Chapter 1

Introduction

1.1 Motivation

The declared objective of the European Commission was to halve the number of traffic fatalities in the period from 2001 to 2010 [European Commission, 2001]. With a decrease of 44% this goal could not completely be achieved (see **Fig. 1**). Consequently, the goal was renewed and adjusted for the period from 2011 to 2020 in [European Commission, 2010] and new strategic objects based on the current "3rd road safety action programme" (RSAP) are derived to propose new actions for the subsequent RSAP. The aim for 2020 is to "halve the overall number of road deaths in the European Union by 2020 starting from 2010".

To pursue the reduction of the number of accidents, automotive manufacturers and suppliers are conducting intensive research on *Driver Assistance Systems* (DAS). These systems support the driver in critical situations or intervene in the driving process to avoid accidents or to reduce their severity. In addition, comfort assistance functions, which make driving more convenient, are an important buying criterion to customers.

This research on ADAS is supported by [European Commission, 2010] with the main objectives n°4 "Safe vehicles" and n°5 "Promote the use of *modern technology* to increase road safety". On objective n°4, actions of the [European Commission, 2010] especially include to

> "make proposals to encourage progress on the *active* and passive *safety* of vehicles […]" and to "further assess the impact and benefits of *co-operative systems* to identify most beneficial applications and recommend the relevant measures for their synchronized deployment."

Actions on the objective n°5 include to

> "evaluate the feasibility of retrofitting commercial vehicles and private cars with *Advanced Driver Assistance Systems*" and to "notably propose technical specifications necessary to *exchange data and information between vehicles* (V2V[1]), between vehicles *and infrastructure* (V2I[2]) and between infrastructures (I2I[3]). The possibility of extending the implementation of Advanced Driver Assistance Systems (ADAS) such as Lane Departure Warning, Anti Collision Warning or Pedestrian Recognition systems by retrofitting them to existing commercial and/or private vehicles should also be further assessed".

[1] Vehicle to Vehicle
[2] Vehicle to Infrastructure
[3] Infrastructure to Infrastructure

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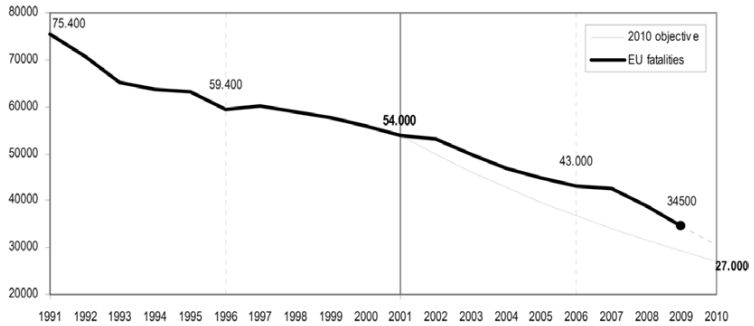


Fig. 1: Development of road traffic fatalities until 2009 (2010 estimation). [European Commission, 2010]

The National Highway Traffic Safety Administration (NHTSA) in the U.S. pursues similar goals. A concrete plan for the years 2014 to 2020 is still under development. However, priority research fields and other significant projects with large benefits for traffic safety are, amongst others, named with forward collision avoidance and mitigation, vehicle communications, (driver) distraction, lane departure prevention, blind spot detection and pedestrian detection [NHTSA (National Highway Traffic Safety Administration), 2011].

Related projects exist, funded by the European Union, and can be found at the European Commission under the area "Road Safety Projects" within the "Transport" policy and under the "eSafety" activity within the "Information Society" department. Current examples are ADVISORS (Action for advanced Driver assistance and Vehicle control systems Implementation, Standardisation, Optimum use of the Road network and Safety), APROSYS (Advanced Protection Systems) and PReVENT (Preventive and Active Safety Applications Integrated Project) [European Commission – Information Society Technologies, 2008], the latter including INTERSAFE, WILLWARN, SAFELANE, APALACI, COMPOSE, ProFusion and more. As a successor of INTERSAFE, the INTERSAFE-2 project [INTERSAFE-2, 2011] was launched.

Advanced driver assistance systems (ADAS) being in research focus help the driver with information or by performing supportive or autonomous actions. This demands an extensive *comprehension* of the vehicle environment and *complex situations*, potentially even unknown situations. Therefore, for further *situation interpretation*, a generic method for *situation description* is needed.

Intersection assistance belongs to the field of ADAS yet to be developed, especially for in-vehicle application. Various approaches to model intersection infrastructure, geometry and dynamics exist, e.g. knowledge-based scene description, graph based methods with map data up to holistic intersection handling with state machines and trajectory planning. However, to the highest extent its complexity of situation description, real-time issues and the lack of sufficient sensory information (e.g. detailed map data, sensor accuracy and field of view) impede the start of a widely spread serial implementation in ongoing automotive development. Since

intersection accidents, depending on the region, accumulate 30 to 60% of injury and up to one 3rd of fatal accidents, interest in this kind of assistance remains high [INTERSAFE-2, 2011].

1.2 Objective and Contribution of this Thesis

The comprehension of a traffic situation plays a major role in driving a vehicle. It transforms perceived raw information into interpretable information. Within the driving control loop, this forms a basis for future projection, decision making and action performing, such as navigating, maneuvering and driving control. Perception, situation comprehension and projection as well as decision making and action performing can be mapped on dynamic decision making as delineated in the model of situation awareness by [Endsley, 2000]. This applies for human decision making investigated by Endsley as well as for substantial advanced driver assistance systems (ADAS).

The aim of this thesis is to provide a generic traffic situation description capable of supplying various ADAS with relevant information about the current driving and traffic situation of the ego vehicle and its environment. With this information ADAS should be able to perform reasonable functions and actions and approach visionary goals such as injury and accident free driving, substantial assistance in arbitrary situations up to even autonomous driving.

This requires assessing more complex situations compared to state of the art assistance systems, potentially including even unknown situations demanding for extensive comprehension of the vehicle environment and the current situation.

Specific goals for the situation description are *modularity* and *hierarchy, expandability*, *exchangeability* and *scalability* for different variants and combinations of ADAS in vehicle applications as well as *determinism* and *correctness*.

Situation Feature Selection

As part of describing a situation, it is of interest, what information is actually relevant to target applications. For ADAS, a number of partially redundant sensors is used to generate a variety of measurement signals. These signals – or features – are then further processed, adding new features. With this high level data complexity and manifoldness, an interpretation and determination of the most relevant features becomes unwieldy. However, selecting relevant information is already asked for by Endsley concerning the perception and comprehension layers in situation awareness.

Mutual Information (MI) is a well-established tool for feature selection and feature comparison, for example, to support image classification methods or computer aided diagnosis. As an advantage, it does not preliminarily need a classifier or other machine learning algorithms for relevance calculation.

Knowledge-based Traffic Situation Description

Most complex traffic situations seem to be those at intersections. Their understanding is influenced by a variety of object and relation types such as intersecting roads with lanes and mark-

ings, allowed and forbidden paths, vehicles coming from different directions and different kinds of road signs. Their constellation directly influences traffic rules which apply and, accordingly, the assessment of allowed actions, expected behavior and impact of traffic participants among each other.

Ontologies are a foundation for knowledge representation and provide a formalism to structure objects, their relations and attributes and for performing logic reasoning with them. Therefore ontologies are well suited for modeling the kind of described multi-object traffic situations and for performing logic reasoning to check satisfiability of the situation ontology, to check consistency of input data and to reason about object types, relations and to e.g. apply traffic rules.

Description logic (DL) is a language for building ontologies and in most cases, depending on the dialect applied, it allows for decidable, complete and terminating algorithms.

Key Research Contributions within this Thesis

Three key contributions are provided by this thesis in the context of advanced driver assistance systems, more precisely to efficiently describe the current traffic situation a vehicle is part of:

1. The empirical proof that *mutual information based feature selection* serves to effectively evaluate the relevance of or select *traffic situation features*, especially those provided by ADAS sensors and ADAS sensor data fusion.
2. Theoretical discussion and empirical proof that *description logic based ontologies* are suitable to describe *complex traffic situations* such as those at intersections, including the evaluation of traffic rule compliance.
3. Theoretical discussion and empirical proof that *mutual information based feature selection* may be utilized on *semantic features* contained in *description logic based ontologies* for a more comprehensive and lean traffic situation description.

Previous work concerning contribution 1 barely exists with respect to vast real world measurement data and driver assistance. Previous work on contribution 2 does not exist when traffic rules are to be included in ontology reasoning or when real-time capability is to be shown. Previous work on contribution 3 does not exist. Existing work, the context and aspects concerning the first two contributions will be discussed throughout Chapter 2.

The following three subsections further explain the three above stated contributions of this thesis to provide a brief overview. Contribution 1 is discussed in detail in Chapter 4, contribution 2 in Chapter 5 and contribution 3 in Chapter 6.

Contribution 1: Mutual Information Based Traffic Situation Feature Selection

Initially, it is discussed how to use and interpret mutual information feature selection and what applications in the context of advanced driver assistance function development it may be used for. A methodical improvement to existing methods including formalization and error calculations is given and empirically shown with this thesis.

As the first main contribution, tremendous benefit in performance and time consumption of MI feature selection could be shown on vast, real world measurement data compared to feature selection by experts working in serial function development (see also publication [Hülsen et al., 2010]).

As the second main contribution, an approach and its interpretation for the usage of mutual information to determine the relevance of the history of situation features is developed. This approach considers past feature values laying back a certain amount of time.

Contribution 2: Description Logic Based Traffic Situation Description for ADAS

This thesis is widely concerned with the investigation and validation of applicability and capability of ontology based traffic situation description. Knowledge engineering for complex traffic situations such as those at complex intersections with an arbitrary number of roads, lanes, driving directions, allowed driving paths, traffic signs and / or lights was performed and is proved to be feasible. Little work is yet existent with this complexity of road structure including traffic infrastructure and legislation elements. No previous work exists that uses an ontology to model this kind and complexity of traffic situations. The contributed traffic situation description ontology fulfils the required aspects modularity and hierarchy, expandability, exchangeability, scalability, determinism and correctness.

Furthermore, the developed description logic based ontology allows logic reasoning of traffic rules, as has not been achieved in any previous work. Previous work struggled with a lack of reasoning capability of utilized reasoners or lack of efficient, target oriented knowledge engineering. Both the developed ontology for complex traffic situations and the inclusion of logic reasoning on traffic rules have been published in [Hülsen et al., 2011b].

Additionally, this thesis provides a proof-by-implementation for logic-based situation description for real-time execution of driver assistance functions. An asynchronous real-time framework is used, especially designed for the herewith proposed ontological situation description. It is usable for arbitrary DAS functions; shown on exemplary DAS functions (see also publication [Hülsen et al., 2011a] and associated master theses [Hesser, 2011, Spinda, 2011]). Previous work did not show generic applicability for several different DAS functions, neither in real-time, nor including reasoning about traffic rules within an ontology.

An open issue with ongoing research is coping with uncertainty in combination with knowledge-based approaches. Early approaches are too slow for implementation, especially with the number of objects and relations required for the proposed, generic situation description. This thesis introduces and discusses a concept of handling and incorporating different types of sensory uncertainty with the deterministic ontological situation description provided in this thesis to facilitate some sensory uncertainty handling.

Contribution 3: Mutual Information Based Selection of Ontology Features

Finally, this thesis defines semantic features derived from ontological content to perform mutual information based feature selection on ontology elements and to determine their relevance with respect to some given target application. Execution of this approach on some experimental data shows its applicability in principle.

1.3 Outline of this Thesis

The next **Chapter 2** briefly introduces the domain of advanced driver assistance systems (ADAS) and their components. It points out some requirements. An integral part of ADAS is situation awareness including a generic situation description. Aspects of and approaches for situation description are then discussed. Furthermore, the usefulness of determining the relevance of traffic situation features and of a knowledge-based method for traffic situation description is explained. The chapter is closed with a delimitation of the area of research relevant to this thesis with respect to the field of intelligent vehicle systems.

Chapter 3 introduces some theoretical foundations relevant to the further line of argument. This concerns mutual information feature selection for relevance determination of traffic situation features. Alongside, the Random Forests classifier is introduced as a machine learning algorithm to evaluate feature selection performance. Theoretical foundations are furthermore provided for knowledge representation, especially ontologies and description logics in combination with logic reasoning and some probabilistic knowledge-base approaches. This forms the basis for knowledge-based situation description.

Determining and interpreting the relevance of traffic situations features for target applications within the driver assistance domain is enfolded in **Chapter 4**. Besides general interpretation issues and the application on data from vehicle endurance runs, methodical improvements, relevance calculation of more than one feature at a time, as well as investigation of historical relevance of situation features are discussed in detail.

Chapter 5 deals with the approach of knowledge-based traffic situation description. The first part introduces knowledge-base engineering to model traffic situations and points out how it can be used to realize assistance functions. The second part then introduces an asynchronous real-time framework that is meant to not only simulate and test the intersection model but also to prepare in-vehicle applicability. Subsequently, the third part discusses possible assistance functions and provides simulation results for exemplary DAS functions. These results are obtained with simulations on the introduced framework utilizing the developed ontology. Finally, the fourth part addresses an approach to handle uncertainty by maintaining the determinism of the used, formal ontology.

With the ontology being part of the situation description and, in a general sense, containing complex features, **Chapter 6** proposes a method to combine mutual information based feature selection with knowledge-bases. Hence, it provides a way to determine the relevance of elements of the developed traffic situation description ontology.

Chapter 7 concludes this thesis and gives an outlook on fields of interest for further research & development and issues of a series implementation within vehicles equipped with advanced driver assistance systems.

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