2012 Intelligent Vehicles Symposium
Alcalá de Henares, Spain, June 3-7, 2012

Data Fusion for Overtaking Vehicle Detection based on Radar and Optical Flow

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***Abstract*— Trustworthiness is a key point when dealing with vehicle safety applications. In this paper an approach to a real application is presented, able to fulfill the requirements of such demanding applications. Most of commercial sensors available nowadays are usually designed to detect front vehicles but lack the ability to detect overtaking vehicles. The work presented here combines the information provided by two sensors, a Stop&Go radar and a camera. Fusion is done by using the unprocessed information from the radar, and computer vision based on optical flow. The basic capabilities of the commercial systems are upgraded giving the possibility to improve the front vehicles detection system, by detecting overtaking vehicles with a high positive rate.**

I. Introduction

RADARS are very common nowadays in road safety applications. It has proved to be a very robust and useful technology in a wide variety of applications such as Stop&Go systems, speed cruise controls, etcetera.

Recent advances in Advanced Driver Assistance Systems (ADAS) demand more robust and reliable sensor sets able to deal with any situation. Here is where usually a single sensor is unable to fulfill the requirements of such demanding applications, thus data fusion becomes necessary. In this approach, a novel method for overtaking vehicles detection is presented.

ADAS systems require detecting a wide variety of situations, overtaking vehicles is one of them. The presented approach takes advantage of two very common sensors that can be found in any ADAS system, such as radar and camera. The former has proved to be a very useful tool to detect vehicles. But commercial radars operating range is mainly oriented to front vehicles detection. On the other hand, the overtaking vehicle detection using computer vision has proved to be a feasible tool, but still problems related with noise, illumination changes and variety of shapes, and colors and computation costs, made it a tough task. Thus a novel approach was necessary to combine both sensors and provide a better and robust detection for overtaking vehicles without the need of adding new sensors that would increase the overall cost of the final system.

This system can be integrated with adaptive cruise control in order to detect vehicles before they are completely visible; another possible solution could be the use of a Blind Spot Detection system, but in this case the installation of another camera is needed.

II. General purpose

Two sensors were available for environment detection. These sensors are a firewire CMOS camera and UMRR Stop&Go Radar Sensor.

The camera mounts a 752 x 480 Progressive Scan CMOS sensor, whose sensitivity covers both visible and near infrared wave lengths. The chosen lens is a 8 mm.

The radar is based on a 24GHz middle range sensor capable to detect obstacles up to a distance of 90 meters.

The camera and the radar were mounted on the BRAiVE prototype (figure1). The detection distance range is intended to be up to 80 meters and the FOV (Field of View) is about 30 degrees, while RADAR FOV is about 60 degrees.

Figure 1. The BRAiVE prototype that is used for this project.

The radar system consists of a radar sensor and a central processing unit (ECU). The latter controls the whole system, receives ego-motion information, interprets and tracks sensor data, and communicates with the vehicle using CAN bus. It gives the final output of radar detections, improved by a tracking algorithm. Moreover also the output of the stand alone radar (raw data) was available. This information, although is limited to position, radial speed and reflectivity level, proved to be useful.

When dealing with overtaking vehicles information from ECU proved to be insufficient since the vehicles were only detected several frames after they totally overtake the vehicle, as shown in figure 2. Thus a new approach had to be developed, based on the visual information and raw data from the radar (which is available from the beginning of the FOV of the sensor). This raw data include numerous false positives and multiple detections for the same obstacle.

The proposal for the application presented here was to fuse raw data information from the radar and optical flow from the camera to increase the field of view of the basic approach detecting overtaking vehicles before they are completely visible in the image and correctly detected by the radar ECU.

Figure 2. A and C the vehicles has raw data detection (on black) but no detection from the ECU (highlighted on red). After the vehicles are completely overtaking they are detected (B and D) by the ECU algorithm. There are situations where even after totally overtaking the vehicle is not detected after several frames (A and B).

III. State of the Art

For overtaking vehicle detection, visual procedures are mainly based on motion detection. Visual based vehicle detection has two main methods. Appearance based methods and motion based. First are more intuitive and easy to implement but occlusions and divergence in shapes and colors makes it less reliable. This situation is found mainly when dealing with less structured environments such as urban environments, where false positive rate increments. In [1] *Broggi et al.* use vertical symmetry and a later analysis of the region. *Liu et al.* take advantage of the shadow underneath the vehicle to detect it [2]. *De la Escalera et al.* use a geometric model to classify the vehicles [3]. A common approach when dealing with motion based method is to compute the movement of the car and predict future optical movement. This predicted movement is compared with the real one found to detect unpredicted moving objects in the image [4][5][6]. Finally in [7] *Wang et al.* propose to model the background into dynamic and quasi-static regions to perform this comparison.

Appearance based methods have proved to be not satisfactory in detection of overtaking vehicles, as features or models of completely visible vehicles are usually considered; on the other hand overtaking vehicles detection based on optical flow have proved to be a successful tool for detecting vehicles but some difficulties arises when dealing with such applications: noise due to camera shocks and vibrations, lack of features to track or noises due to illumination changes can lead to error or misdetections. In all these cases fusion with raw information from radar can help to overcome these limitations.

Figure 3. Optical Flow widow highlighted in black.

IV. Optical Flow Procedure

Optical Flow implementation used for this approach was Lucas-Kanade detection using a Shi and Tomasi Feature Tracking [8][9][10].

As it was told, one of the main problems when dealing with optical flow is errors due to camera shocks, thus it is mandatory to perform a robust stabilization before processing the image. In this work, a previously presented software stabilization system developed by VisLab is used to avoid these errors [11].

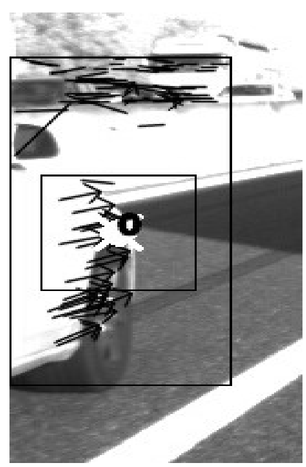

Figure 4. Optical flow movement, arrows show movement of overtaking vehicles, and lines with no arrows are movement in other direction than overtaking vehicles. Radar detection is highlighted with a white “x” and the search window is represented by a black box surrounding it.

The approach is focused in those regions where the overtaking cars are going to appear: a window is created to perform optical flow only where overtaking vehicles are going to be found (figure 3). This helps the algorithm to reduce the region where to perform optical flow, which reduces the computational costs and allows the application to work in real time.

After the flow motion processing a set of features is obtained. These new features are checked with some constraints to see if they fit with the movement of an overtaking vehicle.

Overtaking vehicles would present a movement easy to distinguish among static obstacles since the direction of the resulting feature movement would be totally the opposite to the movement of static objects, as it is shown in figure 4.

Two specific features are checked the velocity of the vehicle and the moving angle. This velocity and angle are checked if they fit within the movement of an overtaking vehicle.

$$f_i \epsilon\ Q \ \leftrightarrow \left(\|\Delta_i\| > th \,\&\, \epsilon\ 0 \le ang(\Delta_i) \le \frac{\pi}{2}\right)$$

where f_i is a given feature among the calculated in the algorithm. Q is the set of valid features and Δ_i is the movement of the feature along the two sequences. $ang(\Delta_i)$ is the angle of the movement as shown in figure 5.

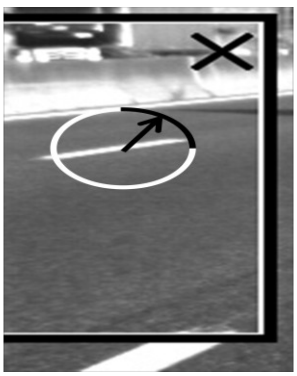

Figure 5. Feature movement angle that fits overtaking vehicle constraints (in black) and not fit (in white).

V. Radar Detections

Raw radar detections are the detections obtained from the radar device without ECU. As it was mentioned before, these detections cover a wider field of view. These detections proved to be a not very trustable information source since the amount of misdetections was relatively high. Moreover, other inconvenient had to be solved. These problems were lack of information since the radar did not differentiate among vehicle and lateral obstacles such as lamppost, milestones, etc. Also multiple detections can be given for each vehicle as shown in figure 6.

The classification among vehicles and lateral road obstacles was performed by the fusion procedure that will be presented below. Problems related by non continuous detections were solved by performing tracking that keeps the tracks even when there were no radar detections.

VI. Data Fusion

A. Data association

A simple metric is used to associate old tracks with new detections from the radar, using euclidean distance. After this association three sets of candidates are available, these three sets are going to be checked using optical flow: updated old tracks, non updated old tracks and no-matching radar detections.

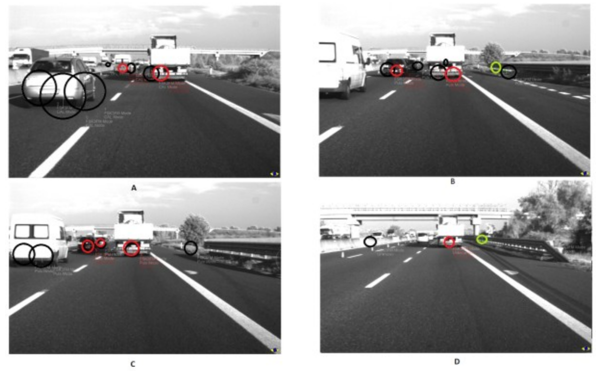

Figure 6. Raw radar data detections on black, vehicles detection given by the ECU on red, and not moving detections on green. A Multiple detections for a single vehicle. B Misdetection of an overtaking car. C and D not vehicles detections at laterals.

To check the three available sets with optical flow information search windows were created centered in the radar detections projections in the image. Thus only the valid features found in the optical flow detection process that are inside these windows were taken into account. For each window if the number of features is higher than a certain threshold, a new matching is reported. Figure 4 shows a case in which a sufficient number of significant features are detected inside the search window of a given radar detection.

Figure 7. Radar detection of a vehicle outside the field of view of the camera and optical flow positive detection.

Radar detections that are taken into account are those with a projection in the camera field of view within the search window. The projection of radar data into the image is based on perspective mapping transformation that uses camera intrinsic and extrinsic parameters, previously computed with an accurate calibration stage. Those detections that are about to enter in the optical field of view are also taken into account since the front of the vehicle is already in the field of view and the rear is not visible (radar provides distance to the rear of the vehicle). Thus the optical flow search window of these later is translated to the beginning of the image, as

Figure 8. Results for daylight condition. Search window is highlighted in back. A signal is triggered to warn the driver that there is a vehicle overtaking. It the signal is showing a black “!!” symbol.

shown in figure 7.

B. Track management

A new track is created when the data association process matches the detections from the two sensors. Alerts are going to be reported only after two consecutive matches, this way false positives both from optical flow and radar are reduced.

To delete tracks no-detections should be provided by both, optical flow and radar during two consecutive detections.

To check the track in the next frame, displacement is computed along the different frames in previous images. Next position is estimated taking into account this displacement.

VII. RESULTS

Two sets of tests were performed, the first one was performed in the day, and the second one during night. It was possible thanks to the ability of the camera to work both in daylight and nightlight conditions.

A. Day light test

The developed application consists of overtaking detection, thus the information provided to the driver was reduced to trigger a warn alarm to inform the driver that there is a car overtaking.

Tests were performed in more than 6,000 frames with a total of 75 vehicles performing overtaking maneuvers. All overtaking vehicles were detected. Even if all the overtaking were detected, in a total of 15 frames the alert is not issued, due to not-continuous detections. Some examples of correct results can be found in figure 8.

During the overtaking process the alarm is maintained most of the time. In several occasions the alarm is disconnected but never more than 2/3 frames.

B. Night test

Night vision test were performed in 2,000 frames. Here the number of misdetection was zero. It was mainly due the fact that in night vision the amount of visible information is reduced, thus the possible misdetection due to wrong feature location is lower. As it happened during day light condition alarm is maintained along time during the overtaking process, only in few occasions during 2/3 frames the alarm was disconnected. Figure 9 shows different examples of correctly detected overtaking vehicles during night.

Finally to provide track performance Figures 10 and 11 are presented. They depict the movement of two vehicles while performing overtaking maneuvers. First shows a vehicle in left lane, as it can be seen in figure 10 C. Also

Figure 9. Results for nightlight conditions. In this case back that shows the search zone is not very visible. The warning signal used to warn the driver in case of an overtaking vehicle is white.

number of features detected is represented in figure 10 B. Figure 11 shows a closer vehicle that performs the overtaking in the closest lane. These figures show how the several echoes that are received from the radar create several tracks, although they tend to converge or disappear fast. The figures also show the period where the overtaking detection system warns the driver in advance before the ECU provides the tracking of a given vehicle.

VIII. CONCLUSIONS

It was proved that a robust and reliable overtaking detection vehicle can be performed by taking advantage of the raw data from radar and complementing the system with optical flow. Thus by adding to low cost vision system the features and capabilities of stop&go commercial radar can be increased. The system algorithm was tested in real conditions with excellent results.

The system was tested on recorded sequences and it allows to work at camera frame rate (10 fps)even using a not performing processor. Unfortunately in some cases, due to the great number of features, the processing time exceed 100 ms: future developments will focus on code optimization and strategy to manage these cases.

This application is a result of a joint action between VisLab, from Università degli studi di Parma, and Intelligent System Lab from Universidad Carlos III de Madrid, using the BRAiVE prototype.

ACKNOWLEDGMENT

This work was supported by the Spanish Government through the Cicyt projects FEDORA (GRANT TRA2010-20225-C03-01) and D3System (TRA2011-29454-C03-02).

BRAiVE prototype has been developed in the framework of the Open intelligent systems for Future Autonomous Vehicles (OFAV) Projects funded by the European Research Council (ERC) within an Advanced Investigation Grant

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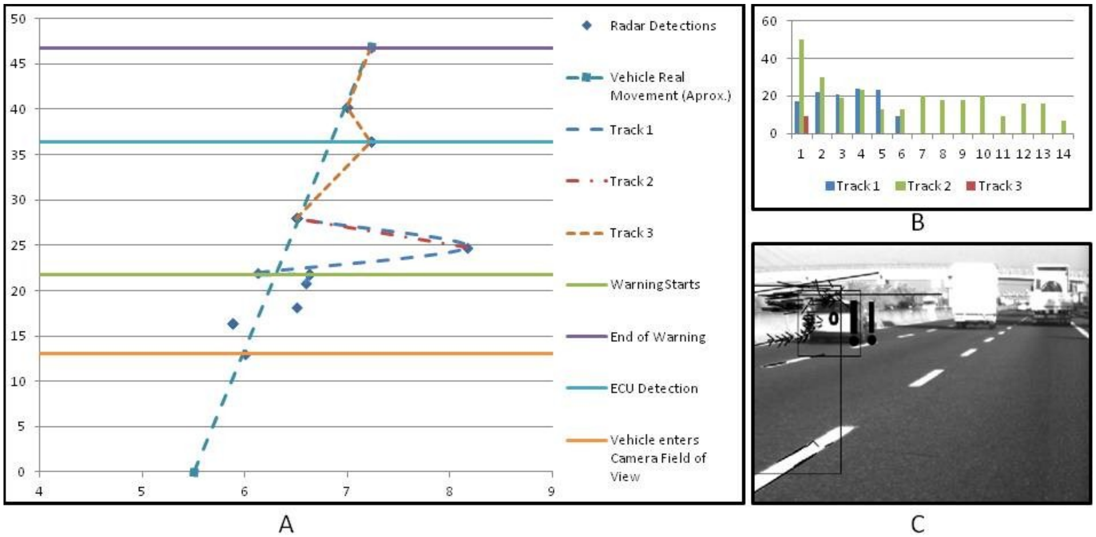

Figure 10. Vehicle overtaking in the left lane. A depicts the tracking behavior, the parts of the movement where the warning is triggered and when the ECU starts the tracking. B depicts the number of features per track in the several frames where they are detected. C is a capture of the image with the features highlighted.

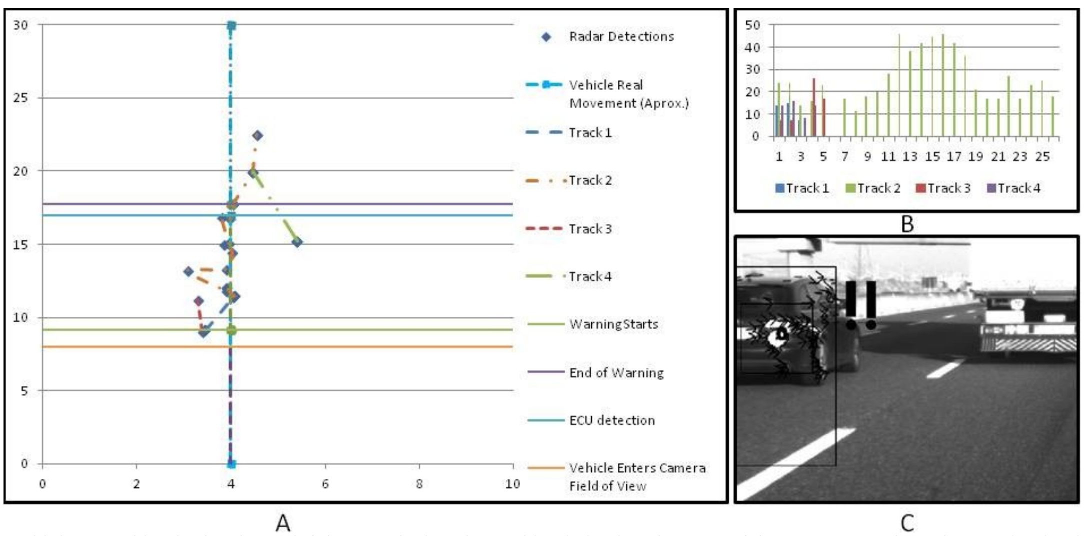

Figure 11. Vehicle overtaking in the closest left lane. A depicts the tracking behavior, the parts of the movement where the warning is triggered and when the ECU starts the tracking. B depicts the number of features per track in the several frames where they are detected. C is a capture of the image with the features highlighted

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