



Automation of Vehicles



Project within Vehicle and Traffic Safety

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

The overall aim of the project is to analyze, integrate and implement autonomous and semiautonomous features in Volvo Construction Equipment machinery. The project contains three major parts: establish a technical roadmap from today's machines to tomorrow's fully autonomous machines; knowledge transfer as well as implementation of a number of robust safety features for verification and demonstrations.

The project has established a very important basis for further work with driver assistance, semiautonomous and fully autonomous systems of Volvo Construction Equipment machinery. It has identified the driving force and target scenarios for autonomous wheel loaders and trucks, then compared the results. The major challenge to achieve the desired functionality is perception. The project has also identified requirements to ensure that safety systems can withstand the harsh environment around a construction site. It has developed an analysis of how tools for increased robustness can be used in the development of safety systems. Risk scenarios were examined and the key risks to reduce were identified. An analysis of how these identified risks can be reduced through introduction of active safety systems has been investigated.

In addition, a number of safety features has been implemented on wheel loaders for evaluation and demonstration:

- A driving assistance system for improved visibility in the immediate vicinity of the vehicle has been evaluated using experienced operators.
- Obstacle detection system has been implemented and evaluated.
- Algorithms for active collision avoidance with automatic brake has developed, implemented on demonstrator and verified together with the implemented obstacle detection.
- Human detection was achieved by detection of reflective vests.
- Algorithms for active warning to operators regarding the risk of rollover has been developed, implemented and verified with experienced operators.

The project has generated several positive effects, and has had a huge impact on VCEs continued efforts to integrate the active safety functions in construction equipment.

2. Background

Safety and robustness is considered as two very important aspects in the development of autonomous functionality for the future. Both, as of active safety systems that can support an operator and safety and robustness requirements on systems to its increasing complexity and capability does not lead to the introduction of new risks.



3. Objective

The overall objective is to analyze, integrate and implement autonomous and semiautonomous features to Volvo Construction Equipment vehicles. The project contains three major parts:

Establish a technical roadmap from today's existing technologies to fully autonomous vehicles. Where, semiautonomous safety and assistant features as well as robustness are included. Also, this includes a risk scenario for construction equipment, with focus on how the introduction of new safety systems can reduce these risks.

Knowledge transfer regarding semiautonomous functionality, safety and robustness. The objective is, according to the above roadmap and towards the features listed below.

Implementation of a number of robust safety features for verification and demonstrations. Both, with applications for fully autonomous machines as well as for today's vehicles.

Through this work, the foundation for further work on autonomous functions will be established. Within the frames of this project, active safety systems are considered as a subset of semiautonomous functions in VCEs vehicles. This subset is seen as a gradual introduction of the fully autonomous machine. The semiautonomous features provide increased complexity and will eventually lead to autonomous vehicles. Active safety systems are a very important component, for today's construction equipment and for the future fully autonomous vehicles. A fully autonomous vehicle/machine is considered to be a system that can work independently for a specific task without interference from an operator/driver. It should be able to operate in a dynamic environment and adapt decisions subsequently through an obviously intelligent behavior.

4. Project realization

The project was divided into a number of work packages according to planned activities. The first three parts: roadmap, risk scenarios and robustness are theoretical parts that form the foundation for further work with implementation on a demonstrator. Work package four to eight are implementations on a demonstrator with a driver assistance system, obstacle detection, human detection, automatic braking and roll over warning. The project has conducted several interviews and group discussions to collect information, including experts in construction equipment, engineers, dealers, and customers. Data used within the project is based on statistics from databases. Features implemented on the demonstrator have been evaluated by experienced operators from VCE. In order to achieve the desired functionality of the system, important contacts with suppliers have been imposed for continued cooperation.



Work package 1, Roadmap

The objective of work package 1 is to create a roadmap, which describes the distance between today's existing technology and what is needed to achieve fully autonomous vehicles. The roadmap takes into account existing technologies, planned developments and visions regarding the semiautonomous and autonomic functionalities. It describes how the new functionality can be designed, when it would be launched as well as the functionality needed for the final product, a fully autonomous machine. The developed roadmap covers both trucks and construction equipment, with focus on wheel loaders.

The project has focused on understanding the motivations and objectives of autonomous vehicles and active safety. A state of the art investigation and a gap analysis between the available and required functionality have been fulfilled. Information and data for wheel loaders are based on interviews and group discussions with experts on VCE in Eskilstuna. Information and data for trucks are based on information from Volvo 3 p.

Introduction of the semi-autonomous and fully autonomous functionality is particularly interesting from a cost perspective, not only from reduced driving costs, but also from reduced fuel consumption and increased productivity. This introduction of functionality will occur gradually in selected applications. Perception is the greatest challenge to achieve introduction of active safety systems. The project has identified interesting technology for the future and for introduction in a demonstrator of today. The environment surrounding the construction equipment is very tough in comparison with other outdoor applications. A final system must be able to handle vibration and mechanical shocks, weather conditions such as rain, snow and fog, as well as direct sunlight and darkness.

The work package has provided the necessary foundation for further work with active safety features.

Work package 2, Risk scenario

The objective of work package 2 is to identify risk scenarios for construction equipment, and examine how active safety systems can be used to reduce the risk of accidents in the identified scenarios. At least two active safety systems that are suitable for implementation should be identified. The work was divided into three steps, namely, data collection, data analysis and active safety.

Data collected on accidents should mainly come from databases. In construction equipment, however, the amount of available data is very limited and has to be expanded to provide better validation of results. Further information was collected through interviews and group discussions with both experts in construction equipment, dealers and drivers/operators. Some statistics could be obtained from the Swedish authority Arbetsmiljöverket (AV), the information system on occupational injuries (Informationssystemet om arbetsskador, ISA) and from insurance companies.



Information from the various sources does not cover all occurred accidents and accidents can be registered in multiple databases. To the extent to which the collected data are overlapping or not cover is difficult to estimate. The registers also contain different consequences: injuries of all degrees, death or more severe injuries and accidents involving non-minor injuries. The insurance companies also include accidents with just economic consequences. The overall information is difficult to interpret gives indications in different directions. The main result is that the accident types are identified and categorized for further investigation into how they can be reduced through introduction of active safety systems.

- Roll over: occur mostly due to an edge that collapses or an obstacle that is not detected. Only a few are caused by careless driving. The machine is heavy loaded in the majority of the cases. It is possible to develop a security system to calculate the maximum lateral acceleration that warns when a limit is reached. For an autonomous machine, it is also very important to verify that the system does not request for too strong lateral acceleration.
- Collision: Often due to the operator who fails in attention and, some areas around the machine are difficult to see. A safety system can be designed to detect objects in different sizes and warn the operator or automatically brake the machine if necessary.
- Runover: Often due to the operator who fails in attention. An active safety system to prevent runover demands a human detection system. The car industry has begun to introduce systems to detect humans in the road, warn the driver and brake the vehicle if necessary. A similar system for construction equipment is conceivable but the surrounding environment is much more challenging and has higher demands on the sensors.
- Work with machine: This category is wide and includes various types of accidents. Often it is someone who helps the operator, such as with the load, and is in the vicinity of the machine that gets injured. To prevent this type of accident a system where the operator can monitor the machine's surroundings is required, e.g., a Bird's eye view system.

Analysis of the accident categories and active systems together with the roadmap as a guide a number of systems were chosen by the project to be implemented and verified. A "Bird's eye view" system was selected as the driver assistance system for today's vehicle, automatic brake to avoid collisions and roll over warning with adaptation possibilities towards autonomous vehicles. Sensors have been evaluated and implemented for obstacle detection and human detection which is required by an automatic brake system.

Work package 3, Robustness

At the introduction of new safety systems, it is very important that new problems are not introduced. A guideline for how to proceed with safety analysis is part of the goal to increase the robustness of systems. The guide is suitable for both research projects and in early steps in production development. The method is also evaluated in a safety feature in development. The analysis is performed in the following activities:

- Describe the function: All tasks should be described, but descriptions of implementation should be avoided as long as possible. The purpose is to assure that there are no inaccuracies or missing information.
- System architecture: Optional, since a safety analysis can be performed even if the system architecture is not known. The description only needs to identify the parts or components and interfaces to which they are connected with.
- Environmental conditions and constraints: Are stated according to common practice. They are needed, because some of them can cause potential problems for a system. It is also important to know if a specific condition can be assumed to occur or not.
- Preliminary hazard analysis: Is already described quite well in ISO 15998. The project has made some additional advice and clarifications.
- Fault tree analysis: For each identified risk with SIL in at least one. The hazard is the top event and tree is created by expanding the top node to detect all the immediate events that result or may result in the top event. The process is repeated until all the fundamental causes are identified.
- Initial safety requirements: The top level of safety requirements can be defined from the SIL classification of hazards. The safety requirements are stated relatively high level and need to be refined and decomposed in order to determine more precisely what is necessary and sufficient to reach the top safety requirements.

The work has provided an important method to ensuring robust systems.

Work package 4, Driver assistance

A Bird's eye view system complements the visibility for the driver, in mirrors and windows. A view will be created with the help of a number of cameras, where the machine is seen from above, from a bird's-eye view. The idea is to create an intuitive picture of the machine and the objects in the vicinity. This technique is previously used on trucks and buses. An important difference to consider during installation and evaluation are the



shape of the wheel loader. Parts of the view can easily become hidden by the fenders which come outside the camera position on the top of the cab. Even the articulated steering can cause problems.

Installation of the system has been optimized for the best term in accordance to the information from the risk analysis. An investigation was carried out in order to verify the usefulness of the system. Experienced drivers evaluated the system in a number of different applications. A great deal of interest in this type of driver assistant system was shown. The drivers agreed that man has the most use of the system when working in environments with narrow spaces or where there are pedestrians. The system is considered to be less useful in environments with few obstacles, such as in gravel production.

The system was delivered by ASL Vision who performed the actual image processing. The project has also created contacts with different suppliers in the area. The result is seen as a first installation for evaluation. A system with integrated algorithms for the detection and tracking of objects and people are under development by the supplier.

Work package 5, Object detection

The objective of work package 5 was to identify and integrate active sensor systems for object detection. The work includes development of basic algorithms and interface to active braking. Selection of sensor technology was made by the evaluation of the work package 1. A study of commercial system was based on the requirements for construction equipment in general and for the project's specific requirements. Most sensor systems are customized for cars/trucks where it can be assumed that the vehicle is on the road. A system, GreenSight, is adapted to the environment at constructions sites and installed in cooperation with the supplier. The system is based on ultrasonic sensors and has, for the purpose, relatively limited range; approximately 9 m. Through a CAN interface, information on the distance to an object behind the unit is received. The system's accuracy and ability to detect various objects were evaluated. The detection is stable with good accuracy during normal circumstances where the machine and the target object were stationary. Also, the detection in low speeds work well while the behavior is not as robust in higher speeds. Even weather conditions such as rain and wind, has been shown to have influence on how early objects are detected and how robust it is.

The advantages of using commercially available systems are of course that the development time for systems is avoided. It is preferable to evaluate the system even if they do not meet all requirements. In this way, it is evaluated what might be on the market in the near future. It also allows feedback to manufacturers who are given the opportunity to further develop and adapt their products. The project has helped relationships with several sensor manufacturers who are working to find products more adapted for construction equipment in the long term.

A second sensor system evaluated within the project is a laser scanner, where also the detection algorithm was developed within the project. A laser scanner has very high



precision when compared to other technologies. The disadvantage of the evaluated system is the update rate in 3D. By compromise in terms of coverage area and size of the detected objects the update rate could reach 1 Hz. The evaluation of the system shows, as expected, that precision for detected objects is very accurate, even in e.g. snowfall, and the developed algorithm was satisfying. However, with the current problem with low update rate, that system cannot be used for collision warning in higher speeds. It can be noted that there is laser scanner with 15 Hz in 360 degree perspective available, which would be sufficiently fast even at higher speeds. Although the faster laser scanner falls outside the frames of this project due to cost, it is expected that the price will be less in the long run.

Work package 6, Human detection

There are cases where it can cause more damage to the vehicle and/or the load to unexpected brake than running into smaller obstacles. If the obstacle is a person an immediate brake should take place regardless of the consequences on the vehicle or load. Therefore, it is very important that an active safety system can distinguish humans from other obstacles. An investigation of commercial systems shows that they are customized for the automotive industry. The project chose to develop a concept suitable to the construction environment. The system detects people in reflective vests, which must be used in working areas. Algorithms to detect reflective material was developed and how to classify the reflections from the jackets in comparison with other reflex areas, as other vehicles and road markings. The system works in real-time, > 15 Hz. It will detect both stationary people, in all positions (crouching, lying) and people moving fast. Since no distance measurement was implemented an interface to test platform was never created.

Work package 7, Automatic brake

In this package an algorithm for automatic collision avoidance was developed. Collision is avoided by active intervention, braking. The algorithm was integrated on a prototype vehicle and was evaluated for cases identified in the work package 2. The algorithm consists of two main parts, namely decision algorithms and interaction with the operator:

- Decision algorithm

Discussions with experts on VCE were held about wheel loader feature. Literature was studied for the choice of method for threat estimation. The software was implemented as a number of separate components that then was put together to get the final function.

- Interaction with operator

It was decided to first warn the driver by using diodes and then active braking. In order to achieve an interface collaboration with transmission group on VCE were started.

The resulting feature was integrated on wheel loaders for verification. The evaluation consisted of testing on both the component and functional level. Tests show that the



function works according to specification. Objects are detected and function alerts the operator, if the operator ignores the warning the machine will automatically brake. The result of a single test is very dependent on sensor functionality and range. At low speeds the sensor works well and the function both warn the operator and slow down the machine to avoid a collision. At higher speeds the sensor data and the range is too short for the feature to function optimally. In these cases, there is usually not enough time to warn the operator and the machine must slow down immediately when an object is detected. In many cases the machine does not stop in time for the object but the speed, and thus the consequences of the collision is reduced.

Work package 8, Roll over Warning

The aim was to create a demonstrator with a roll over warning. The calculated risk should be sent to both drivers as to other active systems that can use the results. Implementation was divided into three different parts; data collection, modeling and evaluation.

- **Data Collection**
To develop as exact model as possible good data is a necessity. The work was initiated with collecting data on the vehicle geometry, sensors and limitations. Then, a number of interviews with select technicians and engineers with great knowledge in the design and development of wheel loaders were carried out.
- **Modeling**
With support from data and geometry information a model was created to model how angles and weight affect stability. The concept behind the model is in short, calculate the overall Centre of gravity of the machine and determine the risk is to overturn. The machine is divided into five different parts that can move individually, as a result of articulated steering and variable linkage. By using the geometry of the different parts of the machine to calculate the different elements location in each calculation cycle and summing to a total of gravity placement.
- **Evaluation**
The system was evaluated for drivers with great experience of wheel loaders.. The scenario was that the bucket was loaded and then the machine was run over a hill. The purpose of the scenario was to trigger the roll over warning forward since it is too risky to try to trigger the sideways. Risk assessments from the drivers comply well with the system's risk calculation.



5. Results and deliverables

5.1 Delivery to FFI-goals

The project has contributed to FFI objectives through the following activities:

- By identifying where accident risks are and how they happen the understanding of which systems can reduce the risks is improved.
- Evaluation of available technologies, Bird's eye view and the GreenSight.
- Developed new technology for construction equipment and sites by reflective vest detection, roll over warning, and automatic braking.
- Developed methods to ensure the robustness of the introduction of new systems.
- Promoted knowledge transfer from VTEC on the implementation of safety systems
- Promoted knowledge transfer from Örebro University on perceptual systems.
- Results of implementations can be transferred to other areas e.g. in cargo handling, logistics and materials management in production.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The project has demonstrated results at Volvo Techshow in May 2011. An early version of the Bird's eye view feature on a machine was shown and personnel were there to discuss the project. Volvo Techshow is an exhibition where news and research from the Volvo Group is presented during a week's time. Visitors are both internal and external, among others, politicians, representatives of haulage contractors, retailers, academic staff and students.

To disseminate the work internally, a number of information seminars has been held by the project. During these meetings the project results dissemination and discussions on active safety have been held. Normally people from the product platform, product planning, law and regulations, as well as functional developers have been invited

- Platform Wheel loaders, Eskilstuna, two occasions 2009 och 2010.
- Platform Excavator, Konz, 2010.
- Platform Hauler, Braås, 2010.
- Platform Road Utility, Shippensburg, 2011.

The reaction has been very positive and the project has provided a much better awareness of the facts and issues. This is also transferred into the operational planning. Some of the results have been presented externally, and it has increased awareness of the seriousness of the topic as well as increased focus on the area. It has also initiated cooperation with other colleges and universities on technology development, e.g.



Mälardalen University and Penn State University, United States. The project has helped relationships with several sensor suppliers, working to eventually develop products more adapted for construction equipment.

The project has had cooperation with the EU financed projects HAVEit and Intersafe 2 on VTECs part.

A major seminar with presentations and demonstrations are planned when the project ends. On this occasion, all work packages will be presented in detail and implemented systems will be demonstrated.

6.2 Publications

Henrik Andreasson, et. al. “Vision-based People Detection Utilizing Reflective Vests for Autonomous Transportation Applications” IROS 2011

Todor Stoyanov, “Reliable Autonomous Navigation in Semi-Structured Environments using the Three-Dimensional Normal Distributions Transform (3D-NDT)”, PhD thesis, in preparation.

7. Conclusions and future research

This work has yielded multiple effects and has had a huge impact on VCEs continued efforts to integrate the active safety functions in construction equipment. The project has developed a structure to transfer to other platforms. For example, in the accident statistics an in-depth customer survey has been conducted. Work on accident investigations have continued for other platforms, e.g., hauler and excavators, both on a national and on an international level. The approach has been a direct transfer of from the knowledge archived from the project, with respect to method and data. It provides an improved picture of accident statistics and customer perspective in most parts of the construction segment. This strengthens Volvo CE's competitiveness. Bird's eye view systems have also been evaluated on the excavator and paver.

Work on the roadmap has made improvement of the situation of increased cooperation with technology development within Volvo AB. The approach to safety analysis has provided tools to manage the integration of active safety technology, which can be used in the industrialization process.

There is a clear cooperation with VCEs work for autonomous machines, ALL4eHAM and its continuation project ALLO. The common parts are perception and obstacle detection. Also, Örebro University work with reflective vest detection has continued.



The next FFI project, “Zero accidents and increased productivity on road construction”, is based on the accumulated knowledge from this project.

8. Participating parties and contact person

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