Developing intelligent Blind Spot Detection system for Heavy Goods Vehicles

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***Abstract*— Collisions between Heavy Goods Vehicle and Vulnerable Road Users such as cyclists or pedestrians often result in severe injuries of the weaker road users. Blind Spot Mirrors and advanced Blind Spot Detection systems assist in avoiding collisions. Blind Spot Mirrors are however only useful if the drivers are trained to use them. The paper describes the development of a monitoring solution for assist in truck driver training. The system also can be used as a blind spot detection system to warn truck drivers. The work is performed within the DESERVE project, which aims at designing and developing a Tool Platform for embedded Advanced Driver Assistance Systems (ADAS) to exploit the benefits of cross-domain software reuse, standardised interfaces, and easy and safety-compliant integration of heterogeneous modules to cope with the expected increase of functions complexity and the impellent need of cost reduction.**

Keywords—driver monitoring, blind spot detection, heavy good vehicle, ADAS

I. INTRODUCTION

The DESERVE (DEvelopment platform for Safe and Efficient dRiVe) project, which is funded by the European Commission under the ECSEL Joint Undertaking Program, aims at designing and developing a Tool Platform for embedded Advanced Driver Assistance Systems (ADAS) to exploit the benefits of cross-domain software reuse, standardised interfaces, and easy and safety-compliant integration of heterogeneous automotive modules.

The DESERVE project has selected 22 different modules [1] for implementing 11 driver support applications selected according to user needs analysis. The developed applications are tested in different of demonstrations to show that platform is not limited to one single vehicle type. In this paper we discuss the training truck application, built in co-operation between VTT and TTS.

Drivers of heavy goods vehicles have similar driver inattention problems as passenger car drivers. Consequences of traffic accidents between heavy goods vehicles and other road users are more severe, when compared to passenger cars [2]. Scenarios, in which vehicles turn into the path of a cyclists, or pull out into the path of an oncoming cyclist, are the most frequent occurring scenarios in accidents between vehicles and cyclists at an intersection between vehicles and cyclists [3].

There have been improvements in the safety through legislation. For example side guards and extra mirrors for minimising blind spot areas are required nowadays. Nevertheless, these extra mirrors increase safety only if the driver does look at them. Therefore improvement of the driver's professional skills is essential to improve the overall safety. One of the targets of the project was to introduce driver monitoring in training vehicles of professional truck drivers. For the training supervisor, it is challenging to recognise all situations when the candidate is not paying sufficient attention to traffic during the driving session. Thus, the driving monitoring system helps to gather the data during the education period.

More advanced ITS solutions are Blind Spot Detection systems, which detect objects in blind spots and warn drivers. Blind Spot Detection systems have the capacity to save up to 66 lives and around 10000 injuries in Europe yearly by 2030 at full system penetration [4].

II. DESERVE PLATFORM

The automotive industry has set out a roadmap from driver assistance to automation of driver tasks. Automation requires a number of sensors, actuators and algorithms in the in-vehicle platform. The system perception ability should be very close to human perception capabilities to cope with the large variety of traffic conditions and to adapt assistance functions or even conduct manoeuvres in traffic autonomously.

The DESERVE project has picked up this challenge by [5]:

- Drafting a new *software architecture* (to master complexity, enable seamless integration of new advanced driver assistance system (ADAS) functions and to reduce overall costs of components),
- Designing and validating a novel design and more efficient development process for new ADAS functions that is enabled by a platform (to reduce the development time of ADAS);

- Designing and validating a novel platform that enables the development process (to reduce the development time of ADAS).

The idea of DESERVE is that the architecture, design and development process are interlinked. New ADAS functions are designed within the existing software architecture and after having being developed added to the software architecture. The platform enables this interlinked process as seen in Fig. 1 [**Error! Bookmark not defined.**].

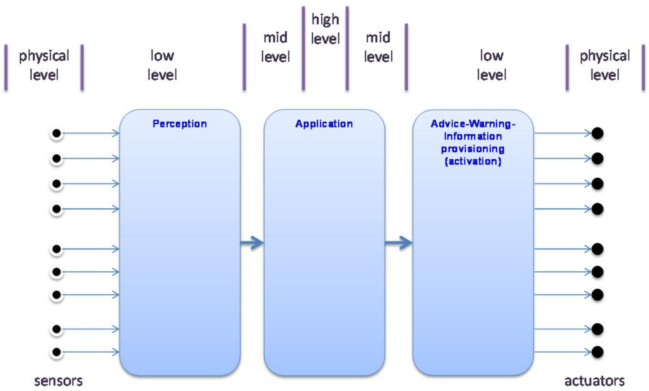

Fig. 1. Modularisation of ADAS functions from streaming data perspective. [**Error! Bookmark not defined.**]

Fitted in the vehicle approach, this gives modular software architecture for the in-vehicle platform, as depicted in Fig. 2

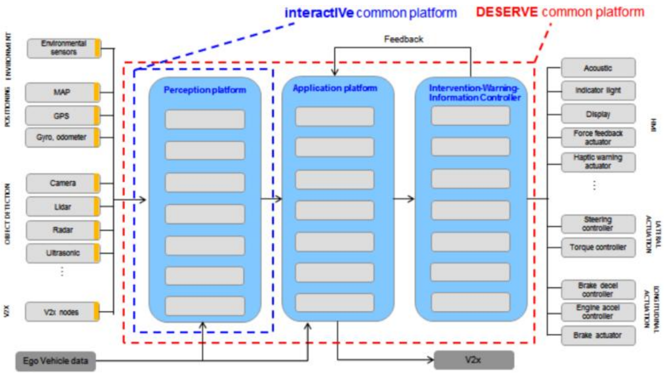

Fig. 2. DESERVE's in-vehicle platform software architecture [**Error! Bookmark not defined.**]

III. Implementation

Selected ADAS functions for the training vehicle are:

- Blind Spot Detection
- Collision warning
- Safe start functionality
- Lane change assistant

Because the training vehicle is intended to be used in the daily traffic, its street legality cannot be compromised. This limits control to vehicle actuators to situations when the vehicle is not moving. In other cases only warnings are allowed.

The design of the system follows the principles developed in DESERVE-project. The development platform was RTMaps from Intempora S.A. [6], which is one of the development platforms adapted in DESERVE platform. RTMaps provides reusable components for the typical sensors and processing algorithms. Components data flows are connected via an easy-to-use graphical interface. The Prototype system can be built without any programming.

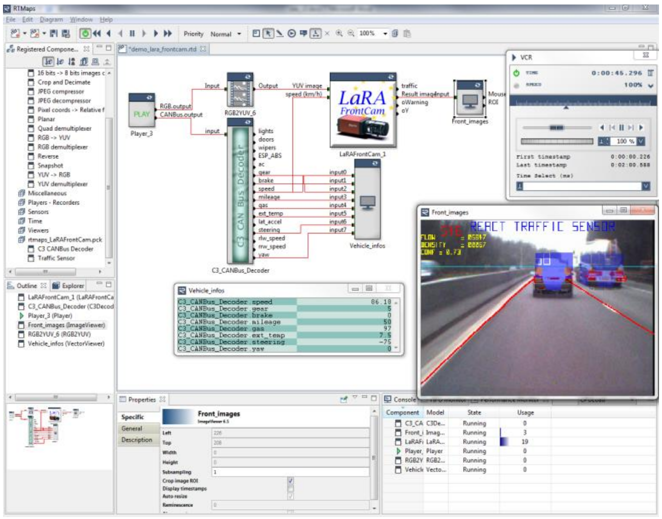

Fig. 3. Example view of the RTMaps development environment [**Error! Bookmark not defined.**]

A. *Driver monitoring*

The driver monitoring functionality is implemented using three RGB HD cameras installed in the cabin of a training vehicle. The aim of the driver monitoring is to ensure that critical safety information has been properly registered by a driver. The locations of the cameras are optimised on that way that drivers' face is in the field of view of the camera; even if the driver is not turning head to see out from the side windows (see Fig 5). However, monitoring is more challenging since the driver needs to turn head to see out from the large cabin of a heavy goods vehicle [7]. Therefore, this implementation requires new way of adapting the driver monitoring system to detect the driver's gaze direction and calculate the activity index of driver awareness.

The main focus in driver monitoring is to classify the driver's gaze direction to match the view areas inside the cabin. For this purpose the driver's view area (outside the cabin) is divided in 3 main and 7 smaller and more detailed classification areas (Fig. 4). These areas are selected based on user experiences, containing areas that need more attention when the driver is trying to see outside the vehicle or is performing driving tasks. These areas include the blind spot mirrors, the dashboard and the side mirrors.

After the cameras have detected and calculated the driver's gaze direction, gaze direction vectors are classified based on these areas. The first phase of the algorithm is to classify which one of the main 3 areas (Fig. 4) the gaze direction vector is pointing to. With this information, one of the cameras is selected for more detailed classification. When the camera is selected, the gaze direction is classified to connect it to a classification area shown in Fig. 4.

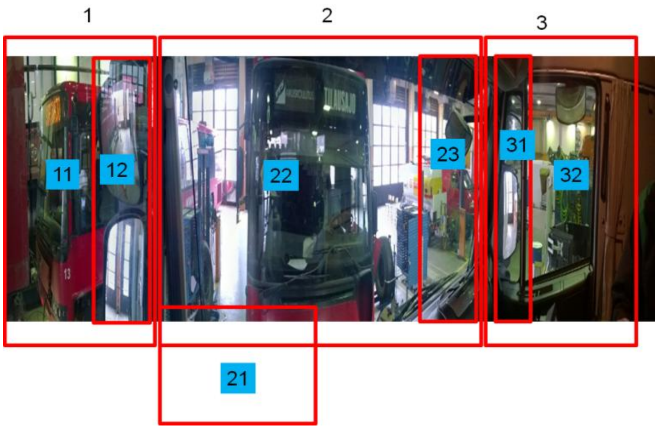

Fig. 4. Drivers view inside the cabin is divided in 3 main and 7 more detailed classification areas. Small areas numbered between 11 and 32 are pointing interesting areas i.e. blind spot mirrors, dashboard etc.

The classified gaze direction is used as input for fusing results from obstacle detection and driver monitoring system. If the obstacle detection functionality is detecting an obstacle outside of the vehicle, the system will use gaze direction information to make a decision if driver is giving enough awareness and attention to obstacle. In most of the cases this means that the gaze direction of the driver is so, that the object should be possible to detect by the driver trough blind spot mirrors or windows.

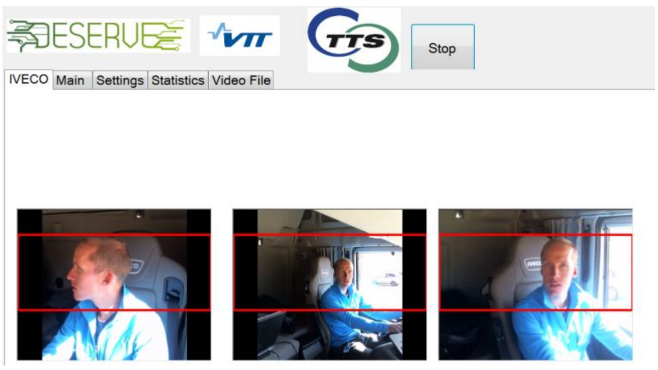

Fig. 5. Development view of the gaze detection system. Red bounding boxes show image areas where faces are searched.

The test truck also collects data concerning the behaviour of the driver. The behaviour is analysed for different situations (braking, acceleration, curve driving, turning of the steering wheel etc.) and with the driver monitoring system installed into the cabin dashboard. The monitoring system detects the driver's gaze and head activity indexes. Rules have been created for the gaze orientation variation in various driving situations which are based on careful, economical, safe driving and perception of the driving environment. For example, when starting to reverse, the driver should pay attention to the side mirrors. Or when changing the lane, the driver needs to check the free space from the mirror first.

B. *Obstacle detection*

The obstacle detection functionality is focused on blind spot areas of the training truck, which are shown in Fig. 6. The frontal area has a blind spot very close to vehicle nose. From the driver's seat is not possible to see obstacle which height smaller than 1.5 meter. Other blind spots are on left and right side of the cabin. A limitation to sensor installations is that protrusions over 50 mm from vehicle are not allowed by regulations.

Fig. 6. Environment sensor setup in the Iveco driver training vehicle Stereo cameras install locations are marked with red circles. Approximation of the field of view is marked on the ground..

In order to find the best combination of the overall performance, reliability and cost, different sensor setups will be used for the obstacle detection functionality. The aim is to compare the performance of these three different sensor setups.

The following sensors are used:

- Vislab 3D-E Stereo camera system with 639x476 image array and 57 degrees field of view.[8]
- Continental SRR 20X 24 GHz Short Range Radar Sensor. Range 50 meter with lateral angle 75°deg and vertical angle 12° deg. [9]
- Maxbotix MaxSonar MB7047 I2CXL ultrasonic range finders. Range up to 6,25 m [10]

The sensor set 1 consists of three Vislab 3D-E cameras, one in the front and on both sides of the vehicle (see Fig. 6). All cameras are installed near the top of the vehicle and the field of view is downwards. Thus any object is elevated from the ground level and obstacle detection is rather straightforward. Moreover the setup can detect small objects, for example a small child lying on the ground. Fig. 7 shows an example of how a human object is seen from the depth image and the original grey scale image taken from the front camera.

The sensor set 2 has a single Vislab 3DV-E stereo camera in the front. Additionally three Continental SRR 20X radars will be installed under the cargo bed. One on the left side and one on the right side and one at the rear end of the vehicle.

The sensor set 3 has one Vislab 3DV-E camera in the front and several ultrasonic range finders installed under the cargo bed.

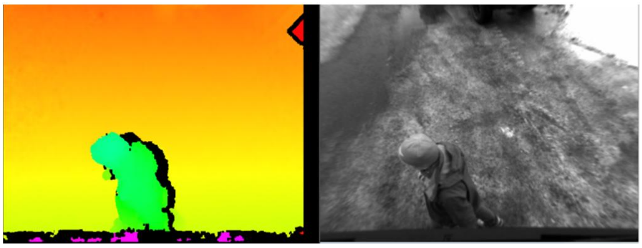

Fig. 7. Disparity image from the frontal stereo camera

C. Vehicle interface

Our test vehicle is an Iveco Stralis 560. Iveco supports the project by providing the full documentation of the electrical system. Therefore vehicle internal signals on the CAN-bus, such as lane detection, axle loads, fuel consumption, speed, braking, engine torque, steering angle, selected gear and other valuable information provided by the vehicle, can be used for system development. There are certain modules like brakes, where alteration is not allowed for the safety reasons. One has to keep in mind that vehicle has to be stay street legal after implementation of selected ADAS functions. On the other hand there is an analogue interface to for example the switches on the parking brake. According to the implemented ADAS functions, the system triggers different warning devices (sound, voice signal, light, vibration, etc.) to alert the driver if necessary. There are built in warnings for the collision avoidance and lane keeping using radars and camera as standard features of the vehicle.

D. Human-machine interface

The images from the cameras for obstacle and gaze detection are not shown to the driver. The Human-machine interface (HMI) is based on audible and visual warnings and a bird-eye view of the vehicle. The latter is based on the ASL360 surround view system from Continental [11] as seen in Fig. 8. The ASL360 has the possibility to combine up to six fish-eye cameras to a single image. In our case, there were only four cameras (front, left, right and rear) installed around the vehicle. After installation, a calibration process is required to produce an undistorted single image. Through adding 2 cameras to the current camera setup, a better result would be obtained for the 10-meter long vehicle. The ASL360 contains trigger inputs and the possibility to program different views to the display.

Audible warnings can be produced through the vehicle's audio system according to the direction of the detected safety hazard. In addition to audible warnings a set of lights are installed under the cargo bed, which are controlled via the computer system. These lights have two purposes: they provide additional illumination to improve the driver's ability to see what is happening on the critical vehicle section that side if there is poor visibility outside. The second purpose is to warn the Vulnerable Road User about the dangerous situation.

If the obstacle detection system detects an obstacle for example on the right side of the vehicle, audible warning is given from that side and the right side of the vehicle is stressed on the display image.

Fig. 8. HMI display showing 360° view from ASL360 camera system.

IV. Results

We have performed laboratory and outdoor test with different sensor systems for driver monitoring and object detection. The first tests for driver monitoring were performed in a simulator environment (Fig. 9). The main focus was to specify the camera constellation and to assess if the camera technology is reliable enough for multipoint driver monitoring.

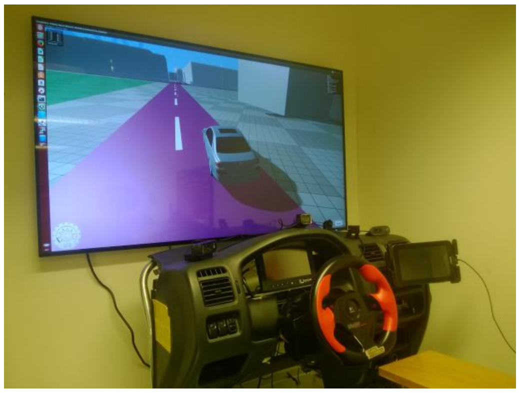

Fig. 9. VTT's simulator environment for testing vehicle sensors. The major part of the algorithm development for driver monitoring was performed in the simulator environment.

After the first tests in the laboratory, the sensor systems were installed to the Iveco Stralis 560 test vehicle for outdoor test. Tests were performed during winter 2014-2015 in southern Finland's road network. The main effort of the test was concentrated on finding the best sensor constellation for driver and environment monitoring. At this moment, sensor systems are tested separately but after testing, the main focus was concentrated on fusing the driver monitoring system output with obstacle detection.

A. Obstacle detection

Obstacle detection system initial tests show that stereo imaging system is capable of detecting very low obstacles. Fig. 10 presents a human lying on the ground in the front of the vehicle. Obstacle can be detected form the disparity image (red rectangle). The second example in Fig. 11 presents the detection of the motorcycle from the side of the vehicle. Motorcycle is hidden in the shadow, but is clearly detectable from the disparity image.

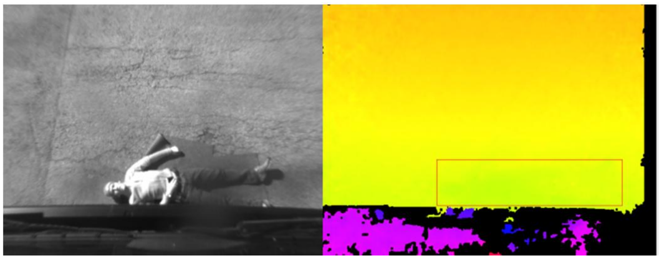

Fig. 10. Detection of the low obstacle from the front of the vehicle. Obstacle is seen in the disparity image on the right as a green colour inside red rectangle.

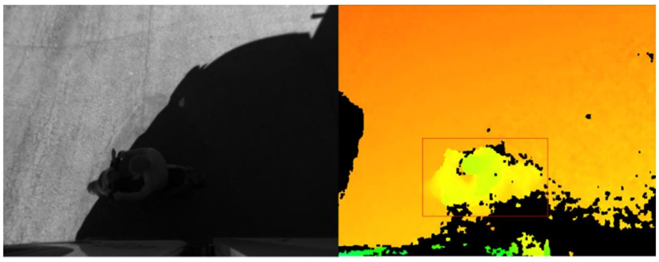

Fig. 11. Motorcycle driving in the blind spot. Obstacle is hidden in the vehicle shadow, but it still can be detected from the disparity image right (red rectangle).

B. Driver monitoring

The driver monitoring system was tested with different drivers in both a stationary and a moving vehicle. Based on the first results from the tests, gaze detection in large cabins is a challenging task especially from long distances. At this moment, tests are concentrating on finding the best camera and illumination combination to find drivers' eyes even in challenging environment conditions with variable drivers.

In Fig. 12 are illustrated three different scenarios which decrease performance of driver eye tracking in driver monitoring system. On the first row, is shown typical situation when driving in bright lighting (against the sun). Driver needs to almost close the eyes making algorithm difficult to detect pupils.

On the second shown typical situation when i.e. driver is reversing the vehicle and needs to turn head to see clearly outside the cabin. In this case, eye tracking is challenging because side window doesn't provide any installation points for the camera and direct view to drivers eyes.

Third tested situation was concerning drivers using eye classes. In this case camera algorithm can easily detect and find drivers face, but detecting pupils, is challenging. With eye classes, lens can easily distort eye area and therefore make difficult to detect pupil.

By using the results, it was possible to find best possible camera constellation inside the cabin. Cameras installed near the driver (left mirror and dashboard) gave good results in all conditions but the detection of the gaze direction to the right mirror or the right blind spot mirror was challenging especially in changing illumination conditions. Under good illumination conditions (day light or cabin interior lights) the gaze detection gave good and reliable results. In night time with low illumination, the camera's dynamic range is not sufficient enough to provide an image for detection. This can be boosted i.e. using IR-illuminators to boost interior lighting.

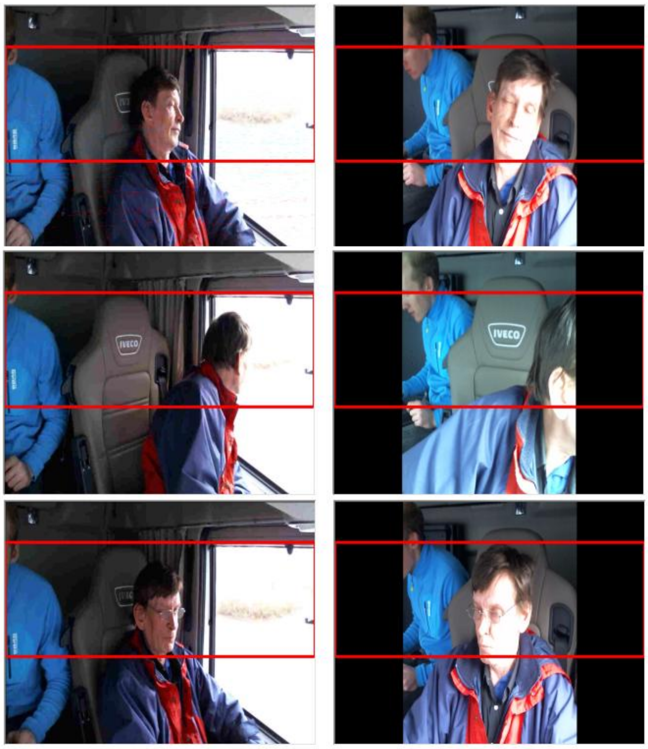

Fig. 12. Three examples of failed eye tracking with driver monitoring system. On the first row driver is closing eyes because dense illumination. On the second row, driver is turning head to see outside of vehicle. On the third row, driver uses eye classes and blocking direct view to pupils.

The second challenge for driver monitoring is to adapt for different drivers. Drivers have different size (height, width), use classes (Fig. 12), wear caps or are simply sitting in an ergonomically challenging angle. In these cases the driver's face and eyes can be outside or partially outside the camera field of view and is therefore not detected.

Preliminary tests with driver monitoring system shows that gaze detection inside the large heavy vehicle cabin can be challenging task compared to small vehicle. Based on these test we have managed to determine functional and reliable installation constellation for driver monitoring cameras which can detect drivers face with eyes reliable enough to support obstacle detection.

At the moment of writing the obstacle detection system sensors are selected and installed to the vehicle. The next development step is to determine the specifications for sensor system functionality in different environment conditions and to gather test data with both the obstacle detection and driver monitoring system. Collected data are used to create a multilayer warning system to raise the driver's awareness of possible incidence. The special warning protocol will be applied if the driver is not reacting in a safe way. For example: the driver's intention is to change the lane. Does the driver look at the side mirror first? Does the driver react to the lane change warning? Does the driver recognize the blind spot area? How does the driver react when an obstacle is noticed in the other lane? Does the driver slow down the speed or continue the manoeuvre?

V. FUTURE WORK

Future plans are to develop the system further and to bring the concept in use in professional truck driver training. It shall bring different means to adapt e-learning solutions, serious games, practical exercises with real vehicles and simulator (high-end and low-end) based training together. The individual development of learned skills is followed during the training period. This enables personalised learning methods and duration. An important part of the concept is to pre-test the drivers and to plan training accordingly

The measurement units are installed to the cockpit of the truck and data gathering can be executed during the normal work hours, which is attractive for cargo companies. This enables the opportunity to measure real learning instead of a number of separate training days. The driver receives feedback from real driving instead of being in an artificial simulator environment which makes it possible to pretend driving habits in order to pass the exam. The solution reported in this paper collects data from long term driving, making artificial improvement of results almost impossible

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