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A COMPREHENSIVE SURVEY OF VISION BASED VEHICLE INTELLIGENT FRONT LIGHT SYSTEM

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Abstract- Vehicle intelligent front light system is one of the advanced driver assistance systems. Vision based intelligent front light system is currently the research focus in this field. The purpose of this paper is to present a comprehensive survey of the vehicle front light system development and the latest vision based key technologies and proposals. By analyzing the significant disadvantages of traditional intelligent light systems, some possible improvement proposals and algorithms for lane, vehicle lamp recognition and track are provided. This survey shows that the Matrix-LED system could make the system more flexible and more effective and vision based vehicle intelligent front light system can improve the driving environment for the ego driver and other road users at night.

Index terms*:* Vehicle intelligent front light, Matrix-LED, Lane recognition, Light detection.

I. BACKGROUND AND INTRODUCTION

ADAS (Advanced Driver Assistance System) which acts as an assistance for the driver while driving has been a popular research focus of many car manufacturers, universities, research institutes and companies. Many kinds of ADAS systems such as ACC (Autonomous cruise control), CACC (Cooperative Adaptive Cruise Control), LDW (Lane departure warning), FCW (forward collision warning) [36], BSS (Blind Spot Information System) , AFS (Adaptive Front-lighting System), PCW (Pedestrian Collision Warning) , V2X (Vehicle to X), Start/Stop system have been presented. With the assistance of these new systems, both the inside and outside driving environment would be greatly improved. Nowadays, many of them are already adopted by vehicles and some are being tested in the real road conditions. However, only the general functions of them have been realized. There are still many key technologies which need to be ameliorated.

Among these various kinds of intelligent technologies, the intelligent front-lighting system which aims to improve the illumination conditions and reduce the accident rate at night is the main topic of this paper.

The paper can be divided into five sections. Section one explains the general background and introductions of intelligent technologies of front-lighting systems. Section two details the development of intelligent front lights. Section three and section four present the main proposals and algorithms of lane and light detection/track respectively. And conclusions about the survey of vehicle intelligent front light system are made in section five.

II. DEVELOPMENT OF INTELLIGENT FRONT LIGHTS

The vehicle lamp has been developed from the original incandescent lamp to halogen lamp and HID (high intensity discharge lamp) during the 20th century. Nowadays, halogen lamp and high intensity discharge lamp have been widely utilized in all kinds of vehicles. Meanwhile, as the LED (Light-Emitting Diode) vehicle lamp matures, it is increasingly being used. Because LED lamp has energy saving, flexibility, high efficiency characteristics, choosing it as vehicle front-light lamp is a trend.

At the same time, the intelligent lighting system has been changed from static illumination to AFS and up to various kinds of intelligent lighting control systems.

The AFS adjusts the movement of traditional front lamps both in horizontal and vertical levels. The illuminated areas in front could be changed automatically according to the vehicle conditions. The lamps adaptively adjust the horizontal illumination area to the left/right front area of the roads while turning left/right and revise the vertical lighting level while the vehicle is in ramp road.

In general, the traditional AFS has experienced three generations, the static curved road illumination, the combination of following lighting and static curved road illumination, and the multi-function illumination which includes the basic mode, curve road mode, highway mode, town mode, village mode and rainy day mode.

At the very beginning, the AFS captures various kinds of driving conditions such as vehicle speed, steering wheel angle, front/rear axle loads, ambient light intensity, visibility and the road conditions(dry, wet, fog), etc. Due to the limitations of these sensors, this kind of AFS has some main shortages. In some situations, the light distribution of the front lamps will not be spread on the street, where the driver needs.

As seen in figure 1, at the beginning of a curve , because the AFS only starts horizontal distribution adjustment 1 or 2 seconds after entering the curve, the beam shines straightly forward rather than to bend along the curve [1]. In this short period, the curve area is not well illuminated and the driver could not well concentrate on the curve, which is dangerous and may cause uncomfortable to the driver. Also, as shown in figure 2, in the end of a curve, because the steering wheel is not yet back to the middle position, the beam still bends into the left side while the lane in front is already straight or extending to the right [1]. In this scenario, there is response lag as well.

Figure 1. Beginning of a curve

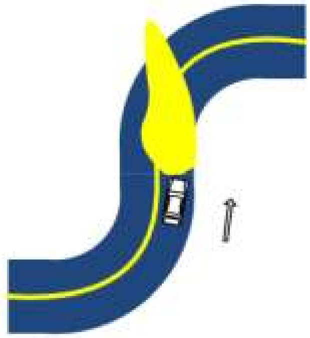

Figure 2. End of a curve

Additionally, the traditional AFS focuses on the low beam adjustment and considers less on the glare of the high beam to other road users.

In order to overcome the curve response lag disadvantages, AFS combines GPS (Global Positioning System) to form the prediction AFS, which can predict various kinds of driving conditions ahead. In this way, the system could realize different kinds of illumination area distributions and precisely provide better illumination for the driver.

And, in order to improve the utilization of high beam and avoid glaring other road users, some kinds of proposals have been presented to avoid glaring other vehicle drivers in front. The AHC (Adaptive Headlamp Controller) is a system which can detect the front vehicles and automatically switch between high beam and low beam according to the front vehicle information. If there is a vehicle in front, the low beam is switched on. And if there is no vehicle in front, the high beam is switched on. In this way, the driver operation fatigue could be avoided, the high beam usage in crowded roads could be increased and the driver safety is improved. However, as described in figure 3, when the high beam is deactivated, there is a dark area between the cut-off line of the ego vehicle lights and the front vehicle [1]. The obstacles in this area are not effectively illuminated and can be missed.

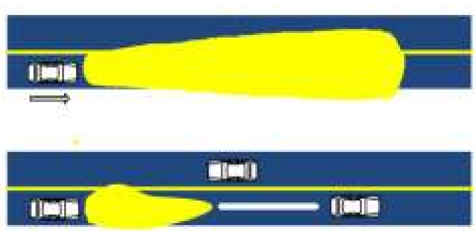

Figure 3. Dark area between high-low beams

Also, there are some other kinds of prediction AFSs which use vision or infrared sensors to detect the obstacles and pedestrians at the crossroads and corners. But due to the low accuracy of GPS in the intensive building areas and the complex of distinguishing pedestrians, vehicles and obstacles, these kinds of AFSs have not been widely used.

Nowadays, many car makers and auto parts manufacturers have quoted the traditional kinds of AFSs in their mid-class and high-class vehicles. And prediction AFS is the hot research topic for them. The leading companies include BMW, Mercedes-Benz, Audi, Opel, Volkswagen, Hella, Bosch, Valeo, Denso, Koito and Viston.

Meanwhile, BMW, Mercedes-Benz, Audi, Opel, and Volkswagen are developing the Matrix-LED based intelligent front-light lamps [5], which can be seen in the latest Auto shows worldwide. Combination of AFS and Matrix-LED is the development trend of intelligent front lighting system in the future.

By using Matrix-LED lamps, the beams can be generated as a single main beam or separated beams. When the camera behind the wind shield detects other vehicles in front, the relevant LEDs could be statically switched off or the beams that are responsible for these areas should rotate some degrees to avoid glaring the drivers in the front vehicles. In this way, the main beam could be much more energy efficient. And the illuminated areas in every kind of driving condition would be more perfect, which could enhance driver safety and comfort.

Audi adopts the continuous illumination distance function in the Audi A8 2010 model. This auto model utilizes a new camera to identify the brightness ahead, detect and classify the head lights and rear lights of the front traffic and recognize the distance between ego vehicle and the front vehicle, thus to continuously adjust the illumination area between low beam and high beam according to this distance. In this way, without glaring other vehicle drivers, the illuminated area could be as large as possible if permitted. If there is no vehicle in front, the illumination area could be increased to the high beam mode. And if other cars are near to the ego car, the area will be in the low beam mode. In the latest 2014 model, as seen in figure 4, a new Matrix-LED based front lighting system is to be presented. The horizontal illuminated areas can be separated by switching on /off or dimming different LED lamps to form different light shapes as showed in figure 5. It can also be connected with the GPS to perform different kinds of illumination modes according to the road conditions.

Figure 4. Matrix-LED lamp from Audi

Figure 5. Renderings of Audi's Matrix-LED

Opel's Astra series of auto models apply the Matrix-LED showed in figure 6 as the front head lamp. Also, the ambient brightness is detected by the camera behind the wind shield. And the brightness, shape and area of the front light can be automatically adjusted accordingly. If the vehicle enters into a tunnel, the front light will be switched on. When a car is oncoming, the lamps Irradiated on the front car will be dimmed and lowered and the other lamps will be kept at the same bright level. The pedestrians and animals could also be recognized as well. After passing, the front light is illuminated as large and bright as possible. In this proposal, all the matrix areas in front could be fully range adjusted. This Matrix-LED technology might be implemented in all Opel auto models in 2015.

Figure 6. Matrix-LED lamp from Opel

Besides the traditional AFS, Mercedes-Benz 2014 E-Class Cabriolet adds the adaptive high beam assist system. As shown in figure 7 It can automatically lower the illumination height and intelligently compensate the illumination area of the low beam according to the traffic conditions, which could make the drivers both in the ego vehicle and in the front vehicle more comfortable and safer.

Figure 7. LED front lamp from Benz

Unlike the proposals provided from Audi and Opel, BMW and Volkswagen have adopted the horizontal rotating method in their models to generate different light shapes so as to avoid dazzling other drivers. The BMW LED lamp can be seen in figure 8. And its principle is described in figure 9. By rotating the left front lamp to left, it can avoid dazzling the vehicles far in front. Also it can avoid glaring the near car drivers by changing to low beam mode.

Figure 8. LED front lamp from BMW

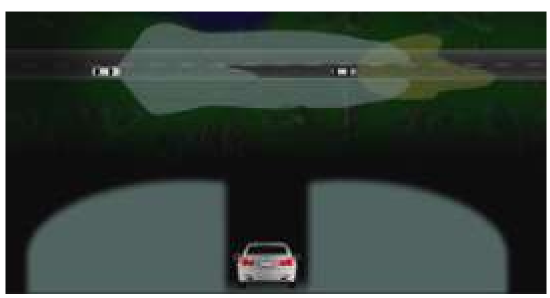

Figure 9. Principle of BMW's Matrix-LED

It is worth mentioning that some companies use shading plates to block the lighting areas so as to generate different light shapes, such as Volvo, Hella, etc.

Overall, vision-based adaptive front-lighting system is an intelligent technology which extract the road lane information from the camera in the front of vehicle, distinguish the front lights of incoming vehicles and rear lights of forwarding vehicles, combine the vehicle driving status, adaptively adjust the front lights switches or rotations both vertically and horizontally, form different kinds of lighting shape. In this way, the front efficient vision field of the vehicle could be maximized and much clearer for the driver. And also the dazzling influence to other road users could be reduced. Compared with the traditional AFS, there are two key technologies that need to be captured for this new kind of system, the lane recognition at night and the vehicle or vehicle lights detection which would be discussed in the next two sections.

III. LANE RECOGNITION AND TRACK

Based on the current technology level, the reliability of the vision detecting system in vehicle is mainly influenced by the factors such as shadows, weather, and intensity of the illumination. Specially, in night situations, the valid image is more difficult to fetch due to the front and rear lights of vehicles, reflections of constructions and wet roads, etc [22]. The algorithm for the nighttime implementation would be much more complex and very challenging. Basically, according to different recognition algorithms, vision based lane recognition methods can be divided into region segmentation [10], feature [27][34], model [35], 3D vision [6], multi sensor merging based methods [11], etc.

a. region segmentation based method

Usually, the region segmentation based method evenly or non-evenly divides the interested region into several small rectangular windows as showed in figure 10 and then binaries every window as showed in figure 11.

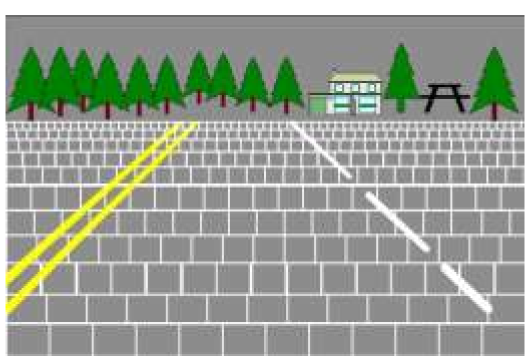

Figure 10. Non-evenly divide the interested region

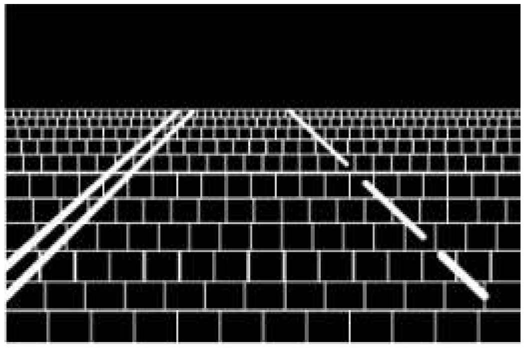

Figure 11. Binarize every window

The interested windows that include lane information can be picked out as showed in figure 12 according to the contrast information. After that, the lane markings in each interested window can be linked together to generate the stepped lines. Thus the lane characteristics in the interested area of image can be described by these stepped lines so as to form the final lane markings in figure 13. This method could describe every kind of lane markings including straight lines and curves and has good flexibility. However, some artificial noises might be added during the region segmenting.

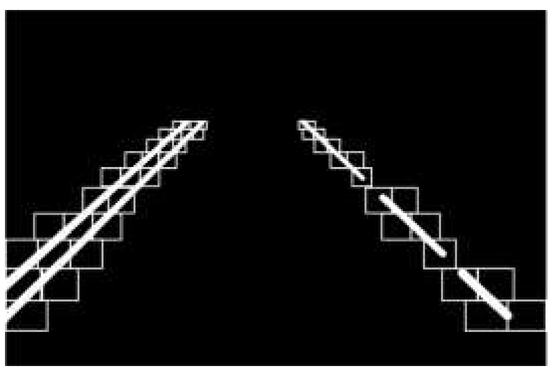

Figure 12. Pick out interested windows that include lane markings

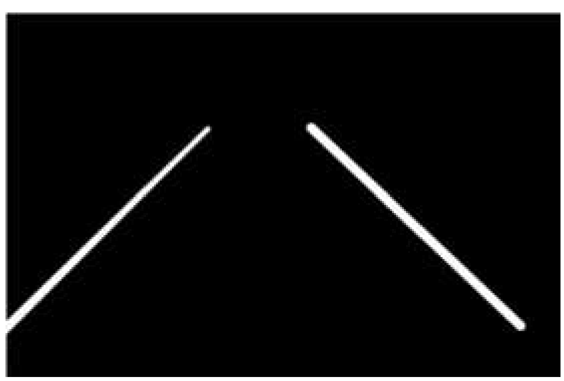

Figure 13. The final lane markings generated

b. feature based method

The feature based method may detect the lane markings by the start points of lane boundaries, the forward trend, the gray values, etc. Based on this information, the lane can be presented as some possible lane vectors. In these vectors, the vector that has the lowest distance from the former vector can be selected to best express the lane trend, so as to confirm the lane boundary. This mean has lower calculation time and good real time performance, but can only be adopted in the optimal lane marking areas as it often fails when the interferences are bigger.

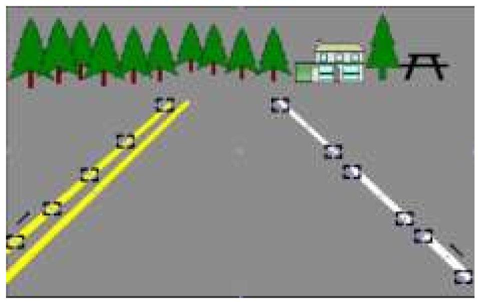

Figure 14. Feature based lane marking detection

Also, the Hough transform method could be used to pick out the straight lines from the preprocessed image so as to determine the final lane boundary. This method could largely reduce the processing time and increase the real time performance. But it does not work well in the shady or broken lane situations.

c. model based method

The model based method cites parabola (see figure 15), hyperbola (see figure 16), B-snake (see figure 17), even triangle model (see figure 18) to express different lanes. After detecting the basic edge of lanes, a model curve with to-be-determined parameters is provided to express the actual lanes. The parameters of this curve are adjusted to optimally match the lanes. The curve with the best parameters is the one that is picked out to describe the lane. But if the number of control points of the curve is big, the processing time might be quite long.

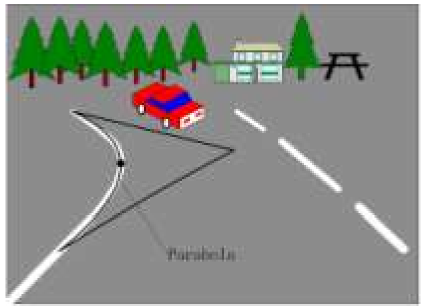

Figure 15. Parabola model

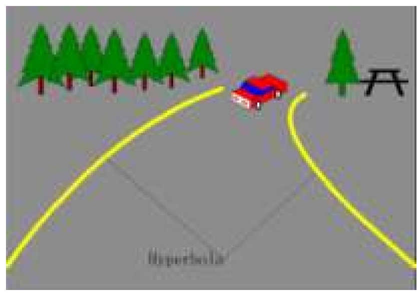

Figure 16. Hyperbola model

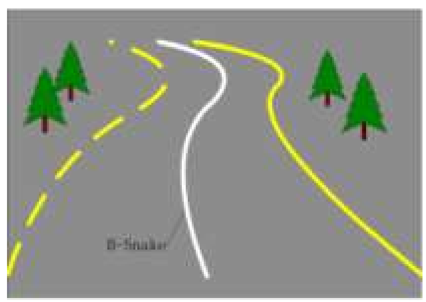

Figure 17. B-snake model

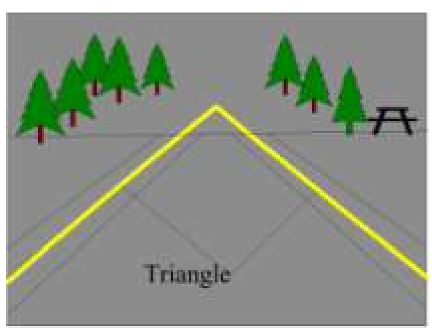

Figure 18. Triangle model

d. 3D-vision based method

All the above methods are based on the assumption that the road plane is flat. However, the road as showed in figure 19 is not flat indeed. So some 3D-vision based methods which can detect the

3D models of lanes and calculate the parameters of them are recommended. Usually, the 3D-vision based method uses the stereoscopic sensors [6]. Both images of the stereoscopic sensors should be matched to generate the real global model of the road lane. If the 3D map of the road lane is constructed, tracking the lane would be much more convenient. Certainly, more processing time is needed and the algorithms might be much more complicated since the models are more complex and more additional parameters should be estimated.

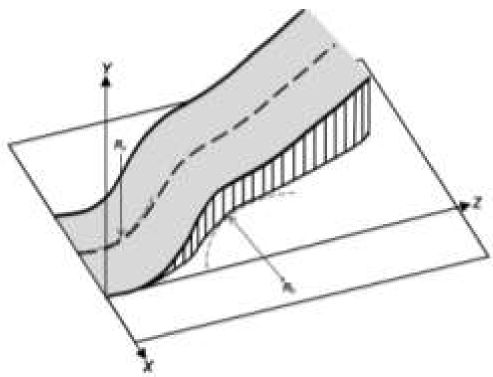

Figure 19. 3D representation of a road lane segment with its horizontal and vertical curvature [6]

e. multi sensor merging based method

Also, more sensors can be applied to the vision system to strengthen the performance of the lane detection. For example, with the help of GPS information, as showed in figure 20, the road information can be firstly confirmed. And then the front lane mark trend could be predicted, which can be used to insure or modify the basic lane recognition result.

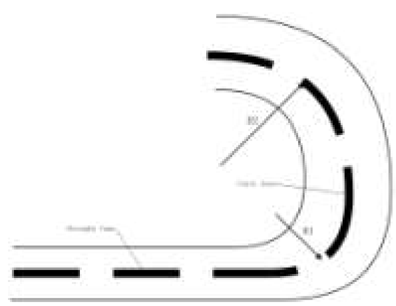

Figure 20. GPS information based lane prediction

In the near future, the communications between the ego vehicle and the surrounding environment would be implemented. In this case, the vehicle can get the front lane information from the infrastructures or from the front vehicle. The vehicles in a small area could calculate and share their information with others. In this way, the processing time of each vehicle might be largely reduced and the real time performance would be improved.

f. some interferences elimination methods

In order to eliminate the interferences, some image processing algorithms are cited. For example, the histogram tapered stretch algorithm can be used to increase the contrast of the original image so as to pick out the lane markings under intense light illumination condition. The SUSAN operator can be firstly utilized to extract the edge of the processed images. The edge images can be filtered by tracking the directional boundaries. And then the Hough transform can be used to collect the parameters of the lane markings so as to pick out the most possible lane. Finally the interested region can be used to realize the tracking of the lane markings. This method pertinently analyzes and processes the images in intense light illumination situations and has good effect. But the calculation time might be much longer, which may lower the real time performance.

While the processing speed of computer increases, more and more complicated algorithms that adapt on different kinds of severe environments are quoted. With these algorithms, the situations such as lane mark missing, shadow covering, and bright light interference can be cleared up in different degrees. For example, the shady, broken lane mark could be identified in the following steps. Firstly, turn the color image into grey scale and filter out noises by median filter. Then, extract the lane by using symmetrical local threshold segmentation method. Finally, considering the distribution of feature points, the improved RANSAC algorithm based method is put forward for the lane identification. This method solves the lane recognition problems under the shady and broken lane situations, and has a better result in identification compared with the traditional methods. But the lane in the near vision is roughly considered as straight lines in this proposal. Therefore, this method is more suitable for straight lane detection than curve detection.

g. tracking method

After recognition of lanes, tracking of the lanes is necessary. It could also enhance the next lane detection performance. The classic lane tracking methods include Kalman filtering, Particle filtering, etc. With these algorithms, some information of lanes could be strengthened and some noises of the image could also be removed. Meanwhile, the processing speed could also be largely increased.

IV. VEHICLE RECOGNITION (LIGHT RECOGNITION) AND TRACK

In night situations, because of the severe dark conditions, vehicle recognitions basically rely on the front and rear lights recognitions as showed in figure 21 [7][8][14][15][21]. Similarly to the recognition of lanes, the vision based vehicle lights detection methods can be divided into feature [3], lane detection merging [14], motion based methods [38], etc.

Figure 21. Front and rear lights of a vehicle

a. feature based method

As showed in figure 22, feature based methods usually recognize the front and rear lights by their color, size, shape, symmetry, aspect ratio, etc [2]. Usually, the front and rear lights can be distinguished by their different colors. There are also some constraints to identify the vehicle lights. For example, the vehicle lights to be confirmed should be surrounded by a rectangle. The two white spots should be symmetrical and in a reasonable region [33]. Specially, the rear lights areas could be constrained by the red light emitted from them, which can enhance the reliability of rear lights detections [24][37]. These different constraints could be considered as ideal conditions to detect vehicle lamps.

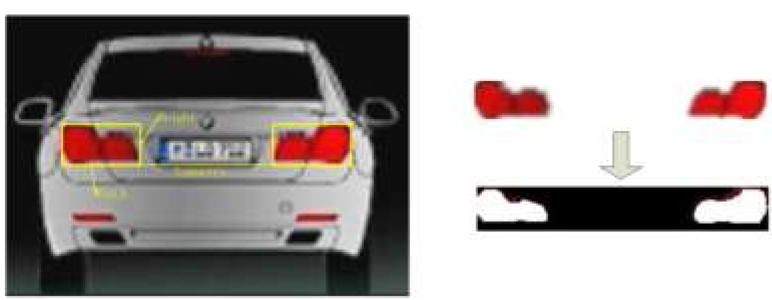

Figure 22. Color, size, shape, symmetry, etc. feature based recognition

If the light emitted from the vehicle lamp appears to be enlarged bloomed region as seen in the left part of figure 23, the low-exposure camera could be used to generate the right low-exposure image where the lamps appear as separate, distinct regions so as to distinguish different lamps [33]. This method could enlarge the detection rate of the front lamps and the near rear lamps, but lower the detection rate of the distant rear lamps.

Figure 23. Typical automatic exposure image and static low exposure image [33]

b. lane detection merging method

The lane detection merging method [4] is presented to constrain the possible vehicle lights in a region near the road by using the lane detect information as showed in figure 24. With the match of the lane, many non vehicle light sources could be filtered, which can improve the precision of vehicle rear lights detection. By the constraint of the interested region for the vehicle lamp detection, the processing time for searching vehicle lamps could be reduced. Certainly, since the lamps possess height relative to flat ground, the detected lane should be offset as seen in figure 24.

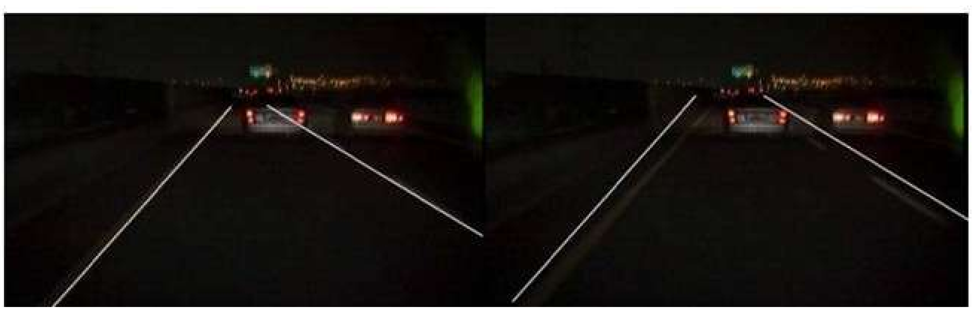

Figure 24. Lane information merged vehicle lights detection without and with offset [14]

c. motion based method

As the detection of vehicle lights in one image frame might be influenced by the intensity, shape of lights, several frames can be used to identify the final lights detection, which can improve the detection performance. By tracking the undetermined lights in continuous different image frames, some interference light sources could be removed. As seen in figure 25, since two similar cars will have similar taillights and show up with quite similar shape features of spots in the frame, additional motion dependent features are needed. The two taillights fixed on the same vehicle must have a common movement. The horizontal movement on the image plane will differ due to distance changes and depend on whether the vehicle is in the center of the image or left or right of the vanishing point. But the vertical movement will always be the similar [7]. As seen in figure 25, the undetermined spot A and spot B seem to be for the same vehicle. But according to the vertical information from different frames, they indeed belong to different vehicles.

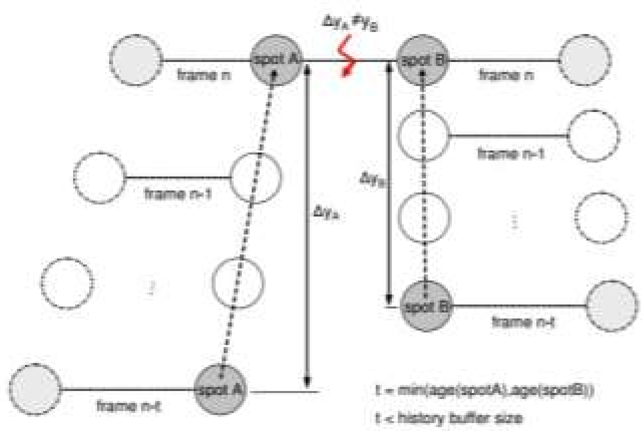

Figure 25. Movement similarity [7]

Usually, the trajectories of vehicle lights are fixed and regular. Thus, as showed in figure 26, bright spots might be split, merged or occlusive. A probabilistic model could be developed, in which the densities representing the application knowledge have been learned from training data. This tracking algorithm could improve the previous classification results without hampering its real time requirements. It can encode complex relationships between the target characteristics. The combination of the tracker and the classifiers could improve the overall vehicle detection performance, particularly for distant vehicles [38].

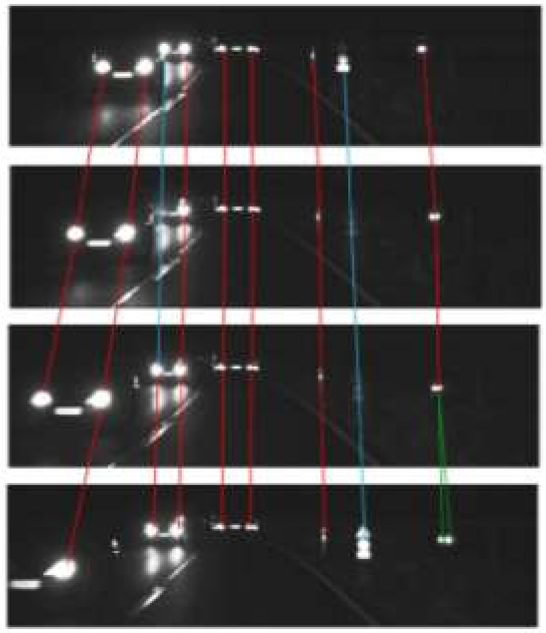

Figure 26. Blob trajectory tracking along four frames [38]

d. relative distance estimation

For the purpose of realizing the continuous adjusting of the illumination area, the distance between the front vehicle and ago vehicle should be calculated. Usually, the distance between the left light and the right light of front or rear is in a confirmed range. The front or rear of the front vehicle is assumed parallel to the image plane of the camera.

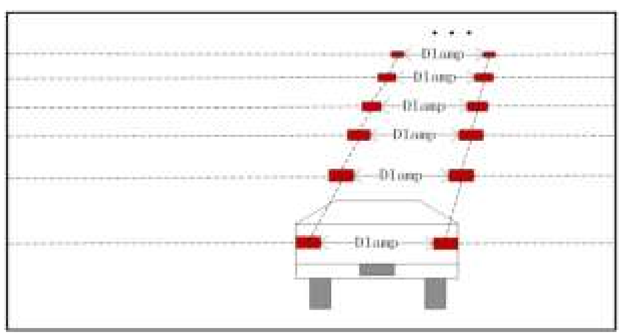

Figure 27. Horizontal distance between two ego vehicle lamps

After fetching the vehicle lights in a frame, according to the horizontal distance of them (see figure 27) and the calibration parameters of the camera in ego vehicle, the horizontal headway can be roughly calculated [16][19][31] (see figure 28). Therefore, the vertical distance and angle of the two vehicles in vertical direction can also be roughly confirmed [25].

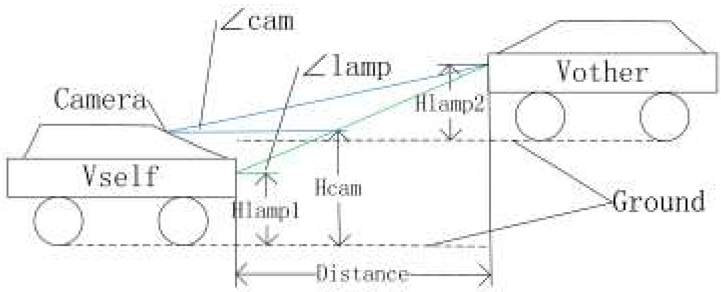

Figure 28. Horizontal headway calculation

If Lidar sensor is installed, the distance between the ego vehicle and the front vehicle would be much easier to be confirmed. And it is also worth mentioning that if the location information of the ego and the front vehicles provided by the positioning systems is precise enough and the ego vehicle could real time share information with the front vehicles, the distance between the ego vehicle and any front vehicle could be more precisely calculated and the illumination area of the ego vehicle could be more accurately adjusted.

V. CONCLUSIONS

In this paper, a comprehensive survey of vehicle intelligent headlight system development is presented. Many factors such as road geometry, road conditions (intense light, wet, fog) or glare from other light sources (vehicles, road and structure reflected lights, lights along the road) may cause reduced illumination range or uncomfortable feelings for the drivers in ego vehicle and other vehicles, which may lead to traffic accidents.

An optimal vehicle intelligent headlight system should take as many parameters from the ego vehicle and the surround environment as possible into consideration and be able to adapt on many kinds of driving conditions to provide a maximum illumination area of the street for the driver, without glaring other road participants.

By investigating the development of vehicle intelligent front lights, discussing some latest key technologies and algorithms of lane detection and vehicle light detection and providing some possible proposals we come to the conclusion that the Matrix-LED system could make the system more flexible and more effective and vision based vehicle intelligent front light system can improve the driving environment at night and. However, this kind of system is still a challenging task for many car makers and auto parts manufacturers.

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