according to the driver's manoeuvres. However, this kind of lighting is not anticipative and does not take the global driving situations and contexts (bend, city, motorway …) into account. The use of navigation systems can provide good anticipation results and information about the driving environment. This paper presents an active automotive lighting system using predictive navigation data. This approach concerns several types of lighting strategies according to the driving situations and contexts considered. The originality of this work relies on an event-based analysis of the driving situation carried out with the navigation as a virtual sensor. This solution provides complete information on the driving situation and not only nodes and shape points dependent data. For the headlights control, a control law using a continuous curvature path model is implemented. This curvature-oriented preview control technique ensures the required anticipation level as can be seen in the experimental results presented.**

I. INTRODUCTION

NIGHT-time driving with conventional headlamps is particularly unsafe. While it represents 25% of everage driving time, 55% of the driving fatalities occur during this period [1]. To reduce these figures, several automotive manufacturers and suppliers participated in the European "Adaptive Front-lighting System" (AFS) project. Its principal objective is to define new lighting functions based on an adaptation of the beam to the driving situation. It is to end in 2008 with a change in the automotive lighting regulation which will allow new AFS functions. The impact of these new promising lighting functions on road safety is under evaluation notably within the European CLARESCO ("Car and truck Lighting Analysis: Ratings and Evaluations for Safety and Comfort Objectives") project [3].

AFS functions are currently integrated in some vehicles available on the market. But this first generation of active lighting does not help to anticipate and/or to announce a change in the road profile ahead of the equipped vehicle. That is why research work is being carried out about the design of anticipatory lighting functions. To this aim, numerous simulations of navigation-controlled automotive lighting devices have been performed in the past [1], [2]. One of their major conclusions is that this approach offers a real interest for the driver as it supplies additional beam correction and helps him to better negotiate the changes in the road shape, using information provided by the navigation system. The basic idea is to take advantage of the performance of existing independent devices by integrating them into a common architecture [4]. This explains the approach of automotive manufacturers and suppliers which improve vehicle functionalities with Advanced Driver Assistance Systems (ADAS).

This paper presents a predictive lighting system. It concerns the fusion of a navigation system with the embedded vehicle sensors and with an AFS in order to improve lighting capabilities. A navigation-based virtual sensor has been implemented. This sensor provides information extracted from the digital map in an original event-oriented structure. The path in front of the vehicle is represented by a succession of driving events (straight lines, roundabouts…) which helps to easily determine the appropriate lighting strategy (Town lighting, Motorway lighting…). Using current digital maps to develop new ADAS is a real challenge, mainly because of their limited accuracy. For effective navigation-based lighting functions, the road curvature information is of the utmost importance. This data is in general not available or not precisely stored in the maps. The solution presented here consists in the computation of a continuous-curvature path representing the driving situation in front of the vehicle. Finally, a curvature-based preview controller is implemented to drive the headlights.

The outline of the paper is as follows: section II gives a description of the AFS principle and the interests of a predictive solution. Section III presents the implemented ADAS, the considered lighting functions and the identified lighting strategies. Section IV describes the importance of the predictive map data and the virtual sensor developed. In section V, the AFS curvature-based preview controller is described. Finally, the last part presents real night tests results obtained with the predictive AFS.

This work was performed in collaboration with the University of Haute Alsace (UHA), and with Valeo Lighting Systems, Driving Assistance Domain.

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II. Adaptive Front Lighting System

A. Outline of AFS

AFS is a next generation headlamp system that uses onboard sensors to identify driving environments (curve driving, urban driving…) and thereby automatically changes the light distributions [5]. In the Eureka project, the European car manufacturers, including their headlamp- and bulb-suppliers, began to investigate the interest of adaptive lighting technologies [6]. Since October 2002, AFS bending functions have been allowed and such systems already equip some vehicles. Two different approaches are currently available: swivelling systems (dynamic orientation lights) and additional bulb systems for static side lighting. Both solutions mainly take account of the steering wheel angle and thus associate the AFS function with the direction taken by the vehicle and with the driver's requests. In 2008, a regulation change will allow new improved beam patterns, such as "motorway light", "town light" or "adverse weather light" [7].

B. Interests of predictive AFS

Comparative studies have been carried out to evaluate the contribution of the AFS approach to safety. They show for instance, that the improvement of vision conditions directly extends the driver's capacity to detect in time potentially dangerous situations. The main interest of the AFS approach is then an appreciable increase in safety and comfort. In this context, Hamm and Rosenhahn [6] compared three types of lighting strategies in particular: conventional lighting, lighting based on steering wheel angle and finally predictive lighting based on road profile detection using image processing techniques. As can be seen in Fig. 2, steering wheel based AFS improves the detection distance mainly in a curve and at the end of the curve. Nevertheless, this strategy is not interesting for curve anticipation. For this specific situation, the greatest improvement has been obtained with the predictive system. Compared with the conventional system, the increase in the detection distance is approximately 35% at the entrance of the curve and approximately 29% inside the curve. In addition to the safety increase, the same study has shown a significant comfort enhancement, thanks to AFS technology.

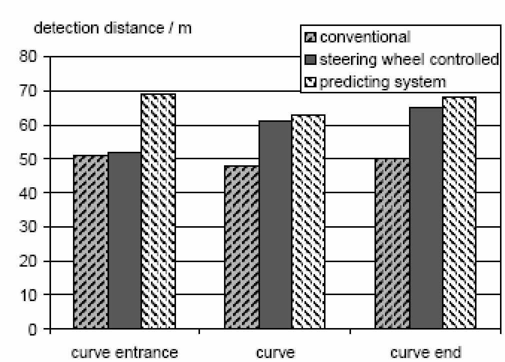

Fig. 2. Object detection distance in curve situations for various lighting systems according to [6].

It appears that the use of predictive data, giving information on the road shape and the driving situation, enhances the performance of AFS and improves vision conditions.

III. Navigation-based Predictive AFS

A. Principle

Navigation systems have contextual information linked to the infrastructure and to the road geometry. Consequently, playing the role of an embedded virtual sensor, they can produce good anticipation capabilities by providing information (road shape, curve radius, number of lanes…) on the road ahead of the vehicle. For lighting functions, the contribution of navigation mainly consists in the identification, anticipation and prediction of the road profile.

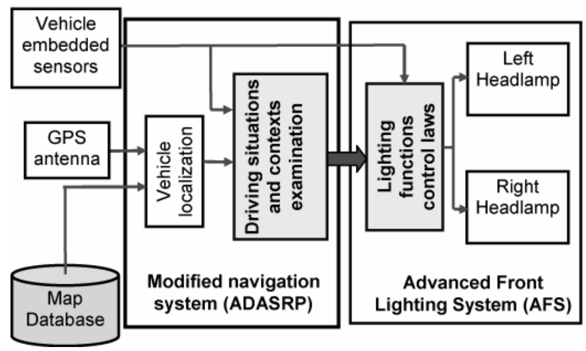

Fig. 1. Predictive AFS architecture.

The principle of predictive lighting assistance consists in coupling a navigation system with an AFS [8] (cf. Fig. 1). The ADASRP ("Advanced Driver Assistance Systems Research Platform") navigation system from Navteq used here provides an access to the digital map database information [9]. From the vehicle location obtained with the navigation system, the extraction of a so-called Electronic Horizon (EH) is carried out. The EH represents an image of the road in front of the vehicle. With the points of the digital map it associates information describing the environment of the vehicle. After the extraction of the EH, the digital map data is examined thanks to an original method which consists of an event analysis of the EH (cf. §IV.B). This analysis leads to the precise determination of the vehicle driving situation and so allows to choose the appropriate headlight control strategies (cf. §III.C). Considering bending light control for instance, the event analysis consists in the determination of the straight lines and curves in front of the car. This leads to the computation of a reference trajectory used to control the headlights (cf. §V).

In this work, the navigation can be considered as a sensor with extended capabilities, providing measurements to the AFS in order to determine the most suitable lighting strategy. With the original concept of event analysis, navigation is used as a global virtual sensor for advanced driver assistance systems.

B. Lighting Functions considered

The ADAS developed here is meant to improve the driver's perception in numerous night driving situations and contexts. So, it integrates different lighting functions:

- Motorway Lighting (ML): the beam pattern is directly linked to the vehicle's speed, i. e. long and thin for high speed, wide and short for lower speed,
- Town Lighting (TL): the purpose is mainly to increase the lateral light under city lighting conditions allowing pedestrian and cyclist identification at crossings,
- Fixed Bending Light (FBL): the FBL allows better lateral visibility in sharp curves or intersections,
- Dynamic Bending Light (DBL): dynamic lighting following the road shape.

C. Lighting Strategies Identification

The lighting strategies concern the decision to apply one of the lighting functions (TL, ML, FBL and DBL) or a combination of them, considering an identified driving situation (intersection, roundabout…) and a given context (city, outside city, motorway…). Fig. 3 shows the various lighting strategies identified for the predictive AFS presented in this paper. Those were defined following expertise. It can be noted that the FBL and DBL lighting functions are always used together. According to the context obtained through the navigation, it will be relevant to associate another AFS function (ML in case of motorway driving, TL in urban zone…) with the previously mentioned combination. Finally, this figure shows that the use cases are limited to three different lighting strategies. Nevertheless, considering the diversity of the driving situations to be taken into account, especially those requiring the combination of different lighting functions, the implementation of these strategies is not obvious. Its efficiency is closely linked to the perception and analyses of the driving context. Here, a virtual sensor based on a navigation system is used to establish a reliable diagnosis.

	Motorway		City			Outside city		
	Int	Bends	Int	Rdabt	Bends	Int	Rdabt	Bends
ML								
TL								
FBL								
DBL								

Legend
Int : Intersection
Rdabt : Roundabout

Fig. 3. Definition of the lighting strategies.

IV. Navigation as a Virtual Sensor

A. Predictive Map Data

Navigation, and more precisely digital maps, has a large potential for road safety enhancement. It allows preventive and active safety applications by extending the driver's horizon ahead of the vehicle [10] [11]. It can provide the driver a more global view of the situation and so allow him to better choose his driving commands. The in-vehicle digital map is a predictive sensor offering on the one hand an important source of information, and on the other hand look-ahead capabilities for ADAS applications.

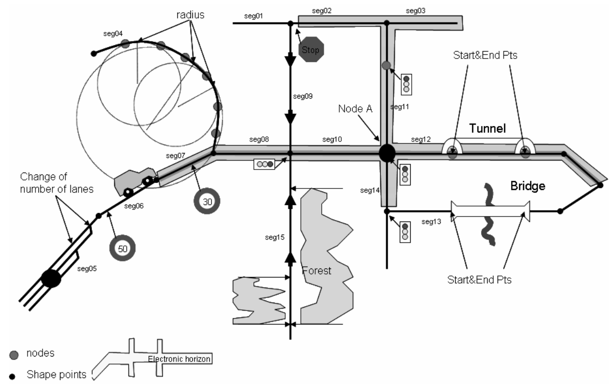

Fig. 4. Electronic Horizon concept (extracted from [9]).

In current navigation systems, the environment information around the vehicle is known via the Electronic Horizon concept. The EH contains a distance-, time- or cost-limited tree of potential paths the vehicle may follow, given current vehicle position and heading. Fig. 4 shows a graphic representation of the EH. This horizon contains all the possible paths the vehicle can take. Furthermore, it associates information called "attributes" describing the vehicle environment with points ("nodes" or "shape points" on Fig. 4) of the digital map. For instance, these attributes represent the radius of curvature of the road, the number of traffic lanes, the associated speed limits, etc. On the basis of these attributes and thanks to an event analysis, the predictive AFS developed here defines the most suitable control law(s) according to driving situations.

B. Event Analysis of the Digital Map Data

Digital maps, originally designed only for navigation purposes, contain sufficient information to reach this goal. Moreover, the accuracy of the vehicle location is great enough to provide relevant guidance information to the driver. Nevertheless, neither location precision, nor database data are well suited for the objective of navigation-based ADAS. For this kind of systems, complete information of the road shape is required.

On current digital maps, road geometry is basically represented by shape points on the road centreline. This representation is characterized by a relative accuracy of ±5m. Map data suppliers currently enhance their maps within European projects like PReVENT [12] by collecting more accurate shape points. For current navigation systems, the information is point-dependent, i. e. the relevant attributes (city, roundabout, intersection…) are only associated with nodes and shape points. This concept helps, for instance, to know that a given point is part of a tunnel but it is quite impossible to have a global view (height, length, starting point…) of this particular driving situation. So, each point

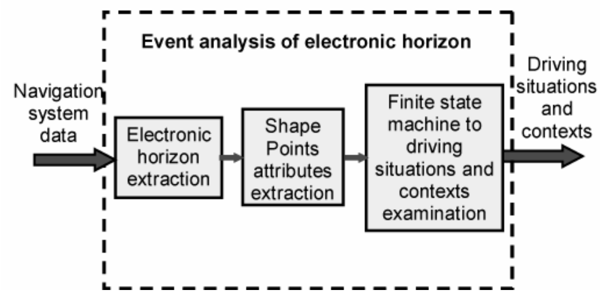

Fig. 5. Digital Map event analysis concept.

defined on the digital map has its own attributes. While this gives punctual information with respect to the vehicle location, it does not allow the driver to have a global view of both the present and coming situation he will have to face. However, this would help him to analyze the driving task and adapt his manoeuvres.

That is why, a new method is proposed here. This solution uses the punctual information from the navigation and carries out an event analysis. The aim is then a complete definition of the driving situations in front of the vehicle and their associated contexts. Fig. 5 shows the principle of this analysis. After the extraction of the EH, all nodes and shape points attributes are analyzed using a finite state machine. This state machine classifies these attributes in order to define the different driving situations and corresponding contexts contained in the given EH. Finally, after this processing stage, the EH is defined by a succession of driving events. Using this technique, the ADAS is able to predict relevant situations and engineering works to the driver in an event-based mode and not a punctual or segment-based mode. This virtual sensor provides well suited contextual data of the driving situation for enhanced control strategies.

V. AFS Navigation-Based Curvature Control

A. Principle

For evolved ADAS applications and especially for predictive AFS, it is advisable to have precise curvature information to guarantee fluid lighting control. Current navigation systems are not adapted to meet these aims, mainly because they integrate very basic curvature calculation techniques [8] coupled with a low resolution of the digitized points. The determination of the curvature through more precise methods is thus necessary. The solution presented here is based on a continuously derivable mathematical trajectory model obtained after the event analysis. Preview control then aims to control lighting in order to follow this path.

B. Continuous Curvature Model

The basic idea consists in determining -according to navigation information- a reference trajectory used for headlight control. The principle used for trajectory estimation is derived from the path planning technique for

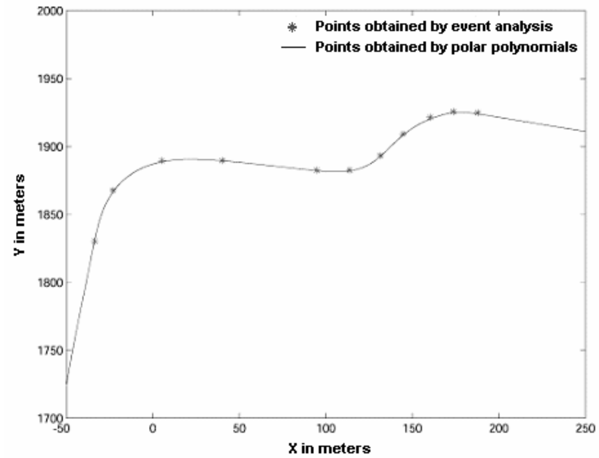

Fig. 6. Generation of the continuous curvature trajectory using the digital map points.

Autonomous Guided Vehicles in robotics [13]. The mathematical model used here is based on a representation of the trajectory in a polar coordinate frame, expressing the radius of the path r with a polynomial relation with respect to the polar angle ϕ [14]. The coefficients are calculated imposing conditions on position, slope and curvature. Thus, using the location information and the data contained in the digital map database, the ADAS is able to produce a reference trajectory used for headlight control. Contrary to length-dependent curves like clothoids, the polar polynomial curve has a closed-form easy to compute expression even in real-time conditions. Moreover, it is not subject to mismatching at its end-points because no integration is required for the determination of the points forming the curve.

The general expression of the polynomial is given by equation (1) where the number of parameters a_i defining the polar radius r as a function of the polar angle ϕ depends on the number of conditions (continuity constraints) imposed:

$$r(\phi) = a_0 + a_1\phi + a_2\phi^2 + a_3\phi^3 + \cdots + a_n\phi^n \quad (1)$$

Satisfying the position, heading and curvature constraints at each end-points and with identical initial and final values of the radius leads to the solution [14]:

$$r(\phi) = R\left(1 + \frac{\phi^2}{2} - \frac{\phi^3}{\alpha} + \frac{\phi^4}{2\alpha^2}\right) \quad (2)$$

In a polar coordinate frame, curvature is defined by the relation:

$$k(\phi) = \frac{d\theta}{ds} = \frac{r^2 + 2.r'^2 - r.r''}{(r^2 + r'^2)^{3/2}} \quad (3)$$

Where $r'' = d^2r/d\phi^2$, ds is the variation of the path length and $d\theta$ is the variation of the vehicle's heading whose centre of rotation follows the path. It can be noticed that this solution allows an easy computation of the curvature used by the predictive AFS.

Finally, an example using this method is illustrated in Fig. 6. Using the shape points extracted with the navigation system, a polar polynomial trajectory was generated. This figure shows, on the one hand, that the number of points defining a curve in the database is weak and that their distribution is not constant, but depends on the curvature, and on the other hand, that an adapted continuous path can be generated from the mathematical model presented.

C. Curvature-based Preview Control

In general, path following techniques are based on a geometrical approach [15]. It consists in evaluating errors between a reference point of the vehicle (centre of gravity, middle of the rear axle…) and the trajectory ahead. This technique, called "preview control", is based on a term which depends on the *a priori* known curvature of the desired path. In order to anticipate changes in the road profile, the solution consists here to use the curvature of the computed trajectory as preview data. This allows a continuous movement of the headlights. It is first assumed that the headlights' electrical motors accurately follow the reference trajectory without feedback. In this control solution, the preview horizon is variable and depends on the EH, on the event analysis and finally on the vehicle dynamics.

VI. Experimental Results

A. Test Vehicle

The predictive AFS driver assistance system has been implemented on a VOLVO S80 test vehicle. This vehicle integrates a dSpace MicroAutobox. This device is used on the one hand, for the in-vehicle data measurements (via CAN-bus) and on the other hand, for the real-time execution of preview control. The ADASRP navigation platform runs on a master controller as described in Fig. 7. Finally, new directional Bi-Xenon headlamps have been integrated in order to produce the ML, TL, FBL and finally DBL functions. The master controller also implements an HMI informing the driver of the coming situation and the required lighting strategy.

B. Night Test Drives

Night test drives were performed in two different French regions, namely in Mulhouse and in Paris. The test scenarios were chosen in order to perform a suitable evaluation of the navigation assisted AFS in real driving situations for each lighting strategy. The goals of these tests were first to study the real-time feasibility of navigation as a predictive virtual sensor especially for lighting control and secondly to evaluate the advantages (maximum anticipation, effectiveness…) and possible disturbances of these new functions for the driver. To illustrate these points, the next section describes the results obtained with the predictive AFS compared to a steering wheel based AFS in case of the DBL strategy.

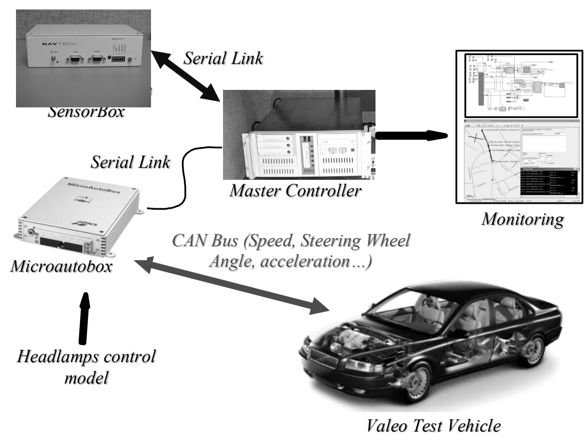

Fig. 7. Architecture of the instrumented vehicle.

C. Results

Fig. 8 presents the rotation angles for the right headlamp on the one hand for a navigation based AFS, and on the other hand for a steering wheel based AFS. On this figure, the angles were normalized according to their maximum rotation. In the case of the steering wheel angle control strategy, and in the interval from 0 to 5s, the headlights movements refer to operations required for positioning the vehicle on the way after parking. As the navigation-based AFS only reacts to changes in driving situations and/or contexts, no rotation of the headlights is observed in this first phase. For the steering wheel control strategy, the curve negotiation really begins at t=15s.

During the curve negotiation, the system based on navigation shows a significant anticipation compared to the strategy based on the steering wheel angle. This diagram shows a brief rotation of the predictive AFS. This corresponds to an important variation of the curvature taken into account by the preview controller. After a constant

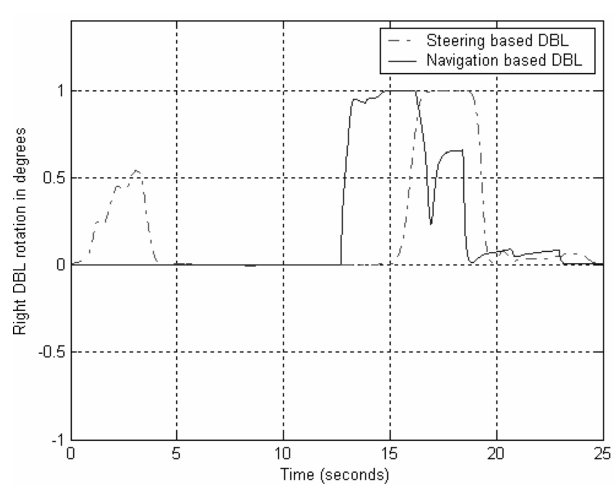

Fig. 8. Right headlamp normalized rotation angle (°) for a steering wheel DBL strategy and a Navigation DBL strategy.

rotation phase corresponding to the anticipation of the start of the bend, it can be noted that the headlights return in a shorter position (almost 25% of the maximum rotation). This can be explained by the fact that the vehicle is then in mid-curve and so, that the lights could rotate back to their nominal position for effective road lighting of the second part of the bend. Finally, a new rotation of the headlamp occurs with the increase in the curvature in the second part of the curve. Then, this rotation is cancelled even before the end of the bend in order to anticipate the negotiation of the straight line after the bend. This strategy really guides the driver and informs him of the road shape changes.

Concerning the steering wheel controlled AFS, the headlamp rotation starts nearly 2.5s after the navigation-based AFS because the driver turns the steering wheel only after the change in road curvature. Due to the constant steering angle during the whole curve negotiation, the lighting orientation remains constant, which is not optimal, mainly at the end of the curve. Moreover, when going out of the bend and due to the fact that the driver's manoeuvre ends after the change in the road curvature, the headlights go back to their nominal position nearly 1s after the predictive AFS strategy.

VII. Conclusion

A new approach to an advanced driver assistance system has been described in this paper. This ADAS consists in an intelligent predictive lighting system using a navigation-based virtual sensor and a curvature-controlled Adaptive Front-lighting System. The choice to use navigation was motivated by the necessity of informing and warning the driver of coming driving situations and contexts in order to better assist him. To reach this goal, a virtual sensor using navigation data has been developed. It consists of a finite state machine performing an event analysis of the electronic horizon provided by the navigation. Driving situations (curves, straight lines…) and their respective contexts (motorway driving, city driving…) are provided by the virtual sensor and then used to discriminate the appropriate lighting strategies. Four lighting functions have been implemented and tested: Motorway lighting, Town lighting, Fixed Bending light and finally Dynamic Bending light.

Using current navigation information for dynamic headlight control is really challenging. Basic data such as road curvature are currently not available or not precise enough for these advanced applications. For this reason, a control law using a continuous curvature path model has been implemented here. A curvature-oriented preview controller ensures the required anticipation level of the ADAS.

The predictive navigation-based AFS has been validated in real night driving conditions with an instrumented vehicle. The obtained results show the interest of navigation as a virtual sensor for predictive and anticipating assistance systems and generally for applications lying with driver safety and comfort. If these tests highlighted the interest of such control in given driving situations, they also showed the need to take the driver's requests into account, in particular during specific manoeuvres (parking, etc). Moreover, due to the lack of information of the database or to their inaccuracy, this ADAS could be improved by the integration of other sensors. Then, fusion techniques are required and are currently studied in the context of this work in order to extend the control capabilities of this kind of ADAS.

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