The ConnectedDrive Context Server – flexible Software Architecture for a Context Aware Vehicle

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Abstract

Focus is pointed on the ConnectedDrive Context Server (CDCS), a central server component managing the situational context of an automotive human-machine-interaction, that is capable of providing key functionalities for a flexible prototyping process in the development and evaluation of "intelligent" vehicle behaviour. The main features are an object-oriented, shared knowledge management database and both generic, flexible I/O and knowledge analysis interfaces, offering a high compatibility for the connection to existing applications and for the implementation of intelligent reasoning algorithms. Our prototyping architecture is currently used in the development and evaluation of several context aware applications like a context-sensitive lane departure warning system (LDWS).

1 Introduction

Complex vehicles with certain cognitive capabilities have increasingly become incorporated in research areas of car manufacturers in various segments. Providing the driver with a maximum amount of security, luxury and comfort, future vehicles will be equipped with a wide range of intelligent systems like advanced driver assistance (ADAS) and in-vehicle information systems (IVIS). Research and development in these upcoming ADAS and IVIS has often been connected to the topic of contextual awareness and cognitive automobiles. Today, adaptive automotive system behaviour is mostly limited by the lack of context information and intelligent reasoning capabilities of the systems. However the recent evolvement of new sensor technologies like radar or lidar provides new possibilities in obtaining a more detailed view of the environmental situation and vehicle status. In addition to these "vehicle-related" information sources, "Driver Monitoring" sensors can yield aspects to one crucial, in today's systems left out component of the context: the driver himself. The knowledge of the complete situational context "vehicle, environment and driver" offers extended possibilities for the development of enhanced automotive applications, both ADAS and IVIS, capable of intelligent reasoning and adapting to the needs of the situational context.

At BMW Group Research and Technology, research in advanced vehicle technology has a long history. The central idea of the "ConnectedDrive" paradigm [1] is an intelligent, symbiotic combination of these contextual information fields of an automotive framework as illustrated in Fig. 1. The vehicle environment, the current driving state parameters and driver information can be interpreted as the vertices of the so-called automotive contextual triangle, representing an image of the global situation context. A cognitive vehicle would observe all these areas to offer an evolution of higher level context aware applications. One missing aspect, e.g. driver information, limits the intelligence of future ADAS and IVIS developments. Following this paradigm of situation sensitive vehicle behaviour, we have developed a new prototyping architecture, which provides us with a very flexible and powerful tool chain to develop and evaluate context aware vehicle applications, covering the three areas of contextual information in one single vehicle. In this work, the latest research of BMW Group Research and Technology in the field of intelligent vehicle behaviour is described in detail.

Fig. 1. Environment-Driver-Vehicle: The situational context

The following sections are organized in the following way. Section 2 gives a short overview of related work on context awareness in automotive research fields. The developed architecture is described in detail in section 3. Section 4 gives a short overview on our prototype vehicle and one example of a context aware application, that we developed using our architecture. A summary of conclusions and our future work is presented in Section five.

2 Related Work

Dealing with context awareness always demands a definition of the terms "context" and "context awareness" first, as their meaning has often been adjusted to the field of work it is used in. Dey et al. [2] have formulated a rather global definition proposing that context is "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a use and an application, including the use and applications themselves". A context aware system "uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task". We believe that this definition suits our research area very well as it can be adapted to the idea of the "ConnectedDrive" context with the core entities being the vertices of the context triangle shown in Fig. 1.

Research on context and context awareness has drawn much interest in recent years in both automotive and non-automotive areas, where it is most often summarized under the term of "ubiquitous computing". Automotive research work in this area can be separated in the development of context management architectures and context - aware applications. Several EU-funded projects have dealt with the idea of a context management component.

The Project COMUNICAR (Communication Multimedia Unit Inside Car) proposed an Information Manager (IM), which collects the feedback information of assistance-, telematics- and entertainment functions and estimates the driver's handicap respectively workload according to the impact of the current driving and environment situation. The overall system-feedback is adapted using a combination of the derived information parameters and the priority of the information display requests in order to enable a safe interaction between the driver and a multitude of in-vehicle systems [3].

The EU-Project AIDE (Adaptive Integrated Driver-vehicle InterfacE) is following a similar approach to maximize the efficiency and the safety benefits of advanced driver assistance systems while minimizing the level of workload and distraction imposed by in-vehicle information systems. The project architecture is based on a central high level perception instance, called the Driver-Vehicle-Environment (DVE), which senses and estimates the state of the driver, the vehicle and the environment. A communication assistant, which then controls a secure display of applications feedback information to the driver through the vehicle human-machine-interface [4], then adapts the applications feedback behaviour according to the contextual information provided by the DVE.

The NHTSA project SAVE-IT (Safety Vehicles Using Adaptive Interface Technologies) also has focussed on a central component monitoring the roadway conditions, the vehicle’s and driver's state parameters [5] in order to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems.

While the results and experiences of these projects have shown that there is a lot of potential in the idea of a central information processing unit, we think that context management is directly connected to the topic of context awareness and knowledge analysis, which in the development of automotive applications hast often been linked to the research topic of driver intention analysis, which several research projects have dealt with for adapting user interfaces and ADAS. Geiser and Nirschl [6] have suggested that the Driver Warning System (DWS) should analyse intention information for suppressing premature warnings in the European PROMETHEUS program. Likewise, in the United States the NHTSA Benefits Working Group [7] has proposed that an “ADAS like a collision avoidance system should be intelligent enough to discern driver’s intention (e.g. intent to change lanes, lane change start) though this is difficult to do. If available, such indicators might selectively alter the drive alerts or warnings” (e.g. thresholds, presentation mode, stimulus magnitude, etc.) and reduce the number of nuisance alerts thus increasing the driver’s acceptance of these assistance systems [8]. Regarding this development of intent inference algorithms, the NHTSA-Project SAVE-IT has recommended to use a combination of theory-driven and data-driven approaches including methods from the machine learning sector and implying the use of driver monitoring information [8,9].

Looking at the previous work on context management and awareness in the automotive area and motivated by the robustness and flexibility of inter-human communication, we see highly integrated contextual awareness as being a key component to provide an intuitive human-machine interface to the wide range of functions the driver is being confronted with in a modern driver’s working place. We therefore have decided to merge the ideas of central shared knowledge management entity and intelligent reasoning capabilities with focus on a flexible framework offering both powerful knowledge and intention analysis services for the application development phase and a generic usage of derived knowledge parameters in the application runtime phase.

3 Architecture

A cognitive vehicle has to be aware of all available context information. By analyzing the time course of the context, it is able to interpret the situation and predict the necessary behaviour for upcoming situations. A basic system layout of a context aware vehicle application is shown in Fig. 2. It receives raw context information from a wide range of different sensors operating on various levels of abstraction. It processes this data, and adapts its behaviour or actions based on the results of a context inference engine, analysing the contextual situation.

This inference engine possesses on intelligent reasoning capabilities, which either can be realized by applying decision rules based on a-priori knowledge or by any other statistical learning scheme, e.g. neural networks or support vector machines, which learn their classification functions in an offline processing of labelled raw sensor-data. The inference engine then uses these models to combine incoming raw context parameters from the sensors and generate high-level knowledge context parameters, which cannot be measured by a sensor. Examples for this so-called meta context parameters are any kind of driver intention analysis results either related to the primary driver task, e.g. lane change intention, or any other secondary task, e.g. suggesting the destination in a navigation system based on an analysis of the entries in the calendar. This aspect of intelligent reasoning capabilities for the generation of context aware behaviour is a key constraint of our architecture.

One major drawback of the basic layout showed at Fig. 2, is that the knowledge generation process is application-bound, and therefore it is only used for the behaviour of the application with the results kept inside of it. Each application is producing its own application specific context resulting in a distributed knowledge or context management. In order to obtain a flexible platform we have decided against this type of system topology for our context aware prototyping architecture.

In order to separate the data pre-processing and intelligent reasoning capabilities from the application, we have chosen to build a central knowledge management component, the ConnectedDrive Context Server (CDCS). The principle layout of the architecture is shown in Fig. 3. The CDCS is the core component of a client-server-based knowledge management and distribution architecture.

Incoming raw sensor data is collected by a central I/O layer and forwarded to the CDCS. Raw contextual information is then transferred into an object oriented knowledge representation inside the core context management unit. Each object has its own value and timestamp history (memory functionality) and also a set of methods delivering statistical values like mean or derivates etc. and quality values.

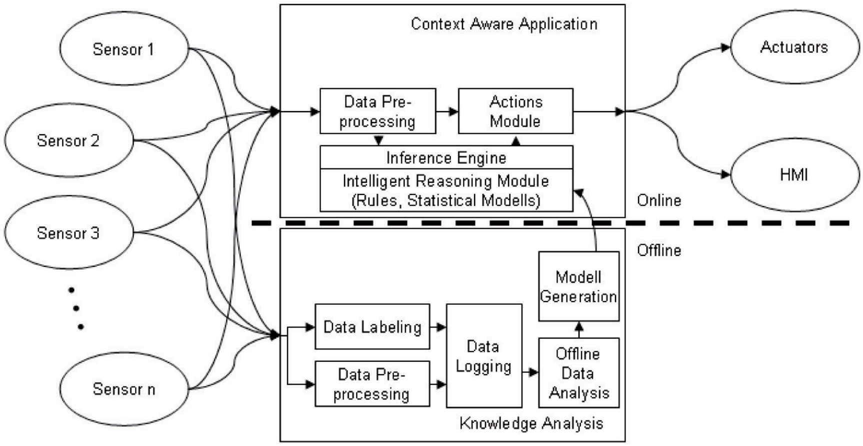

Fig. 2. Layout of a context aware application

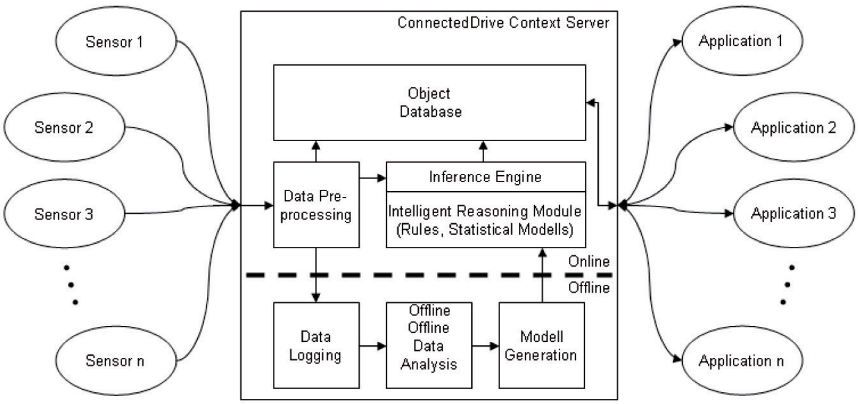

Fig. 3. ConnectedDrive context server architecture

Each parameter is assigned to a parameter management agent monitoring the objects state and when necessary updating the objects attributes.

The complete data I/O management of the CDCS is provided by its communication agents (CA). They listen for incoming request from external client applications, providing the information which context parameters an application would like to request and also which knowledge it might want to contribute to the universal shared context database. The submission requests of the applications have to match a defined XML syntax (see example request in (Fig. 4), defining the requested I/O operations. A CA then checks the compatibility of the request to the existing knowledge base and initializes the I/O interfaces according to the communication request. After that it prepares the object database for possible new context parameters from the application and opens an outgoing data stream providing the application with the requested context parameters. We have chosen the UDP protocol for incoming and outgoing data streams to secure the compatibility to a wide range of programming languages to use in our development process of context aware application.

```
<context_request application_name=“app1“  application_adress=“127.0.0.1“>
    <parameter_request udp_port=“xxxxx“>
        <parameter name=“param_1“/>
        <parameter name=“param_n“/>
    </parameter_request>

    <parameter_insert udp_por=“yyyyy“>
        <parameter name=“param_x“ parameter_type=“Double“/>
     </parameter_insert>
</context_request>
```

Fig. 4. XML-based context request

The second key feature of the CDCS beside its data management and distribution function is its both flexible and powerful toolkit and interface to generate high-level information parameters, so-called meta parameters. These context values can not be measured directly, but can be calculated through an intelligent combination of raw context parameters. For example, the driver's intention could be inferred out of his steering and gaze behaviour. For this purpose the CDCS is equipped with a flexible interface for the integration of statistical models for knowledge generation processes like neural networks, support sector machines or other learning techniques known from the field of machine learning.

The interface is designed for models generated in an offline training and evaluation process, which is done with the "Waikato Environment for Knowledge Analysis" (WEKA) [10], a powerful tool offering a wide range of data mining and machine learning capabilities provided with a flexible JAVA API. Furthermore the CDCS not only offers the interface to integrate these models in an agent-based generation process for meta parameters in real-time, but also provides the toolkit to record, label and prepare the data needed for the training of the models. After the generation of a new model, it is inserted into the intelligent reasoning module of the CDCS, where it is bound to a so-called enhancement agent, which uses the model to create a new meta context object in the object database. In this way our architecture offers a uniform process for the development, evaluation and usage of intelligent reasoning capabilities. One example of generating a meta context parameter in the described process to enhance a ADAS with intelligent reasoning will be mentioned in Section 4.

Besides a central knowledge management server, our framework also envisions one central Human-Machine- Interface (HMI) management instance, which, using the knowledge of the CDCS, arranges all applications' requests for HMI output modalities in a queue in order to guarantee an optimal context sensitive display of the applications outputs. Details about this component will not be topic of this article. The following section deals with our prototype vehicle and the first example application, a context sensitive lane departure warning system, which has been enhanced with intelligent reasoning capabilities using the tool chain of our context-aware framework.

4 Prototype Vehicle and an Example Process Scenario

Former studies have shown that research projects dealing with context awareness benefit most from a prototype application that can be experienced in real-life situations. We therefore have built up an experimental vehicle, whose hard- and software has been designed to provide the best possible framework for the development and evaluation of context-aware applications. It has been equipped with a wide range of sensor techniques (e.g. a lane detection camera system, a radar sensor for vehicle detection, a driver monitoring camera system (Fig. 5) to acquire a large set of context information from the areas environment, vehicle and driver. We have installed our context management prototyping software platform on a standard Windows based personal computer and have connected it to the vehicle's CAN bus system to obtain the data from the sensor systems. In the following we want to briefly describe an example prototyping process for a context aware driver assistance system we have started to develop and evaluate using our architecture.

We have chosen a lane departure warning system (LDWS), an ADAS application, which is already available on the market, to evaluate the impact in intelligent system design by introducing enhanced cognitive vehicle capabilities. In our LDWS we have used CDCS architecture to adapt the application to the driver's intention. In case of departing the current lane, the system has to judge if this is intended or not. The criteria for a lane departure is fulfilled in case of the Time-to-Line-Crossing (TLC)-value [11] falling below a given threshold. The TLC-value indicates the remaining time until the lane marking will be crossed by the car's wheels under the assumption of a constant lateral velocity.

In our first experiments we wanted to use the architecture to create an inference model to estimate the driver's intention to leave his current lane by observing his steering behaviour and vehicle dynamics before the TLC value reaches its decision threshold. We therefore have implemented a basic LDWS, and used its system behaviour to trigger the recording of context data for an intention analysis. During several hours of driving on German highways, where the drivers have not been told about the motivation of the drives, we have recorded observations of natural driving characteristics with multiple intended lane departure scenarios like lane changes, corner cuttings and lane oscillation, yielding in one set of characteristic context parameters every time the TLC value dropped below a defined threshold value. While it has been rather easy to collect data of intended driver behaviour, we have found out that is hard to model unintended lane departures due to the lack of data available. In comparison to other researchers, we have voted against a provoked generation of unintended lane departure scenarios in our data recording sessions with test persons, as we believe these experiments are too dangerous.

Fig. 5. Sensors: radar (top left), lane detection system (top right) and driver monitoring system

Instead we have used data from our researchers simulating unintended lane departures (with full vehicle and environmental security control) to get relevant data for our inference analysis. After recording and labelling the data in real-time, our CDCS architecture provides an interface to store the data already prepared for an offline data analysis with the knowledge analysis tool WEKA. We have had the possibility to run several test regarding the features' information theory statistics and the suitability and performance characteristics of several classification schemes. In this way we have calculated an optimal set of features and classification scheme for our inference problem. At this point of the design process of intelligent reasoning capabilities our architecture offers one of its most powerful features, providing an interface to directly integrate the models created with the WEKA environment into the inference engine of the CDCS, without writing a single line of programming code.

The key to this functionality is again based on the generic XML layout of the context management unit, which has been mentioned in section 3. Only a single entry has to be added to the central XML configuration file of the CDCS, causing the engine to instantiate a context enhancement agent. The agent begins to insert a new meta context parameter into the object database and then during runtime updates the inferred context parameter, in our case a lane departure intention, according to the input parameters defined in the provided classification module. The LDWS in a next step only has to request this intention value from the CDCS and adapt its warning behaviour to the calculated value.

This uniform process of consisting flexible creation and integration and powerful evaluation of intelligent reasoning capabilities for the enhancement of applications with adaptive behaviour can be used regardless of application type or scenario. Whether it is a different ADAS, like a collision avoidance system, or for example an adaptive application which modifies the mirror and seat settings of a vehicle according to estimated positions based on a measurement of the drivers head position, our framework provides a uniform and independent process framework for the development and technical evaluation of intelligent reasoning capabilities. The system architecture yields the several advantages but from an industrial point of view also involves extra costs due to the additional soft- and hardware requirements. This has to be taken into account, when further pushing the idea of a central context management instance from a research architecture to a component of a future series vehicle.

5 Conclusion and Future Work

In this work, we have presented a prototyping architecture that is capable of managing the situational context of the automotive human-machine-interaction. In comparison to other recent approaches to context management systems (AIDE, COMMUNICAR) our architecture has been designed to create a uniform research process for context aware behaviour in automotive applications. The both flexible and generic software framework offers great possibilities for a fast and uniform prototypical development, implementation and evaluation process. Furthermore, the flexible interface to a powerful data mining and machine learning tool has great potential for a detailed evaluation and comparison of a multitude of learning schemes for different intelligent reasoning tasks without time-consuming conversions between different toolkits. The server-client-based system layout enables us to easily connect existing applications to our framework providing them with either completely new sensor information or offering new enhanced context parameters for a more intelligent behaviour of these applications.

The work on the topic of contextual awareness in an automotive environment is strongly connected with multiple new sensor and machine learning technologies. It has been found that there are still some problems, which have to be solved in the related sub-topics. Sensors and recognition algorithms will have to be improved to provide more reliable context information to the inference algorithms. Furthermore, a systematic process not only for evaluation of the technical reliability of context sensitive algorithm design but also for the psychological perception of the adaptive behaviours by the driver has yet to be developed.

Nevertheless, our system has made a significant contribution to our research of advanced human-machine-interaction concepts and context sensitive applications. Our first experiments with an adaptive LDWS have shown that intelligent application behaviour based on an overall context analysis has clear potential to enhance the basic application regarding its situational awareness. We therefore plan to push forward the research and development of highly integrated contextual awareness as a key component of future automotive applications. We will explore the creation of completely new and the enhancement of existing ADAS systems, e.g. a frontal collision warning system. We further will evaluate the impact of enhanced situation-awareness on IVIS, for example in a dialog system equipped with reasoning capabilities based on affective computing aspects.

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