

# A Rule-based Collision Avoidance System – Scene Interpretation, Strategy Selection, Path Planning and System Intervention

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## ABSTRACT

To reduce accidents and fatalities on the roads, active safety systems which can avoid accidents or mitigate their effects are increasingly required. Contrary to already available driver assistance systems a future system can be a Collision Avoidance System which will be able to solve many critical traffic situations by warning, braking or steering. This paper will present a system consisting of environment sensing and situation analysis blocks as well as intervening strategy blocks. The main focus will be put on the scene interpretation of a situation and its optimization. Therefore a rule-based Fuzzy System will be described. Furthermore the Strategy Selection and the Path Planning in case of system intervention will be shown by simulation.

The system has been developed during the work at the Adam Opel GmbH.

## INTRODUCTION

At the beginning of vehicle development, the performance as well as comfort of vehicles was the primary focus. Forced by the changed traffic situation the focus has changed to vehicle safety during the early 1970s. During the last 35 years the number of registered vehicles in Germany tripled (**Fig. 1**). At the same time the number of people killed in traffic accidents has decreased to a fourth since 1970.

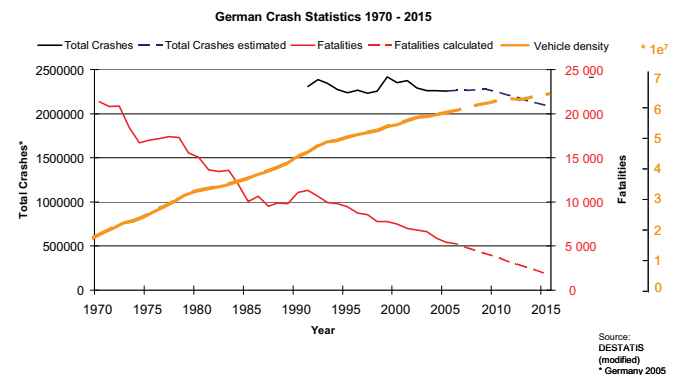


Fig. 1: German accident statistics 1970 - 2015

This trend can be explained by the enormous increase of vehicle safety over the last years which is a result of the importance of safety for the customer of a new vehicle. At the beginning of the development of safety systems primarily passive safety systems which serve to safeguard occupants against severe or fatal injuries were deployed in new vehicles. Examples for such systems are seat belts, stiff passenger cells, collapsible zones, belt pretensioner and diversity of airbags.

Passive safety systems are activated when a collision occurs so that this collision cannot be avoided anymore but only mitigated. In comparison there are also active

elements which assist the driver to avoid or mitigate an accident. Such elements are vehicle stabilization systems like ABS (since 1978), TCS (since 1989) and ESC (since 1995). The anti-lock braking system (ABS) prevents the wheels from locking while braking to guarantee steer ability and stability. The traction control system (TCS) prevents traction of the vehicle by controlling the slip when excessive throttle or steering is applied by the driver. Electronic stability control (ESC) uses individual braking of front or rear wheels to avoid skidding at the limits where the driver might lose control of the vehicle to improve a vehicle's handling.

In the next step comfort systems and active safety systems will grow together.

The fact that such systems do not fatigue and are not influenced by psychological strain like drivers are, can be seen as an advantage, as these aspects are the reason for many accidents. Thus the purpose of driver assistance systems is to avoid accidents or to mitigate the injuries [4]. The role out of driver assistance systems has already begun and will continue in the following years. This is necessary due to the increased traffic density over the last years. Systems like Forward Collision Alert (FCA), Adaptive Cruise Control (ACC), Emergency Braking (EB), Lane Departure Warning (LDW) or Lane Keeping (LK) are already in production or will be soon just to mention some of these systems. However, the represented systems act only in one direction either in longitudinal (like FCA, ACC or EB) or lateral direction (like LDW or LK). A combination of both directions will result in big advantages and benefits.

Therefore the goal of this paper is to describe a Collision Avoidance System which works in longitudinal and lateral direction. The purpose of this system is to inform or warn the driver if an accident is possible and to intervene if the driver does not react to the warning. The intervention is not only in one direction like the EB system for instance, but it also contains braking and/or steering to avoid a collision. The following parts will describe the different modules of the Collision Avoidance System.

## SYSTEM OVERVIEW

There is already research on going in the field of Collision Avoidance Systems. In order to realize a Collision Avoidance System it is important to define the functional architecture for such a system (**Fig. 2**). There are many steps between gathering environmental information and vehicle data to system intervention.

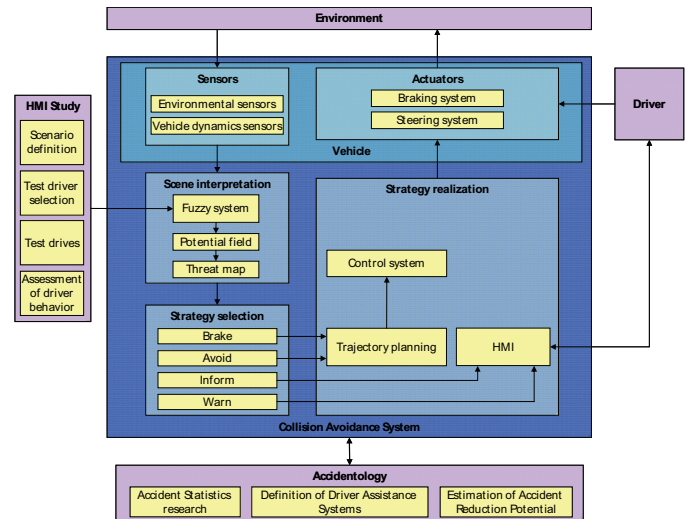


Fig. 2: System overview of the Collision Avoidance System

The first step is the interpretation and assessment of the situation. In the next step the system can decide how to react, depending on the information of the situation interpretation. Is it enough to give the driver information or a warning or is it necessary to intervene by braking or avoiding / mitigating? After deciding how to react, the system can plan the maneuver by planning an optimal path and leading the vehicle on this path as shown in [1].

In the next sections each part of the Collision Avoidance System will be described.

## SENSORS

Progress and performance of driver assistance systems is dependant on the technological progress of environmental sensing, because most of these systems require environmental sensors with increasing performance. A short overview of the most used automotive sensors radar, lidar and image processing will be given here. For more information see [13]. Radar "Radio Detection and Ranging" and Lidar "Light Detection and Ranging" use active sensing for detection of objects and have their benefit in measuring distances and velocities. They both use time-of-flight measurement to detect objects and measure their distance. Radar uses Doppler Effect for velocity measurement as well, whereas Lidar uses a calculated velocity only. Analogously to the driver's eye, image processing uses optical information for detecting objects and gathering environment information. Currently available image processing sensors are cameras with a processing device which is limited in calculation power. Image processing sensors use passive sensing principle and have other capabilities than radar or lidar sensors as they have a wider field of view of about 40° and also

better lateral resolution. Additionally, the image allows object classification and detection of lane markings and traffic signs among other things. However, they do not have such a longitudinal range like Radar or Lidar sensors and less environmental robustness than an active sensor.

After capturing of environmental data the situation has to be interpreted by a scene interpretation module.

## SCENE INTERPRETATION

The environment is noticed particularly by the driver's eyes and processed in his brain. Since this process is very complex, a simplification of the environment is required to make a vehicle controller able to process this data. In order to achieve this goal, a scene interpretation layer has to be implemented.

Some approaches for the scene interpretation or scene representation already exist and can be seen in [5], [6], [7], [8], [12]).

A behavior based approach is the best solution to interpret the driver's intention or the driver's feelings concerning a threat. For the interpretation of traffic situations, drivers usually use a rule based behavior based on vague information and not on precise equations. Therefore Fuzzy Logic is applied to develop a collision avoidance system. In this system the lateral and longitudinal movements which are very important for the scene interpretation have to be taken into consideration. Thus two Fuzzy systems in longitudinal and lateral direction will be described.

## LONGITUDINAL FUZZY SYSTEM

The longitudinal direction is described by using three inputs which relate to the drivers association for interpreting a situation. In **Fig. 3** the inputs and the output are shown.

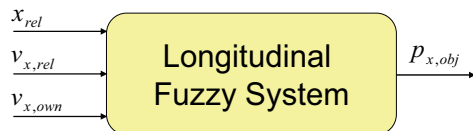


Fig. 3: Longitudinal Fuzzy System

The result of the longitudinal Fuzzy System is a value for the possible relevance  $p_{x,obj}$  of an object in longitudinal direction for the driver. This means that this value gives a degree of importance to each object on a normalized scale. For instance, if an object is far away and the relative velocity is low, the relevance value will be low, but if the distance is small, the object relevance will be high. The longitudinal relevance  $p_{x,obj}$  depends on the

distance  $x_{rel}$ , the longitudinal velocity  $v_{x,rel}$  of the detected object relative to the own vehicle and the own vehicle velocity  $v_{x,own}$ .

After having defined the input and output values of the system, the first step of designing a Fuzzy System can be done by describing linguistic expressions for the crisp input values. Therefore membership functions have been designed which are described in **Fig. 4**.

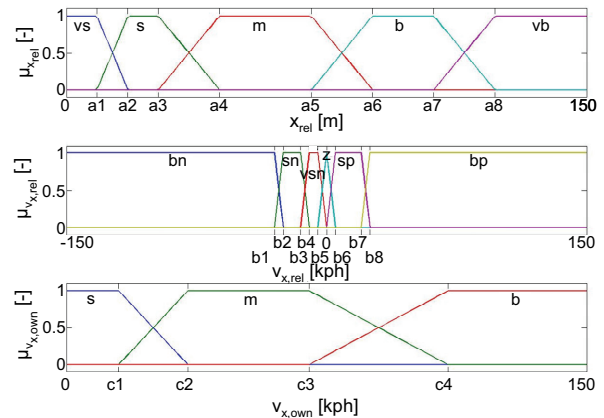


Fig. 4: Membership functions of the longitudinal Fuzzy System

The membership function for the relative distance  $x_{rel}$  is described by five linguistic expressions (very small, small, middle, big and very big), so that the entire speed range is captured. For the relative velocity  $v_{x,rel}$  a more detailed description of the range around zero has been done as it is the range of most traffic situations. For  $v_{x,rel} < 0$  three membership functions (big negative, small negative and very small negative), for zero one function and for  $v_{x,rel} > 0$  two membership functions (small positive and big positive) have been defined. The third input is the own velocity  $v_{x,own}$  with three membership functions describing the whole speed range (small, middle and big).

The second step is the formulation of the rules to interpret the traffic scene in longitudinal direction. The matrices has to be set up for each input expression of the own velocity  $v_{x,own}$  as the described system is a four dimensional system and thus has to be described by three matrices for each input expression.

An example of a rule is:

R1 : IF  $x_{rel}$  = very small AND  $v_{x,rel}$  = big negative AND  $v_{x,own}$  = small THEN  $p_{x,obj}$  = very big

Due to confidentiality reasons the system rules will not be shown here.