IEEE Instrumentation and Measurement
Technology Conference
Budapest, Hungary, May 21-23, 2001.

A multi-sensor approach for the protection of vulnerable traffic participants - the PROTECTOR project

Dariu M. Gavrila
DaimlerChrysler AG, Research and Technology, Wilhelm Runge St. 11, 89081 Ulm, Germany,
Email: dariu.gavrila@DaimlerChrysler.com, WWW: www.gavrila.net

Martin Kunert
SIEMENS Automotive, Osterhofener Straße 19 - Business Park 93055 Regensburg, Germany,
Email: Martin.Kunert@at.siemens.de

Ulrich Lages
IBEO Automobile Sensor GmbH, Fahrenkrön 125, 22179 Hamburg, Germany,
Email: ul@ibeo.de

Abstract

This paper describes ongoing work in the E.U. project PROTECTOR (Preventive Safety for Unprotected Road User) on the important problem of detecting vulnerable traffic participants from a moving vehicle. We focus on the three sensor technologies that are pursued: laser scanner, radar and video. We discuss their characteristics and present the relevant pattern recognition techniques. First prototype systems have been integrated in our demonstrator vehicles.

Keywords

PROTECTOR, vehicle safety, unprotected road users, pedestrian detection, sensor fusion.

I. INTRODUCTION

The large majority of work on sensor-based intelligent vehicles has dealt with issues related to lane detection and vehicle recognition for applications such as advanced cruise controls. Little attention has been given so far to the issue of protecting vulnerable traffic participants. Yet more than 150.000 pedestrians are injured yearly in traffic accidents E.U.-wide [7]. Of these, more than 6000 are killed - children are affected disproportionally.

The European Union fifth-framework project **PROTECTOR** [1] represents the first concerted effort to bring together major vehicle manufacturers, electronic system suppliers, and research and technology partners, in order to develop intelligent systems on-board vehicles for the reduction of the accident rate involving pedestrians, bicyclists and other vulnerable traffic participants. Of interest are sensor-based solutions as well as solutions which rely on communication between vehicles and vulnerable traffic participants that can detect potential hazardous situations ahead of time; this facilitates the use of warning and preventive measures to avoid or minimize the impact of upcoming collisions. The complete list of PROTECTOR partners is given in Table 1.

The initial phase of the PROTECTOR project involved an analysis of relevant accident statistics [7] and a study of user needs [3]. In this paper, we focus on the subsequent sensor processing phase and cover the main three sensor technologies that are pursued within the project: laser scanner (Section 3), radar (Section 4) and video (Section 5).

Centro Studi sui Sistemi di Transporto (CSST)	IBEO Automotive GmbH	Centro Ricerche Fiat S.C.p.A
Institut für Kraftfahrwesen Aachen (IKA)	Tel Aviv University - RAMOT	DaimlerChrysler AG
TÜV Kraftfahrt GmbH	Siemens Automotive	MAN AG
Universita di Pavia	Israel Aircraft Industries - TAMAN	

Table 1: PROTECTOR partners

II. LASER SCANNER

The IBEO laser scanner (see Figure 1a) has a field of view of 180° and is mounted in the mid front section of the vehicle. From this position it can detect all relevant objects as shown in Figure 1b. It has a range of up to 40 m onto targets with at least 5% reflectivity and an angular resolution of 0.5°. One scan consists of 360 measured distances, each of which is measured with an accuracy of +/-5 cm (1σ). The scan frequency is 20 Hz which allows to track all objects with high accuracy in both lateral and longitudinal direction. The built-in DSP computer runs the corresponding algorithms for object identification and tracking; it has sufficient computational power to track up to 20 objects in real-time. The scanner is eye-safe with laser class 1.

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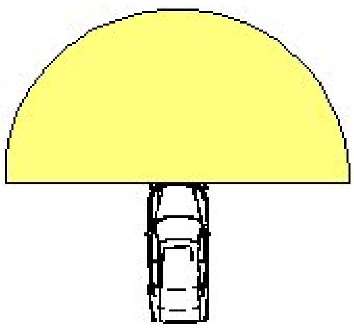
(a)

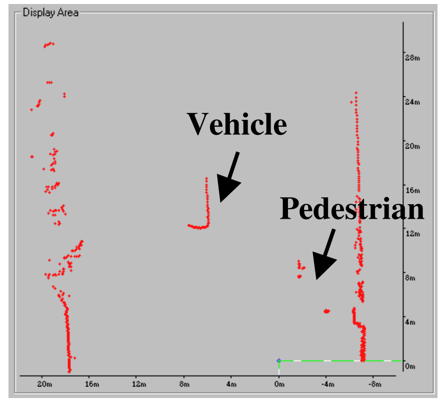


(b)

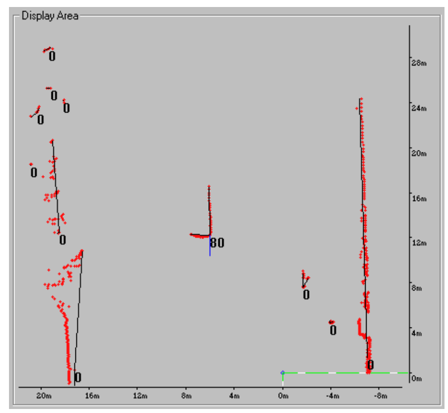
Figure 1: (a) the IBEO laser scanner (b) coverage area (not drawn to scale)

The laser scanner measures the distances to all targets within its scan area. A sample scan is shown in Figure 2a. To the left and right of the road, bushes and walls can be seen. A vehicle is approaching on the left side, and a pedestrian is standing on the right. The object detection and tracking algorithm interprets this scan data and tracks the detected objects through subsequent scans. Object velocity is derived from the positional information of each scan. Figure 2b shows the same scene as in Figure 2a, but with object information. The number shown for each object shows the relative velocity of the object in km/h. The dark straight line at the vehicle is the velocity vector, showing that the object will pass us at a distance of approximately 5 m.

The object classification is an important addition to object tracking. As shown in Figure 2, the laser scanner measures the outline of objects with high resolution and accuracy. From this outline, a classification into different groups like pedestrians, cyclists, cars, trucks etc. can be made. The sensor reports the classification of the object together with the raw data. All object information is sent to the host computer via a standard CAN bus. This information includes the object outline, the relative object velocity in lateral and longitudinal direction, and the classification, together with a confidence measure. For more details, see [2].



(a)



(b)

Figure 2: Raw data from the laser scanner, without (a) and with (b) object labeling

III. MICROWAVE RADAR

The technical approach of near distance sensing with microwave radar is based on a multi-functional system concept which provides information situation-dependent to different on-board systems. The motivation to use several radar modules placed on strategic positions of the vehicles outer contour is to achieve a seamless awareness system around the car without any blind zones. Figure 3 shows the realized near-distance micro wave radar.

Radar technology provides all necessary requirements to operate in the harsh environment of exterior sensing and can also respect all automotive specifications. It further has the advantage that it can be hidden behind un-shielding materials.

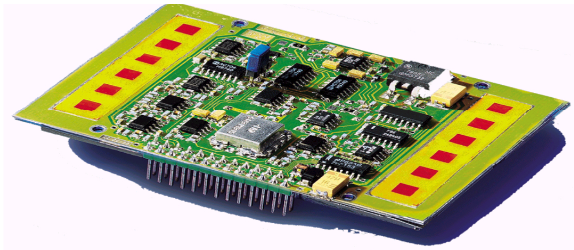


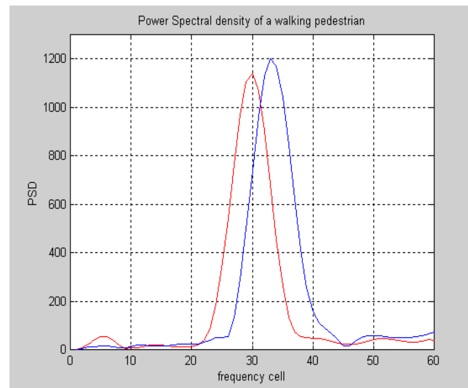
Figure 3. Prototype microwave radar sensor (dimension 90mm x 64 mm)

This invisible mounting has no influence to the vehicle's appearance and thus does not disturb vehicle design in any way. A generic Near Distance Radar System has the following basic specifications:

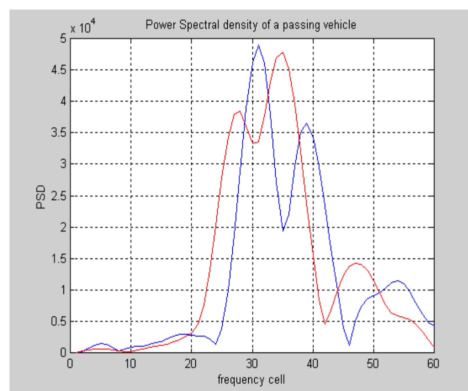
- Distance coverage 0.2 m … 10 m
- Relative speed coverage up to max. 200 km/h
- Azimuth coverage -50° … +50° (full sensitivity)
- Elevation coverage -10° … +10° (full sensitivity)
- Speed accuracy 1 m/s
- Data renewal time < 10 ms
- Resolution capability distance: ± 10 cm

The use of microwave radar sensors for obstacle detection in the near vicinity around the vehicle has advantages in special situations like bad weather, poor visibility or harsh environmental impacts like ice, snow or dust coverage. Due to the high water contents of the human body, microwave radar systems can detect pedestrians and other road participants with high reliability. The pedestrian detection algorithm with microwave radar is mainly based on the evaluation of the pedestrian-specific reflection characteristics. A separation of persons from other obstacles is done by evaluation of typical human reflection signatures in the radar signal. Some basic parameters that can be evaluated are the reflected power, the power variance over time, the dimensions and prevailing dynamics of the obstacle.

Figure 4 shows the characteristic power spectral density (PSD) values for a pedestrian and a car, both obtained at approximately equal distance. They differ both in signal amplitude (PSD value of vehicle is 40 times higher) and in shape (the vehicle signal is larger in width and more structured). With special recognition techniques and knowledge-based reasoning the signals issued from pedestrians can be separated from other reflective objects with a high degree of robustness. The position determination of persons with respect to the vehicle is done via triangulation techniques. By evaluation of the measured radial distances of the distributed radar modules the azimuthal angle to the sensor basis line can be calculated. For multi-target capability a sophisticated triangulation algorithm is necessary. By data fusion of the signal characteristics recorded from the distributed radar modules the detection probability of pedestrians can be further improved. The integration of a sensor unit onto the bumper of a vehicle is shown in Figure 5.



(a)



(b)

Figure 4. Typical power spectral densities (PSD) values for (a) a pedestrian and (b) a vehicle

Figure 5. Radar sensor on-board demonstrator vehicle

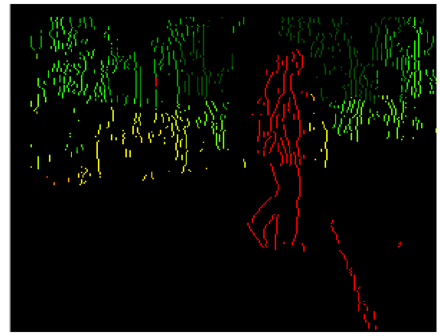
IV. VISION

Video sensors have the advantage to provide a high spatial resolution, both horizontally and vertically. Furthermore, many recognition tasks depend on the availability of texture information. Our generic approach to dealing with vulnerable traffic participants involves two steps: object detection followed by object recognition. The purpose of the detection step is to efficiently obtain a region of interest (ROI) in the image that is associated with a potential obstacle. An important contribution to vision-based obstacle detection is provided by stereo vision, which computes depth by triangulation of matched image features in a left and right camera image. See Figure 6. But there are other vision cues as well that can be used to facilitate the detection of vulnerable traffic participants such as pedestrians. Motion and shape have shown to be quite discriminative as well.

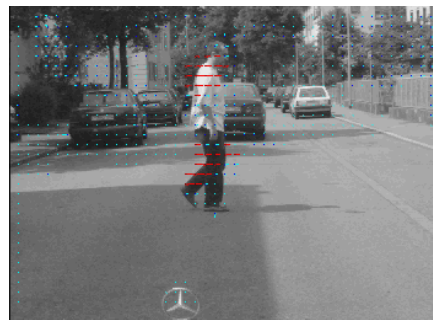
Figure 6. Stereo camera on-board demonstrator vehicle

Once a region of interest has been determined in the image (e.g. a rectangular bounding box), one can proceed to a recognition step where the type of objects is determined. Because explicit models are seldom available, models are derived implicitly by learning from examples. Recognition is thus addressed as a classification problem. We typically aggregate the image pixels in the resulting region of interest into a feature vector and use pattern classification techniques (e.g. Polynomial Classifiers, Multi-Layer Perceptrons, Radial-Basis Functions, Support Vector Machines, Hyper-permutation Networks) to classify these.

Figure 7 provides an overview of some of the algorithms that have been developed at DaimlerChrysler Research over the years and applied to pedestrian recognition [4][5][6][8]. Stereo-based obstacle detection followed by a combination of shape and texture-based pedestrian classification runs quite successfully in our Urban Traffic Assistant (UTA) demonstrator vehicle at 4-10 Hz, using a 600 Mhz dual-Pentium with MMX. For some related video clips, visit the web page: www.gavrila.net.



(a)



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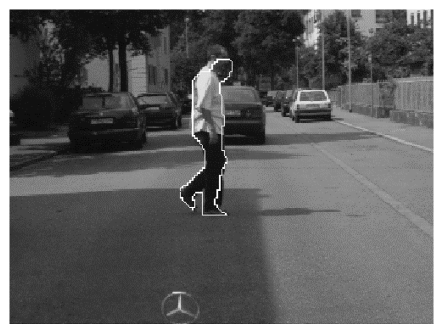

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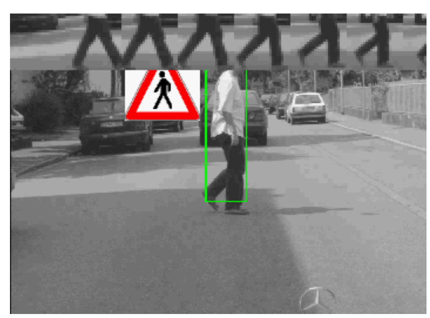

(d)

Figure 7. Video-based pedestrian detection and recognition [4][6]:
(a) depth image computed by stereo,
(b) detection of independently moving objects using optical flow,
(c) shape-based pedestrian detection using the Chamfer System [5], and
(d) pedestrian gait recognition using a Time Delay Neural Network [8]

V. DISCUSSION

We discussed various sensors and corresponding pattern recognition techniques for detecting (and recognizing) pedestrians from a moving vehicle. We evidently only stand at the beginning of solving this very difficult problem with the reliability necessary to actually deploy such system. More work is required to improve on the trade-off between correct detection and false alarm rate for the individual sensor technologies. We furthermore expect a future PROTECTOR system to benefit considerably from an integrated multi-sensor approach. Finally, it will be necessary to model the traffic environment on a higher (symbolic) level for improved scenario interpretation, risk prediction, control strategies and decision management.

VI. REFERENCES

[1] P. Carrea and G. Sala, "Short Range Area Monitoring for Pre-crash and Pedestrian Protection: the Chameleon and Protector Projects", in *Proceedings of the 9th Aachen Colloquium on Automobile and Engine Technology*, Aachen, Germany, pp. 629-639, 2000.

[2] A. Ewald and V. Willhoeft, "Laser Scanners for Obstacle Detection in Automotive Applications", in *Proceedings of the IEEE Intelligent Vehicle Symposium*, pp.682-687, Detroit, U.S.A., 2000.

[3] T. Frese, "User Needs Analysis" – PROTECTOR deliverable, 2000.

[4] D. Gavrila, U. Franke, S. Görzig and C. Wöhler, "Real-time Vision for Intelligent Vehicles", to appear in *IEEE Transactions on Instrumentation and Measurement*, 2001.

[5] D. Gavrila, "Pedestrian Detection from a Moving Vehicle", in *Proceedings of the European Conference on Computer Vision*, Dublin, Ireland, 2000.

[6] D. Gavrila, "The Visual Analysis of Human Movement – A Survey", *Computer Vision and Image Understanding*, Academic Press, vol. 73, nr. 1, 1999.

[7] G. Sala, "Accident Analysis" – PROTECTOR deliverable, 2000.

[8] C. Wöhler and J.K. Anlauf, "An Adaptable Time Delay Neural Network for Estimating Image-pattern Shape and Motion", Image and Vision Computing, vol. 17, pp. 281-294, 1999.