Cooperation based on Communication: An Approach for an Autonomous Driving System

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Abstract. Autonomous driving in real road traffic is still an unsolved challenge. While sensor systems and image processing certainly make up a great part of the needed system, intelligent algorithms for the actual driving behaviour must likewise be developed. Communication and cooperation between different vehicles on the road can be a great help for achieving such a system. In the CarTalk2000 project, a new system for inter-vehicle communication is introduced. This system, which allows the generation of wireless ad-hoc networks between all equipped vehicles on the road, can be very efficiently used for driving assistance systems as well as fully autonomous driving systems. The following paper describes the cooperative driving system developed during the project, which enables the autonomous handling of typical freeway situations like lane merging, overtaking up to fully autonomous freeway driving.

1 INTRODUCTION

In the CarTalk project, street vehicles are equipped with efficient communication devices, which are able to build a wireless ad-hoc network while on the road [1][2]. Together with data acquired from GPS-systems and external sensors, the communication system can be used to realise an autonomous driving assistance system based on inter-vehicle cooperation. In the CarTalk project, the developed communication system was used for different driver assistance applications, ranging from the simple passing on of warning messages, to assistance functions for lane changing and merging, to complete autonomous driving systems for freeway traffic. For the realisation of the system, methods from cooperative multi-agent systems were used to build a multi-level hierarchical system for autonomous freeway driving.

2 THE WORLD MODEL

As a basic interface to the sensor and driving systems, an abstracted world model of the surrounding environment and the traffic situation is used. Data from different sources like sensors, GPS-systems and sensor data from other cars are fused together to a consistent world model, which is used by all higher-level assistance functions as a data base. While the road topology can be abstracted to a certain degree, non-communicative cars and objects must of course be included. With the world model, the driving controls are no longer dependant of certain sensor or communication characteristics, and the same driving systems can be used for very differently equipped cars, as long as a world model is provided.

3 THE DRIVING SYSTEM

For the actual driving system, we used a three-level hierarchical approach.

- **First-level safety system:** This system is responsible for avoiding collisions of the car, regardless of any other driving commands given by lower-priority driving systems. It continuously checks the safety situation of the car, and only intervenes with the driving process if it detects a potential safety breach.
- **Second-level geometric planner:** The purpose of this driving system is to find a specific driving action for a given goal based on the geometric analysis of the traffic situation. It is the main system for planning simple driving actions, and is taking into account already the future intentions of other cars and their potential cooperation. The system is potentially able to solve all traffic situations on its own, although it will often lead to non-optimal solutions in a given situation.
- **Third-level conflict solver system:** This is an additional rule-based system, which is used to solve situations which are too complex for the geometric planner alone. It can also to used to add new behaviour patterns to the system.

In short, the geometric planner controls the driving most times, the conflict solver handles complex situations, and the safety system avoids collisions even if the other systems fail.

3.1 The geometric planner

For the implementation of the geometric driving planner, it was necessary to cluster the driving controls according to the level of control. For this purpose, a role model was introduced, using structures common for multi-agent systems. The state of a vehicle can now be described with

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the following constructs:

- **Goal:** Each car has a specified driving goal (e.g. "Stay on road with speed x", "Depart from road" etc.), which is given by the human driver or a higher-level navigation system.
- **Role:** A role describes the current behaviour of a car. Roles should start and end in a safe and stable driving position, which means that the vehicle drives straight in the middle of a lane. Examples for a role are "Change to left lane" or "Try to reach speed x".
- **Action:** An action is an indivisible driving command, e.g. a change of the steering angle or the switch of the lane change indicators.

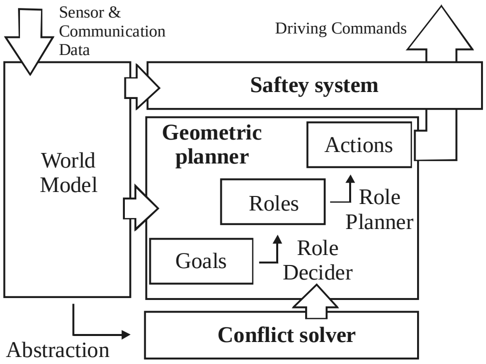

Figure 1. **A**rchitecture overview

Two instances are now responsible for continuously choosing the right role and action: The role decider determines which role is needed for the given goal, while the role planner cares for the execution of the right actions within this role. Special condition checks are used to decide if a role is finished or must be aborted.

The cooperation between cars can now be included into this role behaviour. For example, the role "Change to left lane" has a sequence of actions for preplanning a gap on the left lane. During this sequence, the driving system checks for free space on the desired lane, taking into account the communicated positions and states of the cars in the world model. To reduce communication effort, the driving systems uses implicit cooperation as the main strategy to plan the drive actions. This means that the car does not send out a "Request gap" message to another car and than waits for an answer (that would be explicit cooperation), but instead predicts the cooperation attendance and behaviour of the other cars with the help of the communicated states, plans the gap for itself and then just sends out the resulting sequence.

There are still situations in which two or more cars compete for a certain action or resource, for example the same gap on a road. To solve this situation with implicit cooperation, the cars must have a specified way to inform each other about the degree of desire (or need) to get the resource in question. For this purpose, the CarTalk system uses a "frustration" value. This value decreases if the current goal criterion is met, e.g. the car drives on the desired lane with the desired speed. If the goal is not met, the frustration rises while the time is passing. The driving systems of all cars will automatically give the resource in question to the car with the highest frustration value. It is now only needed to submit the frustration level together with the vehicle state information, and all cars can adjust their planning according to it. Additional communication is not needed to solve competitions between cars.

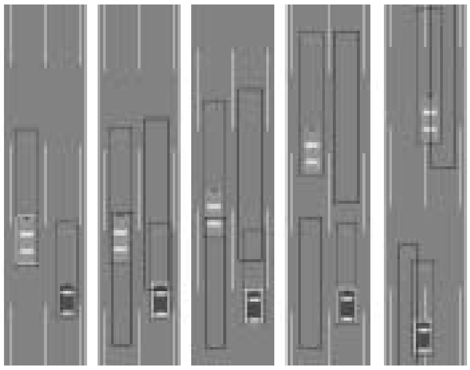

Figure 2. Example for the geometric planning: Two cars with the same speed want to change to each other's lane. As the position of the cars and the intention to change the lane is known by both cars, each car can plan a gap on the other lane and a collision-free path to it without further communication. The other car will not directly influence the planning, although it has the right to reject the plan with explicit communication if it detects any planning errors. In the example, the right car will decelerate to reach its planned gap, while the left car accelerates. Note that gaps are planned with full position, speed and validity period.

4 RESULTS

The system described above was implemented and tested on a traffic simulator to validate its practical applicability. The system proved to be indeed able to allow fully autonomous freeway driving, but can be used as well as a more limited assistance system. The generation and quality of the world model is still an open issue. At the moment, the system is optimised more for safety than for performance. Tests with real cars are planned for the future.

ACKNOWLEDGEMENT

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REFERENCES

[1] D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, W. Schulz, *CarTALK 2000- Safe and Comfortable Driving Based Upon Inter-Vehicle-Communication*, in *Proceedings of IEEE Intelligent Vehicle Symposium*, Versailles, France 2002.

[2] J. Tian, L. Han, K. Rothermel, C. Cseh, *Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks*, in *Proceedings of IEEE Intelligent Transportation System*, pp. 1546-1551, Shanghai, China 2003