PreScan, testing and developing active safety applications through simulation

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Abstract

Equipping cars with sensors may let cars anticipate on dangerous situations. Multiple questions arise concerning the development of such Active Safety systems, regarding sensors, traffic scenarios, responses, etc.

To answer such questions TNO has developed a design and evaluation environment, called PreScan, in which the complete road situation can be simulated. The simulation environment is built up in four parts, Scenario, Sensor, Control System and Running Experiments. They are all explained and elaborated upon in a concrete example of Car-to-Car communication.

The simulation environment has a number of benefits over real world testing, being the investigation of: phenomena independently, more complex scenarios and 'unsafe' scenarios, in a reproducible way. Finally, the introduction of a simulation environment in the development process will allow for a shorter launch time, because the initial design is improved.

Introduction

Road vehicles are becoming increasingly 'smarter' and safer as a result. Using sensors enables cars to 'see' danger before it happens and therefore anticipate what action to take. But what is it that the sensors should be observing and what are relevant traffic scenarios to test your system? How can the observations be translated into a response from the vehicle, what is the influence of unexpected disruptions and, even more challenging, how do you ensure that information from different sensors is combined in such a way that the vehicle responds appropriately and in a robust way?

These questions were mostly answered by testing developed systems in real vehicles. But what if the traffic scenario becomes unsafe, like investigation of near-collisions, or if the traffic scenario consists of many vehicles? Simulation of such scenarios could solve the problem.

To develop a simulation environment, the product you want to simulate, as well as the development process for that product, needs to be looked at. A widely used concept to characterize the product, an Active Safety system, is 'Sense', 'Think', 'Act', see Figure 1. The development process of an Active Safety system, which is basically a control system, is mostly built-up as a V-cycle, with main stages: 'Specification', 'Design' and 'Test', see also Figure 1.

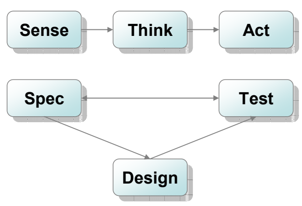


Figure 1 Product and development process concepts

With a simulation environment you could have a potential number of benefits over testing in real world:

- Investigation of phenomena independently, like light intensity reduction and effect by droplets in case of rain;
- Exact control over test conditions and reproducibility: consider how hard it is to recreate the previous test conditions, exactly;

- And as mentioned, investigation of more complex scenarios, e.g. with many vehicles;
- Possibility to investigate 'unsafe' scenarios, such as near collision without the risk of colliding vehicles.

Extra benefits could be gained by design, development and testing in one environment:
- causing less misunderstandings between disciplines;
- work can be (re-)used during the whole development;
- everybody is working in the same environment.

As an extension to real world testing, and as a help in the design, TNO Science and Industry has developed PreScan [1], a design and evaluation environment in which these smart cars can actually see the surrounding in which they are driving and can subsequently respond to it. For this purpose, sensor models containing physical relations can be used.

An example Active Safety system with environmental sensors is implemented and simulated in PreScan. The test en design choices are explored. The results show how simulation of the sensors, vehicles and the surroundings will help the design and development of active safety systems.

Concept

The concepts defined in the *Introduction* are used as a basis to define the main parts of the PreScan simulation environment, allowing PreScan to be used during the whole development process, and for the whole product.

From product perspective, the Sensor (=Sense) and Control System (= Think) are most important. The Act part is considered given. These two parts make up the Design phase in the development process. In the Specification phase, Scenarios are the most important, as they are the true problem to solve. Finally, running simulations (evaluation studies) is the last main part (=Testing).

Therefore, in our vision the simulation of an Active Safety system consists of four main steps (depicted in Figure 2):

1. Building scenarios
2. Adding sensor systems
3. Adding control systems
4. Running experiments

Figure 2 Four main steps

Creating a simulation is started by the question what problem needs to be solved. The problem in our case usually consists of a road situation that is (potentially) critical enough to result in an accident. This step is called Problem Definition.

Building scenarios

To be able to simulate the road situation needs to be recreated in the virtual environment. First, the road lay-out and infrastructural elements obscuring the sensor view are created. Secondly, vehicles including their trajectories and dynamics need to be modeled. Finally, as an Active Safety system should function in all circumstances, variations with respect to the nominal case should be modeled.

Adding sensor systems
The sensor is the first basic component of an Active Safety system. From simulation perspective, the virtual sensor system should provide a similar output as the real sensor, including particular phenomena related to that sensor (system) such as noise.

The virtual sensor might range from a freely adaptable idealized sensor to a highly detailed physics-based sensor including sophisticated data interpretation algorithms. The output may therefore range from detected objects to raw sensor data.

Adding control systems
The control system comprises the intelligence of the Active Safety system. Most of the Decision-based development of the Active Safety system is to be performed in this step.

Running experiments
The *Running Experiment* step is mainly related to investigating the robustness of the Active Safety system. Seen from a simulation perspective, this is achieved by making (small) variations to parameters of the Sensor or Control system, or the Scenario, e.g. adding noise to the Sensor, delays in the Control system, and changing speeds in the Scenario.

PreScan program
The basic idea of PreScan® is building a scenario in a Graphical User Interface (GUI) and running the experiment using MATLAB® / Simulink®[2]. Sensors will be simulated in an engine behind the Simulink model. Control Systems will be developed by the user in the Simulink model.

In the GUI, the scenario is built. A scenario consists of library components that can be dragged and dropped into the Build Area to obtain a rough layout of the experiment. Details can be set by changing the properties of these components, using the appropriate configuration windows or property editor, reached with right-click of the mouse. All parts of the GUI are shown in Figure 3.

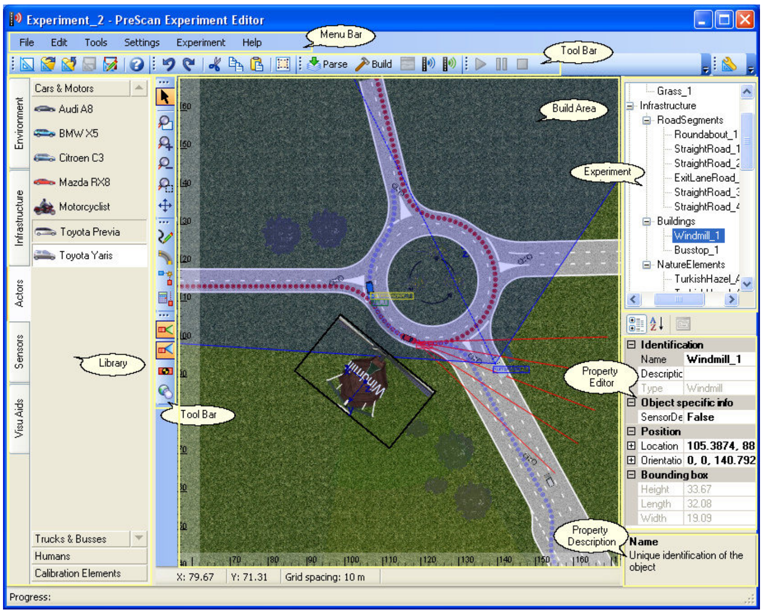


Figure 3 PreScan Graphical User Interface

Once the experiment is built in the GUI, a Simulink model of the experiment is prepared, see Figure 4. The user can add his Control algorithms to this Simulink model and play the model normally.

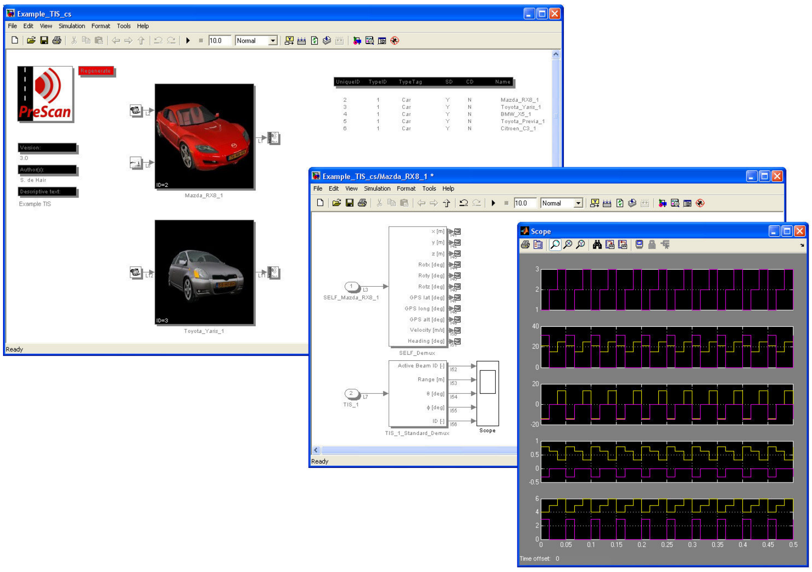


Figure 4 Simulink representation

Since the MathWorks' products MATLAB / Simulink and Stateflow® and associated toolboxes can be used in conjunction with PreScan, these world-class tools will help to verify the correctness and completeness of code developed.

PreScan has strong visualization features helping you to sell your products as well: sometimes a movie tells more of a story than a big report containing engineering graphs, see Figure 5.

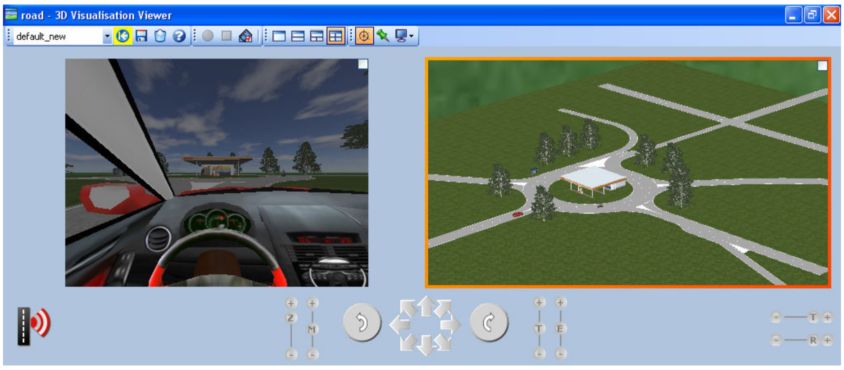


Figure 5 3D Visualization viewer

Active Safety example

This chapter shows how the methodology is used in a concrete example. For each step, as defined in *Concept*, the modeling choices are elaborated.

Problem Definition

As an example to explain the implementation and simulation of an Active Safety system, a scene recorded on a crossing in Delft was chosen. The vehicle indicated with a circle is waiting for the van to pass to make a left turn (Figure 6 (left)). It pulls up (middle picture), and crashes into the approaching vehicle (right picture).

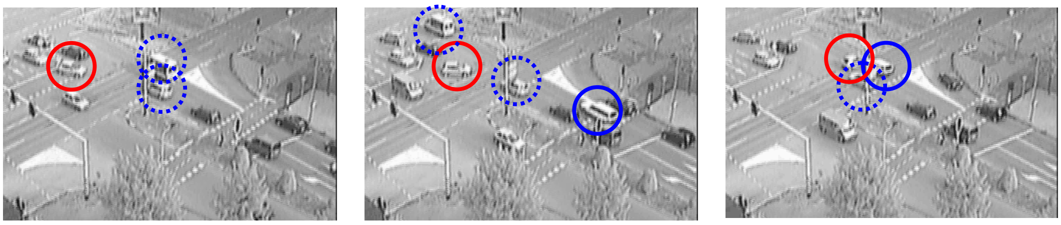


Figure 6 Problem definition: real-world situation

At first sight this accident seems strange: the approaching vehicle is clearly visible in the movie. However, by analyzing the situation in more detail it turned out that from the view from the encircled vehicle the approaching vehicle is completely obscured by the line of waiting vehicles.

From this observation, it may be concluded that a sensor, that needs a direct line of sight, cannot solve this situation. Car-to-Car communication (C2C) seems a logical choice to avoid this collision.

Scenario

The goal of the *Scenario* step is to rebuild a real-world situation in PreScan. To rebuild the scenario described in the *Problem Definition* in PreScan, only those elements of the real world that are relevant to the sensor system need to be taken into account (plus those elements that make the experiment look realistic if you need to present your work).

As already became clear in the Problem Definition, the encircled vehicle, the approaching vehicle and the line of waiting vehicles are of key interest. A second step could be to extend the simulation with all other cars present to investigate the interaction of numerous C2C systems functioning at the same time. In this paper we will concentrate on the first step.

Figure 7 Rebuilt road network

As the scenario is taken from a real life situation, we may use Google Earth [3] as an 'underlay' (see Figure 7 (left)) to recreate the road lay-out (see Figure 7 (right)). The road lay-out, including correct number of lanes, splitter islands, correct position and orientation, etc., could be recreated using PreScan.

Secondly, the vehicles and their respective paths are recreated (see colored lines in Figure 7 (right)). Paths include correct velocities, waiting points and waiting times. The overall scenario is depicted in Figure 8, resembling the middle picture of the Figure 6.

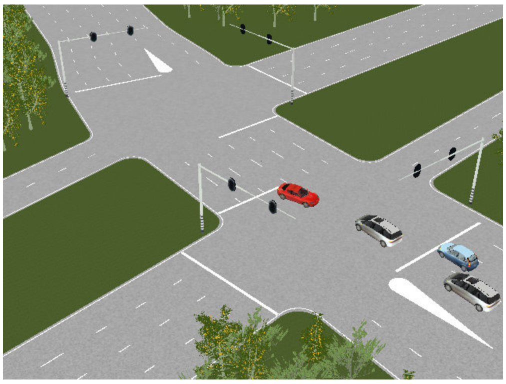


Figure 8: Scenario: Rebuilt situation

Sensor System

The *Sensor System* in this example is Car-to-Car communication. There is always a close relation between the sensor and the control system: the sensor system prescribes the information the control system should work with. Or in this case: the control system dictates which signals should be sent over the communication channel. Therefore we will continue with the Control System, and summarize the signals to be communicated at the end of that section.

Control System

The *Control System* is the heart of the Active Safety system. A Control System was implemented to illustrate this example. The basic idea of the implemented Control System is that each vehicle communicates its intention {turning left, going straight, turning right}. From this information and its own intention, the red vehicle can decide whether it is safe to continue its path. In short, the warning signal is calculated from the other vehicle's intentions, combined with its own intention.

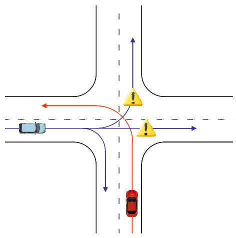


Figure 9 Concept Control System

This is elaborated in Figure 9. When the intention of the red vehicle is to turn left, it is not safe to continue its path, when an approaching vehicle is turning left, going straight and turning right. Combining all three options for the red vehicle with all three options for each vehicle coming from each three lanes provides a so-called truth table for safe and unsafe possibilities, which can easily be solved using MATLAB® Stateflow®.

Several restrictions apply:

- A crossing is considered to be straight: i.e. all entry lanes are roughly perpendicular;
- This specific crossing is a "double" crossing; only the lower part is considered, see red square in Figure 10;
- The motion of the vehicles is equal to the intention;
- When a vehicle is standing still, it does not cause a warning;
- The GPS location of the crossing is know (e.g. from map data);
- Only three vehicles are considered: the van, the first vehicle waiting in the line and the approaching vehicle;

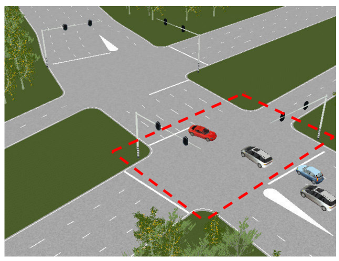


Figure 10 Considered part of the crossing

Combining the basic idea with the restrictions, it may be concluded that the signals to be communicated over the C2C system are:

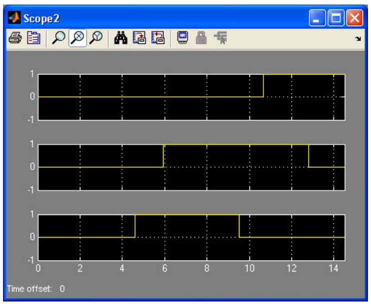
- Intention
- GPS location
- (Compass) heading
- Vehicle identifier

Running experiments

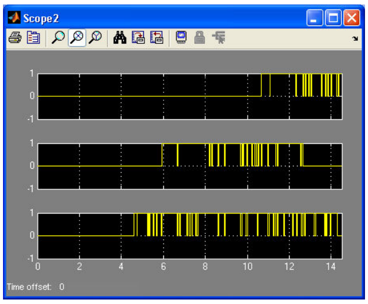
As mentioned, the *Running Experiment* step is mainly related with investigating the robustness of the Active Safety system. Variations need to be made, which may lead to the acceptance of the system, or the requirement for adaptation to the (Control) algorithm.

One variation is made to the Sensor to illustrate this: missing messages. Missing messages relate to the fact that in (C2C) communication a certain percentage of the messages do not arrive at the receiver. A common number is 20% [], although this number is mainly used for demonstration purposes.

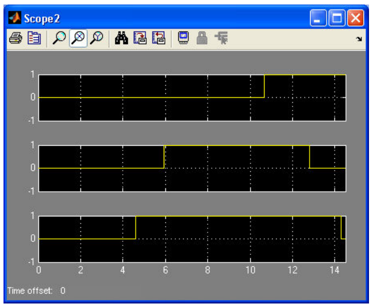
First the nominal case is investigated, see Figure 11 (left) in which the warning signal per vehicle is plotted. The first vehicle is the approaching vehicle, which is detected at the end of the simulation; the second vehicle is the waiting vehicle, which appears halfway the simulation and stops producing a warning as it stops; and the third vehicle is the van passing the red vehicle.



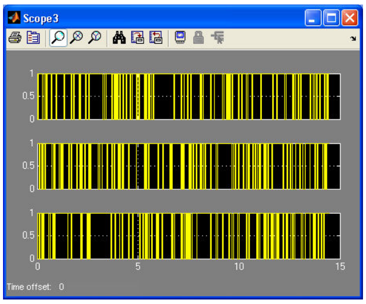
Ideal world



Missing messages (20%)



Adapted algorithm



Signal validity

Figure 11 Warning signal per vehicle

The second case is the simulation of the missing messages, see Figure 11 (middle). When a signal is missed, the sensor output is not updated. It is assumed that this can be detected, e.g. using time stamping included in the signal.

It can be seen that at many times when the signal is lost, no warning occurs (false negative). At these times the conditions to produce a warning are not met. An adaptation to the algorithm is, obviously, required.

In the third case a 'memory' is implemented in the Control System that memorizes the previous value when the signal is not valid, see Figure 11 (right). The warning is now a straight line again. However, the algorithm now fails to recognize the passing van to be off the crossing.

This process of evaluation and adaptation (iteration) will continue till the system passes the evaluation for all variations. At this time the algorithm may be implemented into the vehicle for further testing. Note the iteration process may be sped up by using tools like Control Desk.

Discussion

This paper showed PreScan and the main parts a simulation environment for Active Safety systems should have, explained using a basic example. It was never intended to present a complete solution to the problem described, but to present, and show the benefit of, using a simulation environment for Active Safety systems.

The level of detail of a simulated sensor will in most cases be lower than that of a real-world sensor. However in the (early) design phase, this level of detail is not required. It is more important that the output is qualitatively correct, than that it is exactly quantitatively correct. All important phenomena should be present; the exact numbers are not so important, so to speak. When the larger part of the design has been made, the final, quantitative testing should occur in a real vehicle.

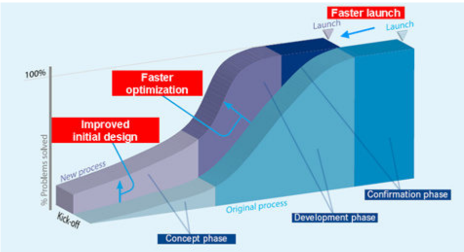


Figure 12 Benefit introduction of simulation environment in the development process

When introducing a simulation environment in the development process, a better Initial Design can be made, as more effects can be investigated, and solved, in the early phase of the development. A better initial design allows for a faster Optimization. With the Confirmation phase hardly effected, because the final testing needs to be performed in the real world, the launch of the product can be advanced, see Figure 12. On the other hand, a simulation environment could be used to investigate more complex systems, keeping the same launch date!

Conclusion

This paper presented PreScan, a simulation environment for Active Safety systems. Scenarios form the basis of the environment, as they are the true problem to solve. Three more parts were identified that, together, would build up a simulation environment with the capability of designing and evaluating an Active Safety system: Sensor, Control System and Running Experiments.

All these parts are included in PreScan, making it possible to use PreScan during almost the complete development process up to the phase of Confirmation Testing, and for the complete product.

Several benefits are possible by using PreScan: investigation of phenomena independently, reproducibility of tests, and investigation of more complex and unsafe scenarios. Although PreScan cannot help much in the confirmation phase of the product, it may lead to an improved initial design.

Outlook

PreScan will be developed further to accommodate the needs of the Automotive industry. New features will include: photo-realism (for simulation of camera sensors), weather effects (like rain, snow and fog), 3 dimensional roads, a real-time connection to a driving simulator, a HIL interface, and a maps and radar plug-in.

References

1. Gietelink, O.J.,Verburg, D.J.,Labibes, K.,Oostendorp, A.F.,Pre-crash system validation with PRESCAN and VEHIL, *Intelligent Vehicles Symposium*, 2004, IEEE, 14-17 June 2004, p. 913- 918
2. *Matlab/Simulink*, www.mathworks.com
3. *Google Earth*, earth.google.com