Project IST-1999-10108
CHAMELEON
Pre-crash application all around the vehicle

FINAL REPORT

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Pre-crash Application All Round the vehicle

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List of Partners

The following partners participate in the CHAMELEON project:

CRF, PCA, CONTI-TEMIC, THALES, VOLVO CAR, PORSCHE, REGIENOV, IBEO, SAAB BOFORS, EICAS, IKA, CSST, TAMAM-IAI

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1. PROJECT OBJECTIVES AND APPROACH

1.1 Objectives

Main objective of the Chameleon project has been to develop and evaluate **a pre-crash system** for vehicles, able to detect an imminent impact with high reliability.
Aim of a pre-crash function is **to increase the protection of all the occupants**, optimising the effectiveness of restraint systems by an adaptable or anticipated action, or even conceiving new types of passive safety devices.

The focus of the project is on applications for passenger cars. The sensor technologies investigated are especially the microwave radar, laser and computer vision. All the different scenarios of road and traffic are taken into account.

Starting from the existing knowledge on Advanced Driver Assistance Functions (ADAS), the Chameleon objective involves therefore the following main aspects:

- To define a **system concept** for this new function, exploring how to link preventive and passive safeties in order to obtain an added safety value;
- To investigate the sensor requirements, identify the most useful technologies, develop and test suitable **sensor solutions**;
- To define what **type of information** should be delivered to the passive safety systems and especially the correct **timing** before the crash;
- To evaluate **effectiveness and safety benefits** of a pre-crash system, analysing new solutions for restraint systems.

To reach these results, a first important point is to improve the performance of **sensors** now available for ADAS, particularly in term of range, data rate, and capability to track close objects. This is related to the shorter times and distances involved in the pre-crash application domain.
A further key issue is to develop **crash prediction** algorithms, able to estimate when a risky situation is about to turn into an unavoidable crash, with suitable advance time but maintaining an acceptable reliability.

The final pre-crash evaluation in Chameleon involves a **demonstrator vehicle** and several ad-hoc **test procedures** defined in the project itself. Besides a technical analysis, the evaluation framework includes an **impact analysis** and a study on safety, legal issues and standards.

With these specific aims, the Chameleon project intends to contribute to the **introduction of advanced information and communication technologies** on modern cars, to increase the level of **safety on the road in all circumstances**.

1.2 Summary of main achievements

- The Chameleon project, starting from basic ideas, has defined a **concept for the pre-crash application** and implemented the system in a **demonstrator car**.

- A **functional Road map** to guide future developments has been identified, with four steps in sequence: pre-setting of air-bags, activation of reversible restraints (e.g.: seat belt pre-tensioners), activation of irreversible restraints, vehicle controls. Progressive steps in sensor performance are correspondingly needed.

- **Prototypes of advanced sensor solutions** for the pre-crash have been developed and tested:
  - → A compact multi-beam laser with three channels near-range detection and high update rate (100 Hz);
  - → A short range radar at 24 GHz, covering a range down to 0,5m;
  - → A 77 GHz radar complementary to the ACC sensor, in order to extend the car functionalities to pre-crash and enhanced ACC;
  - → A laser scanner to detect and track objects in the near field with wide field of view (270º) and precise distance measurement (few cm);
  - → An active stereoscopic video sensor for the detection and the classification of road objects, also deriving distance and direction for multiple applications.

- **Crash prediction algorithms** have been developed and tested, delivering good predictions of the time to impact and of the impact speed and position:
  - → A first approach using the laser scanner data and the car longitudinal and yaw rate measurements;
  - → A second approach based on all the radar and laser sensors, with a crash prediction for each of them.

- The project has shown **the feasibility of the pre-crash concept**; the application is still in a **preliminary phase of development**, considering the present performance of sensor technologies. Gaps to the realization have been defined by suitable testing and analysis.

- **Tools and methods for an effective evaluation** have been defined, with innovative approaches to test ‘crash’ or ‘quasi-crash’ conditions by non-destructive methods: a dummy obstacle, a method in a crash facility and a virtual crash procedure have been developed.

- The potential impact of pre-crash has been confirmed by bio-mechanical simulations and expert evaluations, considering some promising candidate solutions for passive safety: the availability of pre-crash information makes possible the development of **restraint systems more effective than the state of the art.**

1.3 Approach followed

Chameleon can be seen in the frame of the **integrated safety** approach, linking preventive, active and passive safety, up to rescue functions, as shown schematically in Figure 1

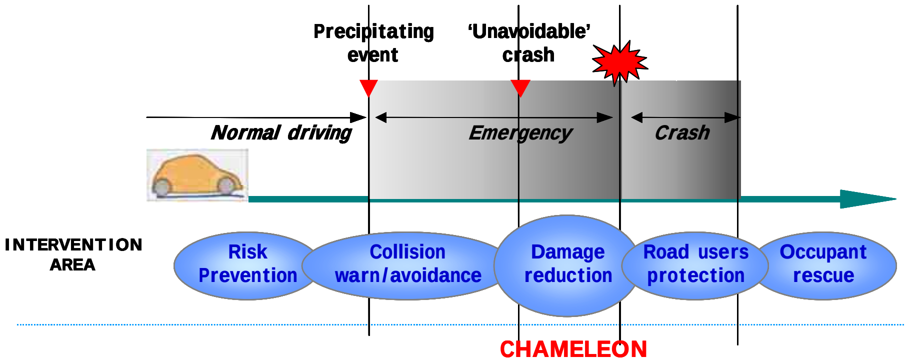

Fig. 1: A frame for Chameleon: integrated safety

It operates when warning and driver support are no more effective, and it anticipates the activation of protection systems, in a synergic progression of intervention levels for overall safety. Therefore the Chameleon system can be linked:

- to preventive safety for the possible share of sensor technologies and for the understanding of the instant when a crash becomes unavoidable;
- to passive safety regarding actuation devices and integrated control logics, including the fire/no-fire decision.

Chameleon system

The approach here outlined is reflected in the general **scheme of the Chameleon system**, shown in Figure 2.

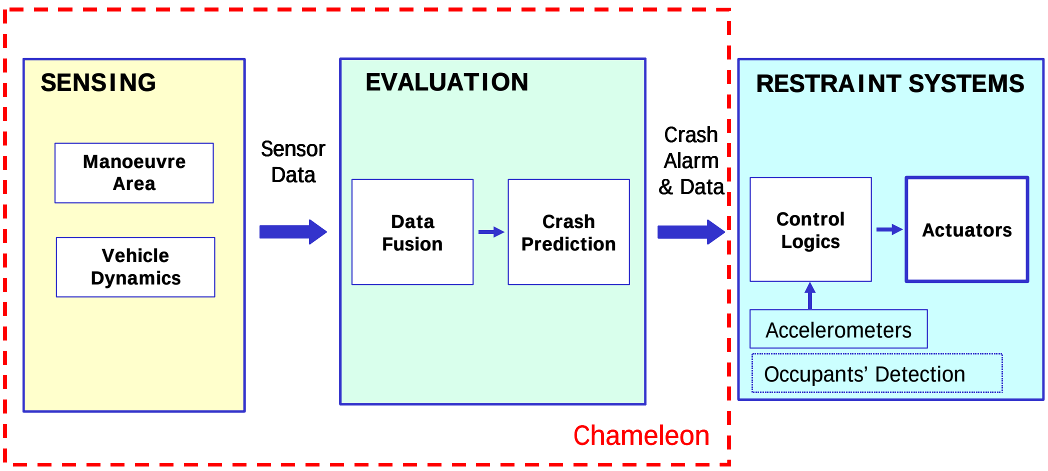

Fig. 2: Scheme for the pre-crash system

The **sensing system** investigated in the project is based on several sensors, from different technologies. The main advantages of this approach are: reliability from multi-detection, different physical characteristics obtained according to the best performances of the technologies (e.g.: distance, speed, object type, object outline), improved accuracy for main parameters.
In addition to sensors for the external environment, the on-board dynamics sensors (based on ESP for example) can provide information about the vehicle behaviour.

The subsequent module of the Chameleon pre-crash system is dedicated to different **processing** tasks. First the module coordinates all sensors in order to have synchronised data, which is necessary to enable a correct reconstruction of the scene.
Then a fusion of information from all the sensors is performed: the system has to select relevant objects, to track their approach, to recognise if they are potentially dangerous. In this step, the system considers the data time histories, and a model of vehicle dynamics, predicts if a crash will occur, and provides parameters relevant for the optimisation of intelligent passive safety systems.

Two approaches have been followed in Chameleon:
- A **single sensor based** system, using data from the scan laser (Eicas approach)
- A **multisensor based** system, checking crash predictions gained from all the sensors (IKA approach)

The following parameters have been defined in the Chameleon project as the relevant **outputs from the pre-crash system**:
crash alarm flag,
- time to crash,
- impact relative speed,
- impact location and angle,
- object type.

A time of at least 100 ms before the crash has been chosen to deliver these outputs.

This last value regarding the required advance time is obtained considering from one side the characteristics of reversible restraint systems, like electrically actuated seat-belt pre-tensioners, from the other side the desired reliability of the prediction. Higher times could be needed, depending on the specific actuators.

Chameleon evaluation

The system previously defined has been implemented in a **demonstrator vehicle**, as a basic tool for the evaluation phase at the technical level (Figure 3).

Therefore - by means of the demonstrator, the simulation tools, and a general analysis of deployment issues - the evaluation procedure in Chameleon has addressed the following aspects:
- Technical and functional tests
- Evaluation of impact on safety
- Evaluation of legal and standard issues

Concerning the **technical evaluation**, besides testing the performances of all the sensors singularly, the Chameleon vehicle has been the object of a hard and complete set of experiments:

both approaches have been investigated (single sensor and multi sensor based) with the double objective to test pre-crash performance and to collect information useful to improve the system.

Fig. 3 : Chameleon demonstrator

Several tests sessions have been conducted, often with original non-destructive methodologies to test crash or quasi-crash conditions, that can be classified in the following categories:

- basic requirement tests on sensors and their compliance with specifications;
- manoeuvres involving the Chameleon vehicle and an obstacle in the sensor field of view, with no crash (track tests);
- manoeuvres with the test vehicle and the dummy obstacle: collisions and near-miss situations (track tests, see Figure 4);
- situations almost coming to an accident in a crash test facility with very high decelerations (Figure 5);
- Driving in public roads with ordinary traffic, especially to check the false alarm rates.

A total of more than 900 test runs and hours of road tests have been carried out.

In addition, a useful evaluation of the crash prediction SW has been possible in a **virtual environment**, where the same data recorded during the tests have been used as an input, but the geometry of the vehicle and sensors has been artificially changed (introducing a displacement of the sensor position) to simulate in the computer different kinds of crash conditions (Figure 6).

Fig. 4:Example of a test with the dummy obstacle

Fig. 5: Example of a test in the 'quasi-crash' scenario

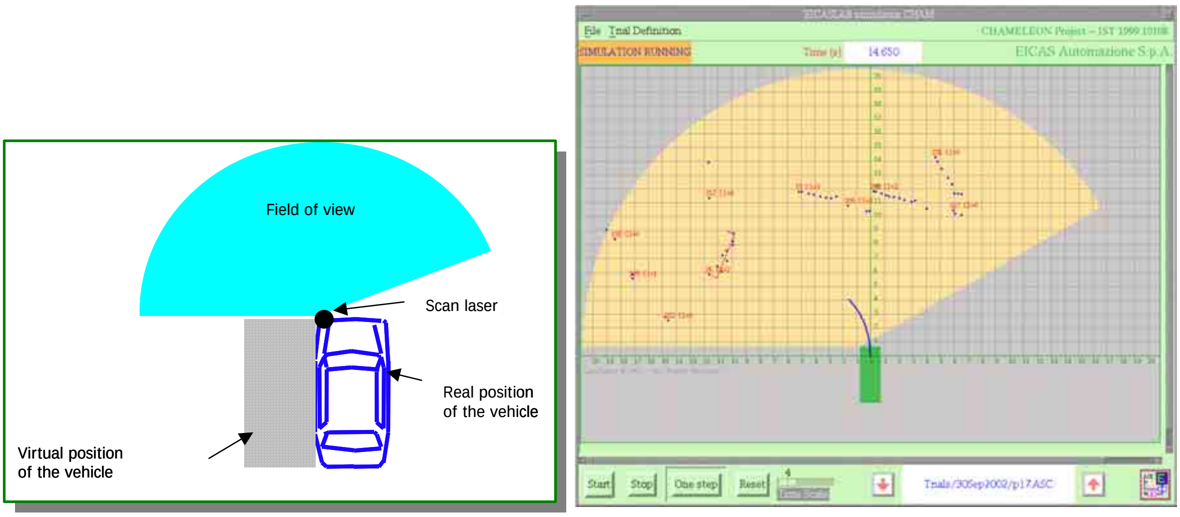

Fig. 6: Scheme and graphical output from the virtual simulation based on real data

With a study on the **safety impact**, the project has addressed how future restraint systems can make use of the pre-crash information.
Biomechanical simulations of the body movements, have permitted to compare a vehicle without pre-crash and a vehicle with pre-crash; different possible applications on intelligent restraint systems have been ranked by a panel of experts in preventive and passive safety using a structured format questionnaire.

These results have also been used for a cost-benefit analysis, based on estimates of the pre-crash effectiveness, accident statistics and injury risk criteria, plus literature data on the comprehensive costs resulting from road accidents.

The evaluation of **legal and standard issues** included a risk analysis, applying a FMEA process and ranking several possible system failures in term of estimated frequency, severity and possibility of detection. Certification procedures have been studied and some experimental methods to set-up the software and system dependability have been developed and applied during the set-up process. First recommendations for the ISO standardisation of Pre-crash applications have been derived.

1.4 Consortium composition and roles

The consortium includes five car manufacturers (FIAT, PEUGEOT/CITROEN, RENAULT, PORSCHE, VOLVO CAR) five sensor suppliers (TEMIC, IBEO, SAAB, THALES, TAMAM,), one engineering company (EICAS), two research institutes (IKA, CSST). The following table shows the main roles of the partners in the project:

Partner	Short name / Country		Main role
Centro Ricerche Fiat S.C.p.A.	CRF	I	Demonstrator vehicle and test sessions; contribution to system definition and impact assessment; project coordination
Conti Temic Microelectronic GmbH	TEMIC	D	Multi-beam laser technology; study of links with preventive safety
Peugeot Citroen Automobile	PCA	F	Definition of system concept and requirements; contribution to assessment
Thales Systèmes Aéroportés S.A.	Thales	F	77Ghz radar module technology
Volvo Car Corporation	Volvo Car	S	Contributions to system definition, evaluation and data analysis
Porsche AG	Porsche	D	Contribution to system definition and impact assessment
Regienov Renault Recherche Innovation	Renault	F	Contribution to system definition and assessment of sensor technologies
IBEO Automobile Sensor GmbH	IBEO	D	Laser scanner technology
Saab Bofors Dynamics AB	SAAB	S	24 Ghz radar module technology
EICAS Automazione S.p.A.	EICAS	I	Simulation tool for pre-crash and crash prediction SW based on scan laser
Institut fuer Kraftfahrwesen Aachen	IKA	D	Testing procedures and test sessions; SW for data fusion based on multiple sensors
Centro Studi sui Sistemi di Trasporto S.p.A.	CSST	I	Dummy obstacle; coordination of the assessment phase
Israel Aircraft Industries – TAMAN Division	TAMAN	IL	Vision system technology

2. Project Results and Achievements

2.1 System concept and road map

The system concept shown in chapter 1.3 is a general scheme, which can be fitted to different applications, depending on the type of passive safety devices and their control logics.
The Chameleon work allowed defining a road map of specific Pre-crash applications, which is here outlined (Figure 7).

Four main steps can be identified, as shown in Figure 7 and described in the following. They involve a progressive improvement in the capability of situation capture by the sensorial system.

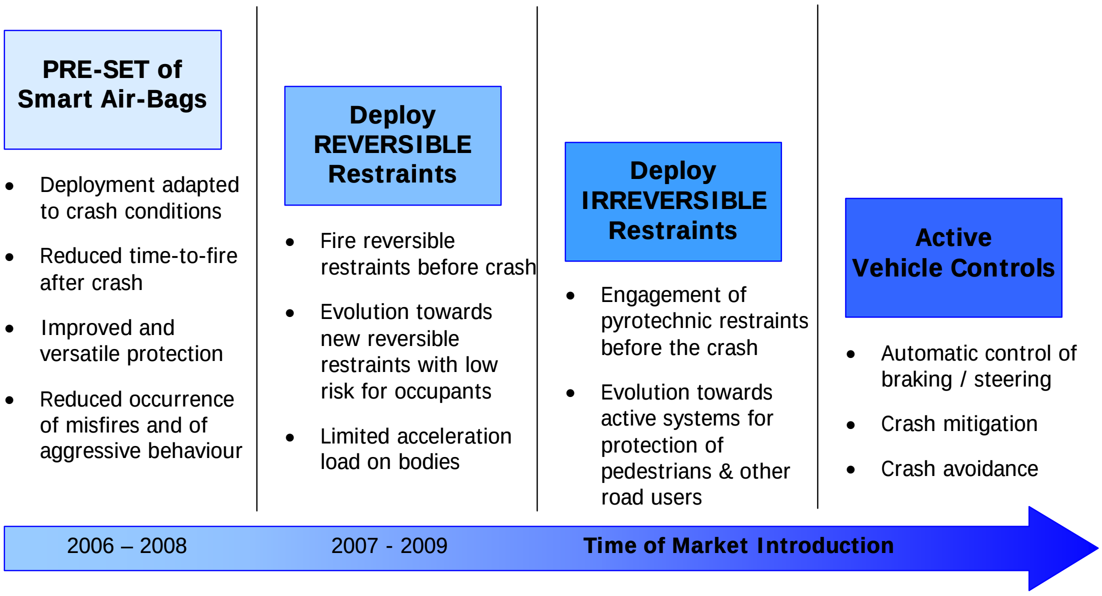

Fig. 7: Evolution of Pre-crash applications

Pre-set of smart air-bags:

<u>Function</u>

For this function, the Pre-crash information is used to tune in advance (e.g. 20-30 ms) parameters of the control algorithm for air-bags activation. Accelerometer data during the crash complement the Pre-crash data and remain the final input for the fire/no-fire decision, to maintain a good safety margin, especially regarding possible false alarms. However the Pre-crash system allows to adapt the type of intervention to the expected characteristics of the crash, measured by the external sensors (e.g. seriousness, impact zone, type of obstacle,…). This aspect complements schemes already existing, where the air-bag firing is adapted to the characteristics of the occupants, measured by sensors in the internal compartment (passengers detection, passenger classification, out-of-position detection, etc.)
In addition, the Pre-crash data can be used to reduce the time needed for the fire decision, by modifying the processing of acceleration signals. This assumes that it is possible to reduce, only for a short time interval just before the expected crash, the robustness against possible misuses.
All these capabilities can increase the performance of existing passive safety systems, in term of more accurate timing of air-bag deployment, activation of devices more suitable for the situation, lower frequency of misfires and reduction of aggressive behaviour.

Actuation:
Some basic actuation devices for this function are therefore: multiple and selectable air-bags, Dual / Multi-stage bags with controllable energy level, adaptive load limiters.

Sensing:
Sensing could involve a platform based on radar or laser technologies with a short range (15-20 m) and large field of view, able to detect the frontal area. In a second phase an additional vision system can be included to classify the objects.

Activate reversible restraints

For this function, the Pre-crash information is used to fire reversible restraints before the crash.
The use of reversible passive safety components with a low risk of injury for the occupants is therefore necessary, since the activation is only based in this case on data from the Pre-crash system. Progress in these technologies can be expected from present trends regarding e.g. seat-belt systems, advanced seats, steering column, child restraints, etc.
This functionality involves additional difficulties with respect to the previous step, mainly related to two aspects: the lower acceptance of false alarms and the longer time interval needed between the information and the crash, to allow the execution of a reversible actuation (this parameter depends on the specific device, with typical values in the range 100-500ms). Accordingly, developments in sensorial and actuation technologies are required.

Actuation:
The main actuation devices to be considered are, in a first phase, electro-magnetic belt pre-tensioners. A second step, still requiring further developments, and investigations especially for user acceptance, could include moving parts in the seat or in the steering column, active knee bolsters, extendable bumpers.

Sensing:
The sensorial platform is an evolution of the previous configuration, with improved accuracy and look-ahead time. A range up to 40-60m is considered, to assure proper recognition of the obstacles and their trajectories.

Activate irreversible restraints

As a further step in the evolution, the Pre-crash information could be used to anticipate the activation of irreversible restraint systems. This functionality is considered only for a long term exploitation, since the reliability of sensorial information must be considerably improved with respect to present performances.

Actuation:
Irreversible restraints include the standard systems already in use for passenger protection. Other active components are considered at research level.

Sensing:
The sensorial platform is characterised by a very high reliability, with a somehow lower look ahead time acceptable, compared to the reversible restraints.

Active vehicle controls

Background:

It is known from accident analysis and statistical data, that in several situations there was no avoidance manoeuvre by the driver. Therefore the possibility that an automatic system takes over the control of vehicle dynamics in emergency situations is being considered, as a means to mitigate the crash severity or even avoid the occurrence of the accident.

In this case, the Pre-crash data are needed to assure that the automatic intervention is suitable and safe in the specific traffic situation. This involves a model for the definition of escape strategies (e.g. emergency braking, obstacle avoidance, etc.) when it is recognised that the driver is definitely unable to cope with the situation.

Important issues have to be considered for this function, like safety in all circumstances, possible false alarms, integration of automatic and human control, liability. These considerations require a very complete and robust monitoring of the surrounding area and a reliable evaluation of the situation, including dynamics of the equipped vehicle, dynamics of other objects all around (not only close to the equipped vehicle) as well as an understanding of driver behaviour.

Therefore the use of Pre-crash systems for Active vehicle controls can be considered today only as a goal for on-going developments. Nevertheless, some partial implementations can be foreseen in a shorter time frame, like for instance a Brake Assist function, where the driver, as described in the following, starts the action.

Function (Brake Assist with Pre-crash):

In a conventional Brake Assist, a greater braking force is provided by an automatic system when the brake pedal has been depressed rapidly. On the contrary, a Brake Assist system coupled to Pre-crash information, can improve this function, activating the brake immediately, as soon as the driver steps on the pedal, and independently from his/her modality of intervention. This can give a safety effect, by reducing the collision speed in all the cases where the intervention on the brakes had not been appropriate.

Sensing:

The sensorial platform considered (for the Brake Assist case) is the same as in the case of reversible systems, with capability to handle more complex scenarios, and with lower look ahead times acceptable.

Actuation:

The actuation device can be a mechanical or electro-hydraulic booster to generate extra pressure in the braking system circuit.

Evolution of general sensors characteristics

A schematic picture to represent in general terms the evolution of sensorial requirements is shown in Figure 8.

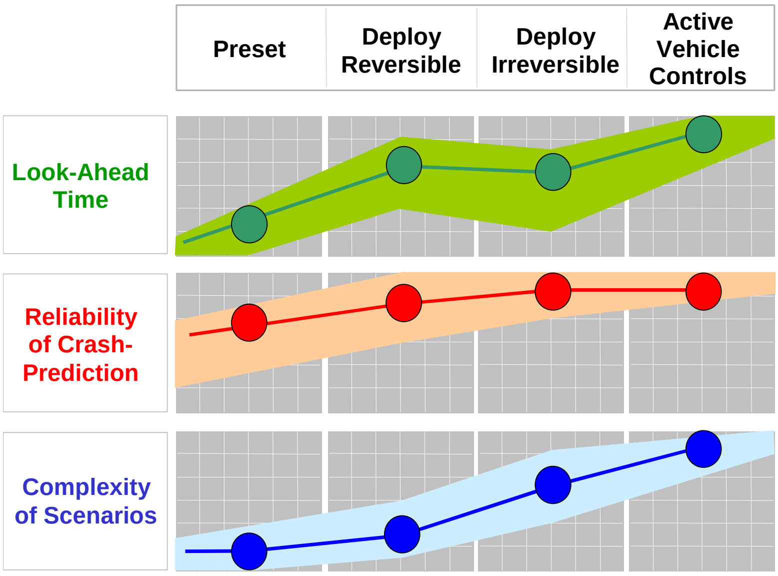

Fig. 8: Characteristics of sensorial system for Pre-crash

The following categories are considered:

- **Look-ahead time:** this parameter describes the time before the crash when data should be supplied to the restraint systems. Starting from short times for the presetting of smart airbags, the activation of reversible restraints requires time intervals of around 100 ms, depending on the actuator characteristics. For irreversible restraints it is slightly less than for reversible – in favour of increased reliability. The effectiveness of active vehicle controls grows with high look-ahead time. The look-ahead time is also reflected in the longitudinal sensor range.
- The **Reliability of crash prediction** is linked to the tolerable level of false alarms, which increases from a Pre-set function to a reversible system, and especially to an irreversible system. In case of missed alarm, the traditional passive safety system still operates.
- **Handling of complex scenarios**: The higher demands for intelligence and reliability, the more complex scenarios and the more different objects have to be handled by the sensorial system.

For scenarios of high complexity, **object classification** is considered a necessary feature. Activation of the restraints can be tuned according to the type of obstacle involved in the collision.

2.2 Advanced sensorial solutions for pre-crash

A description of the main characteristics and innovations obtained in Chameleon for the different sensor technologies is given in the following paragraphs. For reference, a picture of the areas covered in the demonstrator vehicle can be found in Figure 9.

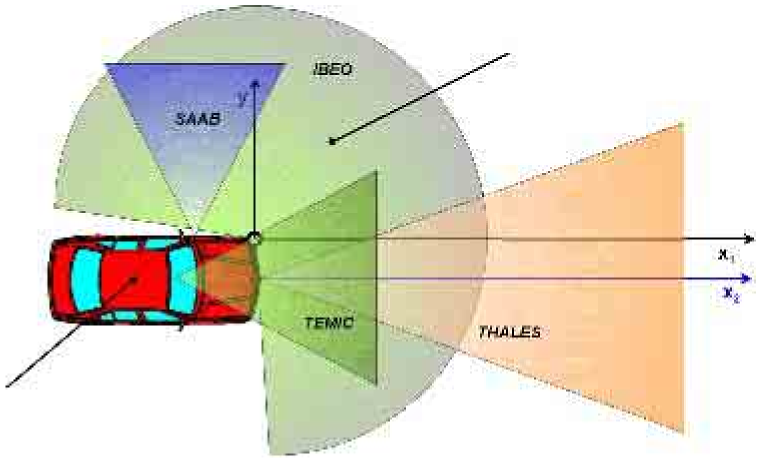

Fig.9 : Field of view of the sensors in the demonstrator vehicle

Multi-beam laser

The Conti-Temic multi-beam laser sensor was especially developed to provide **high data rates**. Size and sensitivity have been a specific subject of work in the project, to meet the functional requirements.
The sensor operates in the near infrared range. It is characterised by a three channel set-up covering a horizontal range of 3 x 15° and a vertical range of 12°. It employs a time-of-flight evaluation of pulsed laser beams received from a PIN diode detector module, to obtain obstacle ranging for each channel. From this, the sensor also computes the relative speed.
The distance measurement domain is at present 0,5 - 10 m, while the speed domain is from 5 to 150 km/h. A Can interface is provided for communication.

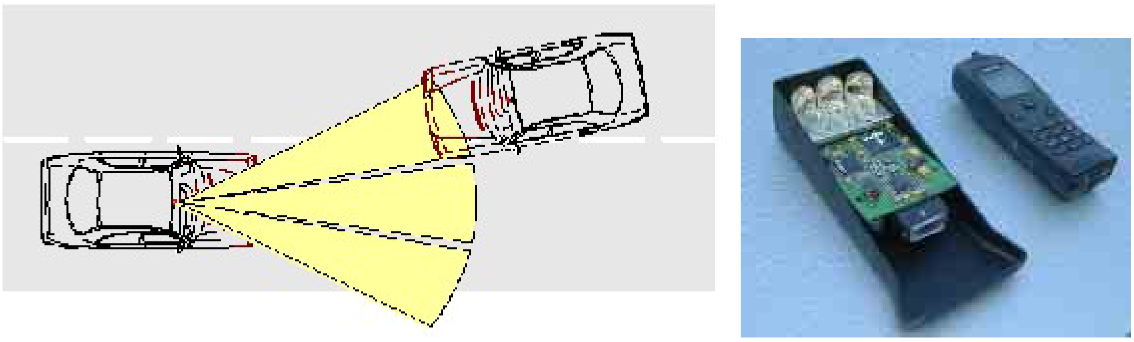

Fig. 10: Conti-Temic multi-beam laser sensor

The device is realised in a single and compact unit, to reduce costs of the sensor (as well as of mounting and wiring). No movable parts are present, in order to support high automotive lifetime and quality standards.
The sensor is typically located behind the windscreen. This allows cleaning of the view area by the wiper. A windscreen transmission of at least 70% for the wavelength range 850...1000 nm is required for the present prototype.

The partner Conti-Temic is continuing specific developments and will focus additional work on improved range, maintaining the laser class 1 eye-safety requirements.

24 Ghz Short range radar

The SAAB short range radar sensor is a wide beam pulse modulated radar operating in the 24 GHz band. The project has been focused on **advancements in the processing schemes.**
The horizontal field of view is 100° and the vertical is ±10°. The active range is 0,5 - 10,5 m (with a maximum range of 20 m) and the scan rate can reach a maximum of 100 Hz with this active range. The distance accuracy is ± 0,1 m. The relative speed range is 15 - 100 km/h with a speed accuracy of ±10%. Multi target tracking is possible up to 4 objects.
The dimensions are: width: 117 mm, height: 83 mm, depth: 38 mm.

Fig.11: Saab 24 Ghz radar module

The pre-crash radar sensor is available as a prototype. The partner Saab-Bofors is expecting a use of this technology for multiple functions, like pedestrian protection, blind spot detection, stop& go, short distance cut-in, etc.
It should be pointed out the 24 GHz wide band sensors are approved in the US, but not yet approved in Europe.

76-77 GHz Radar Sensor

The work on the Thales short/medium range radar sensor has been guided by the idea of creating a **complementary sensor to the long range ACC device**, in order to extend the functionalities to enhanced ACC and pre-crash.
The device is operating in the 76-77GHz band. Its field of view has been enlarged up to approximately +/- 30° in order to cover the front of the car.
The detection distance is up to 40m in the radar axis, with an accuracy of ±5%. The speed domain is ± 180 km/h with an accuracy of ± 0,5 km/h.

The basic principle of this radar is monopulse FSK (frequency shift keying). That means that :

- It transmits a continuous waveform which is modulated with periodic frequency steps
- The antenna has an elliptical shape which provides the expected field of view in azimuth and approximately 7° in elevation
- The detection and target separation is based on the target relative speed measured through a spectral analysis of the received signals

- The azimuth measurement is given by the exploitation of the ratio of the power received in the sum and delta channels of the receiving chains.
- The detected objects are tracked; up to 20 can be tracked simultaneously.
- The tracks information are reported on the CAN bus

Fig. 12: Short/medium range radar sensor

This kind of radar is fully compliant with the current standard EN 301 091
The current demonstrator is fitted within 2 boxes, the first containing the transmitter/reveiver functions as well as the antenna, and the second containing the digital architecture able to perform the adapted signal processing and data processing.
Once designed the future product could fit in a single box not larger than 90x90x50 mm easy to integrate in the front face of a car.

The Thales short/medium range sensor is currently in the A phase of development (concept samples). The test phase of Chameleon helped to identify some situations where the radar operation should be improved: complex target shapes (the brightest point might not be the closest) and flat surfaces (a kind of mirror effect might induce some erratic measurements). The following phases (product definition and industrialisation) are conditioned to a customer response.

Pre-crash laser scanner

The relevant focus for the work on the IBEO laser scanner has been to obtain **precise and complete profiles** of the surrounding scene, giving a large amount of information useful for pre-crash processing. In the Chameleon project, a fixed scan frequency of 40 Hz and a fixed angle resolution of 1,0° have been obtained. The horizontal field of view is up to 270° and the radial detection range up to 20 m. The sensor describes an object by the visible outline and the relative movement. The processor calculates the movement of colliding objects, relative to the host vehicle, in both longitudinal and lateral directions.

These technical characteristics make the laser scanner useful for object detection in the near field, while mounted for instance at the corner of a vehicle. Wide objects can be detected and tracked as well as small objects like lampposts. Specific software developments allowed to track fast moving obstacles even in the lateral side.
Multiple objects in the field of view are tracked independently and their data are transmitted to the CAN bus. Another relevant feature is that the laser scanner is able to refer to a timestamp, to support a fusion of the detected objects with other sensor technologies.

A picture of the laser scanner prototype is shown in Figure 13.

Fig. 13: Prototype of laser scanner for scene profiling

The project demonstrated the following advantages of the scanning technology for pre-crash applications:

- Wide horizontal field of view
- Detailed outline description of each object
- Precise distance measurement
- Accurate relative object speed (longitudinal and lateral)
- Possibility to elaborate object profiles for a classification of the objects

The laser scanner has been developed in Chameleon at prototype level for pre-crash application: IBEO already started new development programs, together with an automotive system supplier, with the aim to reduce the size of the component, and to integrate the sensor into the vehicle, taking into account the design of the vehicle. All the relevant optical, mechanical and electronic technologies are mastered in cooperation with the partner.

Active stereoscopic video sensor

The video sensor has been especially dedicated in Chameleon to the task of **object classification.** However, additional features for object detection have been obtained as described in the following.

The Active Video Sensor developed by Tamam includes a Xenon strobe lamp with near IR filter and a pair of CCD cameras, installed on the both sides of the Xenon lamp. The integration time of each camera is coupled to the strobe start and duration.

The sensor detects vehicles on the road and computes their angular positions and distances in real time. The unique, strong reflectivity of the license plate is used for preliminary detection of vehicles, while contour ratio is used to classify type of vehicle (such as car, van, truck). The sensor module can be used for detection and classification of other obstacles provided these obstacles pass a threshold with minimum required reflectivity and typical pattern (such as pole, wall etc.)

An Active Image Sensor that includes a Xenon strobe lamp is more complicated compared to a passive camera concept, however it has several advantages:

- The performance of the sensor does not depend on light conditions due to utilization of synchronized Xenon strobe light and spectral and temporal filters.

- The strong dependency of reflected energy on the distance to objects of interest enables filtering out objects outside the region interests, to simplify the detection & classification algorithm.
- The algorithm is simple due to the use of xenon lamp and optical filters, enabling real time processing in a low cost processor.
- Using of two cameras in stereo pair configuration together with the detection of vehicle license plates, permits determination of both direction and distance to the vehicle.
- Using an invisible wavelength (NIR) enables using a high power illumination, with no disturbance to drivers.
- Synchronized short pulses illuminator is used to avoid interference between similar systems.

Fig. 14: Prototype of the video sensor

The sensor is in the development stage. A prototype has been realised and tested, obtaining good experimental results. Further tests in various conditions are required.

The two core components, camera and processor are both fast progressing technologies. A considerable number of mass production applications are pushing performance up and price down. Such a trend will enable a compact, low cost component to be used for car safety application.
The Xenon strobe lamp with its linked electronics shall be developed to enable a low cost, compact package, to be installed as part of the vehicle headlights assembly.
The same Active Image Stereoscopic Sensor system that is used for the Chameleon application can be extended to be used for other applications, such as a pedestrian detection, Advanced Cruise Control including Stop and Go mode, Lane Keeping etc.

2.3 Crash prediction algorithm

The single sensor based system

The obstacle detection sensor considered by the EICAS crash prediction SW is the laser scanner, which is mounted in the front left corner of the demonstrator car. Signals from the dynamic sensors on the equipped vehicle (speed, yaw rate) are also taken into account.

Two software modules are installed in the subsequent processing unit:
The first module is a data collection SW developed by CRF to read, adapt and synchronize al the data on the CAN bus.

The second module is the crash prediction SW developed by EICAS, which computes the future trajectories of all the obstacles in the field of view in a stated horizon (up to 1 second), and checks if the crash prediction exceeds a given level of risk, defined for the present study as follows: 1 false alarm per 1000 dangerous condition events, 1 missed alarm per 1000 serious crash events.
If appropriate, the module provides an alarm, together with the output data defined in Chameleon: time to impact, impact speed and position, object classification (see Figure 15).

Input:

Scanlaser sensor measurements
Chameleon longitudinal speed
Chameleon yaw rate

➔ **Chameleon pre-crash computation unit** ➔

Output:

- Alarm no
- Alarm Yes:

  Time to impact
  Impact speed and location
  Object classification

Fig. 15: The general framework of the prediction algorithm

The methodological approach followed in the algorithm uses a sophisticated estimation method based on state equations dynamic models and also takes into account the measurements errors and the model uncertainty.

The choice of the scan laser sensor has been motivated by a theoretical study developed by EICAS, whose conclusions, supported by numerical simulations, are presented in the Deliverable D3.3: "Sensor Fusion Description: Hardware and Software Level". A basic aspect is the unique capability of the sensor to provide at least three obstacle points.

A further relevant feature of the SW is the capability to elaborate the measurements (by a so called slow motion view) and especially to check the crash prediction performance using real recorded sensor data but only simulating a crash by an artificial displacement of the equipped car (virtual crash).

The multi sensors based system

The crash prediction module developed by IKA makes use of data from all the sensors on the demonstrator car described in chapter 2.2, coupled to information on vehicle dynamics.
The main target of this approach has been to enable a sensor and data fusion for the detected objects. A related target has been to check the feasibility of a processing based on radar detection, which is less accurate in position data, but more common in the automotive field up to now. The activity has been aimed to exploit the strengths of each sensor and to achieve a system with a maximum of robustness and efficiency. Further it has been focused on the development of a hardware independent algorithm.

Common understanding of a sensor or data fusion is to take the data of several different sensors and merge their information, to generate a more complete view of the surveyed environment. Moreover, the data fusion allows the implementation of algorithms less dependent on the sensor performance. It is generally agreed that this fusion should be done at a very early state, based on object data from each sensor. An early data fusion for example is mandatory if a high level of information detail is required or if differentiated conclusions are derived from the sensor data. The same amount of data with a comparable accuracy and robustness from all fused sensors is therefore required.

In opposition to these types of applications, the basic requirement of the algorithm in the case of Chameleon is a rather binary decision, predicting whether there will be a crash or not. Besides this, a fast and robust processing is required. These considerations have been considered during the project; additionally, the minor overlap of the areas covered by the different sensors and some limited reliability of the object histories made clear in the experimental phase that an early data fusion would not be realizable in a sensible way.

In fact for the Chameleon application only the approach of a late data fusion leads to success. This late data fusion is a one-dimensional fusion of the crash probability, calculated by each sensor as single state machines. It is based on the same physical output from each sensor and on the fact that the crash information is a binary decision. Therefore fast and robust crash prediction algorithms for each sensor have been developed, which are optimally adapted to the characteristics and strengths of each sensor. After this, the crash data are merged and a general crash warning is delivered, according to the software structure shown in Figure 16.

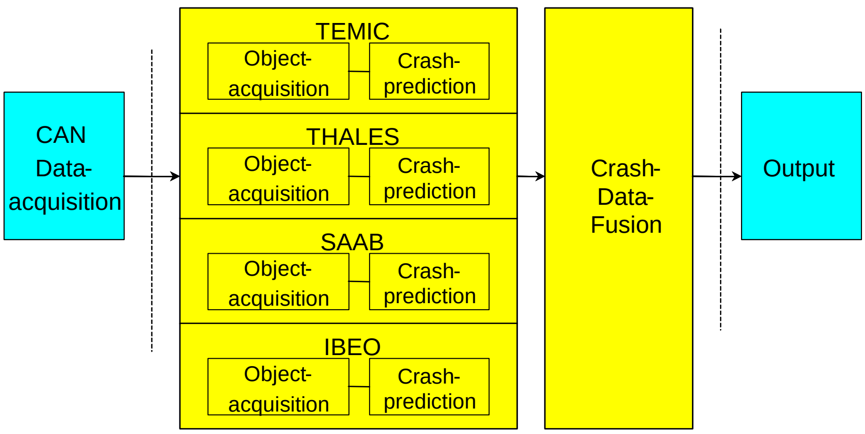

Fig. 16: Scheme of the crash data fusion SW

The object acquisition and crash prediction modules are tuned to the specific characteristics of each sensor. The algorithms should be fast because long calculation time would lead to a later recognition of a crash relevant situation. The algorithms should be robust because the sensors not always deliver consistent information about the detected objects.

To satisfy these demands elementary approaches have been chosen and the algorithms use the actually detected situation to generate the crash warning and the related data.

The crash data fusion module follows the presumption that two main scenarios are possible. First scenario is a front crash, second is a side impact. An additional assumption is that always the object with the lowest time to crash is the most relevant. Therefore the crash data fusion module at first assigns the incoming date to one of the possible crash scenarios. The final step is to compare all crash relevant objects that turned up in one sample step in one of the two scenarios by their predicted time to crash and choose the one with the lowest time to crash. This is the most crash relevant object and its crash data is communicated.

The so established algorithm has proved to be very reliable and fail-safe. This means that if a sensor drops out, reliable results are still obtained. This cannot be guaranteed with the attempt of an early data fusion.

2.4 Evaluation of the system effectiveness

Evaluation framework

The evaluation process in Chameleon has given emphasis to the validation and demonstration of technical feasibility of the concept and the prototypes for the Pre-crash application.
The evaluation plan has included different studies and test sessions, mostly related to the technical analysis at both sensor and system level, but also to the impact analysis, and to some legal and institutional issues, as described schematically in Figure 17.

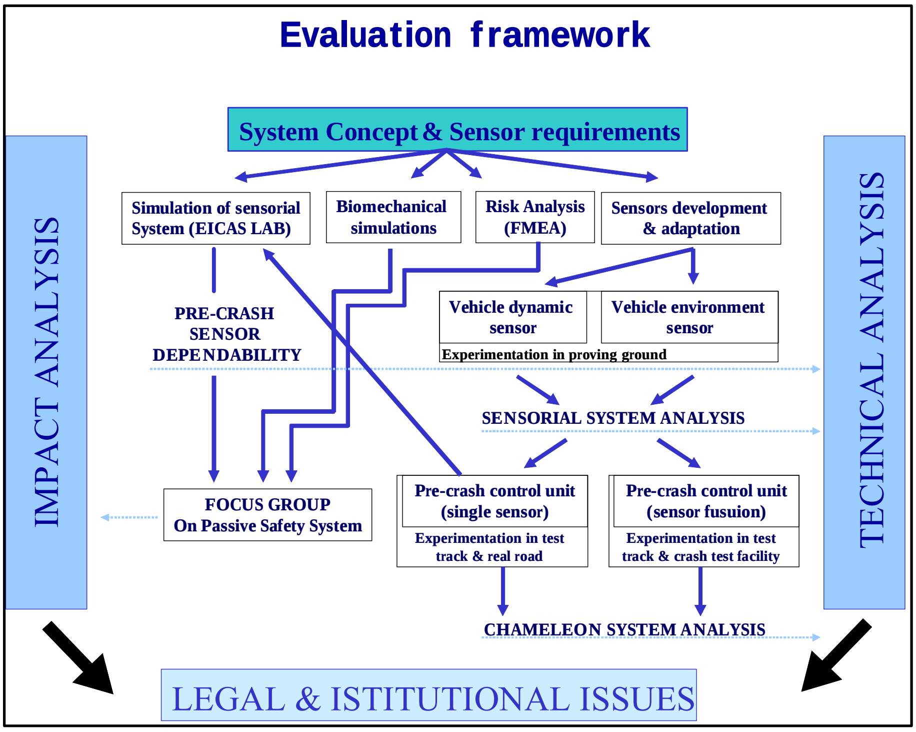

Fig. 17: The evaluation framework in the Chameleon project.

In summary, the main steps have been:
- Experimentation of the sensorial devices developed within the project;
- Experimentation of the demonstrator vehicle developed in the project in different suitable test sites;
- Simulation and expert analysis of the passive safety concepts which can make use of Pre-crash data;
- Safety and Risk analysis.

The evaluation results are summarised in the following paragraphs, considering the single sensor based system, the multi sensor based system, the video based system and the overall simulation with an analysis of occupant protection.

Experimentation of the single sensor based system

The experiments based on the single sensor approach, described in this paragraph, involve the EICAS processing software and obstacle detection based on the laser scanner from IBEO.
The specific goals of these experiments have been:

- To assess the performance in several dangerous situations reproduced in the track, especially verifying the false alarm levels;
- To assess the missing alarm level and the quality of the Chameleon outputs (time to impact, speed, position) in real crashes against a dummy vehicle;
- To assess the false alarms in real traffic conditions, in urban, extra-urban and motorway scenarios;
- To further check the data fusion and crash prediction algorithm using the recorded data by the off-line and the virtual crash analysis.
- To obtain indications on the potentiality of the laser scanner, which is more precise compared to the microwave sensors, but at the moment not diffused (and less experienced) on commercial automotive applications.

The tests have been performed in the "FIAT Centro di Sicurezza" track, and in public roads on a circuit of around 106 Km in and around Torino.
A summary of the tests performed is shown in the following table:

Main characteristics of the tests performed with the single sensor system

	Test Site	Situation	Obstacle	Nr. of tests	Main variables	Notes
1	Track	Dangerous situations	Vehicle: car, truck (3 cases with pedestrians)	54	Obstacle moving or fixed; Test vehicle moving or fixed; Different manoeuvres including several near-misses;	Most situations chosen to allow the virtual crash analysis; Speeds up to 90+ 90 km/h;
2	Track	Crashes or near-misses	Dummy vehicle	32	Approach with different offsets; Orientation of the obstacle; Braking;	Reproduction of dangerous situations: impact speeds: 20-30 km/h;
3	Road	Driving in Ordinary traffic	Traffic and infrastructures	21	Scenario: urban, extra urban, motorway; Driving style: normal, aggressive	11 short tests (1-2 min.) 10 long tests (16 -30 min.): average vehicle speeds: – 22 km/h (urban) – 63 km/h (extra-urban) – 105 km/h (motorway)

Regarding the first class of tests, **no false alarm has been found in all the situations**, including several manoeuvres, frequently executed, which could deceive the algorithm due to the occurrence of risky situations. Examples of those manoeuvres have been: pass-by at high speed (up to 90 km-h for both the equipped vehicle and the incoming vehicle); car following at short distance; close crossing of two vehicles with orthogonal trajectories.

In the second class of tests, **a good correspondence** has been found between predicted and real crashes, as shown in the table. No false alarm has been found, including the "offset 90" scenario, characterised by a very close pass-by (Figure 18). A missed alarm has been found in one case out of the six situations, which has been explained by the specific assumptions in the crash prediction algorithm. Moreover, the missed alarm did not result in the off-line processing, which could be processed with a longer time horizon of 1 sec (while the time horizon in the track tests has been 0,5 sec due to limitations in the RAM memory on-board).

Crash predictions:

SCENARIO		**Crash (Yes/Not)**	
		Real	**Prediction**
Approaches with different offsets (*)	Offset 180	N	N
	Offset 90	N	N
	Offset 30	Y	N
	Central	Y	Y
Braking at close distance	Central	N	N
Low speed	Central	Y	Y
Dummy at different angles	Angle 30	Y	Y
	Angle 60	Y	Y
	Angle 90	Y	Y

(*) Offset is the distance between the axis of the dummy and the exterior of left wheels in the test vehicle

Fig. 18: Example of a test with a close pass-by.

The forecasted values in all the tests resulting in a real crash have been quite encouraging.
The **time to impact** has been predicted with advance times in the range from 300 to 400 msec, larger than the Chameleon specifications, and with a maximum error of 33 msec. Larger values have been found in the off-line analysis with a larger time horizon for the prediction algorithm.
The **impact speed** could be predicted with low errors, with one exception due to a wrong object classification.
The **classification of the obstacles**, as well as the **prediction of the position** of the impact, are generally correct.

Predicted time to impact:

SCENARIO		Time to impact (ms)	Error ms	%
Approaches with different offsets	Central	352	-12	-3,40
Low speed	Central	377	7	2,06
Dummy at different angles	Angle 30	302	33	12,12
	Angle 60	377	-20	-5,14
	Angle 90	327	-7	-2,22

Predicted impact speed:

SCENARIO		Speed (m/s)	Average error (m/s)	%
Approaches with different offsets	Central	7,25	0,07	1,0
Low speed	Central	5,0	0	0,0
Dummy at different angles	Angle 30	7,5	- 0,12 (+15,5)	-1,6
	Angle 60	7,5	0,06	0,8
	Angle 90	7,75	- 0,58	-8,1

Predicted class of obstacle (from the scanner data) and impact position:

SCENARIO		Class of obstacle (a)	Impact position (b)
Approaches with different offsets	Central	3	1
Low speed	Central	3	1
Dummy at different angles	Angle 30	3 (2)	2
	Angle 60	3	2
	Angle 90	3	1

(a) 0 = not yet classified; 1= small moving obstacle (point model); 2 = vehicle; 3 = fixed object; 4 = borderline of the field; 5 =: false close object;
(b) 0 = front-right; 1 = front; 2 = front-left; 3 = left.

The results of the tests on public roads in ordinary traffic are summarised in the following table, where the first line refers globally to a series of short tests.
No false alarm has been found in the 11 scenarios covered during the short tests in a small town.
Approximately one false alarm per 5 km on average has been recorded in the long tests, with lower rates in the motorway and extra-urban roads, and an higher rate in the city centre scenario with dense traffic (central area of Torino).
The subjective descriptions of the situations leading to false alarms have indicated that the most frequent conditions leading to an alarm are: evading an obstacle with high lateral acceleration, aggressive overtaking, passing-by another car in the adjacent lane at high speed.

The results in ordinary traffic are considered quite satisfactory at the present stage of development involving prototype systems. Of course important improvements are necessary for a final application. Already the off-line evaluation using a longer time horizon for the crash prediction could provide a very significant improvement.

Results from tests in ordinary traffic

SCENARIO	Length (km)	Time (min)	Av.speed (km/h)	False alarms	
				number	Rate (nr/km)
Small town	6 (tot)	15 (tot)	25	0	0
Motorway	27,5	16	105	3	0,11
Extra-urban A	28,5	26	65	1	0,04
Extra-urban B	28,0	28	59	4	0,14
Urban A	8,0	27	18	12	1,50
Urban B	14,0	32	27	2	0,14
TOTAL	106,0	129	49	22	0,21

The following considerations summarise the outcomes from this experimental phase.

- The analysis of test data has confirmed the theoretical study and the simulations developed in the Chameleon project, for the approach based on the EICAS crash-prediction SW and the IBEO sensor.
- Experiments in the track test-site with various obstacles and with the dummy vehicle have provided satisfactory results, except for some improvements still needed regarding a few missed alarms.
- Preliminary tests in public roads have given the opportunity to evaluate the system in real-world conditions, focusing at this stage on the rate of false alarms in real traffic. Even if this rate is still not suitable for a final product, it is believed that a good level of performance has been reached, considering the complexity of the pre-crash application and the present stage of prototypes. Especially the pre-setting of air bags (the first function in the pre-crash road-map) could tolerate a reasonable level of false alarms, since the final fire/no-fire decision is left to the accelerometers.
- It is appropriate to remark that the tests in real crash scenarios have been performed in a low range of speeds (20-30 km/h). Two main considerations have led to this choice: an ‘a-priory’ analysis based on the performance of the present prototype, and the constraints of the dummy method. Higher speeds (50 km/h) are experimented by means of the crash test facility: more than 90% of the crashes occur at closing speeds smaller than 50 km/h (and 70% for 30 km/h).
- For a full extension to a larger domain of speeds and situations, the sensor technology remains the key aspect. It is believed that a fundamental step would be to increase both the detection range and the scan rate from the present values by a factor 1,5-2, which is considered a feasible development.
- In addition, some areas for improvement of the sensor technology have been identified during the experiments, regarding robustness and reliability according to the automotive specifications, especially the sensitivity to external factors like dirt or bad weather.
- The increase of the time horizon for the crash prediction can also significantly improve the overall system behaviour, as demonstrated in the simulations: no particular difficulty is expected for this implementation.
- Some final remarks on the virtual crash method are of interest.

  Even with the dummy car, some difficulties to reproduce collision situations remain: impact speeds are limited, and the dummy obstacle does not allow to test crashes against moving vehicles. Therefore the experimental data have been used to reproduce virtual collisions, by changing the reference system of the target.

- The virtual crash method has proved to be very powerful and useful, since it allows to verify from in-field data the correct crash predictions even if the experiment was performed without a true crash.
- Actually the Crash Prediction Algorithm has been tuned so that, using a time horizon of one second, in all the recorded experimental trials neither missing nor false alarms have occurred.

Experimentation of the multi sensor based system

The present paragraph describes the experiments regarding the multi sensor approach, based on the IKA software and a fusion of data from different obstacle detection sensors (from TEMIC, THALES, SAAB and IBEO). For a proper characterisation, a first part of the experiments has addressed the performance of each sensor.

The main general goals for this part of the project have been as follows :

- To assess the sensor performance for each device according to the specifications, using standard targets and basic requirement tests;
- To assess the capability of the sensors to detect real vehicles under realistic driving conditions;
- To evaluate crash situations against a real car at higher speeds (up to 50km/h) in a special crash test facility allowing to decelerate and stop the vehicle immediately before a crash;
- To test and optimise the innovative experimental procedures;
- To test and optimise the data fusion algorithm, which is based on a crash prediction given by each sensor;
- To obtain indications on the potentialities of different microwave and multi-beam laser sensors, which are more close to the market compared to the laser scanner, but provide less precise and less complete measurements of position.

The tests have been conducted in the test track and in the crash facility of the University of Aachen (IKA). The Chameleon vehicle and the obstacle vehicle in the crash test facility in a lateral crash situation are shown in Figure 19 (see also Figure 5). A total of more than 900 tests have been executed in the three situations reported in the table:

Main characteristics of the tests performed with the multi sensor system

	Test Site	Situation	Obstacle	Main variables	Notes
1	Track	Sensor tests.	Standard reflectors for radar and laser.	Obstacle characteristics (reflection, cross section) Position of relevant objects; Velocity.	Tests of sensor performance and basic requirements (min. and max. range, coverage area, distance accuracy, velocity accuracy).
2	Track	System tests with approach, near-miss or crash with the dummy.	Car ; Dummy vehicle.	Geometry for approach, crash or pass-by ; Velocity.	Tests addressing especially the detection of real vehicles; Speeds up to 50 km/h.

3	Special Crash test facility.	System tests with crash conditions.	Body of a normal car.	Front and side crashes; Velocity.	Tests up to 50 km/h; Crash would be unavoidable in real world (high deceleration starting 0,8 m from the obstacle); Evaluation of crash prediction.

Fig. 19: Experimentation in the crash test facility

Regarding the basic requirement tests, an example is shown in Figure 20, and the main results are enclosed in the following table. The values in the table demonstrate that in general the sensors meet their specifications. For all sensors the field depth depends on the degree of reflection of the targets and in some cases the maximum distance is reached only when the degree of reflection of the target is high.
The measurement accuracy in distance for all sensors is marginally worse than expected from the specifications. The distance accuracy in the specifications usually is equivalent to the distance resolution. In practical tests the accuracy of the sensors sometimes does not reach the resolution. The velocity accuracy is depending on the reliability of the target detection. Only when the targets are correctly detected for a sufficient period of time, a nearly exact speed measurement is possible.

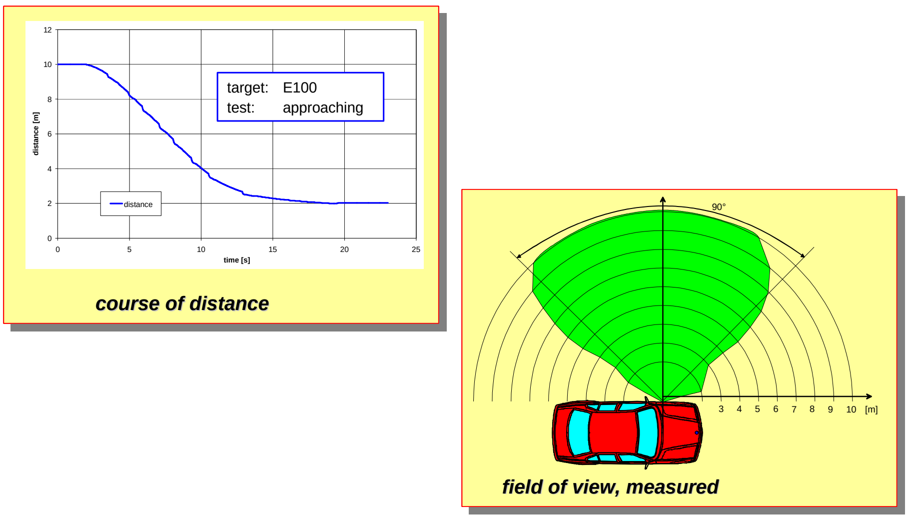

Fig. 20: Example of results for a radar sensor test

Basic requirement tests: measured values

		IBEO	Temic	SAAB	THALES
Aperture angle	spec.	270°	3 x 20 °	100°	60°
	meas.	- [1]	48,2° [2]	100°	63,7°
Field depth	spec.	0,3-20m	0,5-6m	0,5-20m	0-60m
	meas.	0,2->20m	-10m [3]	0,5-10m [4]	-60m [5]
Distance accuracy	spec.	0,05m	0,1m	0,1m	1m, 5%
	meas.	0,15m	0,15m [6]	0,05-0,2m	>1m
Velocity accuracy	spec.	1km/h	10km/h	5%	+/-0,2km/h
	meas.	- [7]	- [7]	- [7]	- [7]

[1] : tuned depending on application
[2] : overlapping beams
[3] : maximum range only with targets of good reflectivity, otherwise down to <4,5m
[4] : maximum range only with targets of good reflectivity, otherwise down to <2,5m
[5] : maximum range only with targets of good reflectivity and increasing distance, otherwise down to <25m
[6] : depending on the distance
[7] : depending on boundary conditions

The experiments in the test track and in the crash test facility have shown that in most cases the vehicle is correctly detected by all the sensors, but some aspects regarding the reliability require attention, as discussed in the following. Examples are shown in Figures 21 and 22.

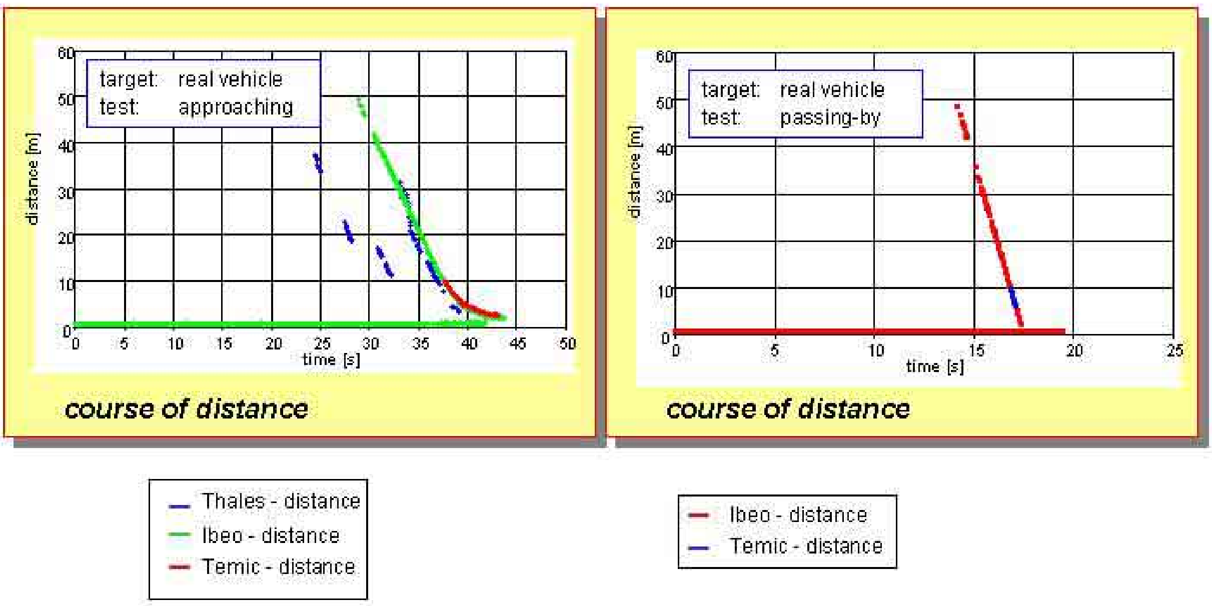

Fig. 21: Tests with a real vehicle in the test track

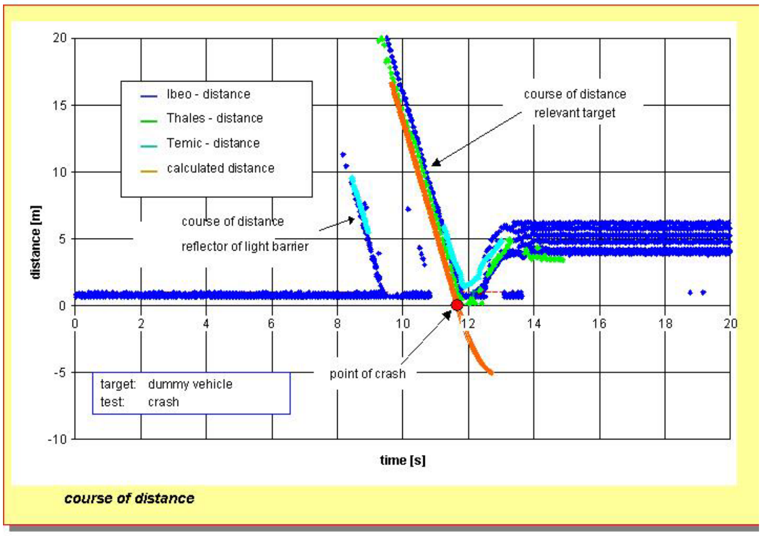

Fig. 22: Tests with the dummy vehicle in the test track

The main conclusions coming from the test phase are as follows:

- the dummy vehicle has provided results quite similar to the real vehicles, showing that it is a suitable tool for system evaluation.

- test results have demonstrated that the procedures developed in Chameleon are a powerful tool in the frame of pre-crash analysis. In particular, the methods, which have been set-up in the crash facility can reproduce an accident which would be absolutely unavoidable in the real world (deceleration starting at 0,8 meters from the obstacle).

- While all the simple situations have provided a general frame for the pre-crash evaluation, some caution has to be taken regarding the variety of real world situations. Actually, in some cases real traffic objects have shown particular reflection properties that can cause unwanted effects in the detection behaviour, or can limit the area covered by the sensor in range or in angle. For example the target detection can have drop-outs in the approach phase, or the distance accuracy can decrease at high velocity. In a few tests, additional difficulties have been found in the near field since the obstacle has been lost. In the test facility at high velocity, the speed signal needs some time to reach the correct value in the vary last milliseconds before the crash. This can induce of course difficulties for the subsequent crash prediction.

- Taking into consideration that the multi-sensor crash prediction module is depending on a good position and speed information to properly deliver its outputs, it turns out that the reliability of the sensor signals has to be improved. The accuracy of the sensorial system is very promising, whereas the robustness of the object detection needs further developments. This is related to the requirements of the pre-crash function, which are rather stringent in term of faultless object information under all conditions.

The results of the tests regarding the SW for crash prediction with the multi sensor system are summarized in Figure 23. The considerations given in chapter 2.3 have been confirmed by the data, with the additional indication that the crash prediction does not behave properly when the sensors provide data of limited quality.

	Detection Rate	Missed Alarms	False Alarms	Time to crash (estimated)	Time to crash (measured)	Impact speed (estimated)	impact speed (measured)
Temic Crash Prediction	1/1	0/1	4/14	530 ms	620 ms	6.19 m/s	8.25 m/s
Thales Crash Prediction	3/3	0/3	0/6	525 ms	410 ms	7.4 m/s	8.25 m/s
				480 ms	-	9.0 m/s	12.8 m/s
				525 ms	-	9.0 m/s	13.4 m/s
Ibeo Crash Prediction	1/1	0/1	0/5	420 ms	430 ms	2.5 m/s	8.25 m/s
Saab Crash Prediction	4/4	0/4	0/0	530 ms	340 ms	3.6 m/s	3.19 m/s
				535 ms	450 ms	4.4 m/s	5.5 m/s
				520 ms	530 ms	8.7 m/s	9.7 m/s
				530 ms	500 ms	9.1 m/s	9.7 m/s
Crash Data Fusion	7/7	0/7	4/14	∅ 480 ms	∅ 468 ms		

Fig. 23: Summary of results from Crash Prediction tests

Experimentation of the video sensor

Experiments with the video based system have been performed separately, due to the project schedule and the modification of the originally planned approach based on the spectral analysis, which provided insufficient performance. The passive multi-spectral concept was tested at TAMAM site during the second year of the Chameleon project, and found to be too sensitive to the environmental lighting conditions.
The Active Video Sensor developed in the third year (and described in chapter 2.2) has been tested at the TAMAM site, as well as at the IKA test site. These tests have shown that the previous difficulties could be overcome.

The main goals of these experiments have been:

- To evaluate the capability of the system to detect objects in real road scenarios;
- To evaluate the capability to classify the object types and the respective range;
- To verify the measurements of object position in distance and angle.

Main characteristics of the tests performed with the video based system

	Test Site	Situation	Obstacle	Main variables	Notes
1	External areas	Road (or parking area) scenes; Sensor on fixed mounting.	Vehicles (Cars, trucks, vans); Fixed obstacles (walls, poles).	Obstacle positions; Vehicle characteristics (e.g. colour); Vehicle dynamics: External lighting conditions.	Tests have been focused on the SW for image processing. Synchronised illumination has been used.

The main results from the experiments have been the following:

- From an analysis of the video imagines it has been decided to detect, as a relevant part of the vehicle, the shape and reflectance characteristics of the vehicle plate. For future applications, the opportunity to use other vehicle part will be explored;
- The license plate has been detected up to 20 meters, and used to correctly identify a vehicle; other objects have been detected up to 8 meters;
- The detection of the contour of a vehicle depends on its reflectivity and colour. The worst case has been found to be 7 meters for a dark vehicle. At that range a classification of the type of vehicle has been proved: car, van, or truck;
- A specific analysis allowed to estimate a significant increase of these distances (almost to 120 meters for identification and 30 meters for classification) by improving the illuminator efficiency in a feasible way;
- Regarding the estimation of dynamic parameters, a distance accuracy of 5% and an angle accuracy of 1 degree have been found.

Some representative examples are given in Figures 24-26.

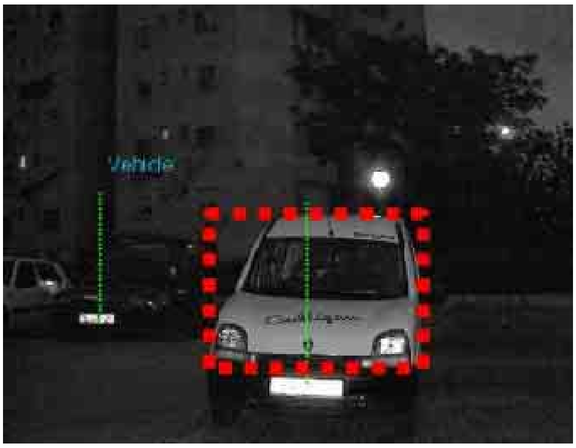

Fig. 24: Object detection and car classification

Fig. 25: Object detection and vehicle classification

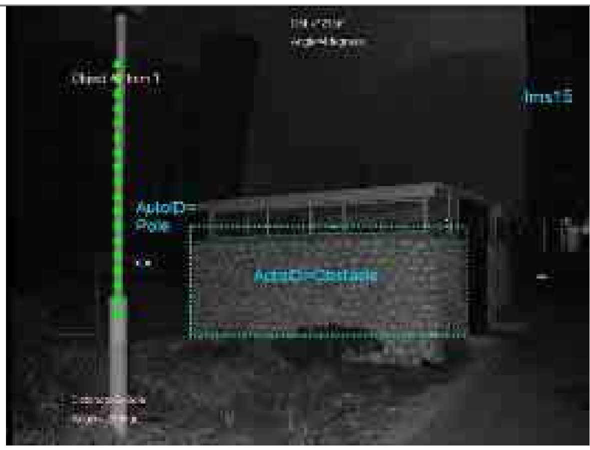

Fig. 26: Detection of other objects: wall and pole

The following conclusions have been therefore derived from the tests:

- The present level of development is a proof of concept, and ways to improve the video system, especially in term of range and coverage of different situations have been identified;
- The active illumination is a powerful approach to eliminate effects from the external light;
- The role of the video system in a pre-crash sensorial platform is mainly the classification of objects;
- The fusion of the video system with other sensor technologies must be done at high level, extracting relevant synthetic information from the image processing and coupling it to the other data;
- Besides providing additional information to the passive safety systems, this fusion is also expected to significantly reduce the rate of false alarms.

Impact on passive safety

A study on the safety impact of a pre-crash system has been carried out in the project. It has addressed the necessary link with passive safety systems, and has finalised the main activities in Chameleon, which were focused on the development and testing of the sensorial system. Such a study has been aimed in particular to clarify the real advantages, for improved or new occupant protection systems, coming from the knowledge of an imminent crash, with an advance time of some hundred milliseconds.

The first step in this activity has been the definition, at consortium level, of a set of passive safety systems, which could be available in the short to medium time scale and could benefit from the pre-crash data. A basic assumption for the study has been that the pre-crash system operates correctly in all circumstances, detecting the obstacle within the ranges and time intervals assumed.
For each of the selected restraint systems, the effect of pre-crash information has been evaluated following two approaches, as follows:

- Simulation: the effects on body dynamics have been investigated using standard tools for bio-mechanical analysis (Madymo SW);
- Focus group evaluation: a number of experts in vehicle safety from car manufacturers and research institutes have provided answers to a structured questionnaire, aiming to a qualitative assessment of the systems.

The applications selected at consortium level (described in deliverable D5.2) are:

- Pre triggered Air bags
- Pre tensioning of seat belts
- Seat moving in optimal position
- Moving steering column
- Active knee bolsters
- Extendable bumpers
- Additional, switchable crash boxes
- Fuel feed stop.

Simulation results

In a first set of tests, **reversible pre-tensioners, optimised time-to-fire and active knee bolsters** have been simulated. A reference mid-size car and a standard Euro-NCAP crash test at 64 km/h against a fixed barrier have been considered for this study (Figure 27).
The baseline has been a state-of-the-art restraint system, with air-bags, load limiters and pyrotechnical pre-tensioners, but no input coming from pre-crash sensors. Thus, the safety benefits are evaluated compared to a situation with an already high level of performance, not found on all circulating vehicles today.

The simulations have shown that occupant protection can be improved by using pre-crash data to control the operation of the restraint systems. This improvement has been found for different body sizes.
For example, computed global scores derived from a series of acceleration loads on different body parts (and related to the Euro NCAP evaluation procedure) can be increased from 12.71 to 15.14 points for the 50th percentile and from 11.10 to 13.71 points for the 95th percentile.

However, the global study indicates that such positive effects can be obtained only if the restraint system is optimised in all its components, in order to take advantage from the early availability of crash information. A simple reduction in the time-to-fire, not accompanied by adjustments in the overall system and especially in the characteristics of restraints (for example the mass flow in the airbag chamber, or the retraction of the pre-tensioner) does not improve the protection of the occupants.

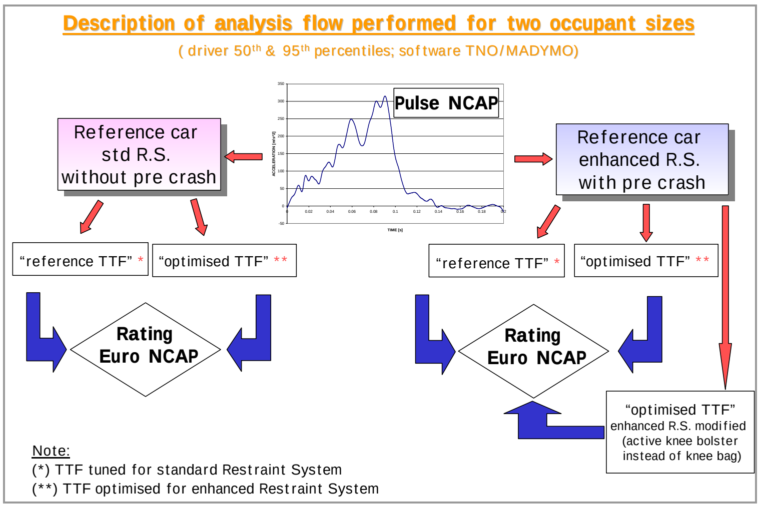

Fig. 27: Simulation approach

More in details, the following enhancements in occupant protection have been obtained for the 50th percentile driver:

- An improvement of the HIC (head injury criterion), from 350 to 150;
- A reduction of the chest deflection from 45 mm to 28 mm;
- A general enhancement of the protection for the upper body segments;
- uncertain results for of lower body segment (decrease for 50th driver, increase for the 95th driver).

These are significant improvements, as shown by some estimations on the probabilities of severe injuries and fatalities for the occupants of the car. By applying the 'Human Injury Risk Criteria', which relate biomechanical parameters to the distribution of injury risks, the following preliminary values have been obtained for the type of crash considered:

- The risk of serious injuries (AIS≥3) is reduced from 17% to 8,4% for the chest and from 6,4% to 1,5% for the head.
- The risk of fatalities is reduced from 0,12% to 0,05% for the chest, and from 0,1% to 0,06% for the head.

These values are referred to the baseline of a modern restraint system already providing a top level performance.

A second sequence of simulation tests has taken into account a **moving steering column and a moving seat**. The goal has been to study how these possible future systems, moving in an optimal crash position, could possibly improve the overall behaviour of the safety restraint system. **Advanced firing times** for the air-bags have also been investigated.
This analysis complements the previous study, by addressing advanced protection systems, which can be extrapolated from on-going research and development work. Of course no solution is available today in the market, which can adjust the seat or the steering column within the short period of time envisaged. On the contrary, earlier firing can be obtained with today's technology.
For the simulation, an approach similar to the previous case has been followed, using the same SW tools, but considering instead the simulation environment of a sports car (Figure 28).

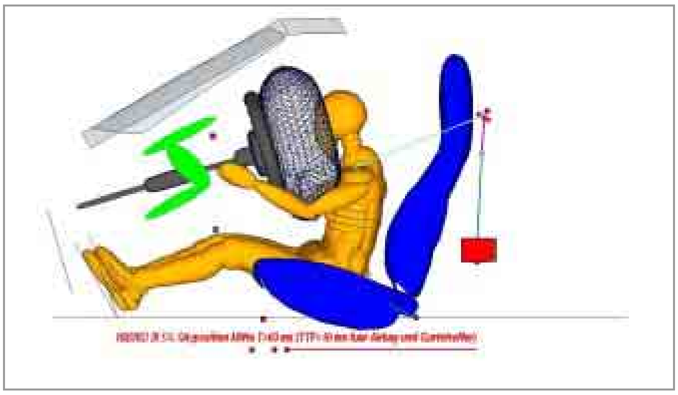

Fig. 28: Simulation environment for a small female driver

Results indicate that positive results can be obtained on most injury indexes, suggesting however a further analysis to obtain a multiple optimisation on all the biomechanical parameters.
More in detail, the main indications are as follows:

- In general, all the relevant load parameters are well below the biomechanical limits, with a comfortable safety margin of more than 20 %;

- Especially the neck and head injury values are reduced, in a range between about 12 and 70%;
- Other loads can be increased in some cases, but they remain well below the biomechanical limits;
- A lower influence has been found for the chest values;
- The implementation of earlier firing times would be especially useful for out-of-position occupants like children or small female persons, sitting too close in front of the airbag system, as well as for unbelted persons in high speed crashes (FMVSS 208 regulation);
- Driver acceptance of this type of solutions remains to be investigated.

Focus Group opinions

The experts in the Focus group have examined the selected applications in term of potential effects on different body part, general advantages and disadvantages, time scale for the application.
A first general remark is that a baseline can be found in some existing applications which are pre-crash triggered, mainly using the signals from the sensors of the ESP (Electronic Stability Program). In about 75% of collisions, the vehicle slingers before the impact, so that the detection by these sensors is suitable. Nevertheless, it is possible and convenient to increase the reliability and the protection potential in the future, by the use of pre-crash-sensors. This will lead to an earlier and more reliable activation of the passive safety systems; in particular the advance time can be significantly increased from the value now possible with an EPS system (estimated around 15 msec).
The focus group confirmed the interpretation of simulation results. The first studies performed already show that the selected techniques can lead to a clear improvement of the protection level and the adaptation of passive safety systems. It is obvious that a further optimisation of the systems is worthwhile, and will show even more effects. In fact a very high protection potential is available, but a good matching of all restraint systems is essential.

Another important consideration is that in a first phase all systems that are triggered with pre-crash-sensing should be reversible and especially should not lead to a confusion of the driver, in case of false alarms.
In order to reach these goals completely, the following points should be addressed, relying on further technical progress:

- earlier and more reliable recognition of the collision, by improved sensor technologies;
- development of faster actuators;
- investigations on the influence of driver confusion on his/her behaviour in critical situations.

In the following figure, the evaluations from the experts are indicated in synthesis, with respect to their expected deployment time and protection potential for different body parts.
In general, an earlier activation of the restraint systems, matched to the crash conditions, keeps a big safety potential. An additional point is that more accurate adaptive systems can be obtained by the combination of pre-crash-sensing and occupant recognition. In this field, sensorial systems are already available and significant improvements are expected in the near future.

System	Time horizon	Effect on						Reversible system	Occupant classification necessary
		Head	Chest/ abdomen	Pelvis	Leg	Different body sizes	OoP		
pre-triggered airbag	4-8 years	++	++	+	o	++	++	O	o
reversibile pre-tensioner	2 years	+	++	+	++	o	+	++	o
moving seats	8 years	+	++	++	++	++	+	++	++
moving steering column	8 years	+	++	+	o	++	++	++	++
active knee bolsters	4-8 years	O	+	++	++	+	o+	++	o+
extendable bumpers	8 years	+	+	+	++	o	o	++	o
switchable crash boxes	4-8 years	+	+	+	++	o	o	++	o
fuel feed stop	already serial	general protection				o	o	++	o

Fig. 29: Summary of the Focus Group evaluations for the selected systems

Considering the general context for the pre-crash application, the following additional remarks can complement the analysis summarised in this paragraph:

- it is appropriate to consider that, in this study, the objective taken for pre-crash has been to optimise modern passive safety systems: these systems, after more than 30 years of evolution, are already well effective in providing an high level of protection to the occupants;

- The study confirms the interest of integrating a pre-crash application with other driver assistance functions, especially in order to share the cost of the sensorial platform for obstacle detection, which is the most expensive subsystem at the moment;

- The analysis has addressed only solutions to improve the restraint systems in the passenger compartment, without including possible applications of pre-crash for active vehicle controls. In particular, an assisted brake function for collision mitigation could be among the not-too-distant applications: by considering the distributions of serious injuries vs. the impact speed, it is believed that such a function could add significant positive effects;

- Finally, the results must be taken with caution, since they reflect the limited knowledge presently available on the performance of a pre-crash system in the various traffic situations.

3. PROJECT DELIVERABLES

The following table lists project deliverables, with an indication of main subjects treated.

Deliverable	Subjects
D2.1 Accident analysis and scenarios definition	- Analysis of available accident data in EU (case study in Italy). - Set of ranking parameters. - Reference crash scenarios to guide further developments.
D2.2 System concept and D2.3 System and Operational requirements	- Definition of the Pre-crash system. - Functional description. - First specification of the characteristics and positions of the sensors on the demonstrator vehicle. - Simulation tool for system analysis, allowing the study of sensor parameters vs. functional requirements, of the data fusion, and of scenarios not reproducible experimentally.
D3.1 Sensing system interfaces and architecture design	- Specification of the demonstrator vehicle. - Physical architecture, technology architecture, communication and sensors.
D3.2 Link between preventive and passive safety	- Examination of the potential of sharing sensorial pre-crash information with other ADAS. - Comparison of sensorial systems developed in on-going ITS projects. - Analysis of gaps between sensor performances and requirements of car manufacturers.
D3.3 Sensor fusion description - Hardware and Software level	- Description of data fusion algorithm based on laser scanner. - Time horizon for crash prediction. - Missing alarms and false alarms requirements. - Different levels of simulation with following cases: ideal error-less sensors, error-corrupted sensors and a proposed solution of improved scan laser.
D3.4 ISO Guidelines Recommendation for pre-crash application	- First recommendations for the ISO standardisation of Pre-crash. - Normative references, summary of the relevant terms, classification for the pre-crash applications. - Basic requirements. - Suggestions for system testing. - Indication for topics which require further analysis.
D4.1 Demonstrator description	- Description of the demonstrator vehicle. - Description of the first prototype of vision system. - Obstacle detection sensors, vehicle dynamics sensors, central unit for data acquisition and processing.
D4.2 Test site description and evaluation procedure	- Test scenarios (track, crash facility, road). - Test procedures and execution plan at three levels (basic sensor tests, sensor fusion, pre-crash outputs). - Original procedures: dummy obstacle and 'quasi-crash' conditions in the crash facility.
D5.1 Safety, legal issues, standards	- Identification of risky situations potentially affecting the pre-crash systems. - Main legal and standard problems related to the market introduction. - Certification procedures. - Experimental procedure to test the dependability of the crash

	prediction software (method and results).
D5.2 Evaluation of sensorial system impact on passive safety	- Definition and benchmarking of eight potential applications based on Pre-crash (advantages and critical points, time perspectives, benchmarking) - Impact analysis by experts focus group - Impact analysis by biomechanical simulation for pre-tensioners, smart bags and knee bolsters. - Evaluation by biomechanical simulation of other future developments (moving seat, collapsing steering column).
D5.3 Preliminary CHAMELEON evaluation plan	- First plan for the assessment process, focused on an impact analysis and a technical analysis. - List of indicators.
D5.4 System evaluation results	- Evaluation framework (assessment objectives, methodologies and main indicators) - Description of data fusion and crash prediction SW modules for two approaches: single sensor based system and multi sensor based system - Development of the final version of the video system. - Test results for the two approaches in the track, crash facility and in ordinary traffic on the road. - Test results with the video system. - Evaluation by virtual crash method. - Main outcomes and comments from the system evaluation experience.
D5.5Project presentation	- Objectives, workplan, and expected results of the project. - Role of participants. - Multimedia presentation
D5.6 Cost benefits analysis	- First evaluation of effectiveness of the system for safety in term of fatalities and serious injuries (Italian accidents case study). - Analysis of biomechanical simulations (using stress criteria and injury-risk curves) and other safety estimates based on project experience. - Economic estimates (reduction of costs for products and services related to the injuries and fatalities).
D5.7 Dissemination and use plan	- Initiatives and tools to be used in the project for dissemination.
D5.8 Final report	- Review of project objectives and approach - Results (sensors, SW, methodologies, evaluation) - Synthesis of lesson learnt and recommendations.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 General outcomes and lesson learnt

The activities within Chameleon have produced valuable results and indications on the potentialities of a pre-crash system in the frame of the evolutionary road-map defined in the project.
The application is now in a **preliminary phase of development**, considering the present performance of sensor technologies. In fact, even if the demonstration car has been able to achieve most of the requirements, it has been clear from the evaluation phase that the characteristics of the system are those of a prototype, optimised to operate in a controlled environment like a test track, rather than in the real world.

However one of the most important challenges of the Chameleon project was to evaluate the performances of one demonstrator vehicle developed within the project life; this demanding objective has been achieved, in particular considering the following aspects:

- the **feasibility** of the Chameleon system concept has been proven on a set of common crash situations when the scenario is simple;
- **effective methodologies** have been developed to test the system without damage even in crash situations: a ‘quasi’ crash method, a dummy obstacle and the virtual crash method;
- the basic limits of the available sensor technologies have been identified, in relationship with system requirements: in particular **new technologies** have been investigated, like computer vision and the laser scanner, for which there is less experience in the automotive field.

Going in more technical details, the project work also allowed deriving the following considerations:

- Today a sensor does not exist, which alone can detect the overall area around the vehicle;
- Today a sensor with good performances both at short and long range does not exist: to cover the complete frontal area it seems necessary to use a sum of different sensors;
- Better results from the accident prediction algorithm can be achieved by a knowledge of the shape of the vehicle, which can be obtained by detecting a profile of the obstacle;
- The role of the computer vision technology is mainly object classification;
- Proper consideration of sensitivity to dirt and adverse weather is necessary for the optical techniques as defined today;
- The time to impact when a crash is predicted (ranging from 300 msec up to 700 msec in particular conditions) is higher than expected;
- The possibility to ‘fuse’ the information coming from different sensors seems to be still difficult at the present state of technology, because of the different levels and qualities of the data collected;
- When considering radar and multi-beam laser sensors, a data fusion approach at high level, based on the crash predictions from the single sensors, has been found more suitable for a function like pre-crash;
- Because of the costs, the sensorial system available for the pre-crash has to be “shared” with other driver assistance systems;
- The characteristics of the sensors and the crash prediction strategy depend on the restraint systems: reversible restraint systems are more appropriate in a first phase of market introduction.

4.2 Future developments

According to the Road-map described in Chapter 2.1, Chameleon will contribute to the realisation of **marketable products**, in a **time frame around five years** for the first categories of applications.

Besides the pre-crash function, several Chameleon subsystems and tools will be available, as enablers for a series of products, especially the sensor technologies, the SW modules, the testing methods.

Even if the final control function will concern the passive safety equipment, Chameleon partners believe that the focal point remains the sensorial technology. Therefore, from a technology and business perspective, Chameleon is strictly linked to the on-going developments for Advanced Driver Assistance Systems; this market is in its infancy, but with high anticipated growing rates.

In this frame, exploitation by Chameleon partners, considering the expected trends for ADAS applications, will be based on the following approaches:

- products will be presented with a strong **'safety related' content**, changing somehow the from previous ADAS commercial applications more focused on comfort;
- specific features of the different sensor technologies, conceived for **accurate and fast detection at short range**, will be exploited;
- the **multifunctional applications** already investigated in the project will be further explored and proposed, due to the remaining high costs of the sensor devices.

Within this overall picture, the future deployment of project results reflects the different business areas for the different partners.

Among the **sensor suppliers** CONTI-TEMIC and IBEO already have launched development programs with automotive partners regarding the technologies of the project, while SAAB, TAMAM and THALES are exploring initiatives for industrialisation. Their specific plans will depend on the response obtained from the market. In the case of the vision system, it is believed that the technology know-how gained in Chameleon might also be exploited in other application domains.

The **car manufacturers** (CRF, Porsche, PSA, Renault, Volvo Car) are continuing their efforts to design and produce safer cars, and will make use of project results concerning especially the system definition, the sensor characteristics, the testing procedures. Sensor fusion still requires R&D work to improve the reliability of situation capture. Most of the programs of car manufacturers now aim to evaluate the integration of different functions based on short range obstacle detection, including pre-crash, to deal with the sensor cost issue.

The **engineering company** in the consortium (EICAS) is actively developing SW products based on the Chameleon approach. The company is now proposing to the customers its "Data fusion & crash prediction algorithm", and will implement more advanced modelling, where pre-crash and active safety are coupled, and enhanced functions are considered like an advanced brake assist for collision mitigation.

The two **research institutes** (IKA, CSST) are using the methods and technologies developed in Chameleon for the realisation of new vehicle demonstrators and for projects in the area of automotive safety and assessment methodologies.

Specific topics of the Chameleon project, which are now intended to be worked upon, are the following:

- Further research on actuation strategies and devices able to improve the protection of passengers based on the pre-crash information;
- Investigation of advanced concepts implementing active vehicle controls, starting with an enhanced brake assist function for collision mitigation;
- Further research especially on short range, and/or wide field of view radar and laser sensors with emphasis on reliable and accurate tracking of obstacles, and validation for mass production;
- Further research on sensor fusion configurations and methods;
- More pilot demonstrations and further research with prototypes for testing the object classification techniques;
- Applied research upon multifunctional approaches for the introduction of advanced driver assistance systems.