IOP Conference Series: Materials Science and Engineering

Geoinformation Support of Ground Vehicles' Autonomous Driving

To cite this article: S S Shadrin 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **386** 012013

Geoinformation Support of Ground Vehicles' Autonomous Driving

S S Shadrin

D.Sc. (Engineering), Head of R&D Dept., Basetrack Technologies Limited, Cyprus

E-mail: dr.shadrin@basetrack.net

Abstract. This article describes relevant challenges of autonomous driving with respect to the strategic and tactical levels of vehicle control, some solutions are offered. Methods for creating a digital terrain model are described. The notion of a "basetrack" is introduced, which is a high-accuracy spatial driving route that contains additional data sets for the vehicle's optimal control with respect to the requested transport task, road and traffic conditions. A "basetrack" data structure is presented with respect to the advantages of its implementation: the predetermined variability of control actions on the route, depending on the tasks of time saving, energy efficiency, or safety; increased reliability, reduced requirements for on-board computing power, and improved performance. We propose to solve the issues in optimal vehicle control for the autonomous driving mode in simulation with reference to a precise geoinformation environment.

1. Introduction

Energy efficiency and safety are traditionally among the main development trends in the automobile industry. The opportunities for automakers to improve the principal design and control algorithms seem to be exhausted, and it is a challenge to improve the safety of road vehicles. The analysis of road accidents involving heavy trucks showed that 85.2% of road accidents are caused by various human factors in France, Germany, Italy, Hungary, the Netherlands, Slovenia, and Spain [1]. Approximately 80% of road accidents in Russia are caused by driver's faults. Thus, the most efficient approach could be increasing the active safety of road vehicles and excluding human drivers from the cycle of vehicle control.

Development projects for autonomous vehicle technologies are currently being undertaken by all global car manufacturers, especially in the US, Germany, Japan, and China. Automobile groups are involved into these projects as well, such as Ford, Daimler, Volkswagen, Toyota, Honda, GM, Geely, Tata, and Tesla, as well as other major technological organizations such as Google, Continental, Delphi, Siemens, and Bosch. Other players in the field include defense departments and agencies of different countries (e.g., DARPA [2]), universities (e.g., Stanford University, Carnegie Mellon University, Technical University of Munich, University of Karlsruhe, Fraunhofer Institute, University of Minnesota, Universidad Politécnica de Madrid [3]), and many other institutions [4-6]. Thus, the development trends of autonomous driving technologies are important and relevant.

2. Problem Statement

The overall act of driving can be divided into three levels of a driver`s effort [7, 8]: strategic, tactical, and operational levels. The strategic level involves trip planning. The tactical level involves maneuvering the vehicle through traffic (lane changes, overtaking, speed limit, etc.). The operational level involves innate actions such as steering, braking, and other vehicle system control for trajectory tracking.

The strategic level deals with tasks of logistics, routing, navigation [2, 5, 6, 9]. One of the main applied problems at this level relates to the creation of high-accuracy models of geoinformation about the spatial terrain, which are called high-definition (HD) maps.

The tactical level deals with the issues of psychophysiology and critically depends on the perfect functioning of the technical system of road scene recognition [10], including the subsystem of technical vision [11]. In addition, there is a huge layer of decision-making problems at the tactical level, which researchers and developers mostly try to solve using artificial intelligence systems [12]. The main problems of the tactical level include all the uncertainties that arise during the process of driving, which require route correction. The operational level of vehicle control is supposed to be well studied [2, 3, 5, 6, 10, 13].

This study focuses on new approaches that solve some challenges of tactical and operational levels in autonomous vehicle control.

3. Geoinformation Support as an Instrument for Rapid Implementation and Wide Spread of Autonomous Vehicles

The known methods of autonomous driving are mostly based on the use of data from various real-time navigation systems and an electronic map loaded into the ECU memory. The exact driving control actions are commonly carried out using computational algorithms that operate in real time and often depend on artificial intelligence systems. These systems require significant on-board computing power for tasks such as object detection, classification, scene recognition, risk assessment, and decision making. Trajectory correction in such systems continually occurs on each segment of the route, which results in high on-board computational requirements, increased lag for control commands with the increase of driving velocity, decreased control accuracy at high velocities, and a risk of unpredictable failures in cases of wrong scene recognition.

We offer a simplified approach for autonomous driving and a more reliable and less expensive solution. We propose the concept of a “basetrack,” which is a high-precision spatial driving route that contains additional blocks that provide optimal control of the vehicle based on the requested transport task and traffic conditions. The basetrack can be compared with a virtual spatial railway for the vehicle, which acts like a train. Accordingly, in the simplest case, the vehicle should decrease its driving velocity and stop in the event of an obstacle or risk detection. If you have trouble, the decision-making system (e.g., the Mivar expert system [12]) should start to switch the trajectory tracking system to another track from the database or to another fragment of a generated detour track.

There are different approaches to HD-map design, but all of them begin with the creation of a digital terrain model (DTM). Informational layers can be added to the DTM with corresponding objects such as road markings and infrastructure elements. Geospatial data for DTM can be obtained by space or aerial photography, laser scanning (ground or air based), radar scanning, and other methods. However, we consider the use of traditional HD maps to be unreasonable in the proposed conceptual approach. Instead thatwe propose the use of basetracks, which are software products designed based on DTM and technical knowledge about a certain vehicle, road, traffic, and environmental conditions.

Figure 1 illustrates the principal scheme for autonomous vehicle control with the use of a basetrack.

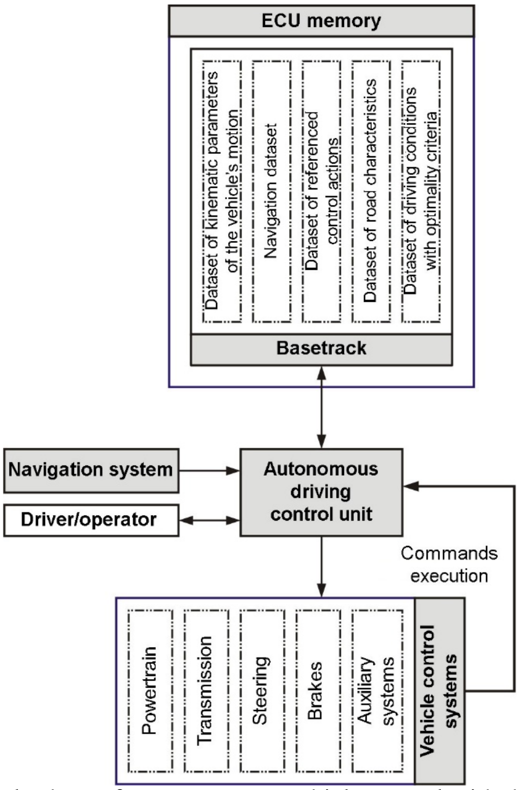

Figure 1. Principal scheme for autonomous vehicle control with the use of basetrack.

The basetrack structure includes:
- a dataset of kinematic parameters of the vehicle motion;
- a navigation dataset;
- a dataset of referenced control actions;
- a dataset of road characteristics;
- a dataset of driving conditions with optimality criteria.

The dataset of kinematic parameters of the vehicle motion contains calculated referenced data that are typical for the vehicle considered when driving in normal conditions (no extra wind load, loaded car weight, dry asphalt, etc.).

The navigation dataset enables vehicle positioning on the basetrack while driving with the help of any precise on-board navigation system.

The dataset of referenced control actions corresponds with the dataset of kinematic parameters and contains control commands for normal driving conditions.

The dataset of road characteristics contains information on the road type, longitudinal and lateral inclinations, average road surface friction coefficient in normal weather conditions, International Roughness Index (IRI), and road curvature.

The dataset of driving conditions contains information that is included but is not limited by the following:
- the maximum permissible speed V_{max} in accordance with traffic rules and road signs;
- the coefficient of weather conditions K_w, by which the permissible speed can be adjusted;
- the critical speed V_{crit} for a certain vehicle (the maximum possible speed for the vehicle and road conditions);
- the complex rate K_{eff} of speed adjustment, which reflects the criterion of energy efficiency;
- the coefficient K_{infr} of speed adjustment, which takes into account the peculiarities of road infrastructure;
- the coefficient K_{sat} of the reliability degree for received satellite navigation data at a given location. This factor takes into account the infrastructural and natural disturbances and is an indicator

of switching from a satellite system to another positioning system (optical, inertial, etc.) when using a hybrid navigation system.

The dataset of driving conditions can be updated interactively.

Importantly, some parameters of the driving condition dataset are mutually exclusive. Accordingly, specific control actions for autonomous driving mode will be determined from the considered dataset with respect to the transport task. Some examples are presented by optimality criteria such as the minimum travel time, fuel economy, or safety driving with risks reduction. In the case of a race car driving on a circuit, the autonomous driving control unit will use the speed determined as $V_{crit} \cdot K_w$ from the dataset of driving conditions. In another example, a heavy truck driving autonomously with the task of minimizing fuel consumption will cause the control unit to use speed determined as $V_{max} \cdot K_{eff} \cdot K_w$.

A set of files with sequential basetracks forms a track of a larger length. Before the start of autonomous driving, the track file or at least the first file of a long track should be loaded into the on-board memory block. The rest of the track files and the dataset of driving conditions can be downloaded or updated as the vehicle drives along the route. It is also possible to preload all track files into the memory block.

We propose using a basetrack concept at the strategic level of autonomous vehicle control while considering the information of modern HD maps to be redundant. The use of basetracks at the tactical level excludes or minimizes the problem of decision-making and dynamic route correction, which leads to increased reliability of the autonomous driving system, reduces requirements for on-board computing power, and improves the system performance, allowing it to drive the vehicle at higher velocities.

For the prototype of an autonomous road vehicle, speed of 130 km/h was achieved for stable driving in the corridor of road markings using the basetrack in autonomous mode. This was achieved without the use of road marking recognition systems in accordance with the experiment's goal, which was to demonstrate the pure basetrack technology on a real road.

At the same time, the basetrack concept provides different predetermined ways of driving along the same route. An economic advantage is obtained based on the correlation of optimized control actions in autonomous mode with respect to the requested transport task.

4. Conclusion

The results of this study are as follows:

1. The notion of a basetrack has been introduced, which is a high-accuracy spatial route of driving that contains additional datasets for optimal vehicle control in autonomous mode with respect to the requested transport task, road conditions, or traffic conditions.

2. We proposed using basetracks at the strategic and tactical levels of autonomous vehicle control instead of HD maps or as a separate layer of an HD map.

3. The use of a basetrack concept at the tactical level excludes or minimizes the problem of decision-making and dynamic route correction, which could increase the reliability of autonomous driving systems, reduce requirements for on-board computing power, and improve the system performance, allowing vehicles to operate at higher velocities.

4. It is essential to solve the issues in optimal vehicle control for the autonomous driving mode in simulation with reference to a precise geoinformation environment.

References

[1] Shadrin S.S., Ivanov A.M., Karpukhin K.E. Radical improvement of road safety by integrating autonomous wheeled vehicles into an intelligent transport environment. Bulletin of Machine Building, 2018, No. 1: 85-88.

[2] Buehler M., Iagnemma K., Singh S. "The DARPA Urban Challenge. Autonomous Vehicles in City Traffic," Springer, 2009: 651 p.

[3] J Naranjo. E., Clavijo M., Jiménez F., Gómez O., Rivera J. L. and Anguita M. "Autonomous vehicle for surveillance missions in off-road environment". IEEE Intelligent Vehicles Symposium (IV), Gothenburg, 2016: 98-103.

[4] Saikin A. M. et al. "Tendency of creation of 'driverless' vehicles abroad," Biosciences Biotechnology Research Asia, 2014, vol. 11 (Spl. Edn.): 241–246.

[5] "Autonomous Control Systems and Vehicles – Intelligent Unmanned Systems" K. Nonami et al.

(Eds.), Springer Japan, 2013: 306 p.
[6] Cheng H. "Autonomous Intelligent Vehicles – Theory, Algorithms, and Implementation," Springer, 2011: 163 p.
[7] Michon J. A. "A critical view of driver behavior models: What do we know, what should we do?" In L. Evans & R. C. Schwing (Eds.), "Human Behavior and Traffic Safety," New York: Plenum Press, 1985: 485–520.
[8] SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, U.S.A.: SAE, 2016: 30 p.
[9] Tahirovic A., Magnani G. Passivity-Based Model Predictive Control for Mobile Vehicle Motion Planning. Springer, 2013: 64 p.
[10] Shadrin S.S. Methodology of autonomous road vehicles, integrated in intellectual transport environment, driving control systems design: dissertation … doctor of technical science. 05.05.03 [Place of the thesis defense: Bauman State Technical University]. Moscow, 2017: 400 p.
[11] Saikin A.M., Buznikov S.E., Karpukhin K.E. "The Analysis of Technical Vision Problems Typical for Driverless Vehicles," Research Journal of Pharmaceutical, Biological and Chemical Sciences, 2016. Vol. 7, No. 4: 2053-2059.
[12] Shadrin S.S., Varlamov O.O., and Ivanov A.M. "Experimental Autonomous Road Vehicle with Logical Artificial Intelligence," Journal of Advanced Transportation, 2017, Article ID 2492765, 10 pages, doi:10.1155/2017/2492765.
[13] Shadrin S.S., and Ivanov A.M. "Algorithm of Autonomous Vehicle Steering System Control Law Estimation while the Desired Trajectory Driving," ARPN Journal of Engineering and Applied Sciences, 2016, Vol. 11, No. 15: 9312-9316.