



**CARSENSE**

*IST 1999 – 12224*

*Sensing of Car Environment at Low  
Speed Driving*

## ***Final Report***

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Autocruise S.A.

Thales Airborne Systems (ex Thomson-CSF)

REGIENOV (Renault)

TRW Automotive (ex Lucas Varsity)

IBEO GmbH

BMW AG

C.R.FIAT

Jena-Optronik GmbH

INRETS

LCPC

INRIA

ENSMP

ARMINES



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## **ANNEXES**

### **ANNEXE 1 :**

**Fourth Framework Programme of European Community activities  
in the field of Research and Technological Development  
" INFORMATION SOCIETIES TECHNOLOGY "  
Sector: Transport**

**FINAL PROJECT REVIEW REPORT**

*Project Number* 12224

*Project Acronym* CARSENSE

*Project title: Sensing of Car Environment at Low Speed Driving*

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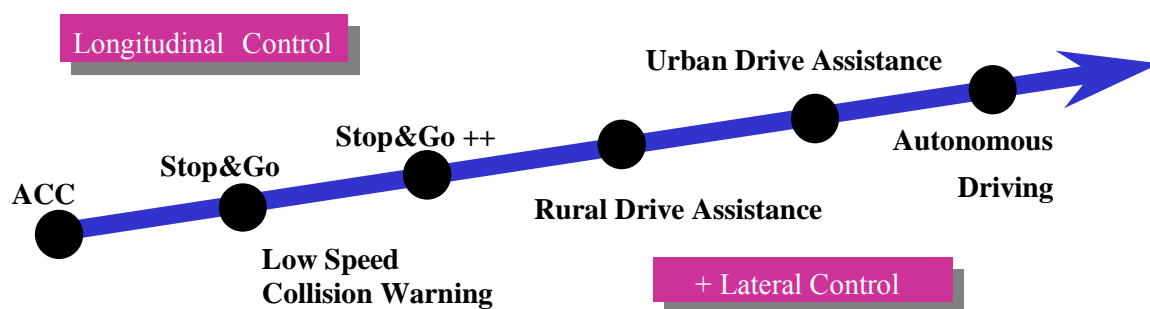
<i>Organisation</i>	<i>Role</i>	<i>Country</i>
Autocruise S.A.	CO	F
BMW AG	CR	D
C.R.FIAT	CR	IT
Thales Airborne Systems (ex Thomson-CSF)	CR	F
Jena-Optronik GmbH	CR	D
REGIENOV (Renault)	CR	F
IBEO GmbH	CR	D
TRW Automotive (ex Lucas Varity)	CR	UK
LCPC	CR	F
INRIA	CR	F
INRETS	CR	F
ENSMP	AC	F
ARMINES	AC	F

*Date 29.11.2002*

## 1 PROJECT OBJECTIVES

Based on the research activities of the last years within DRIVE II, PROMETHEUS and the EU 4th Framework Programme, the concept of Adaptive Cruise Control (ACC) is in the development process as a first Advanced Driver Assistance System and has been introduced to the market in this year (1999). All surveys and experimental assessments have proven that users have shown a high interest and product acceptance for such kind of systems.

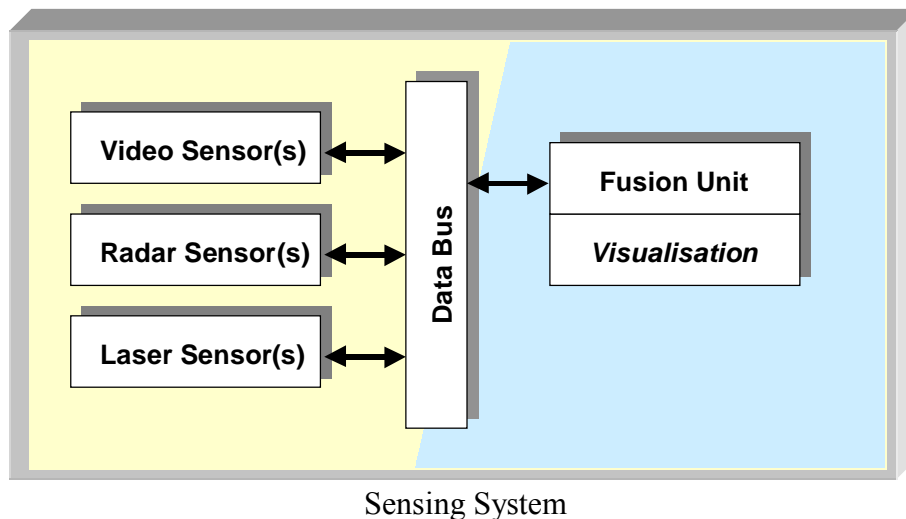
It is clear, that this is only the beginning of developments towards more advanced functions. Future Advanced Driver Assistance Systems (ADAS) may help the driver in more and more complex driving tasks. They can partly take over the control driving a car in traffic situations in which the driver hands over the control of the car to the Driver Assistance System.



However, today, these commercially available ADAS are based on single sensor approaches with either Radar or Laser sensors. ADAS at present are furthermore very much limited to use on motorways or urban expressways without crossings. Traffic consists essentially of other vehicles (cars, trucks). Traffic scenarios under such circumstances are rather simple and processing can be focussed on a few well defined detected objects. However, even in these relatively simple situations, these first systems cannot cope reliably with fixed obstacles. They also surprise the driver, e.g. in some cases of cut-in, the insertion of other vehicles in the detection beam close to the vehicle. Here, the beam width of the sensor beams does not cover the area in front of the vehicle.

With a wider use of such systems it will be necessary to extend the operation of use to more complex situations in dense traffic environments around or inside urban areas. There, traffic is characterised by lower speeds, traffic jams, tight curves, traffic signs, crossings and “weak” traffic participants such as motorbikes, bicycles or pedestrians. Very soon road scenarios become very complex and it is more and more difficult to reliably operate an ADAS. The reason is that currently available sensor systems for monitoring the driving environment provide only a very small amount of the information, which is necessary to manage these higher level driving tasks. It has been identified within the ADASE joint research project in the 4th Framework Programme that one of the crucial needs to achieve a significant progress in ADAS technology is a significant increase in the performance of the driving environment monitoring systems. This will include higher range and precision and higher reliability of the sensor information as well as additional attributes. The way to reach this goal is to improve existing sensors like radar, laser and image processing as well as to fuse the information/output of these different sensor systems with appropriate scene models to achieve better accuracy, redundancy, robustness, and an increase of the information content.

The present project shall develop a sensing system and an appropriate flexible architecture for driver assistance systems with the aim to get further ahead in the development of ADAS for complex traffic and driving situations, first at low speeds. It has been also identified within the ADASE project that driver assistance at low speed driving is most likely the functionality, which is feasible next after introduction of ACC. However, this functionality requires one of the fundamental steps towards future ADAS: reliable information on stationary objects and wider field of view, however in the near range only. Although, the development of this application will not be done in the present project, the low speed driving application will serve as a mean to define the requirements for the sensor system and architecture to be developed.



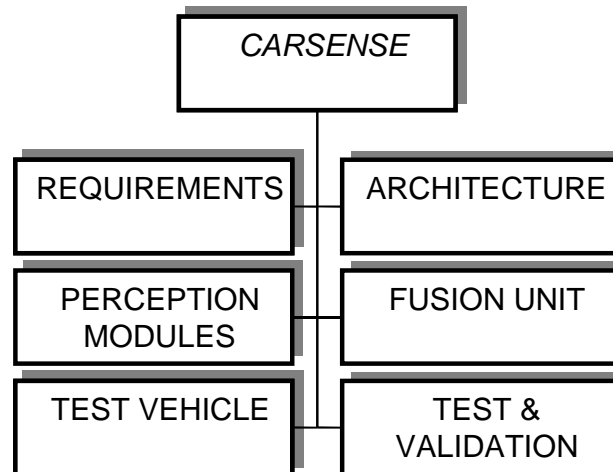
According to the experience from other projects partly sponsored also by the European Commission (such as UDC, AC-ASSIST, ...) the programme shall focus on the following aspects:

- Definition of a characteristic sample of applications for low speed driving
- Definition of an open and flexible hardware & software architecture
- Improvement of sensors for the use according to the defined specifications
- Interface harmonisation and data bus definition for transfer of sensor data
- Fusion of sensor data
- Visualisation of results
- Assessment
- Dissemination

Summary of major expected and measurable results (see also deliverable list):

- Definition of application and related scenarios
- Requirements, definition and specification of the sensing system
- Architecture, interface and bus definition
- New sensors (Laser, Video, Radar) with improved individual characteristics such as
  - wider field of view (radar)
  - improved obstacle detection (radar)
  - improved fail-safe behaviour (laser)
  - robust algorithms for complex scene interpretation (laser, computer vision)
- Tools (Visualisation, «Birds View», Overlay of Video + Data)
- Methods for data fusion, object detection and classification
- H/w platform for data fusion

- Data logger
- Integration of existing sensors in car (first measurements)
- Integration of new sensors and fusion unit (test and validation)
- Video sequences with visualisation of results
- Common test definition for scenarios



Programme Structure

CARSENSE will develop a sensing system and an appropriate flexible architecture for driver assistance systems, with the aim being to advance the development of ADAS for complex traffic and driving situations, initially at low speeds. The ADASE project identified that driver assistance at low speed is the next most feasible function after the introduction of ACC. However, this functionality requires two of the fundamental steps towards future ADAS: reliable information about stationary objects and a wider field of view, albeit only in the near range.

Based on these agreed scenarios, chosen to cover a large spectrum of low speed real-life situations, data from various sensors will be acquired simultaneously and recorded along with additional driving sequence description scripts. The scripts provide the partners with the means for calibrating their sensors and for testing their algorithms. LCPC (LIVIC department) will use its own test tracks to achieve this task.

At the end of the project, a second set of tests will permit a study of the performance of each newly designed sensor. These will also help assess the benefits of sensor fusion and allow an evaluation of the detection performance of the entire system, and its capacity for coping with low speed driving situations.

## 2 PROJECT RESULTS AND MAJOR ACHIEVEMENTS

In the following, a summary of the project shall highlight the major results and achievements of CARSENSE by considering the following questions:

- What is new?
- What can be solved now?
- How complex must a system be?
- How can I evaluate a new system?
- What is the market need for the future (bus, adaptability, functions...)?

CARSENSE has achieved especially the following:

- **Evaluation Means**

LIVIC has developed a “standard” test catalogue that allows evaluating sensing systems.

This is a very valuable result for the DAS industry, as it can now rely on one test that has to be performed in order to certify a certain level of acceptance of the system.

This work could yield an accreditation process, which is a significant result of the project.

For this evaluation the LIVIC has:

  - a) defined scenarios
  - b) acquired experience
  - c) derived a standard evaluation
- **Laser Scanner**

The new type of laserscanner consists of four scanning planes. Based on these scanning planes, the pitch angle can be compensated. Therefore, the sensor has got an improved object detection rate – losses of objects on middle range distances are reduced.

Furthermore, a road detection module was developed. This module is completely based on laserscanner measurements of distances and angles to boundary objects. Based on the width of the road and the curvature, a lane estimation is provided. This information can be used by the vision system as a supplement of the video-based lane detection.
- **Lane Detection with Video (robust)**

TRW has developed algorithms for lane detection by means of a video camera. This lane detection works day and night, at sunshine as in rain. Its robustness has been demonstrated to the consortium and to several OEMs by TRW. This result will probably yield into a series product within few years.

LIVIC has done also a work in this field in combination with obstacle detection by stereovision. This algorithm is very time efficient and very robust.
- **IP/Fusion h/w**

When using video sensors for DAS, image processing is needed. TRW has developed a h/w unit, that serves as powerful basis for algorithm development. The architecture around this h/w allows to develop production intended h/w and s/w. It is used for functional prototypes of DAS systems.
- **Radar : fixed obstacles, s/r-sensor results**

Thales is developing automotive radar sensors of second and third generation with enhanced functionality and reduced size and costs.
- **Visibility Detection / fog detection**

LIVIC has developed an IP feature, that could very much interest the DAS customers. Detection of visibility range is an old request of VMs for their ACC systems in order to limit the abuse in difficult situations.
- **Obstacle detection**



LIVIC has designed an algorithm of obstacle detection based on stereovision. This algorithm is able to detect object, to locate them on a 2D map and even to compute the longitudinal profile of the road, and to estimate the tyre-road contact points (pitch and roll) of the car. The whole process works on a standard PC at 25 images per second.

- Data Fusion Approach (object oriented)

The object oriented data fusion approach seems to be a successful approach. In comparison to other projects, the fusion methods used in CARSENSE seem to achieve the desired result and are thus suitable for further exploitation. LIVIC has developed a real-time fusion algorithm based on the Belief Theory (Dempster-Shafer). This algorithm is implemented on board and is able to track more than 20 targets in real time and to combine the information from various sensors in order to improve the reliability, the robustness and the precision of the detection.

**3 DELIVERABLES AND OTHER OUTPUTS**

<b>Del. no.</b>	<b>Del. name</b>	<b>WP no.</b>	<b>Lead participant</b>	<b>Del. type</b>	<b>Security</b>
1	Programme management plan	7	Autoc.	R	IST
2	Report on Application and Scenarios, Information and Sensor Requirements	1	BMW	R	IST
3	L/R Radar Sensor (existing) for car integration incl. report on delivery	3	Detexis	P	Int.
4	Report on Architecture, bus choice and topology of the system with recommendation on future bus choices	2	Inrets	R	IST
5	S/R Radar Sensor derived from L/R sensor for car integration incl. report on delivery	3	Detexis	P	Int.
6	Laser Sensor (existing) for car integration incl. report on delivery	3	IBEO	P	Int.
7	3 available video camera(s) (test board(s)) with frame grabber; no image processing software for car integration incl. report on delivery	3	LCPC	P	Int.
8	Datalogger and visualisation tool for car integration incl. report on delivery	4	ENSM P	P	Int.
9	Car ready for sensor integration incl. report on delivery	5	CRF	P	Int.
10	Dissemination / Implementation Concept	6	Autoc.	R	Int.
10a	Advertising Paper	6	Autoc.	R	Int.
10b	Dissemination / Implementation Report	6	all.	R	Int.
11	Test scenario definition	6	LCPC	R	Int.
12	Data files with measurements from test scenarios	6	LCPC	O	Int.
13	Intermediate Laser sensor sample for car integration incl. report on delivery	3	IBEO	P	Int.
14	Integrated video processing unit with implementation of initial Image Processing algorithms incl. report on delivery	3	Lucas	P	Int.
15	Upgraded long range sensor with enhanced fixed obstacle capabilities and fusion software algorithms for car integration incl. Report on delivery	3	Detexis	P	Int.

<b>Del. no.</b>	<b>Del. name</b>	<b>WP no.</b>	<b>Lead participant</b>	<b>Del. type</b>	<b>Security</b>
16	H/W platform for data fusion for car integration incl. report on delivery	4	Lucas	P	Int.
17	Report on fusion methods for system	4	INRIA	R	Int.
17a	Report on fusion methods for radar sensors	4	Detexis	R	Int.
18	Car with integrated intermediate system incl. report on delivery	5	CRF	P	Int.
19	3 final video sensors incl. report on delivery	3	JENA	P	Int.
19a	Final video sensor system with final version of IP algorithms	3	Lucas	P	Int.
20	Modified short range sensing functions for car integration incl. report on delivery	3	Detexis	P	Int.
21	Final Laser sensor sample for car integration incl. report on delivery	3	IBEO	P	Int.
22	Final fusion unit for car integration incl. report on delivery	4	Lucas	P	Int.
23	Car with final integrated system incl. report on delivery	5	CRF	P	Rest.
24	Technical report on test results	6	LCPC	R	Rest.
25	Final project report (overview)	7	Autoc.	R	FP 5

## 4 APPROACH

CARSENSE has developed a sensing system and an appropriate flexible architecture for driver assistance systems, with the aim being to advance the development of ADAS for complex traffic and driving situations, initially at low speeds. Earlier projects such as the ADASE project identified that driver assistance at low speeds is the next most feasible function after the introduction of ACC. However, this functionality required two fundamental steps towards future ADAS: reliable information about stationary objects and a wider field of view, albeit only in the near range.

Based on these agreed scenarios, chosen to cover a large spectrum of low speed real-life situations, data from various sensors has been acquired simultaneously and recorded along with additional driving sequence description scripts. The scripts and already existing data provided the partners with the means for calibrating their sensors and for testing their algorithms. Besides road test in Turin and Paris, LCPC (LIVIC department) used its own test tracks to achieve this task.

The results were then used in order to define architecture principles and to test a new architecture in a second vehicle.

Especially the car manufacturers, who represented the final customer in this project, have prepared the scenarios. The results of their work is summarised in [Deliverable 2](#).

The test scenario definition can be found in [Deliverable 11](#).

[Deliverable 12](#) is a compilation of several data files with measurements from test scenarios.

A second set of tests have been logged to study the relevance of each newly designed sensor, to estimate the benefits of the fusion and to evaluate the detection performance of the entire system i.e. its capacity to cope with low speed applications. The results of the analysis show that the fusion algorithms combined with an estimation of the area of interest (i.e. the lane related to the CARSENSE vehicle) allow improving significantly the robustness and the reliability of the detection. In particular very few false alarms are recorded and the locations of the potential obstacles are much more precise.

A description of the results analysis and the criteria used to estimate the gain of the fusion approach can be found in the deliverable 24.

## 5 SYSTEM ARCHITECTURE

Different sensors constitute the CARSENSE multi-sensor data fusion system, which is designed to detect objects in front of the host car. It consists of a set of internal and external sensors from where information is fused within a single data fusion unit. Internal sensors give information about the host vehicle state, such as its velocity and steering angle information. External sensors (Laser, Radar, and image sensors) sense information outside the vehicle, such as obstacles and



**Fig. 1:** Test Vehicle Alfa 156 Sportwagon 2.0 Selespeed

road information. All the sensors and the data fusion unit are connected via CAN busses. A system specification of CAN messages has been built according to external sensors constraints [1]. [2] shows a similar approach.

Special attention has been given to the data-logger, which serves data collection and off-line processing. In fact, the development process requires a reliable and powerful data logging equipment. Often, this equipment has been the bottleneck of a programme. The data-logger designated for this purpose has been developed by ENSMP based on RTMaps. This powerful unit is installed in the first architecture. It represents an essential component for the control of the data flow within the architecture [10]. The data-logger is one of several important results of the programme. It is described in Deliverable 8.

This CARSENSE system is implemented on a test vehicle (Fig. 1). The vehicle serves three main functions:

- Collection of data with available sensors installed in the car and connected to the data-logger;
- Tests and sensor verification of installed equipment;
- Test and validation of final system with improved hardware

The first architecture, primarily designed to allow initial datalogging and algorithm development, is equipped on the first test vehicle. TRW subsequently equipped a second vehicle with a flexible and modular architecture fulfilling the key requirements for real-time automotive data fusion (Fig. 2).



**Fig. 2:** CARSENSE Test Vehicles Alfa 156 and VW Passat

The following paragraphs outline some new hardware and software developments being done within the framework of the CARSENSE project. The complete description of the two different architectures can be found in the two parts of [Deliverable 4](#). The first test vehicle is described in [Deliverable 9](#), its update is described in [Deliverable 18 \(CRF\)](#), the second car (VW Passat) in [Deliverable 23 \(TRW\)](#).

## 6 EXTERNAL SENSORS AND DATA FUSION HARDWARE

Three kinds of sensors are embedded in the system (radar, laser and video sensors). Each one has an intelligent processing unit and a CAN interface. A specific hardware has been developed for data fusion.

## 7 RADAR SENSORS

Thales has developed prototype radar sensors (Fig. 3). They are commercialised by its subsidiary Autocruise, a 50/50 joint venture with TRW Automotive. The technology uses GaAs based Monolithic Microwave Integrated Circuits (MMIC). MMIC based radars have the potential to be produced at a low cost level that is acceptable to automotive customers [4].



**Fig. 3:** Thales Long Range Radar

The main technical characteristics of the radar are:

Frequency:	76-77 GHz
Range:	<1 - > 150 m
Search Area:	12°
Speed meas. precision:	< 0.2 km/h
Angular Precision:	< 0.3°

At the core of the radar is the transmitter / receiver module (T/R – Module). It contains all the microwave circuits necessary for the radar function.

[Deliverable 3](#) describes the first long-range radar sensor delivered to the programme by Thales.

Within the CARSENSE project, Thales has improved this radar sensor on two fronts:

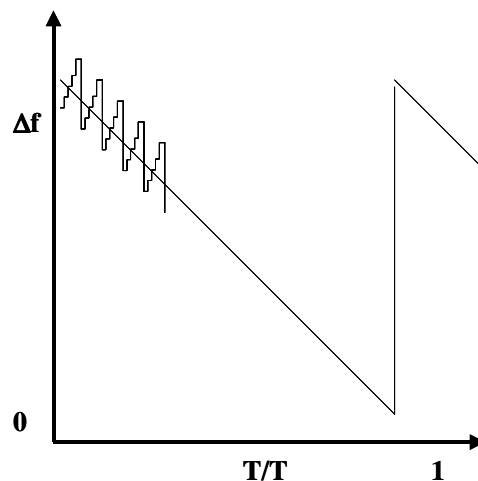
- It has widened the field of view in the short-range area ( $\pm 30^\circ$  up to 40 m) by use of a new optical part for the radar antenna (Fig. 4).
- It has also improved detection of fixed targets by use of a new waveform (Fig. 5).



**Fig. 4:** Thales Short Range Radar Sensor

In order to improve the later one, a “Digital FM” radar waveform is used (Fig. 6). It combines the advantages of frequency shift keying (FSK) with the advantages of Frequency Modulation (FMCW). This waveform has the following advantages:

- Allows a very high speed discrimination
- Allows fixed object detection and discrimination
- Ideal compromise for highway /road operations
- No distance nor speed ambiguity
- Low sensitivity to interference



**Fig. 5:** New Radar Waveform (Digital FM) for detection of fixed objects

Deliverable 5 describes the first short range sensor from Thales, Deliverable 20 the final version of this sensor.

The modifications of the long range radar sensor are described in [Deliverable 15](#).

## 8 LASER SENSOR

The New IBEO laserscanner LD Multilayer (Fig. 6) is a high resolution scanner with an integrated DSP for sensor-internal signal processing.



**Fig. 6:** IBEO laserscanner

The laserscanner emits pulses of near infrared light and measures the incoming reflections of those pulses. The distance to the target is directly proportional to the time between transmission and reception of the pulse. The scanning of the measurement beam is achieved via a rotating prism. The sensor is able to measure in parallel within four planes. The measurements of one scan form a 2.5-D profile of the environment.

Characteristics of the new laser sensor:

scan frequency .....	10 Hz
pulse repetition frequency .....	14.400 Hz
horizontal field of view .....	180°
vertical field of view .....	3,2° (in the driving direction)
horizontal angle resolution .....	0,25° (in the driving direction)
maximum range on reflecting targets .....	150 m
maximum range dark targets (5 % reflectivity) .....	30 m
radial range for object tracking .....	65 m
distance accuracy .....	+/- 5 cm (1 sigma)
distance resolution .....	1 cm
eye-safe .....	laser class 1

A micro controller does the measurement control. The distances and corresponding angles result in 2.5D range raw data profiles, which are transmitted to the DSP where pre-processing is performed in real time. The algorithms for “object detection” and “object tracking”, including the new function “road detection” are running on an IPC with an embedded system.

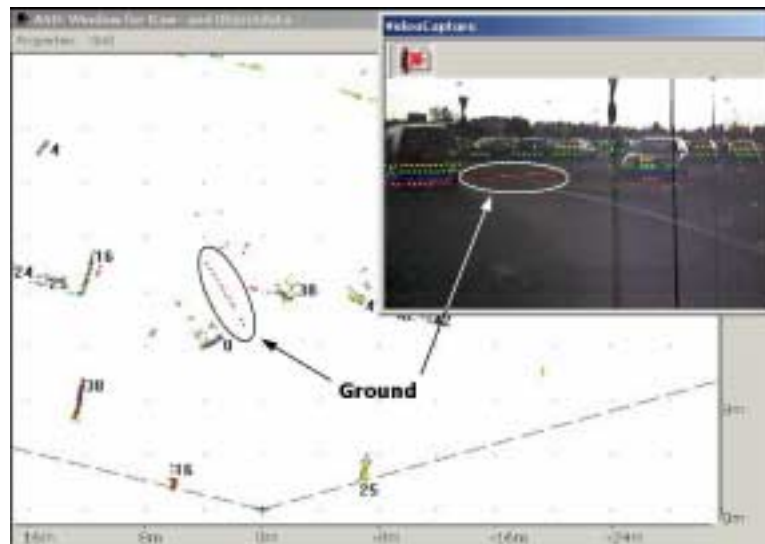


The new IBEO laserscanner gives complete information about all objects in front of the vehicle, including the adjacent lanes with high accuracy in distance and angle, based on a fine resolution of the object outline. According to the mentioned sensor characteristics, this new sensor is suitable for any low speed application.

The laser scanner implemented in the first test vehicle serving mainly at collection of data is described in Deliverable 6. The final result of the development within CARSENSE is shown in Deliverable 21 with some preliminary information summarised in Deliverable 13.

### 8.1 Object detection

The laserscanner consists of four scan planes, which allows to compensate the pitch angle of the vehicle. Figure 7 shows the single measurements of the scan planes as single dots. If the vehicle pitches at low speed driving, there is always at least one plane, measuring on the outline of the object in front. Consequently, losses of objects because of acceleration and deceleration are minimised.



**Fig. 7:** Ground Detection

The vertical improvement of the field of view also increases the probability that measurements are caused by looking at the ground somewhere in front of the sensor. Therefore, a ground detection module was developed, which is able to distinguish between measurements on the ground and on an object, using the fact, that the ground is almost in parallel to the main scan plane and objects are almost orthogonal to the scan plane.

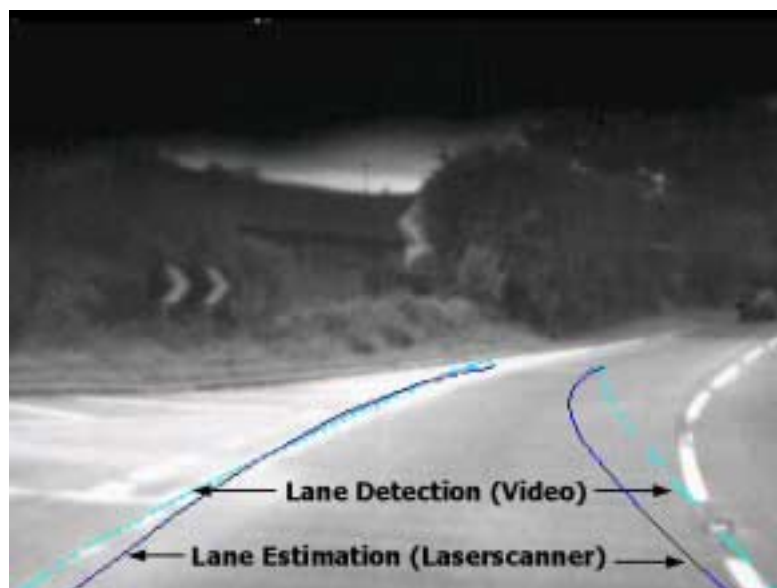
After marking of all ground measurements, the object detection module clusters the single measurements into segments. These segments are combined to objects. Between two scans, the objects are tracked by use of Kalman-filters. Object parameters like position, size and velocity are calculated in this process. The relevant objects are transmitted via CAN bus to the vehicle application.

## 8.2 Road detection

Before Carsense, there were only Video-based Systems existing for lane detection. Based on measurements of distances and angles of the laserscanner, a new algorithm for road detection was developed.

First, all objects on the road are eliminated. Then, the measurements on boundary objects are used for calculation of the width and the curvature of the road. Derived from this information, the visibility range and the road type can be classified on highways and country roads. Furthermore, the algorithm does an estimation of the lane.

In case of missing measurements (no boundary objects existing or boundary objects are temporarily hidden) a non-linear time-based filter stabilises the road type classification.



**Fig. 8:** Results of Lane Detection and Lane Estimation

Figure 8 shows the results of Lane Detection by a video-system and Lane Estimation by the laserscanner. In general the existing systems for lane detection are robust, but in some cases (e.g. deep sun and wet road), the video-system might fail. In these cases, the laserscanner lane estimation can be used to complement the video-based lane detection.

## 9 VIDEO SENSOR

The Jena-Optronik GmbH has developed a prototype video sensor shown in Fig. 9. This new sensor type is characterised by a high dynamic range, stereo vision capabilities and a high speed video interface.



**Fig. 9:** Video-sensor developed by Jena-Optronik GmbH

The use of a CMOS sensor element with non-integrating photodiodes made possible the high dynamic range that is essential for automotive applications.

The video sensor is characterised by:

Sensor element type:	640 x 480 pixel, CMOS
Pixel size:	12 $\mu\text{m}$ (H) x 12 $\mu\text{m}$ (V)
Dynamic range:	logarithmic response, 120 dB
Lens adapter:	C-mount
Pixel clock:	10MHz
Max. line rate/ frame rate:	15kHz / 30 fps
Video output:	CameraLink Standard
Control interface:	CAN 2.0B, 11 bit identifier
Trigger output (Stereo):	differential (LVDS)
Power consumption:	< 6W per camera (@ 12V )
Nominal operation input voltage range:	9.5V ... 15.6V DC

Three prototypes were completed and tested. They have been delivered to TRW for start-up and test with data logger in the second test vehicle and have then been integrated into the first car. The cameras initially used for datalogging are described in [Deliverable 7](#), the final development result is described in [Deliverable 19](#).

## 10 HIGH DYNAMIC RANGE VIDEO SYSTEM

A video sensing system has been developed for sensing features such as stationary and moving obstacles and road information. The purpose of the processing unit is to enable image-processing algorithms to operate at real time (frame rate  $\sim 25$  Hz) while demonstrating a clear relationship between the development hardware and the hardware, which will go into production.

TRW Automotive has developed a high performance platform (Fig. 10) which contains both a Field Programmable Gate Array (FPGA) and Digital Signal Processor (DSP) capable of processing raw video at a high data rate. The hardware consists of an embedded micro controller, which handles communication with the rest of the subsystems. This micro controller has a low overhead dual-port RAM interface to the algorithm DSP that is capable of 800 million floating-point operations per second

(Mflops). The unit has two CAN2.0B interfaces, each running at a maximum of 1Mbps. For visualisation of the data, the DSP has access to an SVGA frame buffer, which can display the road scene as viewed by one of the CARSENSE cameras, with graphics overlaid by the DSP. The whole system is housed as an embedded unit, with an internal automotive power supply unit<sup>11</sup>.

The unit is modular and stackable, so that multiple algorithms can be tested on additional processing boards, and those algorithms that require more processing power than is provided by a single FPGA/DSP subsystem can make use of multiple processors, if necessary.

This development platform demonstrates that complicated image processing algorithms can be realised using a cost effective embedded hardware solution.

## 11 DATA FUSION HARDWARE

The requirement for the architecture to be flexible has led to an Object-Oriented approach being taken. This leads to an open hardware requirement, with the software designed and developed by TRW, being platform independent. The choice of platform is driven by the requirement for enough processing power for the data fusion algorithms at least 2 CAN buses capable of the CAN2.0B specification.

Initially algorithm development made use of a PC platform, for ease of implementation. The final solution is implemented on an embedded platform. This leads to a split of the fusion CPU and the Comms CPU. Depending on the computational requirements of the data fusion algorithms, the system can be implemented on either a single CPU or a platform similar to that in development for real-time image processing. To enable an object-orientated approach, a translation layer is currently required to convert the inputs from the various sensors into a standard object format. Ultimately the individual sensors themselves will perform this, which will then reduce the Comms CPU processing load making it possible to use of a single CPU for system implementation<sup>12</sup>.



**Fig. 10:** Embedded Image Processing & Fusion Unit

Details concerning the unit for integrated video processing and fusion can be found in Deliverables 14, 16, 19a and 22.

## 12 ALGORITHM DEVELOPMENTS

Video processing and data fusion algorithms has been developed by INRIA, LCPC (video and data fusion), INRETS-LEOST, and TRW (lane detection and data fusion).

Deliverables 17 describe this work. **(INRIA to complete !!!!)**

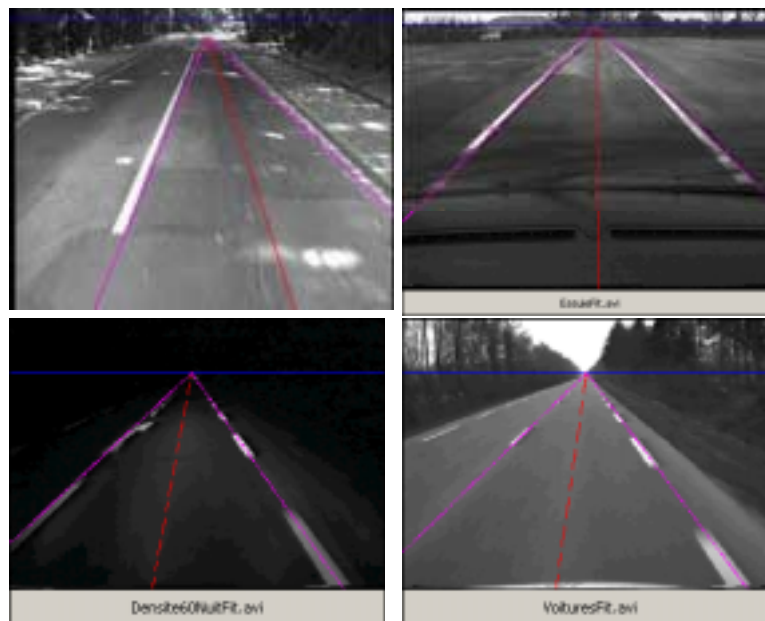
## 13 VIDEO PROCESSING

The vision task (LCPC) can be split into three main topics: Lane Marking Detection; Obstacle Detection and visibility range detection.

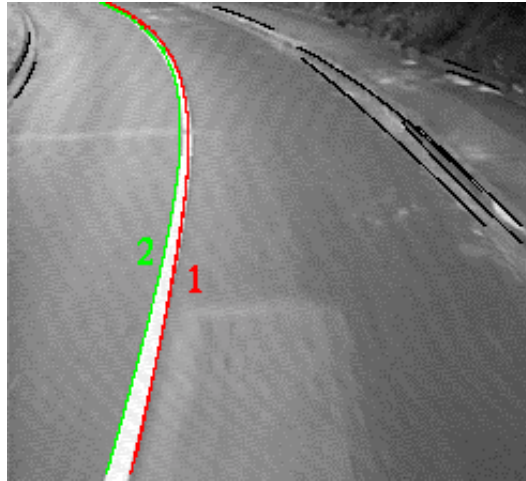
### 13.1 Lane marking detection

TRW have developed a robust lane detection system, which is capable of operating under all weather conditions. This system operates in real time and has been independently assessed as being “best in class” by a major OEM. Careful consideration was made to the implementation of the algorithm in both hardware and software, to enable the development of a cost-effective production solution.

The robust detection and tracking of lane markings and lane boundaries is one of the main topic of the CARSENSE project because it can help to identify the area of interest for the obstacle detection task. LIVIC (LCPC) has set up two types of algorithms able to track the mane marking. One, based on a linear approximation (Fig. 11), is very fast and simple, when the other one, based on polynomial approximation (Fig. 12), is more computational time demanding but more precise.



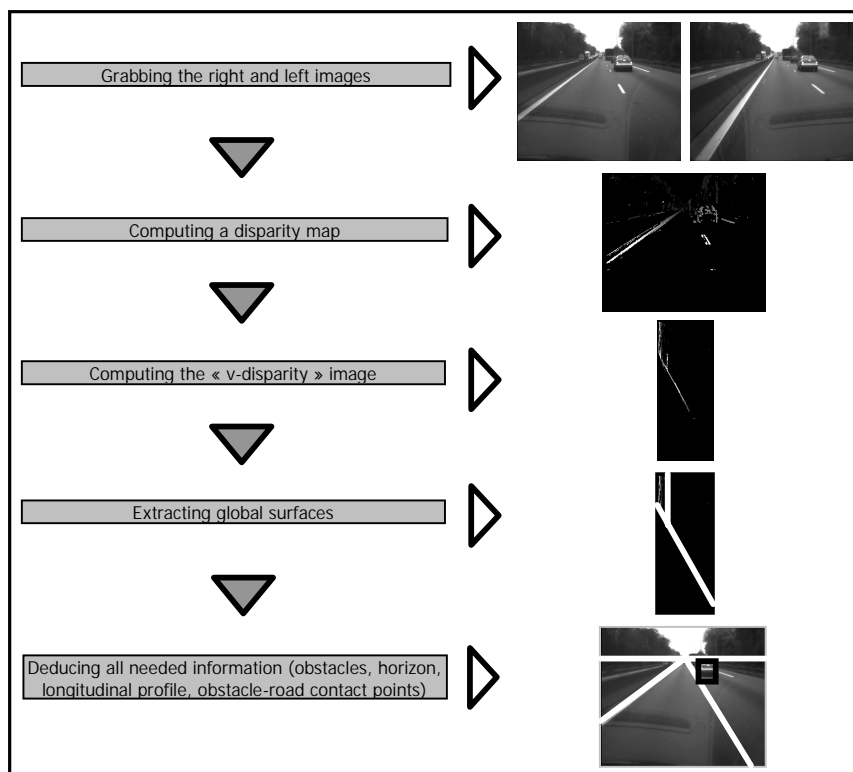
**Fig. 11:** Straight Lane-marking detection within different environments and perturbations



**Fig. 12:** Example of curved lane marking detection

### 13.2 Obstacle detection by stereovision

Presented here is the stereovision algorithm designed by the LIVIC. An overview of the algorithm is given and results of an experimental evaluation are shown. Then some good properties of the algorithm are exposed.



**Fig. 13:** Framework (left) and implementation (right) of the algorithm

In what follows we suppose that the image planes of the stereoscopic sensor are parallel (i.e. the epipolar geometry is rectified). The "v-disparity" algorithm is described in details in [1].

$$\Delta = \frac{b}{ah - d}((v - v_0)(a \cos \theta + \sin \theta) + \alpha(a \sin \theta - \cos \theta))$$

A framework for our obstacles detection process is presented in Fig. 13 (left). Our current implementation of this framework is as follows (see Fig. 13 (right)). First, non-horizontal edges are extracted from the two images of the stereo pair and matched (using normalized correlation) in order to obtain a sparse disparity map. Then, disparity is accumulated along scanning lines in order to obtain the "v-disparity" grey image. In the "v-disparity" image, scene plane of interest with equation  $Z=aY+d$  is projected along the following straight line [1]:

where  $\Delta$  denotes the disparity,  $v$  the ordinate of a pixel in the image coordinate system,  $v_0$  the ordinate of the centre of the image,  $b$  the stereo baseline,  $h$  the height of the stereoscopic sensor,  $\theta$  the pitch and  $\alpha = f/t$  with  $f$  the focal length of the lens and  $t$  the size of pixels.

The road is characterised as a set of planes and obstacles are characterised as vertical planes. Thus, extracting straight lines in the "v-disparity" image leads to extract global surfaces, road and obstacles. All needed information for performing generic obstacles detection is then deduced: longitudinal profile of the road surface (not necessary planar), horizon line location, obstacle-road contact point.

### 13.2.1 Experimental evaluation

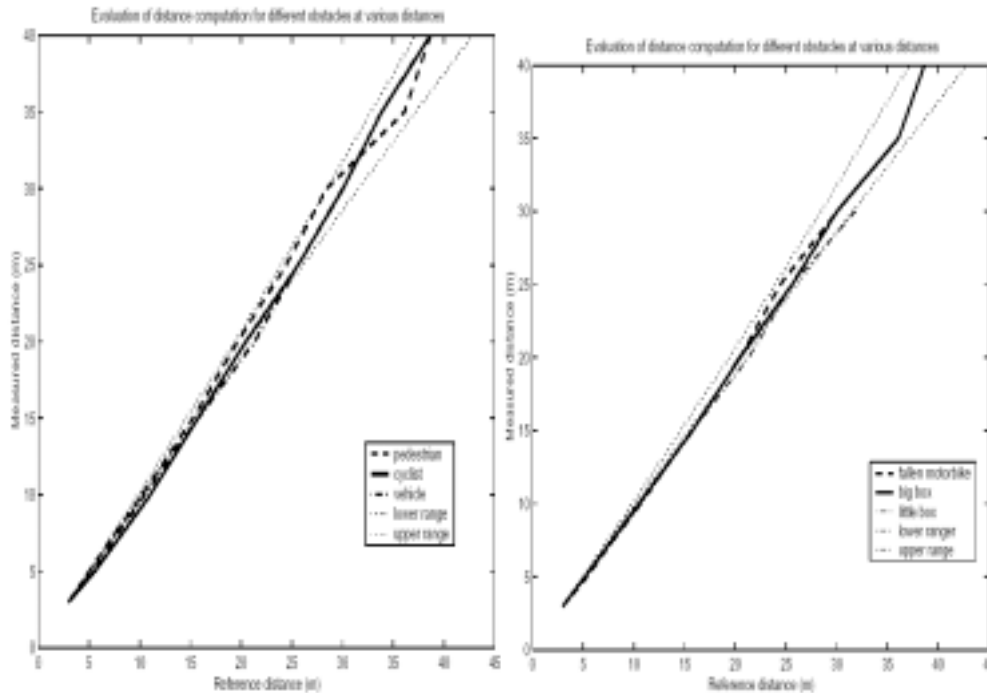
Experimental evaluations of the algorithm have been carried out in [2] and [3]. Six types of obstacles (see Fig. 14) are used for the evaluation of the distance computation accuracy: a 1.90m high pedestrian, a 1.75m high cyclist, a 1.50m high vehicle, a fallen motorbike, a 0.7x 0.7x x 0.4m box, and a 0.3 x 0.3 x 0.2m box. Every obstacle is positioned along the axis of the vehicle, at the following distances : 3m, 5m, 10m, 15m, 20m, 25m, 30m, 35m, 40m. The weather is cloudy. The distance  $D$  between the vehicle and the obstacle is given by :

$$D = \frac{b(\alpha \cos \theta - (v_r - v_0) \sin \theta)}{\Delta}$$

where  $v_r$  is the ordinate of the road-obstacle contact point in the image. Fig. 15 and 16 show the distance computation results.



**Fig. 14:** The six obstacle types used for the evaluation of the algorithm



**Fig.15 and 16:** Distance computation results

### 13.2.2 Some properties of the method

The algorithm needs no explicit extraction of coherent structures in the left and right images. This increases the robustness of the approach as the extraction of coherent structures in 2D images is often a source of errors. Furthermore, all the information in the disparity map is exploited and the accumulation performed increases the density of the alignments to be detected in order to extract global surfaces. Any matching errors cause few problems. It has been shown that the algorithm goes on working efficiently even when there is 96% noise addition or 80% good matches removal in the disparity map.

No back projection that is likely to reduce precision or amplify noise due to digitalisation is involved in the algorithm.

The presence of other, less interesting surfaces has little effect on the extraction of meaningful information (road profile, obstacles).

The method works whatever the robust process used for computing the disparity map or for processing the "v-disparity" image.

The whole process for extracting the longitudinal profile of the road and computing the tyre-road contact points is performed within 40 ms with a current-day PC. The hardware used for the experiments is a Pentium IV 1.4 GHz running under Windows 2000. Images are grabbed using a Matrox Meteor II graphic card. The focal length of the lens is 8.5 mm. Image size is 380x289.

The method can be extended to evaluate roll, pitch, yaw and 3D road shape.

### 13.3 Visibility range detection

In order to reduce the number of accidents, or at least to reduce their impact, more and more vehicles are equipped with security systems such as ABS and ESP. But those



systems are only effective when the accident is going to happen. To avoid being in such a situation, it is necessary to anticipate the risks and to act in accordance. This requires a good perception and comprehension of the vehicle environment. That is why perception equipment has begun to appear on certain vehicles (cameras, laser, radar).

Such equipment is made to work in a range of situations and conditions (weather, luminosity, ...), where variations are limited. Thus, to create driving assistance with the required rate of reliability, it is essential to detect the crossing of their operation ranges. In this context, a system measuring the distance of atmospheric visibility can quantify the current operation range of the embedded sensors. This information is used to adapt the operation of the sensor, the image processing or to warn the driver that his system of assistance is temporarily inoperative.

Furthermore, such a system, which can detect the presence of fog and estimate the distance of atmospheric visibility, constitutes in itself a driving assistance. Indeed, in foggy weather, the drivers can poorly evaluate the distance of visibility. This can lead in consequence to not properly adapted driving speeds. A measure of the available visibility would inform the driver that his speed is not properly adapted, and would even automatically limit his speed.

For instance, we have worked in particular on the problems of day fog detection and the estimation of the distance of visibility, for which an original method has been developed and patented. The approach consists of the dynamic implementation of a model of propagation of the light in the atmosphere, which represents the variation of the luminance in the current image, according to the distance to the sensor. The model used is the Koschmieder model, which includes an extinction parameter, which is the sum of the absorption and diffusion coefficients of the aerosols in the atmosphere. So, the model implementation gives the extinction coefficient, which allows the calculation of the meteorological distance of visibility, defined by the International Commission on Illumination (CIE) as the distance beyond which the contrast of a black object at the horizon becomes lower than 5%.



**Fig. 17: Caption:** three examples of use of the system.

(light fog in a straight line

(dense fog in a straight line

(dense fog in a curve

The horizontal white line represents the estimation of the distance of visibility. The small white triangle indicates that the system is operative. The small black triangle indicates that the system is temporarily inoperative. The black vertical lines represent the limits of the area of interest.

## 14 LANE MARKING DETECTION (TRW)

The robust detection and tracking of lane markings and lane boundaries, using on-board cameras, is of major importance to the CARSENSE project. Lane boundary detection can assist the external sensors in identifying whether obstacles are within (or out of) the host vehicle's lane. Road boundary detection must at least provide, with high accuracy, estimates of the relative orientation and of the lateral position of the vehicle with respect to the road (Fig. 16).

Two approaches, based on different road model complexity, will be tested:

First, a real-time algorithm [7] will allow computation of the orientation and lateral pose of a vehicle with respect to the observed road. This approach provides robust measures when lane-markings are dashed, partially missing, or perturbed by shadows, highlights, other vehicles or noise.

The second approach [8], contrary to usual approaches, is based on an efficient curve detector, which can automatically handle occlusion caused by vehicles, signs, light spots, shadows, or low image contrast. Shapes in 2D images are described by their boundaries, and represented by linearly parameterised curves. We do not assume particular markings or road lightning conditions. The lane discrimination is based only on geometrical considerations.



**Fig. 18:** Lane Marking Detection

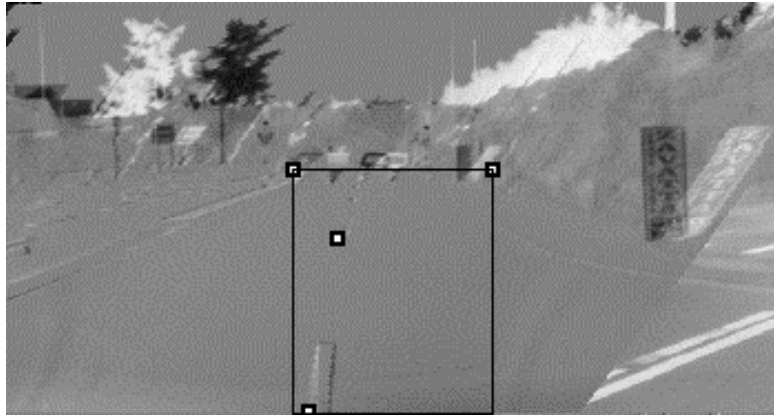
## 15 OBSTACLE DETECTION THROUGH STEREOVISION (INRIA)

### 15.1 Disparity Maps

After tentative improvements the disparity map approach was discarded. The prediction method for the next disparity map in the sequence provides approximated maps in reasonable time but they are not easily enhanced and in the enhancement process the advantage gained in CPU time is seriously reduced.

### 15.2 Image Matching Method

Our current approach tries to match the left and right images on some road surface points. In Fig.17, two points of contrast were found in the black rectangle for matching.



**Fig. 19:** Image Matching

For matching the images, one of them is skewed and the difference of pixel luminosity values is calculated for each pixel.



**Fig. 20:** Contrast points left

With this approach all the surface of the road becomes neutral grey except for approximate matching. For the next step we keep the points of contrast from one image and look for their disparity values.



**Fig. 21:** Detected Obstacles

With this approach the number of points for which we must obtain disparity values is reduced from 65000 to 500 approximately (Fig. 20).

Once the disparity values are obtained, the points of contrast are grouped by their horizontal position and disparity value (and in Fig. 21 are projected on the road surface point of equivalent distance).

The height of the black clumps in the resulting image (Fig. 21) represent multiplicities in the projection, which correspond to certainty values for the obstacles detected. Erroneous detection (as at the end of the first road marking) is due to imprecise alignment from other data captors.

#### *15.2.1 Ancillary problems*

The road surface points to match are not always easy to find. To this end a lane marking detection method using a Hough transformation to find circle arcs across the contrast points' projection on the road surface was developed.

## **16 DATA FUSION PROCESSING**

In principle, the fusion of multiple sensor data provides significant advantages over single sensor data. In addition to the statistical advantage gained by combining same-source data (obtaining an improved estimate of a physical phenomenon via redundant observations), the use of different types of sensors, which may supply complementary information, can increase the accuracy and confidence with which a phenomenon can be observed and characterised. Applications for multi-sensor data fusion are widespread, both in military and civilian areas.

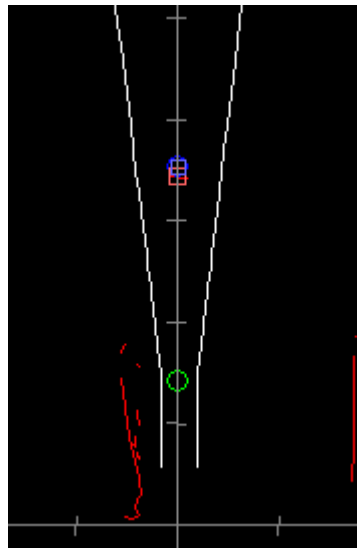
The purpose of the data fusion in Carsense is to build, given the output of the different sensors and image processing modules, the most reliable, accurate and complete map of the vehicle environment featuring the neighbouring obstacles. Such a map is of primary interest in the design of a robust and reliable driver assistance system (Fig. 20).

The fusion problem addressed in Carsense is basically a "Target Tracking problem". The objective is to collect observations, i.e. data from multiple sensors, on one or more potential targets of interest and then to partition the observations into tracks, i.e. sets of observations produced by the same target. Once this association is done, estimation can take place: target characteristics such as position, velocity, etc. are computed for each track. Because of the presence of several targets of interest in the environment, the Carsense problem falls into the Multiple-Target Tracking category.

The primary concern within Carsense is to estimate the targets' position and velocity. It is a classical statistical estimation problem. Modern techniques involve the use of sequential estimation techniques such as the Kalman Filter or its variants. Numerous mathematical methods exist to perform coordinate transformation, observation-to-observation or observation-to-track association. Challenges in this area involve situations with a large number of rapidly manoeuvring targets, which is precisely the case in the traffic scenarios considered in Carsense.

Both Livic (Inret/LCPC) and Sharp (Inria Rhône-Alpes) have addressed this multiple-target tracking problem. Their objective was to demonstrate the interest of techniques based upon uncertainty theories. Be it belief theory, probabilistic theory, possibilistic theory, or fuzzy mathematics, all these theories make it possible to model and reason about incomplete, uncertain, inaccurate data, as well as qualitative and quantitative data.

Livic has developed a multi-sensor data fusion architecture based mainly on belief theory with the use of an extended and generalised belief combination. This new algorithm allows the management of the appearance, the disappearance and the re-association of the different targets and tracks on the road in real-time. In addition to the target position, it is possible to quantify the confidence in both one track and the global tracking. At present, this algorithm is embedded on the Carsense prototype and works with the real data provided by RTMaps datalogger. With similar goals in mind, Sharp explored the use of a novel approach called Bayesian Programming (based on Bayes' probabilistic reasoning), that was first introduced to design robot control programs but whose scope of application is much broader and can be used whenever one has to deal with problems involving uncertain or incomplete knowledge (which is indeed the case in the Carsense framework). Deliverable 17 presents in more detail the approaches and the results obtained by the two groups.



**Fig. 22:** Multisensors fusion and visualization on a 2D map

The main advantages of this algorithm are:

- The **modeling** of the **data imperfections** is made robustly, using several theories.
- The sensor **synchronization** is carried out by a stage of **temporal alignment**.
- The use of belief theory for the association stage allows a trivial management of the objects **appearance**, **disappearance** and **re-association**.
- It is possible to quantify the **confidence** in the object tracking.
- The conflict and ambiguity detection in the association decision is taken into account.
- The multi-source data combination is both **associative** and **commutative**.

Road information can be provided by multiple sources, such as video, laserscanner and navigation systems. Within this project, the detection of the side of the road, in the absence of clear road markings, has been investigated using video and the laserscanner. The video system is capable of detecting the road edge and, although this performs well, this is less reliable than when road markings are present. The mode of operation of the laserscanner, however, is excellent at detecting obstacles raised from the road plane, such as those, which define the road edge. As such it can be used to provide information

complementary to the video system. While this feature was developed late in the project, the potential to usefully combine the output from the sensors is very high.

## 17 TEST AND VALIDATION

Within the CARSENSE project, driving scenarios have been defined, that shall help to evaluate the performance of such sensors systems. LIVIC, who is in charge of this task, has derived from this work a condensed list of scenarios, which can be used by automotive customers in order to order their own evaluation as well as by suppliers in order to certify a minimum of functions as a kind of certification of state of the art. We describe the way the test drives should be conducted and the related data recorded. Some elements of assessments are also given.

In order to process efficiently, for each test, are explained the script, the objective, the location, the necessary equipment, the possible configurations, and the estimated recorded time. Moreover, the organisation in terms of priority and estimated time spent to perform the test are discussed.

Once the tests carried out, it is appropriate to evaluate the performances of the various sensors, in terms of precision and robustness, for the various driving configurations met. For that, we consider the statistical criteria of evaluations of the capacities of detection of the sensors related to their output. The objective is to understand, in the assessment process, how accurate are the sensor and fusion unit detection, and what are the circumstances likely to create disturbances. It is also relevant to evaluate the reaction time of each sensor, and to estimate the confidence intervals for each driving situation. The means of evaluation depends on the test location. If the test drive is recorded on the LIVIC's tracks, by using the GPS localisation, a precise position of each object is known (less than 5cm). It is then possible to use some criteria based on physical measurements. If the tests are recorded on open road, the criteria will be based only on human observations.

Two sets of criteria have been considered :

The first set of criteria aims at evaluating whether the sensors detect or not the obstacles. The whole set of criteria is based on the output of the various sensors.

- Detection rate
- Distance of detection
- False alarm frequency : number of false alarms per unit of time
- False alarm rate (time in FA/total time)
- Weighted False alarm rate (if the sensor provides a measure of the uncertainties, then it is also interesting to compare the estimate uncertainties versus detection rate and false alarms).

The second set of criteria aims at evaluating the accuracy of the detection. They concern just the test drives for which the GPS location of each object of the scene is recorded.

- Position error (meters): square of the distance between the real and the estimated position of the contour of the obstacle (especially the ones that intersect the trajectory). This criteria should be given in average (sum of the quadratic errors over the number of measurement), and the evolution with regard to the time should be also computed.

- Speed error (m/s) : square of the difference between the estimated velocity of the obstacle and the real recorded velocity. This criteria should be given in average (sum of the quadratic errors over the number of measurement), and the evolution with respect of the time.
- Weighted accuracy : comparison between the estimated confidence intervals (if any) versus location error (number of real position inside the confidence interval versus number of real position outside the confidence interval).
- 

The sensitivity of those criteria should be analysed with respect to the concomitant following variables :

- lateral shift of the obstacle,
- distance between the equipped vehicle and the obstacle, speed and acceleration of the equipped vehicle,

The results of the data logged within the CARSENSE project can be found in the deliverable 24.

## **18 PROJECT MANAGEMENT AND CO-ORDINATION ASPECTS**

This project had several major challenges for the project management.

First of all, the numbers of partners, their nationality and their different cultures have been a handicap and an advantage for the programme. The handicap was mainly due to different industrial and technological backgrounds and the way to attack problems. Also communication of problems within the programme had sometimes to be improved during the lifetime of the project. The initial programme management plan (Deliverable 1) anticipated some of these problems and their effect could therefore be limited.

However, there was a very high level of common expectations and motivation, which made the work finally very appreciable between the partners.

Regarding the technical complexity, it appeared very clearly, that it is very important to give responsibility for the equipment of a vehicle and the initialisation of data logging into one organisation.

The fact to having equipped the car in Italy with sensors from all over Europe and then trying to test this car in France was an almost impossible task. Fortunately, it was possible to equip a second vehicle under different circumstances, in which only one partner performed the integration work.

Besides these structural challenges, the programme management had to renegotiate the contract with the EU due to a very early reduction of work by Jena-Optronik. This renegotiation was very heavy due to the different levels of administration in the EU.

A consortium agreement could only be signed at the end of the programme, but this did not prevent the partners to act according its rules already right from the beginning of the project.

In general, giving the programme management of such a complex programme to the company, who realises the test vehicle would perhaps shorten the communication paths.



## 19 OUTLOOK

CARSENSE is now at its end. Most of its basic objectives have been achieved. However, the level of the results can be improved. Therefore, the CARSENSE consortium would like to suggest to the EU to continue the programme within the next framework programme in order to consolidate the results and benefit completely from the developments performed during the last three years.

An integration of such a CARSENS II into the IP of ADASE seems the best way to achieve this.

## 20 SUMMARY AND CONCLUSION

The CARSENSE project is an important step on the way to high performance perception systems in future ADAS. The combination of multiple sensor information will improve object detection reliability and accuracy over that derived from today's sensors. With the development of new sensor functions, such as detection of fixed obstacles and wider field of view, the systems will be capable of use in urban areas, and high integrity (and comfort) ACC systems. Ultimately these sensing systems may be used in safety applications such as Collision Mitigation or even Collision Avoidance.

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## 22 IMPLEMENTATION



Phaton with Autocruise Radar and TRW ACC System



BMW with ACC Radar

The image is a promotional graphic for 'Radar Cruise control' technology. At the top, it says 'TECHNOLOGY' and 'Just stay forward, thanks'. On the left, a vertical list of car features includes 'Easy Go', 'My Car', 'Seat memory', 'Radar Cruise control', 'Dark sensor', 'Rain sensor', and 'Parking sensor'. The 'Radar Cruise control' item is highlighted. In the center, a blue car is shown emitting yellow radar waves towards a silver car in front of it. Below this, a text box explains: 'How many things must you keep under control when driving? Just set your cruising speed and the cruise control will assure that this remains constant while the radar system will operate on the braking system to maintain a safe distance between you and the vehicles in front, taking all the stress out of driving.'

Web-Page of Fiat Stilo with ACC Radar



Mercedes with ACC Radar and TRW electronic brake booster



(Renault-) Nissan Primera with LIDAR



Application of Autocruise radar sensor