APPROACH FOR PROTECTION OF VULNERABLE ROAD USERS USING SENSOR FUSION TECHNIQUES

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1. ABSTRACT

The evolution of automotive radar systems has started with Adaptive Cruise Control (ACC) application some year ago. First commercial products are available on the market today. Newly the range of applications increases rapidly. The automotive industry and sensor suppliers are developing advanced systems for short, mid, and long range applications.

Precrash systems are operating in the short and mid range area with the hardest requirements for sensors and control units. For example, high dynamics of obstacles have to be measured and tracked exactly. The false alarm rate must fulfil very strong limitations to be able to deploy safety systems (like seat-belt pretensioners, or other reversible systems) without false positive. In addition to this, the decision algorithms for safety systems deployment need high accuracies and high measurement rates in high-dynamic street situations.

This paper deals with a special variant of precrash systems, namely **precrash for pedestrian protection**. The goal is to reduce the number of fatalities in collisions vehicle vs. pedestrian. Specific protection systems like active braking or seat-belt pre-tensioners are currently under investigation. To trigger these protection systems a high performance sensor platform is necessary. The object class information (type of object) "pedestrian" or "non-pedestrian" will be provided by a video image processor.

In this paper, approaches from the EC-funded project SAVE-U (5th frame program of the European Commission) are presented. The sensor platform consists of radar, cameras in the visible and infrared domain. The focus will be located on high-level- and low-level-data-fusion architectures to fulfil the strong requirements.

Keywords: Precrash, pedestrian recognition, SAVE-U, sensor fusion, short range radar.

2. INTRODUCTION

Every year in the EU there are around 9,000 deaths and 200,000 injured victims in road accidents in which pedestrians and cyclists collide with a car. Pedestrian accidents represent the second largest source of traffic-related injuries

Figure 1. Typical dangerous situation – A child suddenly crossing the street. (Source: DaimlerChrysler AG)

and fatalities.
Clearly, a Europe-wide effort should be made by the relevant influential parties to reduce the number of accidents and to limit the consequences when they occur.

3. Objectives of the EC-funded Project SAVE-U

Among other initiatives to improve safety of Vulnerable Road Users (VRUs), the European Commission funded a research project called SAVE-U (IST-2001-34040): "**S**ensors and system **A**rchitecture for **V**ulnerabl**E** road **U**sers protection" aimed at developing an integrated safety concept for pedestrians and cyclists. SAVE-U started in March 2002 and will last 3 years.
The main objective of SAVE-U is to develop an innovative pre impact sensor platform that will operate three different technologies of sensors simultaneously and will fuse their data for an optimised VRU detection system in all weather and lighting conditions:

- A radar network composed of several 24 GHz sensors working in parallel,
- An imaging system composed of passive IR and vision systems.

The consortium in SAVE- U consists of the following partners and their respective know-how brought into this project:

- **Faurecia** (project coordinator), automotive supplier expert in front end modules, system integration and pedestrian safety/ protection,
- **SiemensVDO Automotive AG** in radar sensors and sensor fusion,
- **CEA-LIST** and **CEA-LETI** in infra-red sensors, image processing and embedded computers,
- **DaimlerChrysler AG** in computer vision and as vehicle manufacturer (with demonstrator),
- **MIRA Ltd** in automotive safety and validation techniques, and
- **Volkswagen AG** as vehicle manufacturer (with demonstrator).

The total SAVE-U budget for the full 3-year period is about 8,000,000 €.

4. SAVE-U Sensor Platform

The definition of the whole sensor platform specification was one of the first targets of the project. Specifications were established on the basis of several studies:

- the definition of the most relevant accident situations involving pedestrians and cyclists extracted from recent accident statistics analysis,
- the analysis of the appearance of the dressed human body for the considered sensing technologies,
- the evaluation of selected VRU protection systems (e. g driver warning, braking, active hood) on the SAVE-U system requirements.

Another important output of the SAVE-U project is the large database of VRU images. The VRU database is quite unique world-wide, because of its huge size: it contains more than 14,000 images and 180 sequences recorded with infra red and colour video cameras in real road situations. Part of this database has been enriched with "ground truth" data, where "true" VRU locations have been labelled by a human operator. This process consists in outlining the VRU object contours in images and in establishing temporal correspondence across the images of a sequence. The benefits of this database are twofold. First, it provides a wealth of training data for statistical pattern matching techniques. These "learn" the VRU appearance from examples; which is important, since good prior, explicit models are hard to define. Second, it allows evaluating system performance on a truly large data set, so that the results can be considered representative of the true physical traffic situation.
SAVE-U is currently in the development phase to optimise sensors for VRU detection and their related processing Electronic Control Unit (ECU).
For radar detection, SAVE-U will provide completely redesigned 24 GHz radar sensors equipped with new and dedicated raw data processing algorithms. The main innovation compared to the state-of-the-art will be the improved range and sensitivity of these sensors for a suitable detection of VRU in front of the car. Sensors with different beam shape will be organised in order to cover all the requested detection area in front of the car and multi-

sensor processing algorithms will be developed in order to operate the individual single beam sensors in the radar network. In contrast to individual radar sensors the radar network will provide information about the angle of an object relative to the vehicle driving direction.

For the vision system, SAVE-U is modelling and simulating an “IR sensor” specifically designed for automotive applications that will provide synthesised images for an estimation of VRU IR detection. This issue is addressed by means of sensor behavioural modelling and IR scene simulation that reproduce reliable images fully representative of the application.

SAVE-U is also developing an Embedded Image Processor (EIP). The EIP will be composed of a DSP board with a re-configurable module. The embedded board will be able to process IR and visible videos in real-time.

Vulnerable road users protection rely first on the system in charge of obstacle detection. The efficiency of the protection depends mainly on the performance of the algorithms implemented in processing ECUs that have the tasks to detect first obstacles in front of the car and then to classify them as VRU according to specific patterns.

In SAVE-U, algorithms currently under development are innovative on both levels: detection and classification.

In VRU detection, the innovation in SAVE-U is to propose up-to-date algorithms which will collaborate at a low level with the radar subsystem. High level data fusion alone is not sufficient to provide the required quality and reliability of the target data. Raw sensor data will be exchanged between radar ECU and EIP in order to improve the detection process.

A further novelty in this field is resulting from merging the IR segmentation results with those delivered by video cameras and implementing these algorithms on dedicated real-time embedded image processing hardware.

The existing image segmentation and classification algorithms for visible camera systems will be adapted to the images of a passive IR camera.

When all the ECUs and new sensors are available, an initial evaluation of the quality of the detection and classification of VRU will take place. For that, SAVE-U will define and develop new validation test procedures, taking in account the selected scenarios and the various test conditions one could find in the driving environment. Specifically, SAVE-U will develop a test rig to evaluate the sensor performance dynamically using real vulnerable road users (test subjects) for true, combined correct characteristics due to the required real behaviour with respect to the three sensor technologies deployed.

At the end of the project, the sensor platform will be installed on two demonstrator vehicles, which will be equipped with VRU protection devices (driver warning and vehicle control strategies). This will allow SAVE-U to evaluate the efficiency of the whole safety system (integrated approach from sensors through to actuators) on VRU protection in true, real world conditions. This evaluation will provide information about the impact of the overall system in the daily life of EC citizens (as vulnerable road users and as drivers) on two aspects:

- Efficiency of the vehicle control strategies on the accident severity (e. g. vehicle speed at crash, driver response time).
- Acceptance of the driver versus the HMI systems and how HMI helps to better reduce collisions or injuries to pedestrians.

5. System Architecture

The system architecture is as it is depicted in the block diagram in Figure 2. The radar sensor network consists of 5 short range sensors. The measured data will be detected separately in each sensor and transmitted via CAN bus to the radar ECU. The ECU performs the multilateration procedure and the target tracking. In parallel to the radar processing the vision part is operating two video streams, from Colour and IR sensors. The EIP will extract from the images elements on "Regions Of Interests" (ROI) for use in relation with classification function and low level fusion.

6. 24 GHz Radar Sensor Technology

The redesigned 24 GHz short range sensors (SRR) include an optimised antenna structure as well as an optimised signal processing path, to fulfil the dedicated SAVE-U requirements. These sensors show significantly improved range and sensitivity compared to the state of the art and allow detection of vulnerable road

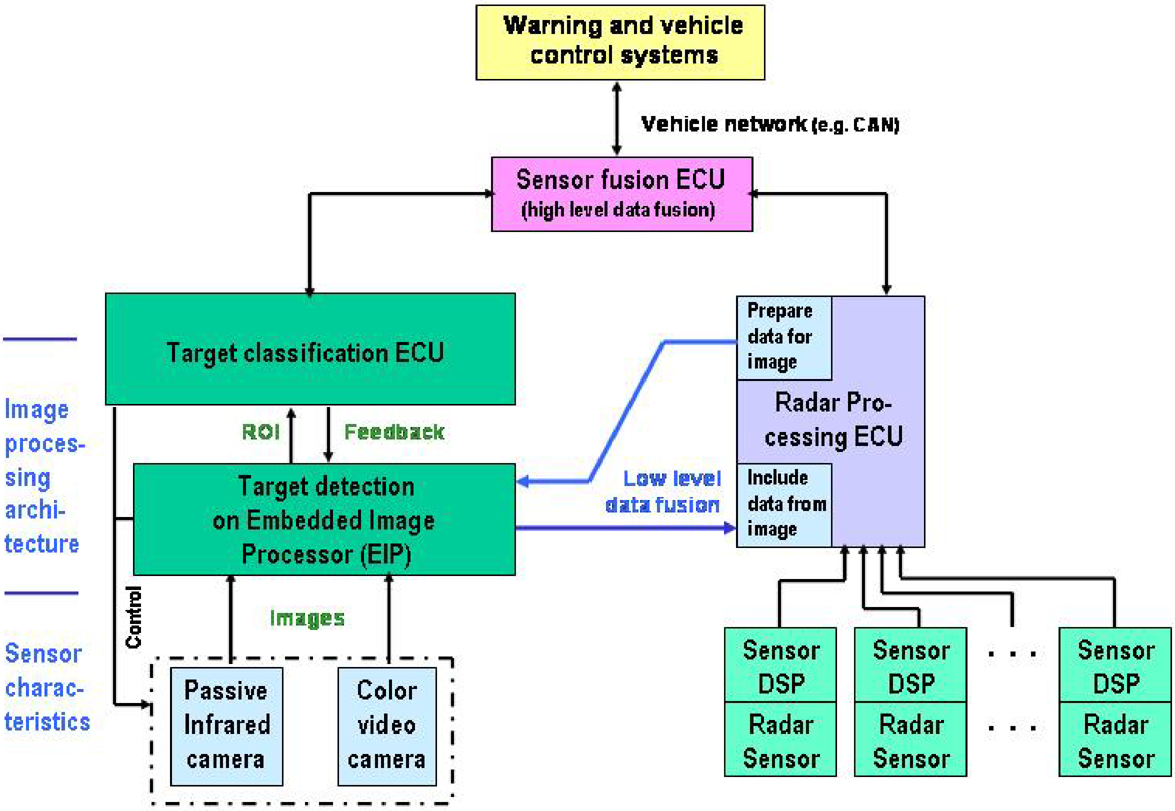

Figure 2. SAVE-U sensor system architecture.

users (e.g. pedestrians with low radar cross sections RCS) at ranges up to 30 m.

Each short range sensors will operate according to the frequency modulated continuous wave (FMCW) principle and provides directly object range and relative speed information.

The radar network to be developed will be composed of several single beam 24 GHz short-range radar sensors (SRR).

These sensors will have overlapping detection areas. Multi-sensor processing algorithms (basic and advanced multilateration: calculation of angle from range information) will be developed in order to operate the individual single beam sensors in the radar network. In contrast to individual radar sensors the radar network will provide rough information about the angle of an object relative to the vehicle, which is important for the data fusion concepts.

The single beam radar sensors will be distributed in front of the car, invisible behind the front bumper, because of the requirement to cover the full car width. The distribution of the sensors is mandatory for the case that the crash cannot be avoided, so it is necessary to keep the VRU information (range and velocity) at short ranges across the full car width.

To reduce the number of sensors in a vehicle for cost efficiency on the one side, the distributed sensors should be implemented with large angular coverage. On the other side, to scale down the false alarm rate caused by unwanted targets from far left or far right e.g. road infrastructure, especially at mid ranges, it would be useful to use sensors providing narrow beam width.

SAVE-U will solve these contradictions by using different radar sensor types according to beam

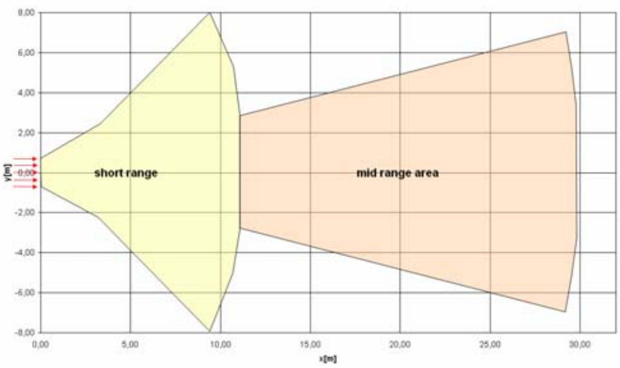

Figure 3: Field of view of the entire radar network

width and maximum range. Wide beam short-range sensors will cover the short-range area (typ. 12 m maximum range). The narrow beam sensors cover the mid range area (typ. 30 m max. range). summarizes the required coverage area of the radar network.
The key requirements of the radar sensors are presented in Table 1.

Short range sensor	
Range for a detection of a pedestrian	12m
Range resolution	0.3m
Range accuracy	0.1m
Relative speed resolution	2.4m/s
Relative speed accuracy	1m/s
Azimuth angle	±35°

Mid range sensor	
Range for a detection of a pedestrian	30m
Range resolution	0.3m
Range accuracy	0.1m
Relative speed resolution	2.4m/s
Relative speed accuracy	1m/s
Azimuth angle	±12°

Table 1 Key specifications of individual the radar sensors

7. SENSOR FUSION TECHNIQUES

SAVE-U operates 3 physically different sensor technologies in parallel and fuses their data: an uncooled IR camera for reliable detection of pedestrians, a network of 24 GHz radar sensors, optimised for detection of pedestrians and cyclists as well as a video based colour camera system including improved signal processing. The SAVE-U platform shall be capable of providing robust information in all weather and in all lighting conditions.
This project utilises a novel approach to reach the goal of reliability: Sensor fusion both at low and at high level.
 depicts the concept overview of the proposed fusion strategy. High level data fusion, meaning merging of object lists from different sensors. In spite of improvements in terms of performance, high level data fusion alone is not sufficient to provide the required quality and reliability of the target data.

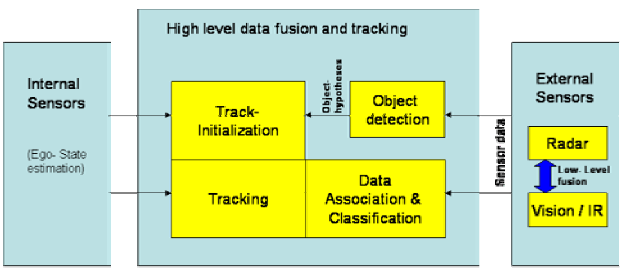

Figure 4 Overview of the sensor fusion concept

SAVE-U introduces a novel concept of low level data fusion. Sensor raw data will be exchanged between the image processing part and the radar processing part of the sensor platform. Having pre-processed raw data from the imaging part available for the radar signal processing and network processing will help a lot to improve the quality (in particular the detection rate versus false alarm rate) of the objects detected by radar. Since the radar processing ECU will also offer pre-processed radar data for the imaging processing part, there will be an advantage for the quality of the imaging results as well.
The multi-target-tracking algorithm performs a position and velocity estimation for all objects in the field of view. In dynamic situations, the ego-state estimation, from the internal sensors, validate the plausibility of the objects.
The picture in Figure 5 depicts the configuration for the first synchronised measurements from radar, vision and IR sensors, which have done in the SAVE-U project. At the end of the project the sensor system will be integrated into Volkswagen and DaimlerChrysler demonstrator vehicles.

8. CONCLUSION

SAVE-U is a high performance sensor platform for the active protection of Vulnerable Road Users such as pedestrians and cyclists. The information provided by the sensor platform (x, y, v_x, v_y, *ObjClass*, etc.) is necessary for automotive application like precrash and especially precrash for pedestrian protection to reduce the number of fatalities in collisions vehicle versus pedestrian.
The reliable object information in front of the car is produced from different sensor technologies:

- A radar network composed of several single beam 24 GHz radar sensors with different beam width.
- An image system composed of passive IR and vision systems.

All sensor technologies will complement each other and an additional low and high level data fusion algorithm will improve the detection, classification and tracking of vulnerable road users. An object classification algorithm generates information about the object type.

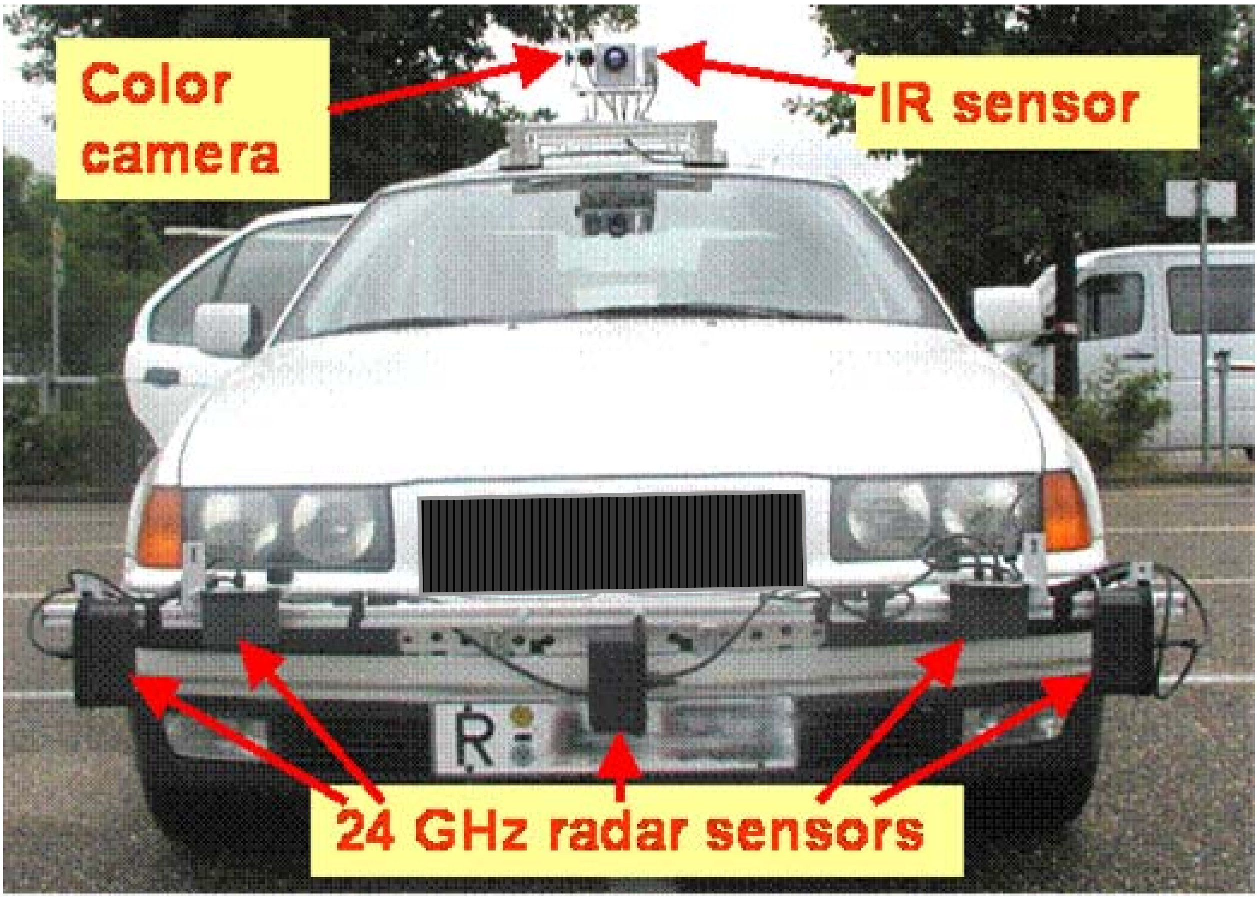

Figure 5: Preliminary sensor platform set-up with IR- sensor, color camera and radar sensors for synchronized data collection.

SAVE-U's object information may well also cover the needs for future night vision systems, pre-crash sensing, stop & go and lane control. This would augment today's ACC, parking aid, urban collision avoidance, collision warning and others.

9. ACKNOWLEDGEMENT

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[7] http://www.protector-eu.org