A radar driven fusion with vision for vehicle detection

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The paper describes a vehicle detection system fusing radar and vision data ready to be used for ACC. Radar data are used to locate areas of interest on images. Vehicle search in these areas is mainly based on vertical symmetry. All vehicles found in different image areas are mixed together and a series of filters are applied in order to delete false detections. The current algorithms analyze images on a frame by frame basis, without any temporal correlation. Results and problems are discussed, and directions for future enhancements are provided.

1. Introduction

Researches on preventive safety functions are now used for several driver assistance systems.

The SeiSS[1] study (Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles: SeiSS final report) estimated that Adaptive Cruise Control (ACC) that performs longitudinal control could save up to 4.000 accidents in 2010 if only 3% of the vehicles were equipped.

ACC and any other system that is used for safety application needs a precise vehicle localization. Using only a radar can be critical for vehicle dimension and lateral position measurement. The fusion of radar and vision can provide position measures with good longitudinal and lateral accuracy.

The advantages and the problems of fusing radar and camera data for vehicle detection are well known [1]; methods differ mainly for the fusion level: low, intermediate, and high level fusion have all proved to reach good results. Low level fusion combines several sources of raw data to produce new raw data that is expected to be more informative and synthetic than the inputs [2]. This work is developed using high level fusion and focuses on validation of radar targets, as shown by Sole [3].In this context, radar targets can either correspond to a vision target, in our case a vehicle, or not: different vision algorithm scan be used for this purpose.

The search for vehicle features provides a simplified way of localizing vehicles: symmetry is a characteristic that is common to most vehicles. Some research groups have already used symmetry to localize vehicle [4], and used a variety of methods to find symmetry on images: using edges, pixel intensity, and other features.

The vehicle detection algorithm used in this work is based on symmetry [5] and uses radar data in order to localize areas of interest. Data fusion operates at high level: the vision system is used to validate radar data and to increase their accuracy.

2. Fusion

The first step of the algorithm converts radar objects into the image reference system, using a perspective mapping transformation that projects the radar point onto the object base. This transformation is performed using calibration data achieved by fine intrinsic and extrinsic camera parameters measurements, as well as radar calibration. Since parameters measurement is performed only once, at system setup, and no stabilization is currently applied, errors may occur when extrinsic parameters change (mainly due to vehicle pitch) due to road roughness or vehicle acceleration. Moreover radar may intrinsically provide an incorrect lateral position: points may not be centered onto the obstacle shape or even fall outside it. In the definition of the image area used by vision to validate radar objects, wide margins are used both on its left and right sides in order to bypass possibly inaccurate radar data (vertical and lateral offset). The area height is defined to be half of its width; the area bottom is positioned at a fixed percentage of height below the radar points in a way that the vehicle should be included even in case of strong pitch variations.

Only radar data that refer to points inside the image are considered; since the chosen radar horizontal angular field of view are approximately the same as the camera one, almost all radar points can be remapped into the image.

In order to simplify and speed up the following steps of the algorithm and to delete details of too close vehicles, all the areas are re sampled to a fixed size.

3. Interest area evaluation

In this project the generated interest areas are used to localize vehicles, but could also be used to search for road features and other obstacles as well; the system has been tested for guard rail and pedestrian search with promising results.

3.1. Symmetry computation

Symmetry computation is the basis of the algorithm, and the most time consuming part as well. Only binarized edges are used in order to reduce execution time First of all the Sobel operator is used to find edges module and orientation; then two images are built, one containing the almost-vertical edges and the other with the almost-horizontal edges.

The symmetry is computed for every column of the vertical edges image, on different sized bounding boxes whose height match the image height and with a variable width ranging from 1 to a predetermined maximum value. The computed value is saved in a 2D data structure (hereinafter referred to as an image) whose coordinates are determined as follows :the column is the same as the symmetry axis and the row depends on the considered bounding box width. This image is then used to search for interesting columns.

3.2. Interesting columns

An interesting column is defined as having a high value in the symmetry image. A column wise histogram is then used to locate candidate columns. In correspondence to these columns the vertical edges

[1] Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles:

symmetry is checked to obtain the expected vehicle width. More specifically if a high value of symmetry is present for smaller widths too, it means that the algorithm has detected a small object; in this case the column is discarded.

3.3. Bounding Boxes generation

Up to now the algorithm provides information about the vehicle's center position, but since vehicles need to be detected with a high precision, a precise bounding box detection is mandatory. Each peak in the vertical edges symmetry image that survived the previous filtering is used: the width of the symmetry box is given by the distance between the peak itself and the top of the symmetry image; the box is then centered within the column.

The shadow under the car is a strong invariant which is always present, even in dark days. The algorithm looks for the vehicle shadow in order to find its base. Since other shadows are present on the road as well, the algorithm looks for a high concentration of edges above the horizontal edge; if no base can be detected in correspondence to the peak, the column is discarded.

3.4. Results mixing

When all radar data have been examined, all the boxes framing the detected vehicles are re sampled to their original size and mixed together.

Using an inverse perspective mapping transformation, real width and position of vehicles can be computed. In the computation of these values, radar provides distance while vision provides position and width so that the radar precision on distance measurement and the vision refinement ability are capitalized together.

Unfortunately not all detected boxes are correct: some false positives caused by road signs or other objects in the scene can be present as well. A filter is used to discard some false positives: it removes too large or too small boxes that are unlikely to represent a vehicle.

It is also possible that a vehicle is detected in more than one search area (it happens when the radar returns multiple radar points in correspondence to a single object), so overlapping results may be present. Only one box per vehicle is expected as a final result, so a further step is required to merge similar boxes and eliminate redundant ones.

4. Results

This vehicle detection system was tested in extra urban and highway environments with good results. A lot of possible scenarios are considered. It is important to remember that no tracking is used at the present moment, as it will be introduced at a later stage of the project.

The system has been proved to localize with a good precision in almost all situation the closest preceding vehicle. Other vehicles can be detected as well. The system capability is not restricted to preceding vehicles, also approaching vehicles can be detected. System performances decrease in case of hard traffic and noisy scenarios. Figure 1 shows good results obtained in different scenarios.

5.Conclusions

In this paper a method to fuse radar data and vision is described.

This method reaches good results both in extra urban and highway environments.

The system can localize the closest preceding vehicle with a good precision, and can localize a large part of other vehicles as well: it is ready for ACC application and it is also promising for other safety applications that need localization of all the receding vehicles.

A hardware or software image stabilization might provide a more precise perspective mapping transformation: while a tracking algorithm might be very helpful to increase the robustness of the system and the detection persistence.

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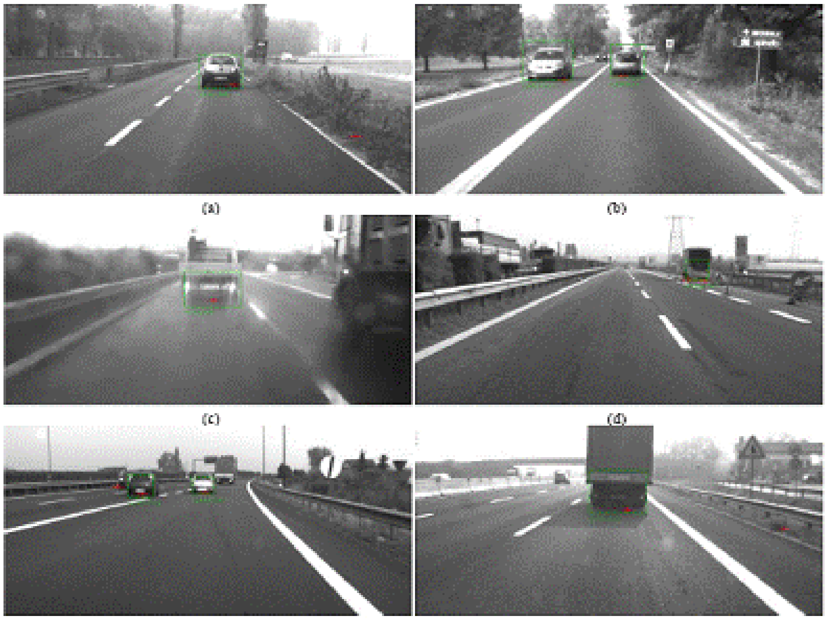

Fig. 1. Examples of correct results: the algorithm works reliably in simple cases (a); it detects both vehicles moving away and approaching (b); it works even in hard cases, such as rain (c) and noisy scenarios (note the double radar detection) (d); it can detect multiple cars (e) and truck (f).