2010 13th International IEEE
Annual Conference on Intelligent Transportation Systems
Madeira Island, Portugal, September 19-22, 2010

RoadGraph - Graph based environmental modelling and function independent situation analysis for driver assistance systems

Jörn Knaup and Kai Homeier

Abstract— **RoadGraph is a graph based environmental model for driver assistance systems. It integrates information from different sources like digital maps, onboard sensors and V2X communication into one single model about vehicle's environment. At the moment of information aggregation some function independent situation analysis is done. In this paper the concept of the RoadGraph is described in detail and first results are shown.**

I. INTRODUCTION

In the current decade environment perception became more and more important for automotive applications such as driver assistance systems, autonomous driving, pre-crash, etc. After addressing various applications for highway assistance, support at intersections came into the focus of research activities nowadays.

In the project INTERSAFE-2 Volkswagen AG develops a demonstrator with on-board sensors as well as communication with infrastructure units to realise driver assistance functions in selected scenarios at intersections. This paper describes a graph based environmental model which combines the information of digital maps, onboard sensors and cooperative data. Due to the a-priori knowledge from the digital maps the RoadGraph offers in combination with data of the onboard sensors an improved basis for situation analysis. Some function independent situation analysis is even done by the RoadGraph. All the knowledge is represented in a concentrated model on an abstract level.

II. MOTIVATION

Current driver assistance systems are dedicated for highways or rural roads. These are systems like adaptive cruise control, lane departure warning or lane change assistance. For urban environment until today only parking support is available.

Accident analysis (see fig. 1) shows that intersection-related scenarios are an accident hotspot in the EU27 countries: 43% of all accidents with injuries happened at intersections. Most of the accidents in these scenarios happen due to distraction of the driver, occluded field of view or misinterpretation of safe gaps. This is the motivation for developing driver assistance systems for urban scenarios especially for intersections.

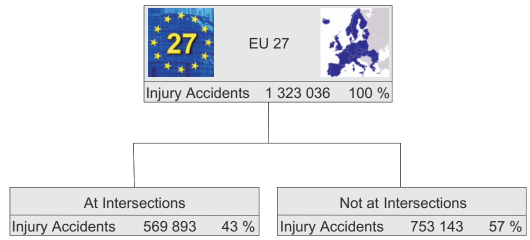


Fig. 1: Distribution of accidents in EU27 [1]

Driver assistance systems consist of the three main parts information sources, environmental models and functions (see fig. 2). For realising reliable driver assistance systems for complex scenarios like intersection-related scenarios, the systems have to deal with a lot of information. Sources for information are for example onboard sensors, vehicle-to-x communication or digital maps. The quality and environment representation of this information sources differs for example in used description models, coordination systems, measurement errors or latencies dramatically (see [5]). The aim is to make this information useful and easily accessible for the function level of driver assistance systems. Therefore an environmental model representing all information in one single model is under development.

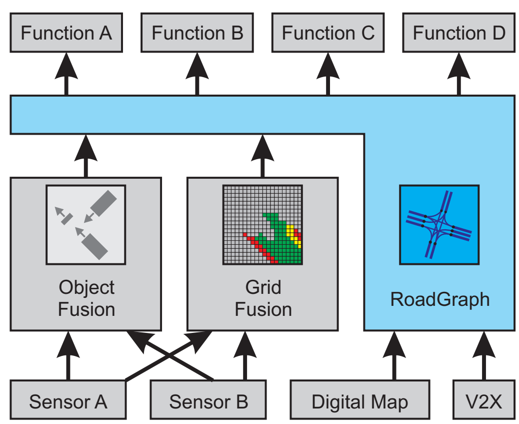


Fig. 2: Architecture for driver assistance systems using the RoadGraph

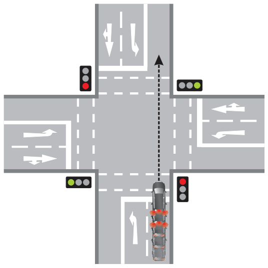
Functions which can be easily build on the basis of such an environmental model are for example traffic light assistance, right-of-way assistance, left turning assistance or crossing traffic assistance (see fig. 3).

The work described in this contribution has been partially co-funded by the European Commission, INTERSAFE-2 project, Seventh Framework Programme.

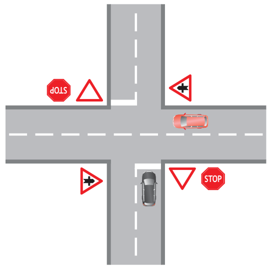
J. Knaup is with the Group Research for Driver Assistance and Integrated Safety of Volkswagen AG, Germany joern.knaup@volkswagen.de

K. Homeier is with the Institute of Operating Systems and Computer Networks, Technische Universität Braunschweig, Germany homeier@ibr.cs.tu-bs.de

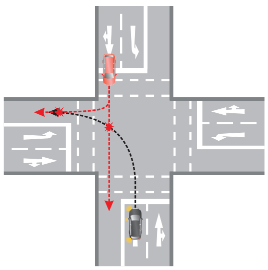
978-1-4244-7658-9/10/$26.00 ©2010 IEEE



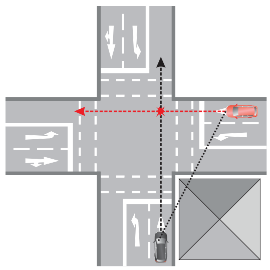
(a) traffic light assistance



(b) right-of-way assistance



(c) left turning assistance



(d) crossing assistance

Fig. 3: Example functions which will benefit by the RoadGraph

III. RoadGraph

This chapter goes into detail how the RoadGraph and its attributes describe the streets of a city. The modular architecture is illustrated with the help of an UML-diagram.

A. *Model description*

The RoadGraph is a directed graph composed of nodes and edges. This classic graph model is a well-established research field giving the advantage of fast access to the elements by using standard programming techniques. Similar approaches where successfully used for the DARPA Urban Challenge in 2007 by the Team CarOLO of the Technische Universität Braunschweig. [4]

The edges of the graph start and end at nodes which interconnect the edges, but hold no attributes. Edges represent single lanes of the streets and hold two or more positions to describe their trace. All additional attributes describing the scene are modelled to the edges as so-called lane side descriptions.

It is necessary to identify the lanes and the relationship between them like if two lanes belong to the same road and if they are parallel or not. Therefore the following ids are used

- road id: a unique id for each road [26 bit]
- way id: a way bundles all lanes of a given road in the same direction [2 bit]
- lane id: which lane on the given way [4 bit]

Every edge in the RoadGraph then has a unique id [32 bit] as a bitwise concatenation of the three ids.

Modelling streets on lane level gives the benefit of interpreting the scene in a very detailed level. Additional information of the environment can be modelled on lane level

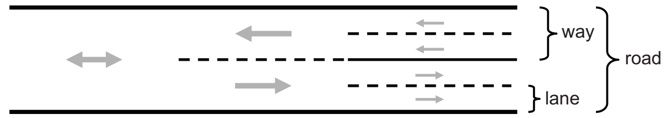


Fig. 4: Definition of road, lane and way

as lane side description. Objects of the vehicle environment sensed by the onboard sensors are a good example for such additional information. Since only sensed objects which can be matched to a lane by their position and direction are relevant to overlying functions, it is important to model the lanes in high accuracy. That ensures a high rate of successful associations of environment information and lanes. Currently available map-data is precise enough, but in most cases only contains the centreline of the road, along with the number of lanes. Our approach is to duplicate and move this centreline into two separate directions and additional lanes.

If a more detailed description of the street-network (e.g. at intersections) is needed, it is feasible to replace the existing description of an intersection by a more detailed one. If an intersection is equipped with V2X technology it can communicate such a detailed geometry to replace the RoadGraph content in the supported area. For example additional turning lanes, positions of stop lines or other details can be added.

Intersections are defined objects holding information about the right-of-way situation like 'right-before-left' or 'traffic light controlled'. They also group nodes and edges on and around the intersection in so-called sectors. Sectors describe an approaching direction and are numbered clockwise, making it easy to access elements from a specific relative direction. At an intersection with four or more sectors, sector-numbers start at zero and go up consistently. If it is a T-intersection (like in fig 5) sector numbers can have a gap where lanes are missing. This ensures that two sectors with a distance of two are lying opposite of each other.

The edges on intersections connect lanes approaching and leaving the intersection. Their existence describes the possibility of going from one lane to another, which corresponds to the turning possibilities. The positions are modelled with the most probable way of traversing the intersection (see fig. 5).

Lane side descriptions are implemented as template classes. They hold start- and end-parameters (where on the

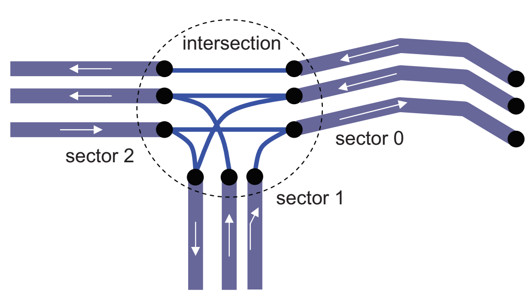


Fig. 5: sectors and connectivity of an intersection

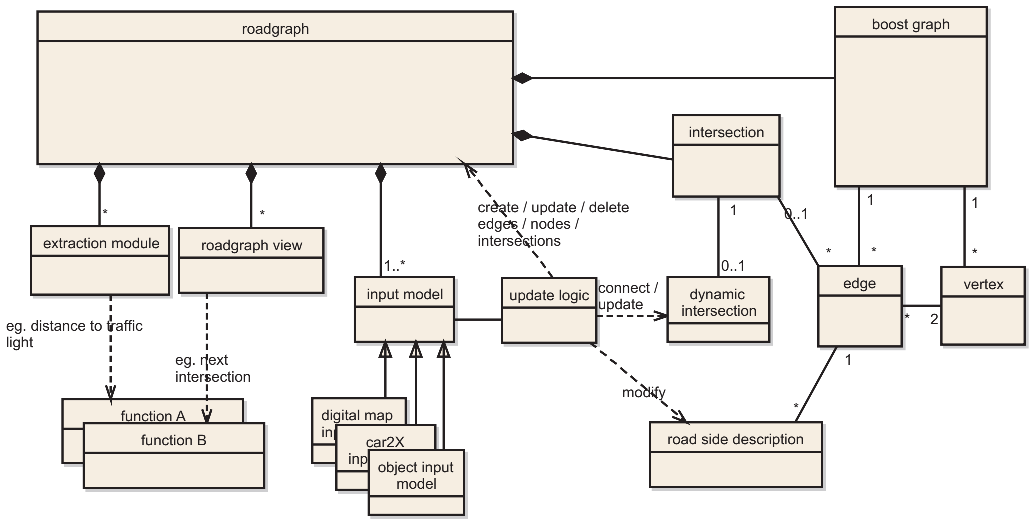


Fig. 6: RoadGraph class diagram

edge they are) and a specialised template parameter. This architecture is easily extendable with new attributes. Already used lane side descriptions are so far:

- traffic signs
- speed limits
- expected speed
- street names
- signal groups of traffic lights, including the current status
- matched objects
- possibility of a lane change to a parallel lane

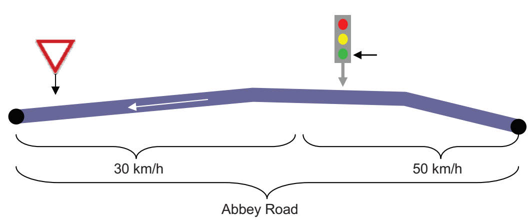


Fig. 7: examples of different lane side descriptions

Lane positions are given in a world-centred coordinate system (UTM - Universal Transverse Mercator), so everything associated with the RoadGraph has to be in world coordinates as well. This demands a relative high positioning accuracy of ego vehicle to get positions of sensed objects right.

B. Software Architecture

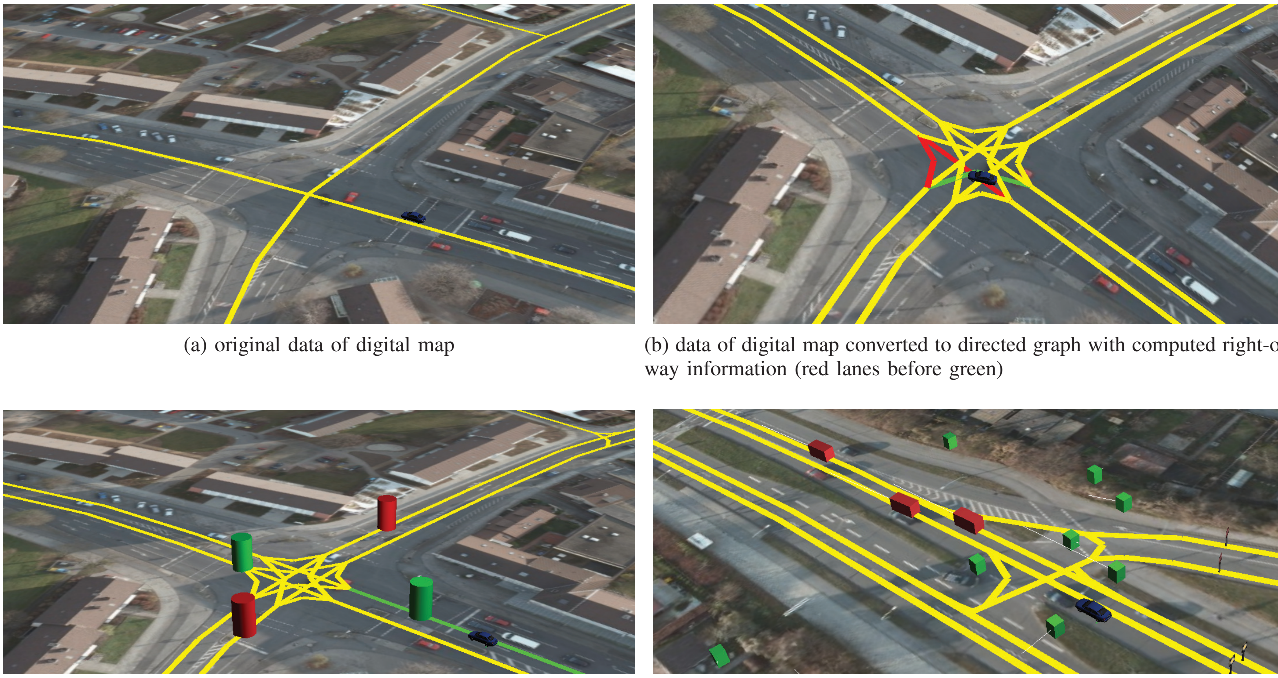
For an overview of the RoadGraph architecture refer to the class diagram in fig. 6. The RoadGraph is based on the Boost Graph Library, which is holding the nodes and edges. For every input (map-data, sensor-objects, V2X, ...) there is an *input model*, collecting and preprocessing the data. The specialised input models are derived from an basis input model. This makes a fast implementation of new information inputs possible. The input models support the adaptation of the information input for the RoadGraph like transformation in the right coordination system or adaptation of digital map data to the RoadGraph map model. Finally an *update logic* modifies the RoadGraph by creating or updating edges or setting lane side descriptions. Update logics exist for generalised data types. This ensures the reusability of such modules. Existing and new data first need to be associated, then the existing data can be validated, aggregated or replaced with the new information.

The RoadGraph has a set of *intersections*, which can have a link to a *dynamic intersection* object received via V2X. The dynamic intersection object is updated whenever there is a change in the submitted intersection object, like the change of a traffic light. The intersection object stores the static information, like its geometry, and is therefore only modified when a new dynamic intersection object is received for the first time.

The *roadgraph view* submits the whole graph or a subgraph with a limited view or only the next intersection with all connected edges to a function or a visualisation tool. Lanes in the subgraphs of course hold all information stored in the original lanes, so a subgraph-receiving function can work with the provided methods on an area-of-interest with all details existing. An *extraction module* seeks for one specific information in the RoadGraph, like distance and colour of the next traffic light, and distributes this information.

IV. Information Sources

The RoadGraph is able to integrate information from different sources. In this chapter the main sources are described. There are ego localisation, digital map, traffic light data and object data of onboard sensors. Integration of additional information into the RoadGraph is possible.



(a) original data of digital map

(b) data of digital map converted to directed graph with computed right-of-way information (red lanes before green)

(c) integrated real-time data from traffic lights

(d) Objects around the vehicle, red objects are associated to a lane

Fig. 8: Screenshots of the RoadGraph in a 3D-visualisation

A. Ego Localisation

An absolute localisation of the ego vehicle is needed for association of information from different sources with different coordinate systems. It is a very important information for generating and updating the RoadGraph.

There are different possibilities to get a reliable ego localisation. For research purposes a differential GPS combined with an inertial measurement unit can be used. It supports a reliable localisation accuracy of less than 10 centimetres even in urban scenarios. This unit is very expensive and far away from series-production. An alternative could be a combination of GPS or differential GPS with ego motion sensors from ESP.

B. Digital Map

The basic graph structure of the RoadGraph is based on a digital map like it is used for navigation systems. For driver assistance systems digital maps with a much higher number of attributes are available. These maps for example include slope, right-of-way or existence and position of traffic lights. Digital maps support the RoadGraph with fundamental a-priori knowledge. Data model of the RoadGraph and most data models of available digital maps are along with the format of Geographic Data File (GDF). The current version of GDF is standardised in ISO/DIS 14825:2004 [3].

C. Traffic Light Data (V2I)

Traffic Light Data can be provided by a traffic light controller. This data can be transmitted into a vehicle via a broadcast at the intersection on basis of IEEE 802.11p WLAN for example or based on client-server principle via UMTS or other cell based communication techniques. Data contain of the current traffic light phase of every single lane, the precise intersection topology and some environment information of the intersection. Environment data may be measured by infrastructure sensors like conduction loops, pedestrian detection cameras or laser scanners for example. This data completes the data measured by onboard sensors.

D. Onboard Sensors

Current data of the environment will be measured by onboard sensors. These sensors are able to measure the relative position of objects in respect to the ego vehicle. Additional to the position some sensors are able to measure the velocity. Object state is described by a state vector $\overrightarrow{x} = [x, y, w, l, v_x, v_y, ...]^T$. With help of tracking the objects and their parameters can be followed over time (see [2]). Objects are associated to edges of the RoadGraph. Object sensors are for example laser scanners, radars or stereo vision systems.

V. First Results

In fig. 8 screenshots of the several RoadGraph creation steps are given.

The initial map-data (8a) has bidirectional edges and the intersection is reduced to a point where edges cross.

This data is split into the directed RoadGraph in fig. 8b. The intersection object is computed, as well as the right-of-way information for each edge on the intersection (red and green lanes). The map-data holds information about the number of lanes, additional turning lanes at intersections are missing. These lanes will be part of future maps or can be added along with the status of the traffic lights.

In fig. 8c the first results for association between traffic light data and the RoadGraph are shown. The current traffic light phase is transferred in real-time into the vehicle via a communication channel. It comes along with the GPS-position defining the intersection centre and the allocation of the signal groups of the traffic lights to individual lanes. The related intersection is identified inside the RoadGraph by using the GPS-position. The relation between signal groups and lanes is identified by using the angles of the incoming lanes of the intersection. The associated signal states are added as lane side description to the graph. This is visualised by cylinders colored like the traffic light in fig. 8c. The ego vehicle (car coming from right) is driving towards a green signal light and is allowed to enter the intersection.

It is confusing to separate between traffic and side-objects that are not of interest, when manually analysing the data of onboard sensors in the sensors coordinate system. If shown in context with the RoadGraph it is directly clear which objects are important. In fig. 8d all detected objects are shown as boxes. If an object could be matched to a lane by its position, speed and direction, it is shown as a bigger red box. Only these objects are added as lane side descriptions to the RoadGraph, and will be processed by driver assistance functions.

For testing the object association a large number of test-data has been collected with predefined scenarios as well as in real traffic situations in the downtown area of Wolfsburg.

An algorithm automatically reducing the number of objects by matching them to lanes of the RoadGraph shows a high success rate.

It is normally hard to predict the objects future attributes, like its position, if you have to do it for several seconds and the movement direction is imprecise. The predicted object may leave the road and may falsely be considered as not harmful. In our case an inexact direction shows no negative effect, because the object is predicted along the lane it is matched on.

In case that the lane splits up at an intersection, the object is duplicated for each lane. An existence probability can be stored with the object, derived by the transition probability from the preceding lane.

Scalability tests show, that the architecture of the RoadGraph and the algorithms used to access and modify edges are fast enough to handle large scenarios with more than 100.000 edges covering 700km^2.

VI. Conclusions and Future Work

This paper describes a new approach for combining data from different information sources into one single graph based environmental model. The modular and easy to enhance system architecture was described. First development steps have been done and the results show the potential of this approach. The RoadGraph can be an enabler for a lot of driver assistance systems in urban and non urban environments. The first example functions which where mentioned in this paper will be developed by using the RoadGraph in the near future.

In the current implementation vehicles build the RoadGraph in real time and enhance it with onboard sensor- and V2X-data. Because resources are however limited we delete parts of the RoadGraph that are no longer in the region of interest. Future steps are to submit the enhanced RoadGraph to a server to avoid loosing the learnt data, like

- Lane topology learnt via V2X at intersections or by the driven trajectory of many participants
- Traffic density averaged by driven speed
- Road works seen with object-sensors
- Road conditions detected with on-board sensors

Other vehicles will be able to use this information for planning a better route or warn the driver earlier. Serverside data validation and aggregation are interesting topics in these next steps.

At the time we use high-precision differential GPS in our prototype which of course is to expensive for a series-production vehicle. Additional information in the lane side descriptions that will help us is

- Position of other moving objects especially distance to oncoming traffic
- Existence of buildings or side rails along the road and how far away the sensors detect them
- Landmarks along the roads (trees, masts of traffic lights or signs, corners of buildings) to use the ideas of simultaneous localization and mapping (SLAM)

One of our future topics is to develop a map-matching algorithm which can map the car on the correct lane, not only the street, like common navigation systems do. This algorithm will use hypotheses and strengthen or weaken them by all details we have in the RoadGraph.

VII. Acknowledgements

The work described in this contribution has been co-funded by the European Commission, in the INTERSAFE-2 project within the Seventh Framework Programme.

References

[1] *INTERSAFE-2 Deliverable D3.1 - User needs and requirements for INTERSAFE-2 assistant system*, available via http://www.intersafe-2.eu/, 2009.

[2] Y. Bar-Shalom, X.-R. Li, *Multitarget-Multisensor Tracking - Principles and Techniques*, 1995

[3] E. C. for Standardisation, *ISO/DIS 14825:2004 intelligent transport systems - geographic data files (gdf) - overall data specification*, Technical report, European Committee for Standardisation, 2004

[4] K. Homeier, J. Effertz, M. Doering, L. Wolf, et al. *Caroline: An Autonomously Driving Vehicle for Urban Environments*, Article, Journal of Field Robotics, 2008

[5] J. Knaup, M.-M. Meinecke, M.-A. Obojski, J. Effertz, G.-P. Ostermeyer: "Latency and Error Propagation for Cooperative Environmental Modelling", 13th Forum on Advanced Microsystems for Automotive Applications, Berlin/ Germany, 5-6 May 2009