Intelligent Driver Assistance Systems

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Abstract

Over the past decade, the automotive industry has made many efforts to improve the comfort and first and foremost the safety of passenger cars. So-called driver assistance systems have been developed, which support the driver in his task of controlling (steering, breaking …) a vehicle. Present-day assistance systems are entrusted with complex driving manoeuvres and are expected to operate correctly in the highly dynamic, non-linear and unpredictable domain of road traffic. The field of artificial intelligence (AI) provides concepts and methods, which are well-suited for the development of intelligent systems, able to act adequately in such an environment. This paper starts with a definition of the properties and abilities of modern, intelligent driver assistance systems and how they can be distinguished from more traditional, older approaches. We explain why there is a demand for artificial intelligence within their development and name the most relevant concepts and methods from this field. Afterwards, we present examples and general frameworks for intelligent driver assistance systems and the concrete application of AI methods within them.

Introduction

The term "driver assistance system" (DAS) is well known today. What is commonly meant, when talking about a DAS, is an electronic device built into a car, which supports the driver in certain situations. We all know about the little helpers in our cars which improve our comfort and our safety. Traditional assistance systems like the antilock brake system (ABS), the electronic stability program (ESP) and also the simpler ones, like the intelligent rain-sensor controlling the wipers, are now standard in almost all cars. Upper-class vehicles are often additionally equipped with systems like the Brake Assist System (BAS) developed by Mercedes, intelligent headlights etc. With the evolvement of computational and artificial intelligence, driver assistance systems are becoming more capable (more "intelligent") in their effort to improve both driving safety and comfort. The tip of the iceberg would be the so-called autonomous vehicles, which are able to drive by themselves, completely abandoning the control of a human driver. In this article we will present ideas and concepts of state-of-the-art driver assistance systems. Some are still at the R&D phase; some are already available or waiting for serial-production. But first of all, we have a word on what constitutes an intelligent driver assistance system.

Intelligent Driver Assistance Systems

An intelligent DAS - or Advanced DAS (ADAS) - should be able to perceive its environment and act/react adequately to oncoming traffic situations in order to fulfil a certain task within the driving domain, which is assigned to it. Ideally this should be done without intervention from the human driver[1]. The driver is given constant feedback about what the system is doing (and why it is doing it). This is important to establish the driver's trust in the system. We can conclude that a modern DAS has to have at least three special abilities, to be able to act truly intelligent: a) sensing and interpreting its current surrounding b) considering this information when deducing appropriate driving manoeuvres and c) communicating and explaining its decision to the driver. These abilities distinguish intelligent DAS from traditional ones.

Traditional systems are programmed to react in accurately defined, simple situations which only take the state of the vehicle (or parts of the vehicle) into account. Information about the driving environment (including the driver) is seldom necessary for fulfilling the assigned task. Take the antilock brake system (ABS) as an example: four sensors are monitoring the rotational frequency of the wheels and the system intervenes into the braking process if one wheel starts blocking. This simple system cannot be called truly intelligent, although it has saved many lives so far.

Present-day DAS are challenged with more complex tasks. They not only make driving safer, they also automatically manage monotonous, but simple tasks in order to take the strain off the driver. The inherent long-term goal of intelligent DAS will be the complete replacement of the human driver – a self-driving vehicle.

Before introducing the most relevant concepts from artificial intelligence, which are used in driver assistance systems, we give a short definition of the term "artificial intelligence" itself.

Definition of "Artificial Intelligence" and relevant concepts

Many definitions have been introduced for the term "artificial intelligence". We have decided to use the one from the Encyclopædia Britannica [Brit06]: " *… the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed*

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[1] Assistance systems for air-crafts (e.g. the Autopilot or the Ground Proximity Warning System, GPW) and trains (the Electronic Interlocking System, LockTrac) are also a very active field of reserach with interesting developments in the past decades, but we are focusing on vehicle assistance systems in this article.

with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience …"

In short, artificial intelligence is the ability of a computer to mimic human behaviour in order to act intelligent in a complex environment. This is also more or less what is expected from intelligent driver assistance systems within the domain of driving a vehicle. The ability to process the large amount of information gathered from the surrounding environment, together with the fact, that this information is often uncertain and incomplete, calls for the use of the latest development in artificial intelligence, next to sophisticated sensing methods and computer-vision algorithms. Traditional approaches, like basic search algorithms or first-order predicate logics are not sufficient for the difficult and complex tasks of an intelligent DAS. Several of the more advanced concepts from the field of artificial intelligence are of particular use when building intelligent behaviour into a vehicle. The most frequently used concepts are **fuzzy logic** (often in combination with traditional rule-based systems and planners), probabilistic approaches like **Bayesian Reasoning**, e.g. Bayesian Networks and Hidden Markov Models, **evolutionary algorithms** and **neural networks**.

We are now going to show the possible application of the presented concepts within specific examples of intelligent DAS.

Application of AI in intelligent DAS

Lane Departure Warning systems (LDW) monitor the vehicles position within the determined driving lane. This task is achieved with sophisticated computer vision algorithms. If the vehicle is found to depart from its lane without an activated turning indicator, some sort of alarm (audio or haptic) is activated to alert the driver. Predicting vehicle departure is often done by using a certain threshold for the lateral position. [Pilutti03] developed a fuzzy logic based "variable rumble strip", where the alarm-threshold varies according to the vehicle's risk of road-departure.

The **Adaptive Cruise Control (ACC)** assists the human driver with the tedious task of car-following. The ACC is an ongoing development of the traditional cruise control, which is only able to maintain a desired speed, preset by the driver. An ACC also takes into account the safety-distance and speed of preceding vehicles, as well as the allowed speed limit, current weather and road-conditions etc. If the preceding vehicle is leaving, the ACC accelerates to the preset speed. Correctly detecting the presence/absence of a vehicle is one of the major challenges for ACC (e.g. oncoming curves). To solve this issue, integration with computer vision approaches is currently investigated. Besides, the driver is always able to override or turn off the system, if he/she starts to feel uncomfortable. At present, several car manufacturers (BMW, VW/Audi, Mercedes-Benz …) are offering simple ACC-systems, where only the distance to the preceding vehicle is measured. However, with the constant progress made in the field of computer vision, which is concerned with automatic traffic sign detection and recognition [Garcia06], integration of road-side information (current speed limits, traffic lights etc.) is soon expected to take place. The idea of enhancing ACC with road-side information has already been introduced in the 90's by Volvo [Palm93], but here additional information is sensed with additional hardware equipment at road-side traffic signs and traffic lights.

Current research on ACC-systems is concerned with making them fit for stop-and-go traffic. Present-day systems are operating at a speed higher than 30 km/h [Bosch06]. A lower speed would require much more information and correct interpretation of the near-vehicle surrounding. The next generation, the so-called Stop-and-Go-ACC, will be able to cope with complete standstills and automated drive-offs, thus making it fit for urban traffic and traffic-jams [Richert04].

Now we know the task of an ACC - perception and evaluation of the near surrounding, as well as deducing adequate behaviour from this information - is a very complex one. This complexity calls for the use of artificial intelligence methods, we have presented above. The concept of *fuzzy logic* has been applied successful so far for ACC-systems [Mars01]. Traditional rule-bases enhanced with fuzzy rules and fuzzy reasoning are used for knowledge representation and decision inference within the system itself. Fuzzy logic has also been applied for driver simulation and driver behaviour models, which are used for evaluation and testing of ACC-systems [Mars01].

The concept of *evolutionary algorithms* has been tried for optimization of ACC by [Laum02]. ACC is a highly dynamic, non-linear system where all relevant factors (distance, speed …) are constantly influencing each other. The main optimization goals are minimization of a) fuel consumption b) acceleration time c) deviation from ideal speed gradient and d) deviation from ideal acceleration gradient with simultaneous consideration of the minimum safety distance. Complete search of the overall problem domain was not possible because of the considerable number of solutions. Evolutionary algorithms were used for problem solving with promising results. The top 15 solutions found where better than all solutions produced with more traditional approaches.

Artificial intelligence is also needed in the peripheral field of driver assistance systems. [Ohno01] has conducted a study about adaptation of driver's behaviour while using ACC. For this, a simulation driver model has been developed, which was implemented with a *neural network*.

Electronic Parking Assistants (EPA) are able to automatically park a vehicle with a parallel parking manoeuvre. This is regarded as one of the most difficult driving tasks. Many human drivers are never able to do a perfect parallel parking manoeuvre, no matter how well-experienced they are. The smaller the parking space, the more difficult parallel parking becomes. In urban areas, where parking spaces are in short supply, drivers are already experiencing considerable problems. An EPA first measures all available spaces to find a fitting one. If one is found, the driver is alerted. After transferring control to the EPA, the optimal steering wheel sequence for parking the vehicle is determined. The driver is expected to manipulate brake and throttle. This is mainly done for liability reasons, fully automated parking would of course be possible.

EPAs are already available in the upper-class vehicles of BMW and Toyota. However, recent field trials showed that there are still problems, especially with their executing speed and user-friendliness.

One of the most important concepts from the field of AI, used for implementing EPAs, is again *fuzzy logic*. Fuzzy rule-based systems (to be more specific, a fuzzy learning automaton) have been applied with great success for planning of the parking manoeuvre [Tigatos01] but also for reinforcement learning of the control component [Song06].

Beside fuzzy logic, probabilistic approaches seem to be well suited for implementation of EPAs. [SuJin02] used *Bayesian robot programming (BRP)* for the difficult task of determining the correct parking path. BRP uses Bayesian inference and learning mechanisms for controlling robots. It has emerged from the domain of robotics, where path and manoeuvre planning is a research field of great interest.

Other approaches and frameworks: Beside these specific intelligent DAS, some concepts from AI are generally used in the development of different DAS. *Dynamic Believe Networks* and also *Hidden Markov Models* are particularly useful for developing complex environment models, where not only the state of the vehicle, but also the behaviour of the driver (distracted, tired etc.) and the state of the surrounding (night-time, weather, road-surface) are considered for task planning. An example for a general framework design of intelligent DAS, based on Dynamic Believe Networks is presented in [Li06]. The integration of the driver will play an important role for future DAS. Current research is already working on systems, which constantly monitor the driver and his alertness, with the main goal of active intervention into the driving process, thus avoiding accidents (e.g. the SPARC-project, where a co-pilot system is developed for heavy good vehicles [SPARC06]). SPARC uses a three-layer architecture for the different levels of intelligence. Sensors have "intelligence" that is integrated within their data analysis. In a 2nd level, sensor data is fused to get a good understanding of the environment. And finally, the 3rd level determines the optimal path with respect to the driver's alertness. A further issue of this framework is concerned with transferring control back to the driver (when and how), after active intervention of the vehicle.

Our research group is currently developing an intelligent co-pilot system we called MIDCO (**M**achine-vision based context-aware **I**ntelligent **D**river **Co**-pilot [Kyamakya06]). The co-pilot is based on a context-aware machine-vision component which is able to perceive the current environment and filter out relevant traffic information needed for the driving process. Irrelevant details are deliberately left out in order to achieve real-time capability. Traffic regulations have to be transformed according to a yet to be developed semantic model. Driver's behaviour and response to certain situations is constantly monitored, for context-based learning from experienced drivers in situations not clearly covered by traffic regulations. Decisions are inferred for the current situation with information from the machine-vision component, the traffic regulations and the driver's state. Deduced recommendations are communicated to the driver via an appropriate HMI, which will be fine-tuned with support from psychologists. In short, our co-pilot builds on the following pillars: context-sensitive environment perception, knowledge of traffic-rules, learning from experienced drivers, adaptation of support-levels according to a specific driver's needs. The goal is a robust, reliable system able to work under difficult conditions (real-time requirements, highly dynamic, complex environment, extensive information volume …). [Handmann99] developed a DAS with a similar architecture (object-related scene interpretation, dynamic/static knowledgebase, behaviour planning …), but in contrast to MIDCO, which will give support for the overall driving task, the main goal of their project focuses on intelligent cruise control.

We have already seen that *fuzzy logic* is a wide-used concept for developing the control and learning units as well as for simulating driver behaviour. *Neural networks, genetic algorithms* and their application in pattern recognition are often used in vision algorithms for traffic sign recognition [Fang04]. The enhancement of DAS with sophisticated computer vision systems is currently a very active field of research and in future will be one of the key enablers for truly autonomous vehicles.

Conclusion

As we have seen, quite substantial progress has been made during the last decade in the development of intelligent driver assistance systems. In contrast to traditional systems, they are able to perceive their environment (driver and surrounding) and to consider the sensed information during the planning phase of their task. Feedback to the human driver is an important part for building up trust. Because the complexity of the given assignments is constantly increasing, the systems' intelligence also has to advance over time. The ability of a DAS to orient itself in its surroundings and to act/react adequately is crucial for successful implementation. In this article we have presented concepts from the field of artificial intelligence and we have described their application in modern, intelligent driver assistance systems. The given examples show that artificial intelligence techniques and improved sensing methods are the key enablers for building a modern driver assistant. It can be safely assumed that this trend will continue over the next decades. Driving will become more comfortable and less dangerous, until the point is reached, where the human driver is taking over vehicle control just for the fun of it.

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