SAVE-U : Sensor data fusion for improved Vulnerable Road User detection

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Summary:
Among other initiatives to improve safety of Vulnerable Road Users (VRUs), the European Commission is funding a research project called SAVE-U (IST-2001-34040): "Sensors and system architecture for VulnerablE road Users protection" aimed at developing an integrated safety concept for pedestrians and cyclists. SAVE-U started in March 2002 and will last 3 years. This paper provides an overview of the results of work performed along the first two years of the project.

Objectives

The main objective of SAVE-U: "Sensors and system architecture for VulnerablE road Users protection" is to develop an innovative pre impact sensing platform that will operate three different technologies of sensors simultaneously and will fuse their data for an optimised VRU detection under different weather and light conditions:

- a radar network composed of several 24 GHz sensors working in parallel,
- an imaging system composed of passive IR and colour video cameras.

Figure 1: A typical dangerous situation of a child suddenly crossing the street (source: Faurecia)

Partnership

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

Faurecia (project coordinator), automotive supplier expert in front-end modules and in system integration,
SiemensVDO Automotive AG in radar sensors,
CEA 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).

Main results

Specifications

The definition of the whole sensing platform specification **(3)** 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 **(8)**,
- the analysis of the appearance of the dressed human body for the considered sensing technologies **(7)**,
- the evaluation of the impact of selected VRU protection systems (e.g. driver warning, braking) on the SAVE-U system requirements **(2)**.

SAVE-U is currently in the development phase to optimise sensors for VRU detection and their related processing Electronic Control Unit (ECU).

24GHz Radar Sensors and Radar Sensor Network

The SAVE-U platform uses 5 single beam 24GHz radar sensors distributed in front of the car and are mounted invisibly behind the front bumper to cover the full car width **(5)**.

Due to this arrangement, range and velocity information – as main characteristics of the radar sensor– are available at short and medium ranges. Additionally, the radar network provides the SAVE-U system an indication of the azimuth angle of objects relative to the vehicle, which is important for the data fusion concept. The single beam radar sensors have overlapped detection areas to calculate the azimuth angle information from the radial range and velocity information by multi-lateration algorithms.

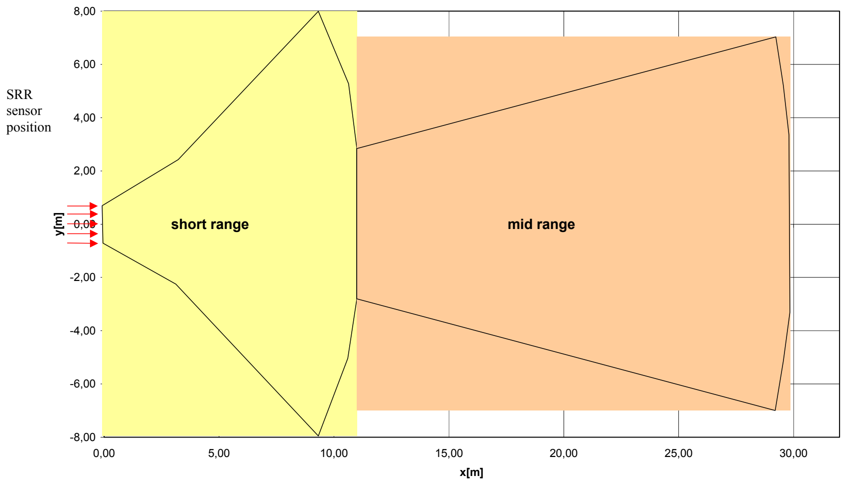

Figure 2: Coverage of the radar network

Two radar sensors emit a wide beam from a sensor group covering the short range area (from 0.3 to approx. 12m). The second sensor group consists of three 24GHz radar sensors with a narrow beam that cover the mid range area (until approx. 30m). Figure 2 shows the required SAVE-U coverage area of the radar network.

The SAVE-U application, which is the protection of vulnerable road users, requires detecting in particular pedestrians ("small" objects in terms of radar cross section of about 1m²) at distances up to 30 meters. To achieve this hard requirement the original microwave sensor system had to be upgraded with a higher sensitivity. Figure 3 depicts measurements of a pedestrian standing at a distance of 30m with the re-designed 24 GHz radar sensors and shows the increased pedestrian detection capability up to 30m.

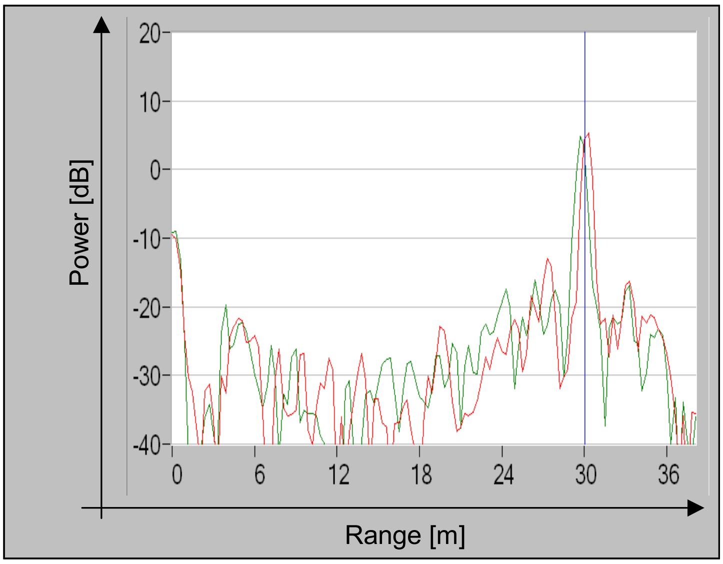

Figure 3: Measurement of a pedestrian at 30m with the new 24GHz radar sensor prototype

IR sensor design

For the vision system, SAVE-U is modelling and simulating an "IR sensor" specifically designed for automotive applications **(6)** 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 (see Figure 4).

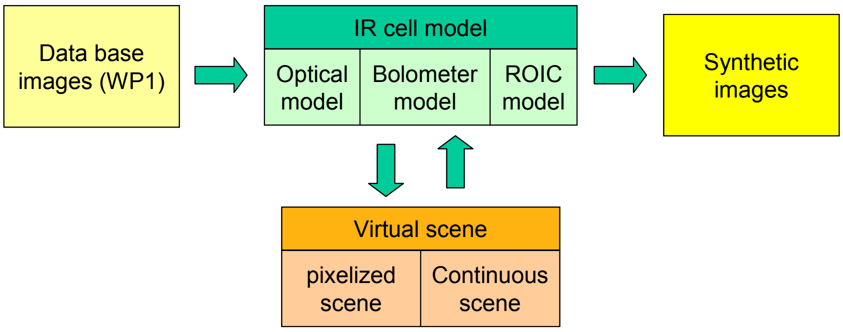

Figure 4: Modelling of IR cell & IR image synthesis

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

Sensor data fusion and algorithms

Vulnerable road users protection relies 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 of 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 sub-system. 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 the radar sub-system and the EIP in order to improve the detection process. Figure 5 indicates how data will be processed on the SAVE-U sensor platform **(4)**.

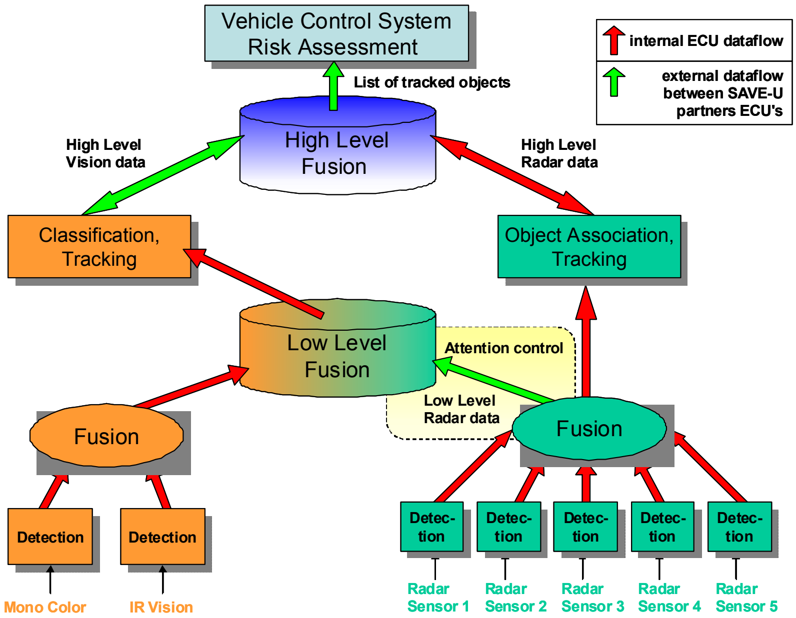

Figure 5: Flow of data for low and high level data fusion

At a low-level, radar information (radial range and speed, angle indication, rough classification) are sent to the video detection stage. This one checks if something can be found in areas of images corresponding to radar indications, as described in Figure 6.

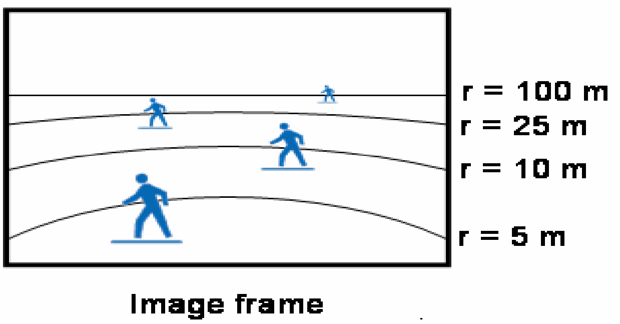

Figure 6: Radar distances put in the video sensor plane

This procedure comes in addition to pure video methods of detection to achieve a better result.

Another novelty in this field is resulting from merging the IR segmentation results with those delivered by colour video cameras and implementing these algorithms on dedicated real-time embedded image processing hardware. This fusion is mostly done at pixel level since areas in sensors are put in correspondence like it is described in Figure 7.

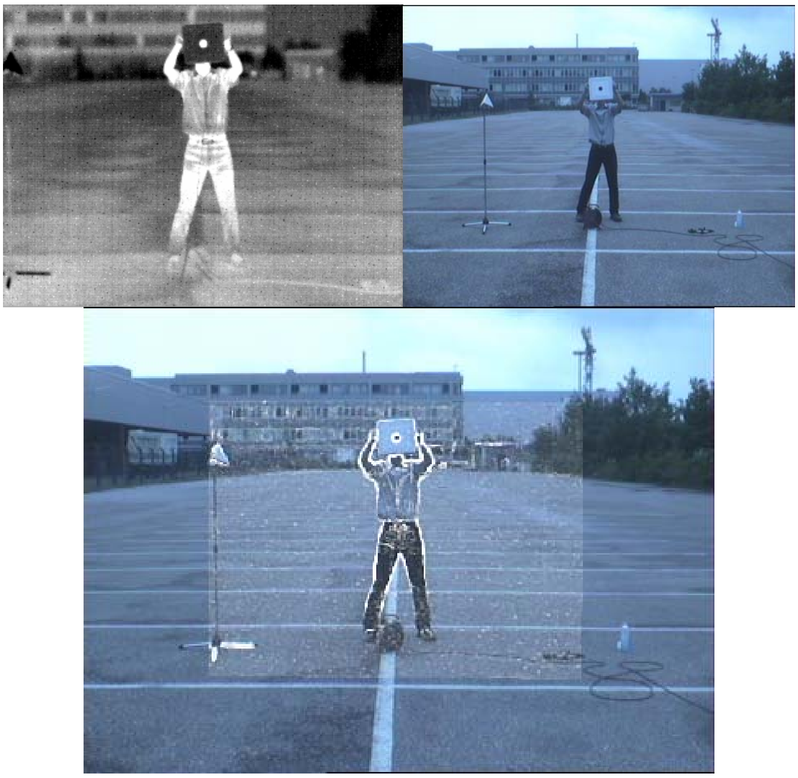

Figure 7: IR image, colour image and edges of the IR image mapped in the colour one

Once the low-level fusion is done, regions of interest (ROI) are sent to the classification stage. They represent potential VRU. The output of the classification indicates whether ROI contained VRU (pedestrians or bicyclists) or not. But the final classification is done in the high-level fusion based on a combination of information coming from different sources. The classification module will also output track identifications and 2D image coordinates.

High-level fusion represents an additional stage to consolidate VRU detection in term of presence or not of a VRU as well as object tracking to get the final object characteristics (position, speed, signature…). A recursive-tracking algorithm on the object level verifies the object hypotheses over time by cyclically assigning feature data to the object hypotheses. The multi-target tracking algorithm solves the object association and correspondence problem in difficult situations often encountered in urban environment.

Object information like position and speed are then passed to the vehicle control system module, which manages the risk assessment. It evaluates the risk of every situation and then acts on the VRU protection systems according to the car manufacturer strategy.

Development of the test method for evaluation

When all the ECUs and new sensors are available, a first evaluation of the quality of the detection and classification of VRU will take place. For that, SAVE-U has defined and developed new validation test procedures, taking into account the selected scenarios and the various test conditions one could find in the driving environment. Specifically, SAVE-U has developed 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.

Till now, most of the work was concentrated on the development of dynamic test technique. The concept for the rig is a self-propelled, free running, radio-controlled device, with tethers to energy absorbers to prevent impacts to VRU. Figure 8 shows the rig.

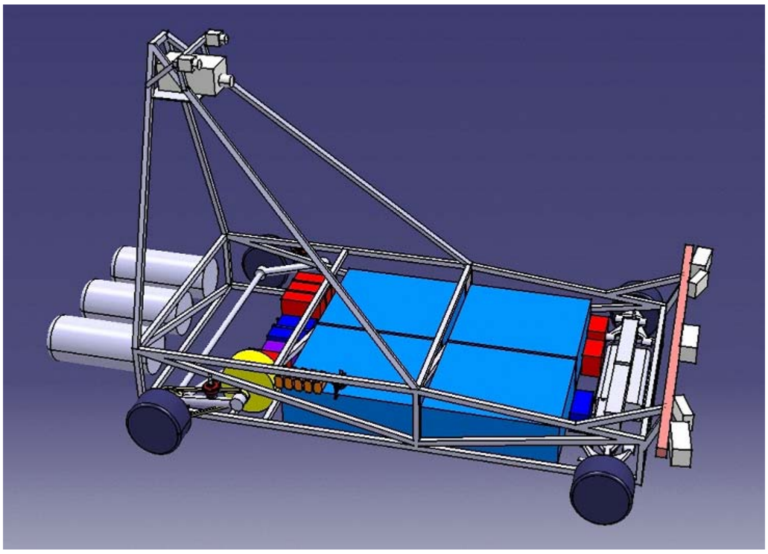

Figure 8: Rig for dynamic test technique

To ensure a rapid, safe and relatively smooth deceleration (to protect the prototype SAVE-U sensor system) an innovative energy absorption system has been developed.

At the end of the project, the sensing 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 Human Machine Interface (HMI) systems and how HMI helps to better reduce collisions or injuries to pedestrians.

Conclusion

SAVE-U is a very complex project because of the development of new sensors (Infra-red, 24GHz radar), of the development of new detection and classification algorithms, of the number of ECUs to make working together and to integrate in vehicles for an efficient VRU protection.

The recent evaluation **(1)** of the radar sub-system has shown that all the requirements were fulfilled, especially the one, which was to improve the sensitivity of 24 GHz radar sensors at ranges up to 30m.
The modelling and simulation of an “IR sensor” specifically designed for VRU detection comes to completion. In parallel of sensor development, SAVE-U has defined more precisely the strategy to follow for high and low-level data fusion.

Ongoing works are dedicated to the optimisation of algorithms implemented on the vision sub-system and on the high-level data fusion ECU. Evaluation of the full platform and of two demonstrators will follow.

Acknowledgements

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References

(1) Matthias Töns, M. Tschernitz, A Hoess, R. Doerfler, M. Spornraft
"Deliverable 15: Evaluation of individual radar sensors as well as radar network",
www.save-u.org, January 2004

(2) Marc-Michael Meinecke, M.-A. Obojski, D. Gavrila, E. Marc, R. Morris, M. Töns, L. Letellier
"Deliverable 6: Strategies in terms of Vulnerable Road User protection",
www.save-u.org, December 2003

(3) Philippe Marchal, D. Gavrila, L. Letellier, M.-M. Meinecke, R. Morris, M. Töns
"SAVE-U : An innovative sensor platform for Vulnerable Road User protection"
Intelligent Transport Systems and Services, 16-20 November 2003, Madrid, Spain

(4) Laurent Letellier, M. Töns, A. Kirchner, T. Graf, M.-M. Meinecke, M.-A. Obojski, N. Allezard, P-E Viel
"Deliverable 8: Sensor system architecture",
www.save-u.org, October 2003

(5) Marc-Michael Meinecke, M.-A. Obojski, M.Töns, R.Doerfler, P.Marchal, L.Letellier, D.Gavrila, R.Morris
"Approach for protection of vulnerable road users using sensor fusion techniques",
International Radar Symposium 2003, Dresden – Germany Sept. 30 –Oct. 2, 2003

(6) Jean-Jacques Yon; L. Biancardini; E. Mottin; J. L. Tissot; L. Letellier
"Infrared microbolometer sensors and their application in automotive safety"
7th International Conference on Advanced Microsystems for Automotive Applications (AMAA), Berlin - Germany, May 22-23, 2003.

(7) Pierre-Emmanuel Viel, L. Letellier , D. Gavrila, P. Marchal, M.-M. Meinecke, M. Töns
"Deliverable 2: Characteristics of the dressed human body versus the different sensing technologies",
www.save-u.org, October 2002

(8) Dariu Gavrila, P. Marchal, M.-M. Meinecke
"Deliverable 1-A: Vulnerable Road User scenario analysis",
www.save-u.org, February 2002