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Lateral Driving Assistance Using Optical Flow and Scene Analysis

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***Abstract*—This paper presents a novel algorithm of image-based motion detection for lateral driving assistance. We propose a feature-based motion detection algorithm, which combines optical-flow estimation and road plane segmentation using FOE concept. The developed algorithm can segment moving objects from a changing background efficiently. Both cars and motorcycles on the lateral side of a driving vehicle can be detected. We have realized the system in a stand-alone image processing platform, which can operate independently on a vehicle using a CMOS image sensor and embedded processor. Experimental results show that the proposed methods are effective to segment moving vehicles from a moving background for lateral safety assistance.**

***Index Terms*—Driver safety assistance, image processing, optical flow.**

I. Introduction

There are blind zones where a driver can not see a vehicle's surroundings through standard rear-view mirror or lateral-view mirrors. Blind zones very often cause danger in driving, especially in car maneuvering such as turning and lane changing. To cope with these problems, many sensors and view-enhancement devices have been proposed to enhance lateral driving safety[1]. Recently, cameras and vision-based driver assistance systems have been an active area of research due to their small size and versatility.

In this paper, we focus on the development of a vision-based system for lateral vehicle detection and driving safety assistance. There have been many researches of image tracking techniques for traffic applications[2-3]. In model-based tracking approaches, a model is first established in the image plane to match and track an interested object over time. Van Leuven *et al*. proposed three refinements to a standard model-based tracking method [4]. However, their approach is good only for vehicles, not for scooters or pedestrians. Gardner *et al.* proposed a graphical vehicle model with six degree-of-freedom[5]. But, such a manual approach cannot meet the requirement of fully automatic driver assistance system onboard the vehicle.

On the other hand, many approaches concentrate on relative motion between tracked objects and image sensor(the viewer). The relative motion will cause consistent change in image intensity of successive imagery and provide information of spatiotemporal apparent velocities. An optical flow field can be obtained to represent the distribution of apparent velocities of movement of brightness patterns in an image. It is well-known that optical flow is useful for motion detection. Combining a tracking scheme with optical flow analysis, a motion field can be estimated. This motion field can then be separated into blobs of similar (real- world) motion. The motion-estimation criteria can be based on the optical flow only, or combined with e.g. edge information [6], color information [7], or using Kalman Snakes [8]. An advantage of such approach is that redundancy of observed data can be exploited to make the method more robust. However, a disadvantage is that optical-flow based approaches require high temporal and /or high spatial resolutions. It is still a challenge to detect robustly in real time multiple moving vehicles from a moving background.

For real-time performance and detecting multiple vehicles in the scene with various sizes and shapes, we adopted feature based tracking approach and combined it with the mixed optical flow estimation algorithm described in [9] for motion detection. However, detecting moving vehicles by flow field will not be robust enough; because the calculated optical flow respectively, of background and moving objects may be very similar. To solve this problem, we propose a computationally simple and efficient method to combine optical flow estimation with the concept of focus-of-expansion (FOE) and scene analysis. Instead of detecting vehicles in the entire image plane, we estimate a road plane region in the imagery to detect the parts belong to a vehicle. Once a lateral car enters this road-plane region, the system sends out a warning signal to remind the driver. The complete system has been designed and realized on an embedded imaging system.

In the next section, we will describe the scenario of lateral driving assistance problem. Section III focuses on the proposed scheme to segment moving objects. The design of a stand-alone motion detection system is described in section IV. Section V presents the experimental results. Finally, section VI summarizes the contribution of this paper.

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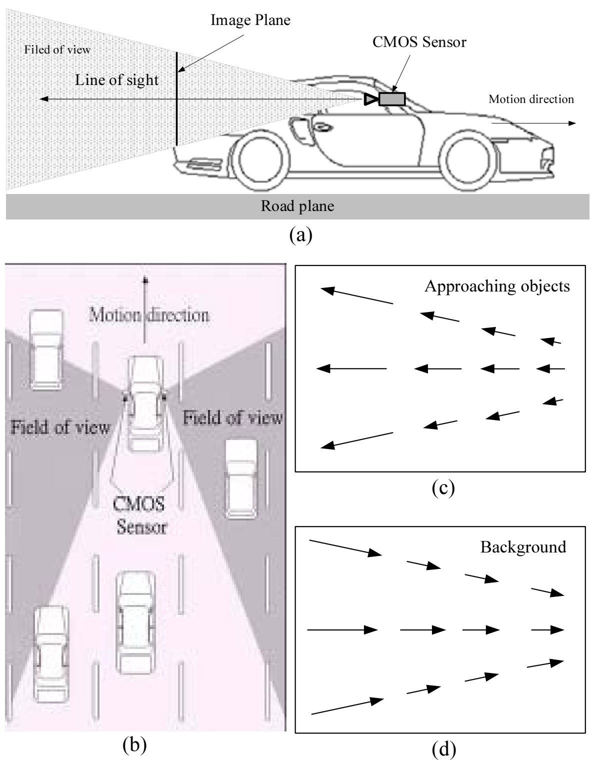


Fig. 1. Scenario description. (a) The CMOS image sensors are mounted onboard the car to capture lateral view. (b) The top view. (c) Optical flow direction of approaching objects. (d) Optical flow direction of background objects.

II. LATERAL SAFETY SCENARIO

The scenario of lateral driving assistance considered in this study is illustrated in Fig. 1. As shown in the figure, a CMOS image sensor mounted on both sides of the car is used to capture lateral views of the vehicle (Fig. 1(a)), covering all vehicles in the surrounding (Fig. 1(b)). Because the depth of scene is not uniform, the motion features become complex. For example, features of background far away move slowly or stay still. On the other hand, if a lateral car has an almost zero relative velocity to the current car, its motion is also slow. Therefore, it will be difficult to distinguish a background object or a moving car by using only the motion field. To solve this problem, we note that detected vehicles must overlap the road plane in the image plane. Through scene analysis to extract the road plane in the imagery, one can separate a vehicle from the background. Further, the road plane is related to the position of the FOE. For a given forward translational motion and direction of gaze of the CMOS image sensor, the FOE can be located, which is normally out of the image plane.

III. PROPOSED ALGORITHM

Figure 2 depicts the proposed architecture of optical-flow based motion detection system. The system is provided with a stream of gray-level image sequence taken from a CMOS

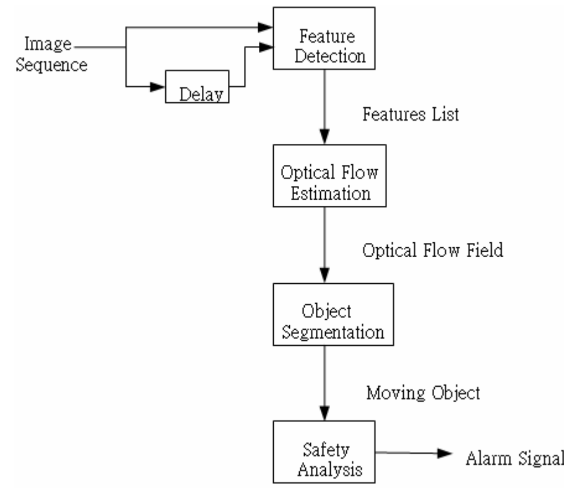


Fig. 2. Motion detection system architecture

image sensor. The feature detector extracts features to form a feature list. In this work, two-dimensional features are obtained using Harris corner detector [10] and Sobel edge extraction algorithm[11]. The feature list records each feature's position, brightness and horizontal/vertical gray-level gradients. The optical flow estimation part adopts the mixed optical flow estimation algorithm[9]. It uses the principle of correlation match technique[12] as the kernel, and combines with the brightness constraint of differential-based technique to reduce the search area of correlation match and in the meantime reduce the possibility of errors.

In this paper, we propose a new scheme for object segmentation from a moving background. It consists of two stages: in the first stage, features with the similar values of optical flow are segmented. Then in the second stage, FOE estimation is performed to find out the road plane, which is the area of the road projected on the image plane. We will explain this part in detail in the next subsection. By the position of FOE and the background flow field, the road plane can be defined. As long as the road plane is defined, the flow field of lateral moving objects can be marked. In the safety analysis step, any vehicle enters this part of road plane, the system will send out a warning signal to remind the driver.

A. FOE Estimation and Object Segmentation

For object segmentation, we classify the horizontal direction optical flow vector u of extracted features into the same category. Fig. 3(a) shows an example of the histogram of u of an image sequence. In Fig. 3(b), distribution of the x and y coordinates of the identical optical flow information u is presented. The blocks of these features spread in the original image frame can be found, as shown in Fig. 3(c).

For FOE estimation, we assume detected lateral vehicles are on the road and in the image plane. Thus the features of lateral vehicles and road plane must overlap, we can write the equation as

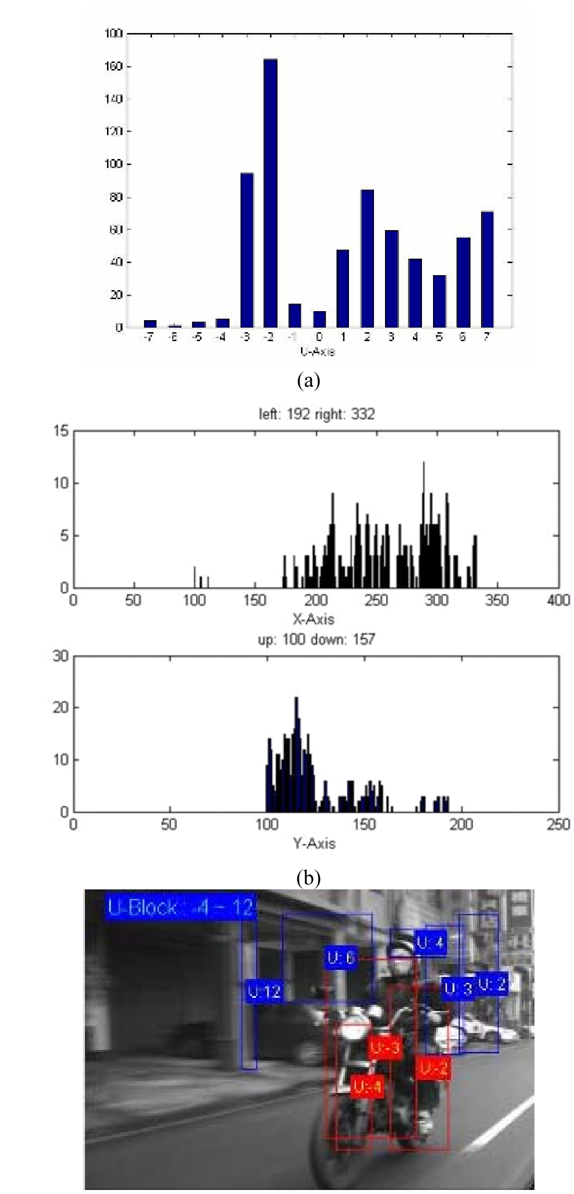


Fig. 3. (a) The statistical result of the features;(b) tThe x and y coordinate statistical distribution situation of the same vector *u*; (c) the result of object segmentation.

$$(\text{Moving\_objects}) \cap (\text{Road\_plane}) > 0 \tag{1}$$

The problem now becomes how one can segment the road plane, which is the area of the road projected on the image plane. As shown in Fig. 4, it is not difficult to see that the road plane is under and to the right to the FOE. One can segment the area under and to the right of the FOE as the road surface. Near the area of the FOE, the resolution of scene becomes low, is not suitable for feature flow analysis. Therefore, road flat surface is established to some extent in the image plane.

The background optical flow can be exploited for FOE estimation. The generation of FOE is due to observer's own motion. Due to the observer's motion, the optical flow of static background will spread inwardly to this point. So, one can find out two flows belong from the background, and their slopes are in I /IV quadrants respectively, as shown in Fig. 4. The intersection of these two lines is FOE. A straight line of optical flow can be found by combining FOE position with the optical flow information at the right side of image. The location below this line in image plane is road plane.

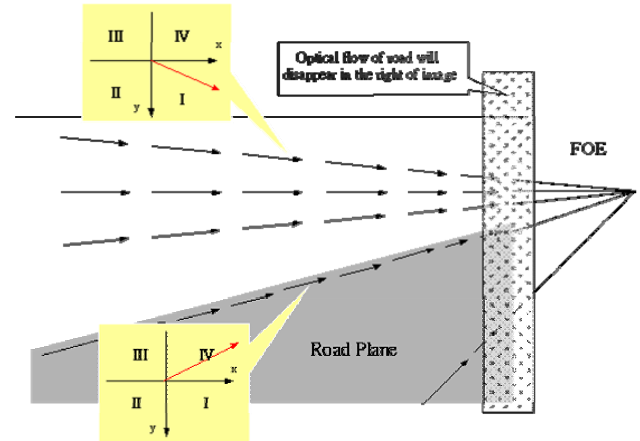


Fig. 4. The vehicle and road plane must overlap; the optical flow of road will disappear in the right of image plane

B. *Safety analysis*

When a block of a moving object is detected in image plane, this block in image plane can be recognized as a part of a moving vehicle. Assume that the horizontal component of optical flow of this block is U_b. The lateral dangerous situations can be divided into three categories.

1) The lateral vehicle moves faster and will overtake the current car, as shown in Fig. 5(a).

2) A vehicle is approaching behind the lateral side of the current car, as shown in Fig. 5(b).

3) There is one vehicle right in the lateral side of the current car, as shown in Fig. 5(c).

As one of the three situations occurs, the driver must be reminded by a warning signal in order to avoid a possible crash simply by without paying attention to the lateral vehicle in blind zones. The judging rules of lateral vehicle behavior are set up as follows:

For the first category, a lateral car is overtaking. The optical flow of a lateral vehicle is different from the background. This situation can be determined by:

$$\text{If}\,(U_b \leqq -1) \cap (\text{Object\_block} \cap \text{Road\_plane}) > 0 \tag{2}$$

In the second category, the behavior of a lateral vehicle is similar to the first category. The difference is where the vehicle is in the image plane. In this case, it is behind the lateral side of current car and the situation is determined by

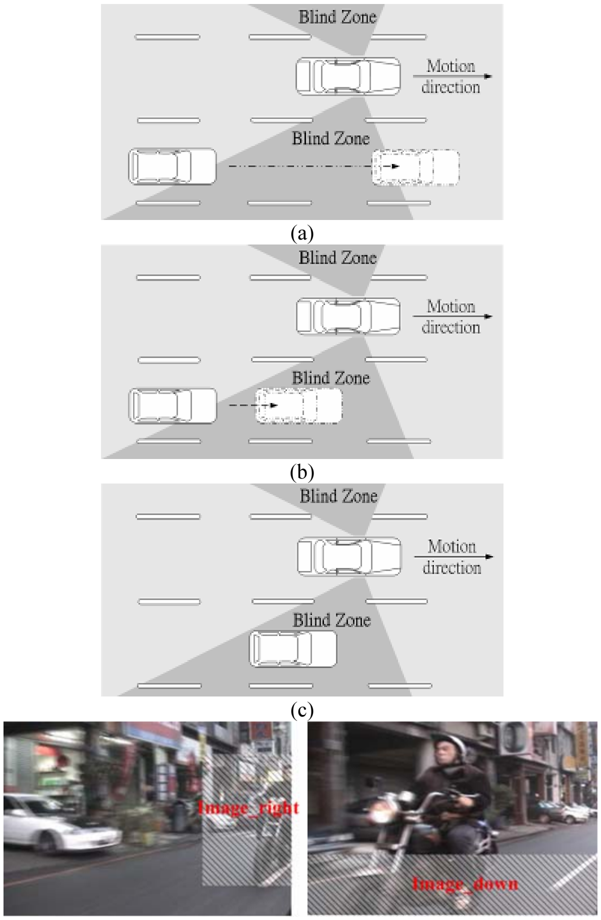


Fig. 5. Categorization of lateral dangerous situations (a) The first category of lateral dangerous situations. (b) The second category of lateral dangerous situations. (c) The third category of lateral dangerous situations. (d) Image_right. (e) Image_down.

$$\text{If } (U_b \leq -1) \cap (\text{Object\_block} \cap \text{Road\_plane} \cap \text{Image\_right}) > 0 \quad (3)$$

In the third category, the lateral vehicle behavior is related to the relative position of current car. On one hand (2) and (3) have implied that the vehicle is on the adjacent lane, and on the other hand the third category includes that the lateral vehicle is driving away from the current car. So this behavior is determined by

$$\text{If } (U_b \leq 0) \cap (\text{Object\_block} \cap \text{Road\_plane} \cap \text{Image\_down}) > 0 \quad (4)$$

When one of the three categories is detected to be dangerous to the current car, the system must send a warning signal to remind the driver.

IV. STAND-ALONE IMAGING SYSTEM

One of the primarily concern of this study is that the motion detection system can operate independently in real time and be mounted in a car. For these reasons, the system is designed and implemented in a compact and low cost embedded system [13]. The proposed system consists of a Nios development kit, Stratix edition with an Altera EP1S10F789C6ES onboard. The system clock is 50MHz. The hardware architecture is shown in Fig. 6. The Harris corner detector is implemented on Galaxy corporation's school boy development board, a Cyclone EP1C20F324C7 device. A CMOS image sensor ICM205B from IC-MEDIA is employed as image acquisition device. It is initialized by an I^2C controller. The input image is 320×240 (QVGA) 4:2:2 YCbCr 16-bit, 30 frames/second format. Only Y, i.e., 8-bit gray-level data is used. The Nios embedded processor is a soft-core RISC microprocessor, which is developed by Altera. It is flexible for user to configure the processor to be integrated with peripherals. In this design, we use a DMA to access data from FIFOs to SDRAM. The width of the DMA length register is set 15 bits, because the maximum size of FIFOs data is 7680×4 bytes and it can be processed in a single DMA command [13]. Receiving the output of Harris corner detector, the Nios processor would execute the following blocks, i.e., feature detection, optical flow estimation, object segmentation, and safety analysis.

V. EXPERIMENTAL RESULTS

Two experimental results are presented in this section. First, the algorithm is simulated and evaluated using MATLAB. Second, the stand alone system is tested on a real urban road to check its effectiveness.

A. *Software simulation*

In this simulation, we use MATLAB to execute the developed algorithms. Pre-record traffic video taken by CCD camera was used as input image sequence. The results are shown in Fig. 7. The results of detection rate are summarized in Table 1. When the moving vehicles appear in detect region of road plane, the system sends out a warning signal to the

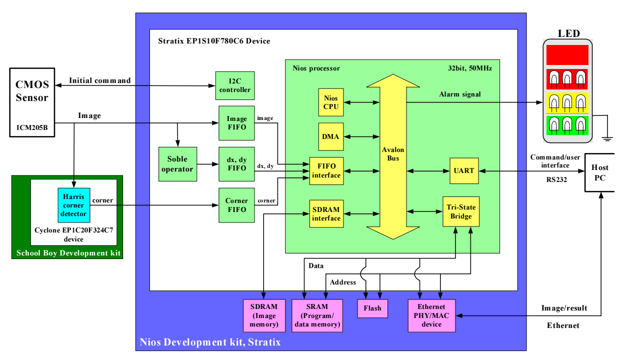


Fig. 6. The architecture of stand alone image system

Table 1.

Correct rate of software simulation results

Sence	Correct/total frames	Correct rate
Background	279/333	83.80%
Motorcycle	347/378	91.80%
Car	44/51	86.30%

driver. The warning messages is *"Don't make a lane change"* with different colors in image frame. The color indicators on left side of image frame show different behavior of the estimated lateral vehicle.

1) *Background test:*

Fig. 7(a) displays a situation when there is no car on the lateral side of road. The background is full of buildings. Fig. 7(b) shows the case when there is no car on the road but there are several cars parked on the road side. Fro background test, the correct detection rate(no danger) is 83.8%. The main reason for detection errors is the vibration motion of the current car, leading to the influence of optical flow feature of far background. These features cause the system detection error.

2) *Motorcycle test:*

In Fig. 7 (c)-(d), the speed of current car is 60 km/hr. There is a motorcycle driving fast from behind to overtake the current car. The speed of this motorcycle is faster than the current car. In Fig. 7 (e)-(f), the speed of the current car is 30 km/hr. There is another motorcycle driving along the side lane from behind the current car. It moved fast to overtake the current car. The correct rate for the motorcycle cases is 91.8%.

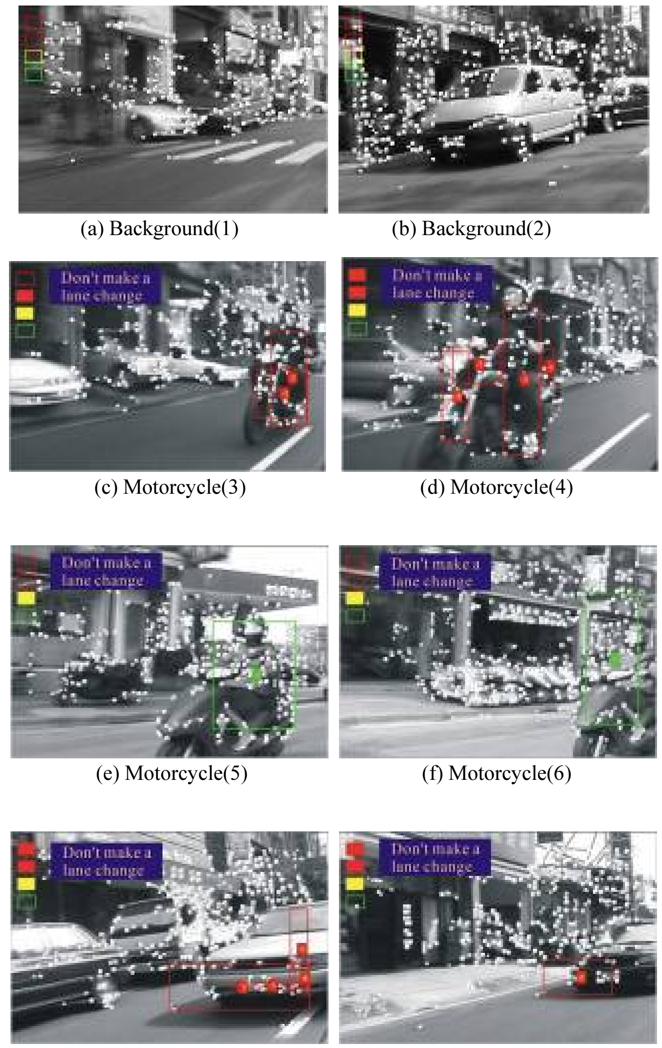
3) *Car test:*

In Fig. 7 (g)-(h), the speed of the current car is 40 km/hr. There were a yellow color car and a black color car driving fast and approaching the current car. The correct detection rate of cars is 86.3%.

These experimental results show that the proposed algorithm can extract two-dimensional features and estimate optical flow of these features. The features of the lateral vehicles are segmented and blocked in the image sequence, for both cars and motorcycles.

B. Real road test

In this paragraph, the experimental results on an urban road are presented by installing the stand alone system onboard a car to verify the proposed algorithm. Fig. 8 shows that a vehicle overtaking the current car can be detected. Different colored LEDs are used to indicate different danger conditions. The green LED means that there are vehicles in the lateral side. The red LED means that there is a vehicle which is fast overtaking the current car, while the orange LED means that there are vehicles gradually approaching the current car. In Figs. 8(a), there is no vehicle appears in the image, but in advance the lighted LED warns the driver that some vehicles will pass through from the lateral side behind the current car. There is indeed a vehicle appearing in Figs. 8 (b), and the LED keeps on for lateral safety warning. In Fig. 9, a motorcycle moves towards the current car from the lateral back location. Because in the beginning, the speed of this motorcycle is slightly slower than the current car, the green LED twinkles, as shown in Figs. 9(a). Afterward this motorcycle speeds up and overtakes the current car. The condition is detected and the red and orange LED light up, as shown in Figs. 9(b)-(c).



(a) Background(1) (b) Background(2)

(c) Motorcycle(3) (d) Motorcycle(4)

(e) Motorcycle(5) (f) Motorcycle(6)

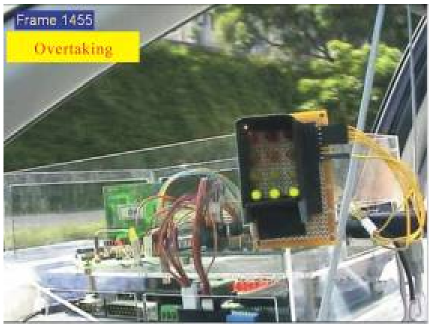
(g) Car(1) (h) Car(2)

Fig. 7. Simulation results of moving vehicle detection

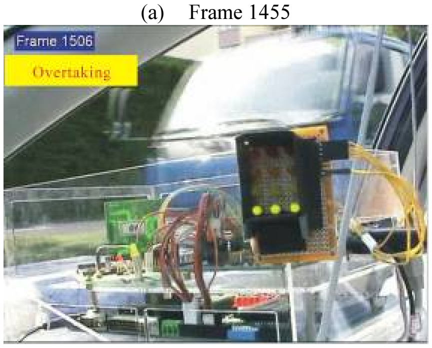
From these experimental results, we observe that the system can detect vehicles in real time on the urban road. Three color LEDs provide real-time warning signals to remind the driver.

VI. Conclusion

In this paper, we proposed a feature-based motion detection system, which combines a mixed optical flow estimation algorithm and FOE estimation. Based on the proposed algorithm, a stand alone motion detection system has been realized for lateral safety assistance of a vehicle. In the experimental study, the system successfully extracts and blocks the features of lateral vehicles. When the lateral vehicle behavior is dangerous to the current car, the system signals the driver with three different colors of LED as warning signals to remind the driver. The execution performance of the current implementation is 1.86~3.26 fps.



(a) Frame 1455



(b) Frame 1506

Fig. 8. Car detection: experimental results on urban road

This can already provide about 0.3 sec earlier to warn a driver about a dangerous situation. The practical experiment on urban roads shows that the development system works satisfactorily. In the future, advance algorithms need to be investigated for the situations such as in raining, under vibration, and for the case of turning of the current car.

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(a) Frame 2153

(b) Frame 2227

(c) Frame 2302

Fig. 9. Motorcycle detection: experimental results on urban road

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