Analysis of the Application of Deep Learning Technology in Autonomous Driving Systems

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Abstract. The purpose of this paper is to analyse and discuss the application forms of existing autonomous driving technology with a focus on deep learning, while also describing the opportunities and challenges currently faced by this technology. By combining a literature review, this paper sorts out the components of autonomous driving technology and lists several typical and effective application examples, providing an overview of their development ideas and principles. Examples include traffic sign recognition based on visual technology, pedestrian trajectory prediction, vehicle speed control based on algorithms, and lane-level path planning. Research shows that deep learning technology can significantly improve the accuracy and stability of autonomous driving technology in complex environments. However, this technology is still in the development and exploration stage, with issues such as safety risks and data privacy. In summary, deep learning is indispensable in autonomous driving technology, but its characteristics also determine that mature applications require the support of comprehensive regulations and data systems. Future research should focus on the development of emerging technologies while also concentrating on this aspect to promote the construction of intelligent transportation systems.

Keywords: Navigation, Deep Learning, Autonomous Driving.

1. Introduction

Autonomous driving technology has made significant theoretical and practical progress in various aspects, but it is still far from an ideal comprehensive application. For example, safety issues have always been a major challenge. Existing visual recognition technology cannot fully handle overly complex scenarios on the road and make accurate judgments. Any accident would severely damage the credibility of the entire system [1]. Therefore, the widespread application of mature autonomous driving technology can be seen as an excellent solution for future transportation strategies and an important part of the intelligent Internet of Things. With the development of sensor technology, CPU computing power, and artificial intelligence in recent years, many previously unresolved issues are gradually being addressed, especially thanks to the diversified applications of deep learning and machine learning technologies [1]. The development of autonomous driving technology has evolved from simple assisted driving to advance autonomous driving. The advantage of deep learning lies in its powerful data processing and prediction capabilities, which can effectively assist various aspects of autonomous driving. This paper focuses on analysing various cases of autonomous driving technology that apply deep learning, explaining their technical principles, and illustrating how deep learning aids the development of autonomous driving technology.

In recent years, with the rapid development of technology in various fields, autonomous driving navigation technology has gradually shifted from traditional satellite and missile positioning navigation to vehicles and unmanned machines. As a result, autonomous driving technology has flourished. However, the legal and ethical issues faced by this technology, including accident liability, cannot be ignored. This requires the public to have a higher level of awareness and tolerance for autonomous driving technology. Therefore, in-depth analysis and discussion of existing autonomous driving technology are of great significance.

The development of autonomous driving technology can currently be roughly divided into two routes: one is to develop directly with the goal of advanced autonomous driving, and the other is to gradually advance from level one assisted driving. The latter's technology is already very mature and is used in existing vehicle models, while the route towards advanced autonomous driving still faces many challenges [2].

2. Autonomous Driving Technology

2.1. Key Components and Characteristics of Autonomous Driving Technology

Autonomous driving is a comprehensive control system composed of multiple dimensions, independently completing tasks from data collection and processing to decision execution. The following points outline the components of each step:

Data Collection: The data collected by the vehicle generally comes from two main sources—various onboard sensors and connected networks. Common sensors include cameras, LiDAR, depth cameras, millimetre-wave radar, and ultrasonic radar [2]. These sensors provide the system with parameters such as the external environment, driver status, lane position, and driving speed, serving as fundamental data references for wheel movement decisions. The connected networks typically provide navigation information and road map models [3].

Data Processing: The vehicle's operating speed usually ranges from 30 km/h to 120 km/h. During high-speed movement, the amount of data collected per unit of time is enormous, requiring efficient and accurate decision-making. This necessitates powerful computing capabilities, where deep learning technology can play a significant role.

Decision and Control: After obtaining various information about the vehicle and its environment, the vehicle should be able to make correct judgments at appropriate times through model calculations, such as executing lane changes, overtaking, decelerating, and accelerating.

2.2. Introduction to Deep Learning

Deep learning is essentially a more complex learning system based on machine learning. By setting up multi-layer neural networks to simulate neurons in the human brain, it can learn and correct automatically. After training with a large amount of data, it can predict possible output results in the form of probabilities based on regular state data inputs [4]. This technology is widely used in fields such as object recognition and complex model calculations.

2.3. Comparison of Deep Learning Methods and Traditional Methods

Compared to traditional model approaches, deep learning can automatically learn features from raw data. This lowers the threshold for constructing training sets and enables the acquisition of higher-quality outputs in complex feature environments.

Deep learning technology, compared to traditional techniques, requires a larger training dataset to obtain more reliable feature relationships, which poses a challenge for model tuning. However, there are many models aimed at reducing this requirement. For example, the 1.0 MobileNet-224 model reduces computational data by 96.28% compared to VGG16, with only about a 1% decrease in accuracy [5].

Robustness refers to the stability of a model's operation under abnormal conditions [4].In this regard, the high-dimensional feature relationships of deep learning make it significantly outperform traditional models. This stability is also of evident value in autonomous driving technology.

Compared to traditional models, deep learning technology also requires higher real-time computational capabilities, thus imposing certain demands on the computational power of the equipment.

3. Application of Deep Learning in Autonomous Driving

3.1. Typical Examples of Deep Learning Applications in Autonomous Driving

In summary, deep learning is useful in all aspects involving data processing and decision-making. Here are some typical cases:

Using deep learning, cameras capture traffic signs ahead, and image processing techniques handle the raw images, which are then fed to the model for recognition and decision-making, such as no overtaking, speed limits, and no honking [5]. Traffic sign recognition often involves image preprocessing to determine if the image meets the model's standards [6]. For instance, uses an image preprocessing system to assess image recognizability (e.g., dehazing, enhancement) before feeding the image to the deep learning model [5]. After successfully recognizing traffic signs, algorithms locate the vehicle and control its behaviour based on the signs.

Deep learning can predict pedestrian trajectories and make decisions from physical, model-based, and planning perspectives [7]. The study in [7] explores pedestrian trajectory prediction using graph convolution networks (Graph Convolution Network, GCN) to build spatial networks and improves the Transformer model framework for this purpose.

Multi-objective deep reinforcement learning processes information about the speed of the vehicle ahead and traffic structure to recommend optimal speeds in real time [8]. Combining feedforward neural networks and recurrent neural networks, algorithms adaptively control vehicle speed based on predictions and feedback from the recommendation system [8]. Outlines a data collection structure involving traffic cameras, magnetic sensors, GPS, mobile phones, and millimeter-wave radar to gather traffic and vehicle information and provide speed recommendations.

Combining camera positioning, online map matching, and deep learning-based wheel odometry error prediction systems to determine the vehicle's accurate position on the map, followed by multi-layer road network model calculations to output the optimal lane path [3]. This involves integrating GNSS (Global Navigation Satellite System) and INS (Inertial Navigation System) for lane positioning, designing lane change recognition algorithms, and conducting practical experiments. Data from wheel odometry and processed data are fed into deep learning models to determine driving conditions (e.g., roundabouts, mountain roads). The processed data, combined with map engine data, enables lane-level path planning to output the optimal path [3].

3.2. Advantages and Challenges of Using Deep Learning

Advantages:

Deep learning can improve accuracy through complex pattern recognition, performing exceptionally well in complex environments [9]. Deep learning models can automatically adjust based on new data, providing flexibility and intelligence to the system [10].

Challenges:

Deep learning models require large amounts of labelled data and powerful computational resources, raising the training threshold and reducing fault tolerance when changing models. The “black box” nature of deep learning models makes it difficult to interpret their decision-making processes, posing a significant challenge for autonomous driving technology, which requires public trust and safety assurance [11].

4. Current Applications of Autonomous Driving Technology

Autonomous driving technology has a history of several decades, but it has only recently entered the public eye, thanks to the development and widespread use of technologies such as deep learning. The current market's advanced autonomous driving technologies are primarily developed and implemented by well-known companies such as Tesla, Waymo, and Baidu [3].

4.1. Tesla's Development and Application of Autonomous Driving Technology

Currently, Tesla's "Autopilot" system is continuously improving its autonomous driving capabilities through regular software updates. Tesla's system uses deep learning algorithms to process data collected from the vehicle's sensors, including cameras, radar, and ultrasonic sensors [12].

4.2. Baidu's Development and Application of Autonomous Driving Technology

Baidu's Apollo platform is an open autonomous driving platform designed to enable different companies and developers to develop their autonomous driving solutions using Baidu's technology and resources. Baidu Apollo has already collaborated with multiple cities and companies to conduct road tests and commercial applications for autonomous driving [13]. The platform integrates various technologies such as deep learning, computer vision, and sensor fusion, using large-scale real data for algorithm training and optimization. The core of the platform includes environment perception, decision-making, and planning modules, with deep learning widely applied in target detection and behaviour prediction. Baidu's Apollo platform has developed the "Robotaxi" autonomous driving vehicles, which are currently undergoing road tests in China and gradually expanding commercial operations. Its technical cooperation projects have also promoted the development of the domestic autonomous driving industry, providing references for policy formulation and the establishment of technical standards [14].

5. Future Trends and Challenges

5.1. Emerging Technologies in Autonomous Driving

With continuous technological advancements, many emerging technologies can also effectively assist autonomous driving technology, such as 5G communication and V2X (Vehicle-to-Everything) technology.

Compared to 4G, 5G offers a significant increase in data transmission rates, providing a carrier for real-time communication connections between vehicles and more facilities. This technology allows vehicles to obtain more timely information to make more efficient and safer judgments and actions. V2X enables vehicles to connect with surrounding traffic equipment, providing more realistic and comprehensive road condition information for real-time obstacle avoidance and risk mitigation. This technology enhances the vehicle's ability to make judgments in complex and dangerous environments [15].

5.2. Ethical and Legal Implications of Autonomous Vehicles

Legal and ethical issues related to autonomous driving have always been unresolved. As autonomous driving continues to develop and be applied, these issues are receiving more attention. Common issues include decision-making problems, liability attribution, and data privacy.

Minimizing accident damage is a challenge. Sometimes, it requires not only objective analysis but also considering the value of each component of the accident, which may involve ethical issues [16].

Autonomous vehicles do not have drivers responsible for driving behaviour. In the event of conflicts and accidents, it is crucial to clarify the responsible parties and standardize legal terms, which can also promote the development and adoption of autonomous driving technology [17].

Autonomous vehicles collect large amounts of data to improve their decision-making and driving capabilities. The secure storage and use of this data need attention. Balancing privacy protection with technological development is an unavoidable challenge in the development of this technology.

5.3. Challenges and Opportunities for Future Development

Despite the promising prospects of autonomous driving technology, several challenges and opportunities must be addressed for widespread application.

The level of technology remains a major obstacle. Although deep learning and sensor technology are advancing, complex urban and climatic environments still significantly impact the vehicle's ability to collect information. Further development requires more technological innovation and extensive testing and validation. Globally, the legal framework for autonomous driving is still in the exploratory stage. Different countries have varying regulatory standards for autonomous driving, lacking unified policies and regulations. Additionally, driving rules vary across countries and regions, posing a challenge to balance these differences [18].

Despite significant progress in autonomous driving technology, public trust remains low. Enhancing public awareness, conducting effective publicity, and improving safety will be key to increasing market acceptance.

6. Conclusion

By analyzing the application of deep learning in autonomous driving technology, it is evident that this technology plays an indispensable role in data processing, decision-making, and execution. Deep learning technology significantly enhances the flexibility and accuracy of autonomous driving systems when dealing with complex environments and large amounts of information compared to traditional models.

In summary, the importance of deep learning in autonomous driving technology is undeniable. Whether from the external or internal perspective of the system, it demonstrates immense capability and potential. This paper primarily introduced several typical examples of developing autonomous driving technology based on deep learning, such as target recognition, pedestrian trajectory prediction, lane route planning, and intelligent speed control. In these cases, deep learning technology is closely related to various parts of the models, highlighting its significant importance.

However, this technology also faces many unresolved issues and challenges, such as stability in complex environments and legal and ethical issues. Therefore, further development and standardization of this technology are necessary. Additionally, the "black box" nature of deep learning, with its opaque internal structure, poses certain risks in the safety-sensitive field of autonomous driving, making it difficult for the public to understand and accept. Further popularization and analysis are also necessary.

Looking to the future, autonomous driving technology combined with deep learning is expected to significantly change travel methods and bring about industrial transformation. However, the development of technology must also proceed in tandem with the formulation of laws and regulations. Based on a sound safety and responsibility implementation system, the promotion of this technology will have a profound impact, laying the foundation for the future intelligent transportation network system.

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