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Intersection Driver Assistance System – Results of the EC-Project INTERSAFE

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Abstract: The INTERSAFE project was created to generate a European Approach to increase safety at intersections. A detailed accident analysis was carried out. Based on the derived relevant scenarios driver assistant functions are developed to support the driver in critical intersection situations. The results carried out in the testing phase are presented and discussed.

Keywords: Intersection safety, situation analysis, risk assessment, Laserscanner, video.

1. Introduction

In the 6th Framework Programme of the European Commission, the Integrated Project PReVENT includes Intersection Safety. The project started on February 1st, 2004 and concluded January 2007.

INTERSAFE
a PReVENT Project

INTERSAFE was established to support the vision of IP PReVENT to create electronic safety zones around vehicles by developing and demonstrating a set of complementary safety functions. These functions assist and protect drivers and even unprotected road users by means of in-vehicle systems.
Since intersections are a major accident hotspot accounting for 30 to 60% of all injury accidents the main objective of INTERSAFE was to improve safety and to reduce (in the long term avoid) fatal collisions at intersections. The project brought together leading vehicle manufacturers (BMW, VW, PSA and Renault), automotive suppliers (TRW Conekt, and IBEO – project leader), SMEs (Signalbau Huber and FCS) and research institutes (INRIA, ika) with complementary areas of competence and expertise.

Intersections are frequented by many and varied road users approaching from different directions. Thus intersection safety has to cover a number of accident scenarios and parties. It deals with the safety of vehicle occupants and unprotected road users such as turning vehicles or vehicles with intersecting paths, pedestrians or cyclists. Accident scenarios at intersections are amongst the most complex. Thus the research scope of INTERSAFE was considered to be quite challenging.
An in-depth accident analysis identified the central position of two accident types in particular:

- Collisions with oncoming traffic while turning left and
- Collisions with crossing traffic while turning into, or crossing over an intersection.

In addition a third critical scenario – the red light violation - was chosen. The traffic light status transmitted via V2I was considered to support the effectiveness of solutions for the previous scenarios as well. Thus, 60% to 70% of all intersection accidents were directly addressed. The majority of the accidents are caused by human errors such as misinterpretation and inattention.
Consequently, the objectives of INTERSAFE were:

- Development of an Intersection Driver Warning System based on bidirectional V2I communication and on-board sensors.
- Demonstration of intersection driver assistance functions based on sensors and communication for relevant scenarios in demonstrator vehicles.
- Demonstration of advanced intersection driver assistance functions in a driving simulator.

A general overview on the INTERSAFE subproject was given in [1]. The main focus of this paper is to give a better understanding of the functionality of the sensor based test vehicle used in this project.

2. INTERSAFE Concept & Vision

To allow effective development INTERSAFE was based on two parallel approaches. The first approach - the so called Basic Intersection Safety System - is a Bottom-Up-Approach. It was based on state-of-the-art sensors (Laserscanners and video) and bidirectional vehicle-to-infrastructure

(V2I) communication. The second approach is a Top-Down-Approach, based on a dynamic driving simulator. The so called Advanced Intersection Safety System.
Following the objectives INTERSAFE realised an Intersection Driver Warning System in a VW Phaeton demonstrator based on on-board sensors and communication for

- left turn,
- turning/ crossing and
- traffic light assistance.

A BMW 5 series demonstrator based on communication for traffic light assistance was built up as well.
In parallel advanced functions of a future Intersection Active Safety System were developed in the dynamic driving simulator. Thus requirements for future functions, sensors and communication are identified.

3. Demonstrators

3.1. VW Phaeton demonstrator vehicle

The VW Phaeton demonstrator was equipped with two Laserscanners, one video camera and additional communication systems, as shown in Figure 1. The video camera was used to process data about lane markings at the intersection while the Laserscanner collected data of natural landmarks as well as data about other objects and road users. The fused data of the Laserscanner and the video camera and a detailed map of the intersection (high-level map) were used for localisation of the vehicle within the intersection. Together with the object data collected by the Laserscanner a broad overall view of the scene is constructed.

Figure 1: Sensor integration in the Phaeton demonstrator.

The additional communication module allowed wireless infrastructure to vehicle (V2I) communication or, in extension, for communication via infra-structure with other road users equipped with such communication facilities.
In a second step, a dynamic risk assessment was done. This was based on object tracking and classification, communication with the traffic management and the intention of the driver. As a result of the dynamic risk assessment, potential conflicts with other road users and the traffic management can be identified.
Consequently, the intersection safety system is able to support the driver at intersections.
The Laserscanner detected and tracked the road users which was essential for the functionality. Nevertheless, the video processing data and the fusion with the Laserscanner data is crucial for the correct functioning of the host localization process [2].

3.2. BMW 5 series demonstrator vehicle

The BMW demonstrator vehicle was based on a standard 5 series vehicle. For its use as research prototype it was equipped with additional systems for e.g. V2I-communication or precise GPS-positioning.

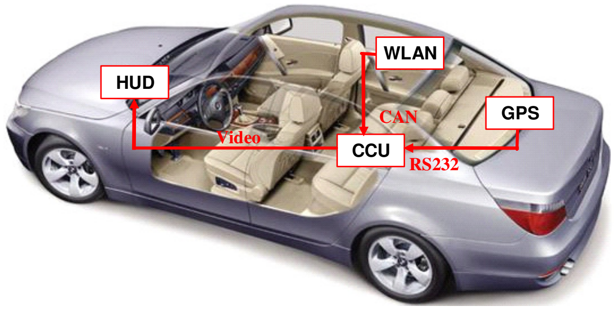

Figure 2: Sensor integration in the BMW demonstrator vehicle.

According to the HMI specifications defined in the D40.44, information and warnings given in highly-complex intersection situations must be intuitive and must not make the driver look away from the scene. Thus the head-up display was an appropriate way to provide information in the driver's field of view. A D-GPS receiver ensured accurate positioning within the intersection area. IEEE 802.11b WLAN-cards were used for the bi-directional wireless data interchange between vehicle and infrastructure. An automotive rapid-prototyping platform was used to run the driver assistance application. It was connected to the other components by the bus as shown in Figure 2.

3.3. BMW driving simulator

Driving simulation is an increasingly used technique in the development process. It is a tool to determine driver behaviour within a man-in-the-loop process. Investigations can be carried out without the risk of accidents as well as having perfect repeatability of scenarios and situations. Thus, the dynamic driving simulator of the BMW Group was chosen to realise the top-down development process for advanced driver assistance systems.

To fulfil the requirements of a realistic driving experience e.g. in intersection areas, many improvements have been realised to ensure high-quality and reliable simulation results:

The simulator – at the beginning of the project only in trial operation – was improved, so its vehicle dynamics algorithms were tuned to realise a realistic kinaesthetic feedback of the driven scenarios. A mock-up of a 3 series station wagon allowed the driver to interact with an authentic environment.

Figure 3: BMW dynamic driving simulator.

A high-end database was installed that consisted of a road network with urban and rural roads, intersections of different type and size, working traffic lights and surroundings with buildings, trees and – currently – static pedestrians. Together with a constant frame rate of 60Hz, which is a reasonable compromise between computing capacity and immediate visual feedback, the visualisation was improved.

The software and hardware architecture was revised to enable the integration of real sensors. The partners TRW (video camera) and IBEO (Laserscanner) provided the algorithms of their sensors and BMW provided the graphics output via DVI. The sensors can now operate within the virtual environment sending their information to the simulator vehicle via CAN as usual.

Figure 3 displays the driving simulator in its settled position, allows a view inside on the mock-up and gives an impression of the visual display.

4. Localisation of the Host Vehicle

GPS-based localisation is generally not able to provide sufficiently accurate or reliable localisation in urban areas where intersections are typically located. The Laserscanner system obtains a relative position within the intersection by detecting landmarks such as posts and other similar fixed objects next to the intersection, which are registered in a digital map. The video system utilized lane markings at the intersection for relative localisation which are registered in a digital map.

5. Object Detection, Tracking and Classification

In order to meet the functional requirements of monitoring crossing traffic two precise Laserscanner were integrated into both left and right front corners of the demonstrator vehicle. Thus a combined scan area of 220 degree around the vehicle was achieved. Based on the Laserscanner data detection, tracking and classification of road users was performed.

In the beginning the generated range profile was clustered into segments. Comparing the segment parameters of a scan with predicted parameters of known objects from the previous scan(s), established objects are recognised. Unrecognised segments are instantiated as new objects, initialised with default dynamic parameters.

In order to estimate the object state parameters a Kalman filter is well known in the literature and used in various functions, as an optimal linear estimator.

Object classification was based on object-outlines (static data) of typical road users, such as cars, trucks/buses, poles/trees, motorcycles/bicycles and pedestrians. Additionally the history of the object classification and the dynamics of the tracked object were used in order to support the classification performance.

6. Test results

In order to inspect the systems' functionality and the user acceptance, the onboard environmental sensors and the full systems have been tested in the last stage of the project. The tests are carried out in following three phases:

- Sensor test - test the system's function on perception level
- System test - test the system's function on application level
- User test - test the system's function on Human Machine Interface (HMI) level

6.1. Sensor Test

Sensor test and system test have proved the functionality of the INTERSAFE system. The systems are able to fulfil the tasks of assisting the driver to avoid potential traffic accidents at intersection.

In order to get a representative result, diverse objects were used as sensor targets in the tests. These targets were: VW Golf (silver estate car), VW Lupo (black compact car), BMW 325i (red middle size car), BMW 728i (black large size car), Honda VFR800 (silver motorcycle), pedestrian (dark clothing) and a wooden dummy target for the test of position accuracy.

Detection Range of the Laserscanner

In this test the Laserscanner maximum detection range for all five test vehicles and the pedestrian was determined. The test started with the target vehicle moving towards the standing demonstrator vehicle.

Three different approaching directions of the target vehicles were applied in this test: frontal, 45° and 90°. In order to avoid coincidences with regard to repeatability, every test was carried out twice for each target and approaching direction.

During the tests, all the vehicles were correctly classified immediately after detection. All the cars were detected at a distance of more than 200 m, both in frontal and 45° tests. Just the maximum detection range of the motorcycle was slightly shorter.

The detection of pedestrian was also tested. Result showed that the pedestrian was detected and correctly classified as a pedestrian at distances of 110 m. In the 90° tests, the VW Golf was detected at about 165 m.

Object Range Accuracy of the Laserscanner

A wooden dummy is used as the sensor target in this test. It is positioned either directly in front of the demonstrator vehicle or in a 45° position. In order to determine the accuracy at different distances, the demonstrator vehicle stands still and the target is moved in every test. The relative distance of the target is measured by the Laserscanner and a reference device. The reference line is located around 15 m in front of the demonstrator vehicle's rear axle (the zero axis of the Laserscanner output). The target is moved from this position until 50 m in five metre steps; namely 20 m, 25 m, 30 m, 35 m, 40 m, 45 m and 50 m.

The test results are illustrated in Figure 4. The average error is about 10 cm.

Localisation Accuracy

This test was applied to inspect the Localisation accuracy of the Laserscanner, the video system and the fusion output. The Laserscanner system localises the vehicle position by detecting landmarks while the video system utilises road markings. As an example, the test for evaluation of longitudinal distance was described here.

In order to determine the demonstrator vehicle's distance to the intersection, a microwave sensor and a light barrier sensor were mounted at the rear end of the car. Four reflectors were put on the ground as reference positions for the light barrier. The distances to the intersection of these references were 10 m, 30 m, 50 m and 70 m respectively. According to the vehicle speed measured by the microwave sensor and the reference positions by the light barrier, the vehicle position could be calculated precisely.

The test was carried out five times. The localisation error for one exemplary test run is shown in Figure 5. The average absolute errors of each test as well as the average of all the tests are better than 0.14 m (Laserscanner system and Fusion system) and 0.21 m (Video system). The outputs of all localisation systems were continuous, meaning no signal drop-outs occurred.

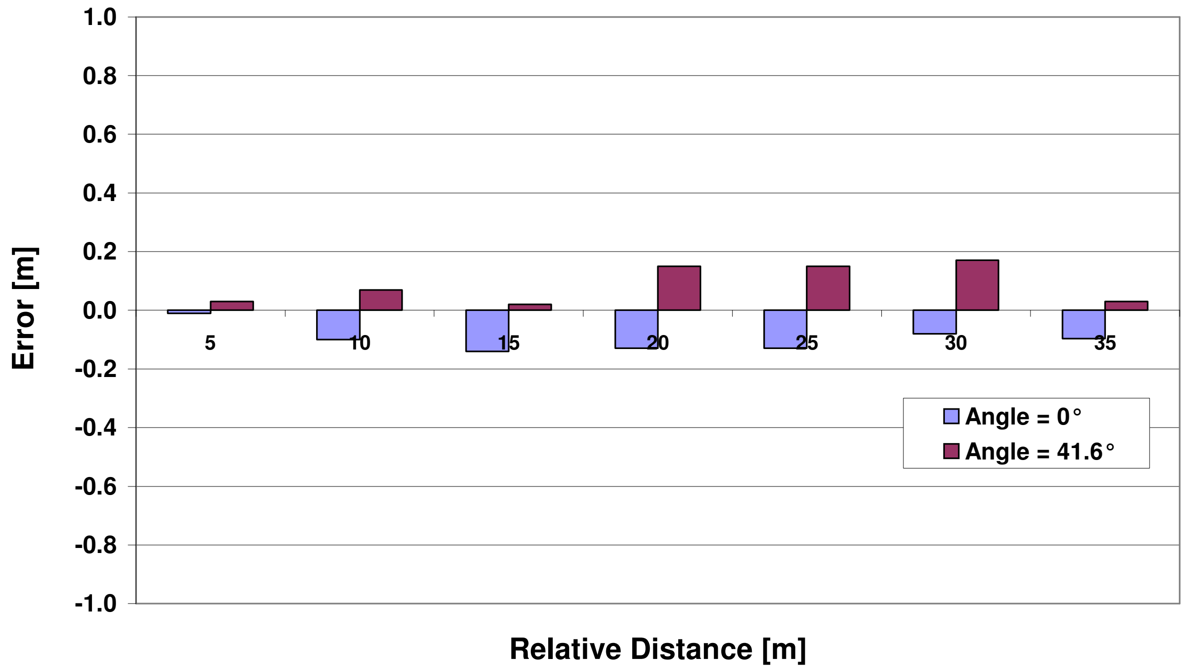

Figure 4: Object range accuracy of the Laserscanner.

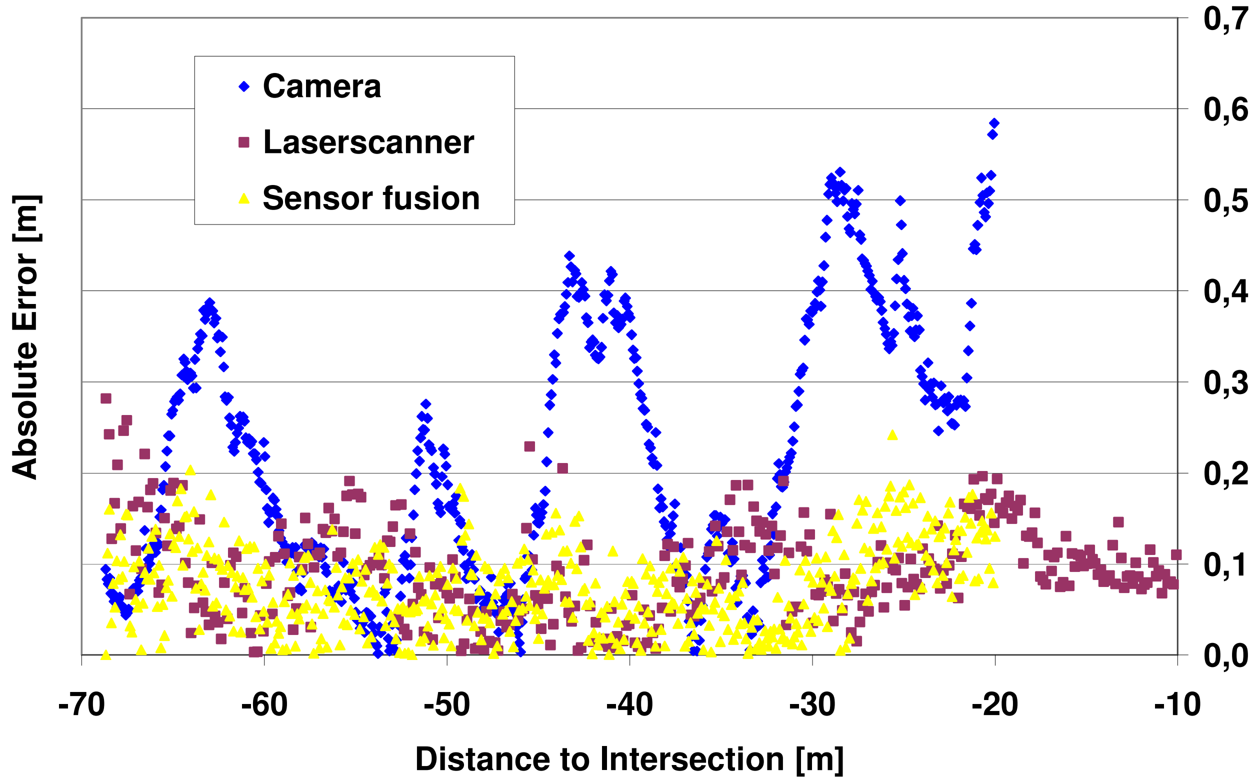

Figure 5: Localisation error over distance for the camera (blue), Laserscanner (red) and the fusion system (yellow).

6.2. System Test

The INTERSAFE system functions at the application level were tested in this evaluation phase. The evaluations were carried out based on the number and the rate of correct alarms, false alarms and missing alarms.

During the test, the demonstrator vehicle was driven through the intersection and the functions of the system were evaluated in the form of a check list.

The results of system test indicated that the Intersection Assistant had a correct alarm rate of 93 % in left turn scenarios and 100% in lateral traffic scenarios. Both traffic light assistant systems achieved together an average correct alarm rate of 90%.

6.3. User Test

User test focuses mainly on the user acceptance of the systems and its HMI design. 16 subjects with different age, gender and driving experience have been selected to take part in the user test. After driving both demonstrator vehicles and experiencing the INTERSAFE systems, they think the systems are helpful and relieving. They state that these systems could have helped them in their daily driving and would improve the traffic safety.

7. Conclusions

INTERSAFE was a project targeted to improve safety and to reduce (in the long term avoid) fatal collisions at Intersections. Drivers were prevented from missing red lights at intersections or from ignoring stop signs. Furthermore, drivers were informed to avoid collisions with oncoming traffic while turning or crossing an intersection. The functions above were achieved by using Laserscanner, video and communication.

A highly accurate relative localisation using Laserscanner and video sensors was developed and evaluated. Based on the Laserscanner data, robust and reliable path prediction of road users at intersections was achieved and evaluated with convincing results. The evaluation has confirmed that the state-of-the-art sensors utilized, the V2I-communication and the functions are fully suitable to fulfil the tasks in the Intersection Driver Warning System.

Furthermore, a bidirectional communication was realised between the host vehicle and the infrastructure (especially traffic lights) to exchange additional information about the status of traffic signals, weather, traffic, or road conditions.

Intersection Driver Warning functions were developed and realised in two demonstrator vehicles with state-of-the-art sensors and off the shelf communication modules. Advanced Intersection Safety functions were developed and evaluated by means of a dynamic driving simulator. Thus requirements for future Intersection Active Safety Systems were derived.

8. References

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