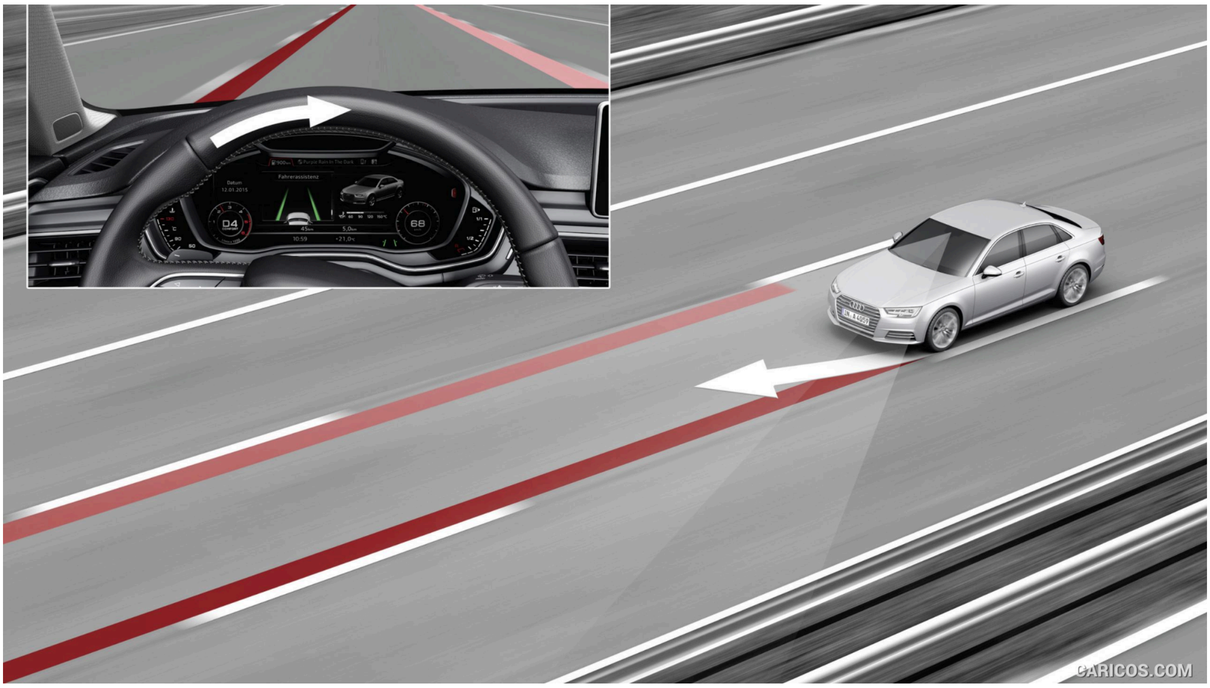
What technology do the current autonomous cars use to drive between lanes?



Luuk de Vries Reilingh - 1053870
Hekkelman, S.M. & Volders, W.B.
16-6-2024
eerste gelegenheid

Table of content

Summary

This research covers the techniques currently used i autonomous vehicles to accurately navigate between road markings, with a particular focus on the applicability in the 2024 Self Driving Challenge. The main research question is to understand what techniques are currently used in autonomous vehicles to correctly navigate between two lane markings. The sub-question is to understand what specific sensors, hardware, algorithms and artificial intelligence techniques are used that support lane detection and vehicle localization. Using a literature review approach, this research compares the effectiveness of two different lane detection techniques: LLDNet, a deep learning model, and a learning-based tracking algorithm. The results show that both approaches have unique advantages in handling dynamic driving environments and embedded system requirements. Main conclusion: A hybrid approach combining both techniques is proposed to improve the functionality and safety of competitive autonomous vehicles and to achieve optimal lane navigation under various conditions.

Introduction

For the 2024 Self Driving Challenge hosted by the RDW (Rijksdienst voor het Wegverkeer / Department of Road Transport) teams from Dutch universities and colleges are asked to make a self-driving car using sensors, AI and code. The challenge consists of multiple obstacles the car needs to handle and the team that comes the farthest wins. One obstacle is to let the car drive between two white lines. To achieve the best result of letting the car drive between two lines and stay in its lane, iso to look at the technology and techniques current self-driving car manufacturers use to navigate lanes correctly and safely.

This research is of interest to the RDW who is closely following the development of self-driving cars and could take learnings from the findings in this research. Future teams participating in the Self Driving Challenge could also benefit from the learnings in this research as it will provide a better starting point when it comes to autonomous driving and navigating between lanes.

The objective of this research is to gain knowledge about autonomous driving between lanes which can subsequently be applied by the Hogeschool Rotterdam team in the 2024 Self Driving Challenge.

One specific problem that needs to be solved in this challenge is the fact that the car needs to navigate a winding path, not simply drive in a straight line and maintain its position in the centre of the lane. The car needs to navigate correctly and complete its winding path to the finish line, thus supporting the Hogeschool Rotterdam team, consisting of 9 people, in winning the challenge.

The best outcome would be that the car self-centres on the lane (A feature of autonomous or semi-autonomous vehicles where the vehicle automatically adjusts its position to stay centred within the lane). To achieve this result an investigation is done into what other self-driving car manufacturers do to drive between lanes.

The main question is: What technology do current autonomous cars use to correctly drive between two lines on the road?
Related sub-questions: What sensors and hardware are currently used by self-driving car manufacturers to keep vehicles between lanes? What algorithms and AI techniques are applied to achieve lane recognition and vehicle positioning?
How can the findings of this research be integrated into the Hogeschool Rotterdam design and implemented for the 2024 Self Driving Challenge?

Theoretical

The first car manufacturer that used some form of lane assist was Mitsubishi.[1] Mitsubishi developed and released a simple camera system that tracked road markings. If the car crossed the lane markings, the system would sound an alarm to warn the driver. This was the first simple Lane Departure Warning system (LDW: A mechanism in a vehicle that alerts the driver if their vehicle begins to move out of its lane). It was used in the Mitsubishi Debonair, which also had the first adaptive cruise control system (A system that automatically adjusts the speed of a vehicle to maintain a safe distance from the vehicle ahead) [2]. Still to this day the problem of creating a good and reliable fully autonomous lane assist is a challenge for car manufacturers.

The problem occurs in other organizations of the self-driving sector. Traditionally, algorithms based on highly specialized handcrafted features were used to solve the lane detection problems. These algorithms include handcrafted features such as colour-based features and the structure tensor.

Furthermore, the features are combined with Hough transform (A feature extraction technique used in image analysis, computer vision, and digital image processing to detect features of a particular shape within an image) to evaluate a binary edge image by discretizing all possible lines in the image into an accumulator matrix and counting the edge pixels that fall on each line. There are some assumptions regarding lanes in existing lane detection methods, such as lanes are parallel and lanes are straight or almost straight. However, these assumptions are not always valid, especially in urban situations. Recently, methods based on deep neural networks were applied to detect lanes for autonomous vehicles. The convolutional neural networks (CNNs: A class of deep neural networks, most commonly applied to analysing visual imagery) had achieved promising results.
There were studies about the lane detection task and the control of autonomous vehicles. McFall et al. proposed an effective lane detection algorithm employing the Hough transform and inverse perspective mapping to estimate distances in real space. Moreover, the estimated distances could be utilized to send steering control commands to an autonomous vehicle. [3]

There are no other self-driving problems that come close to driving between lanes, although self-parking is very similar in approaching the problem. With self-parking the car uses infrared sensors to the right-front of the car and the right-back of the car to detect a free space. When it has found a free parking space and verified that it is the correct size for the car to park in, the car will start its second algorithm, for which the car uses distance sensors and cameras to first drive forward for a short distance and then, like a human being, drive backwards into the spot, all while constantly checking if the car will not bump into anything. [4]

As mentioned earlier in this paper, there are a number of different techniques to self-driving between lanes such as edge detection, deep neural networks and mapping of distances. However, all these techniques are still not completely reliable to achieve full self-driving and most of the time human intervention is still needed during a self-driving trip. Oxa boss Gavin Jackson said that the industry is "a long way away" from producing cars that can match or surpass human drivers, and said that such vehicles would need to become "local experts" before they could be trusted to drive on public roads. [5]

Method

To address the main question and related sub-questions, a literature review was undertaken primarily focusing on scientific- and website articles. These sources are chosen for their relevance and depth of information they provide on this research topic. Scientific articles will help to establish a solid theoretical foundation and provide insights into previous research and findings. Website articles will be used to explore current trends and additional perspectives. Together this will provide a broad foundation to thoroughly address the main question and sub-questions, comparing multiple lane detection techniques on their reliability and types of technology used.

Results

To improve the performance of autonomous vehicles, especially in lane detection under various conditions, recent studies have proposed and evaluated several methods. In this research, the focus is on comparing two different methods: LLDNet, a lightweight deep learning model, and a learning-based lane detection and tracking algorithm.

LLDNet: A Deep Learning Approach
LLDNet uses a deep convolutional neural network (CNN) architecture designed for lane detection in autonomous vehicles. The model is particularly noteworthy for its lightweight design, making it suitable for embedded systems often required in automotive applications. LLDNet integrates channel and spatial attention modules, which improve the model's ability to focus on relevant features in the input image, improving recognition performance. It was tested under various adverse conditions such as bad weather and damaged road surfaces, and achieved high detection accuracy due to its robustness to environmental fluctuations (MDPI: Multidisciplinary Digital Publishing Institute, a publisher of open-access scientific journals where this research is sourced from).

Learning-based lane detection and tracking
Another approach involves a learning-based approach that uses an algorithm that takes into account steering angle (The angle at which a vehicle's wheels are turned,

often used in contexts of automated steering), yaw angle (The rotation of a vehicle around its vertical axis, which indicates the direction the vehicle is pointing), and sideslip angle to control an adaptive controller. This approach has high accuracy and fast detection response time, with performance evaluation showing detection accuracy between 97% and 99% and processing time between 20 and 22 milliseconds under various road conditions. This approach outperforms many traditional techniques and provides reliable lane detection and tracking even in demanding environments (MDPI).

Evaluation and Suitability
Both methods excel in certain aspects of lane detection. The advantage of LLDNet's deep learning framework is its low resource requirements and its ability to adapt to a variety of conditions without extensive recalibration. It excels in scenarios using embedded systems with limited computing power. On the other hand, learning-based lane detection and tracking methods excel in scenarios that require real-time processing and high reliability, such as dynamic driving environments, where fast reactions to lane changes are critical.

Conclusion

This research investigated what techniques are currently used by autonomous vehicles to accurately navigate between lane lines, comparing two lane detection methods: LLDNet, a lightweight deep learning method, and a learning-based lane detection and tracking algorithm. LLDNet uses a convolutional neural network that operates in a stable way under various conditions, including bad weather and damaged roads, and is particularly effective for embedded systems in vehicles due to its low computational power requirements (MDPI). On the other hand, the learning-based algorithm (An algorithm that learns patterns from data through methods like machine learning and deep learning, and uses these patterns to make decisions or predictions) uses adaptive control techniques for steering, yaw, and sideslip angles to achieve high accuracy and fast response times necessary for dynamic driving environments (MDPI). Both approaches offer unique advantages: LLDNet is cost-effective for systems with limited hardware capabilities, while learning-based approaches excel in real-time responsiveness. For the 2024 Self Driving Challenge, a hybrid approach combining both technologies can optimize performance under both standard and demanding conditions, thereby increasing the robustness and flexibility of automated driving systems. This integration will provide a strategic advantage by leveraging the strengths of each approach to effectively address different operational needs.

Sources

1. “What are lane departure warnings and lane keep assistants? | TomTom Newsroom,” *TomTom*. https://www.tomtom.com/newsroom/explainers-and-insights/lane-departure-warnings-and-lane-keep-assistants/

2. Loveday, S. (2021, April 26). What are lane departure warning and Lane Keep assist? US News & World Report. https://cars.usnews.com/cars-trucks/advice/lane-departure-warning-and-lane-keep-assist?slide=2

3. Wu, Z., Qiu, K., Yuan, T., & Chen, H. (2021). A method to keep autonomous vehicles steadily drive based on lane detection. International Journal of Advanced Robotic Systems, 18(2), 172988142110029. https://doi.org/10.1177/17298814211002974

4. O’Donovan, A. (2024, April 2). Everything you need to know about autonomous parking systems. Wayleadr Blog. https://wayleadr.com/blog/everything-you-need-to-know-about-autonomous-parking-systems/

5. Carter, T. (2023, October 14). We are decades off having self-driving cars that have the freedom to go anywhere, autonomous vehicle boss says. Business Insider. https://www.businessinsider.com/fully-self-driving-car-tech-needs-decades-to-develop-2023-10?international=true&r=US&IR=T

Wordlist

Adaptive Cruise Control (ACC) - A system that automatically adjusts the speed of a vehicle to maintain a safe distance from the vehicle ahead.

CNN (Convolutional Neural Network) - A class of deep neural networks, most commonly applied to analysing visual imagery.

Hough Transform - A feature extraction technique used in image analysis, computer vision, and digital image processing to detect features of a particular shape within an image.

Lane Departure Warning (LDW) - A mechanism in a vehicle that alerts the driver if their vehicle begins to move out of its lane.

Learning-Based Algorithm - An algorithm that learns patterns from data through methods like machine learning and deep learning, and uses these patterns to make decisions or predictions.

MDPI - Multidisciplinary Digital Publishing Institute, a publisher of open-access scientific journals where this research is sourced from.

Self-Centring - A feature of autonomous or semi-autonomous vehicles where the vehicle automatically adjusts its position to stay centred within the lane.

Steering Angle - The angle at which a vehicle's wheels are turned, often used in contexts of automated steering.

Yaw Angle - The rotation of a vehicle around its vertical axis, which indicates the direction the vehicle is pointing.