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Development and analysis of autonomous driving technology for wheeled robots

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Abstract. A The remarkable progress achieved in the evolution and utilization of autonomous driving technology in wheeled robots is thoroughly analysed in this extensive review article. It begins by stressing the significance of autonomous driving technology in the functioning of wheeled robots. The article proceeds to explore the advancement and application of the core components of autonomous driving technology, namely perception, decision-making, and control, in wheeled robots. Moreover, the comprehensive examination sheds light on the main stumbling blocks and restrictions faced in the current implementation of self-driving technology in wheeled robots, including the need for advanced perception systems and decision-making abilities. Touching on future directions in this domain and offering suggestions for further investigation, the review ultimately emphasizes the capacity of self-driving technology to augment the efficiency and security of wheeled robots, while stressing the inevitable requirement for continuous research and innovation to surmount existing hurdles and actualize this potential in its entirety.

Keywords: wheeled robots, autonomous driving, lidar, visual analysis.

1. Introduction

The use of wheeled robots, which rely on wheels for movement, has become increasingly prevalent across a range of industries. These versatile machines have found applications in logistics, agriculture, healthcare, military operations, and educational settings. To achieve this flexibility of movement, a key technology known as autonomous driving is required [1, 2].

In the realm of autonomous driving, a plethora of techniques have emerged to empower robots to navigate independently, free from human intervention. At the heart of this technology lies the robot's innate capacity to perceive its surroundings, formulate informed decisions, and exert control over its actions in order to fulfill its objectives. For instance, a technology known as LiDAR has been extensively applied in autonomous driving to aid robots in perceiving their environment [3].

The incorporation of self-driving technology into wheeled robots holds immense significance. Primarily, it has the capability to augment the efficiency of these robots by allowing them to carry out tasks autonomously, without the need for human intervention. Secondly, autonomous driving technology can enable robots to work in complex and hazardous environments, thereby reducing human risks [4]. Lastly, autonomous driving technology can allow robots to better adapt to their working environment as they can automatically adjust their behaviours based on environmental changes [2].

The main focus of this article is to examine the progress of autonomous driving technology in wheeled robots and to discuss the obstacles and limitations it encounters in practical settings. The structure of this article is as follows: Firstly, this article will provide an introduction to the technological background and evolution of autonomous driving technology. Next, this article will delve into the various components of autonomous driving technology, such as perception, decision-making, and control, and analyse their development. Subsequently, this article will explore the application of autonomous driving technology in wheeled robots, highlighting the significant research and accomplishments in this field in recent years. Lastly, this article will address the main challenges and issues currently faced in implementing autonomous driving technology in wheeled robots, and speculate on future trends and advancements.

2. Technologic background

The introduction of autonomous driving technology has been a momentous achievement in the realm of robotics, signifying a fundamental shift in the manner in which robots engage with their surroundings. This groundbreaking technology empowers robots to navigate independently, free from any requirement for human intervention, and has witnessed considerable progress throughout its evolution. The development of autonomous driving technology can be traced back to the early efforts of automakers and tech firms who were racing to generate self-driving innovations [5]. In the initial phases, there was a notable emphasis on incorporating state-of-the-art technologies to introduce vehicles that were not only effective and innovative, but also dependable. Simultaneously, efforts were made to minimize manufacturing expenses. Machine learning and computational intelligence were identified as essential to the progress of automobiles, with these technologies making the innovative concept of self-driving vehicles a reality [5].

The development of new technology has allowed for its application in various industries, with the field of robotics being one area that has benefited. Autonomous driving technology has found its way into the realm of wheeled robots, resulting in notable advancements in their mobility. This journey of autonomous driving technology has been characterized by constant innovation and improvement, leading to its current state. Today, it forms the backbone of many robotic applications, including wheeled robots, and continues to evolve to meet the growing demands of various sectors [6]. The evolution of autonomous driving technology has been driven by the need for more efficient and safer means of transportation.

Various environments have seen the emergence of robots capable of performing complex tasks, thanks to the application of autonomous driving technology in the field of wheeled robots. These robots are equipped with advanced perception systems that enable them to navigate and perform tasks autonomously, thereby reducing the need for human intervention [6]. Various obstacles and limitations have influenced the advancement of autonomous driving technology. These include but are not limited to technical hurdles in perception, decision-making, and control. In addition, ethical and regulatory concerns have also played a significant role in shaping the development of this technology. Despite these challenges, the technology continues to evolve, driven by the ongoing research and development efforts in the field [5,6].

The journey of continuous innovation and improvement has led to the development of autonomous driving technology. From its early stages to its current state, this technology has become a key component of many robotic applications, specifically those involving wheeled robots. As the development of this technology continues, its role in the future of robotics is expected to be even more significant.

3. Technical composition and development

3.1. Perception

Autonomous driving specifically in wheeled robots has a critical element of technology that relies on perception. This involves employing diverse sensors and technologies in order to gather and make sense of the environment that the robot is operating in. This information is then used to make decisions about the robot's actions. LiDAR, a prevalent tool in the field of perception, utilizes light from pulsed lasers to gauge distances. This technology has found widespread use in autonomous vehicles, assisting artificial intelligence in comprehending their surroundings. The technology provides high-resolution, three-dimensional information about the environment, enabling the robot to detect and recognize objects, estimate their distance, and determine their relative velocity [7].

The improvement of autonomous driving systems' perception abilities has seen the application of deep learning, a branch of machine learning. Deep learning, when combined with LiDAR, has yielded promising results in the sphere of 3D object detection, a crucial aspect of autonomous driving. This is due to the fact that deep learning algorithms possess the capability to ascertain intricate patterns and structures within the data, thereby allowing for accurate identification and categorization of objects within the surrounding area. The motivation behind the advancement of perception technologies for autonomous driving stems from the necessity for dependable and precise environmental perception. Despite the significant advancements, challenges remain, including dealing with dynamic and unpredictable environments, and ensuring the robustness and reliability of the perception system [7].

Visual analysis is playing a pivotal role in enhancing the perception capabilities of wheeled robots due to the rapid advancements in autonomous driving technology. An essential component of this is vision-based semantic segmentation, as it significantly contributes to scene understanding, which is crucial for autonomous driving. This involves the use of visual sensors to extract contextual information from the environment, enabling the robot to make informed decisions [8].

Detecting persons and vehicles, analysing transitions and lane changes are all part of the scene understanding process. Despite significant advancements in these tasks, achieving a level-5 autonomy that imitates human operations is still a daunting challenge. Most of the existing techniques for scene understanding heavily rely on deep learning models that require substantial computational power. These models, although effective, have their limitations, especially when deployed in real-world, dynamic environments [8].

The model's ability to generalize across different scenarios is greatly affected by the available datasets. The diversity and quality of data plays a vital role in determining the model's performance. As the demand for fully autonomous wheeled robots grows, there is a pressing need for more comprehensive and diverse datasets that can cater to the unique challenges presented by different environments and scenarios [8].

In conclusion, perception is a key component of autonomous driving technology, enabling the robot to understand its environment and make informed decisions. The ongoing research and development in this area are expected to further enhance the perception capabilities of autonomous driving systems, thereby improving the performance and safety of wheeled robots.

3.2. Decision-making

Decision-making is another essential component of autonomous driving technology. It involves the process of making high-level decisions, such as lane changes, car following, and obstacle avoidance, based on the environmental state perceived by the autonomous driving vehicle (ADV) [9]. The vehicle's operation relies on critical decisions that guarantee safety, efficiency, and smoothness. Autonomous driving benefits from the implementation of deep reinforcement learning (DRL), a subfield of machine learning. DRL has gained popularity in the decision-making process of autonomous vehicles (ADVs), with models like Deep Q Network (DQN) and its variations effectively controlling lateral and longitudinal choices. These models learn from the interaction with the environment to make decisions that maximize the cumulative reward, thereby improving the safety and efficiency of autonomous driving [9].

In a unified framework, Cui et al. have proposed a decision-making model based on DRL that combines lateral and longitudinal decisions. This integrated model uses a shared DQN to make both types of decisions, thereby reducing the complexity of the decision-making process and improving the overall performance of the ADV [9]. The model is trained using a reward function that considers

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multiple factors, including safety, efficiency, and comfort. Despite the complexity and challenges of the decision-making process in autonomous driving due to the dynamic and unpredictable nature of the driving environment, the application of DRL in decision-making has shown promising results in simulation experiments, demonstrating its potential in improving the performance of autonomous driving [9].

To sum it up, the behavior of the robot is heavily influenced by decision-making, which is vital for autonomous driving technology. By incorporating DRL into this process, the performance and efficiency of autonomous driving can be significantly boosted. This ongoing research and development in the field are projected to enhance the decision-making abilities of wheeled robots, ultimately improving their performance and safety.

4. Application in wheels robot

The notable strides made in mobile robotics and non-holonomic wheeled robots are unmistakably attributed to the game-changing influence of self-driving technology. With its emphasis on increased efficiency and safety, this technology has garnered widespread utilization in various fields, propelling remarkable progress in these domains.

In mobile robotics, autonomous driving technology has optimized equipment operation, improved safety, and enhanced workspace awareness [10]. Equipped with this technology, these robots have greatly enhanced the efficiency and quality of tasks carried out. In unstructured scenarios, like autonomous warehouse logistics and systems with multiple mobile robots, the technology has proven to be particularly advantageous. Traditional navigation methods are often insufficient in such situations.

The usage of a hybrid navigation system in mobile robots to incorporate autonomous driving technology is one noteworthy application. In this scenario, a diverse range of navigation methods are combined to accommodate different accuracy needs and application requirements. An example of this is the utilization of a path planning scheme founded on Bezier curves, facilitating a seamless and effective navigation experience. Additionally, a motion controller is designed to enable the mobile robot to follow the target path accurately. To process the navigation signals and the control output of the motion controller, a Kalman filter is implemented, providing a robust and reliable navigation solution [10].

In the realm of non-holonomic wheeled robots, autonomous driving technology has been applied innovatively through the development of an observer-based Type-3 fuzzy control [11]. The outcome is an expert control approach that effectively integrates deep learning and a physics model that can be differentiated in all aspects. This unique approach empowers the neural network with pre-existing knowledge. Consequently, the resulting model surpasses conventional neural network models in terms of its ability to adapt and accurately depict the forces exerted on the tires without requiring supplementary training.

Moreover, the use of autonomous driving technology has led to the development of a risk-aware model predictive controller. This controller uses proprioceptive information derived from the latent features, demonstrating the potential of autonomous driving technology in enhancing the safety and efficiency of wheeled robots [11].

The versatile application of autonomous driving technology in wheeled robots has displayed encouraging outcomes in diverse fields. The ongoing endeavors in research and development in this domain are anticipated to broaden the range of scenarios where autonomous driving technology can be utilized in wheeled robots, thereby bolstering their performance and safety. The continually advancing autonomous driving technology, alongside the growing intricacy of tasks conducted by wheeled robots, hints at a promising future for this technology in numerous applications.

5. Discussion

5.1. Existing challenges and limitation

The application of autonomous driving technology in wheeled robots, especially in warehouse environments, comes with its own set of challenges. These problems can be found in various aspects such as technical, operational, and environmental. Comprehending the main difficulties and issues faced with autonomous driving technology in wheeled robots is crucial.

In the realm of technicalities, a major hurdle emerges in the form of trajectory tracking for wheeled mobile robots navigating themselves within limited areas, including warehouses. As discussed by Jeon and Lee [12], the goal is to generate a minimum-time smooth trajectory that considers constraints on velocity, acceleration, and jerk. A new approach has been suggested to enhance the path-following capabilities of a mobile robot known as PASTRo. This innovative method incorporates a kinematic strategy and focuses on the improvement of trajectory tracking. PASTRo consists of a main body, four tracks, two rockers, and a differential gear. The proposed solution involves the careful analysis of terrain gradients at specific points for the purpose of compensating for speed variations. However, the successful implementation of this solution in practical settings presents a considerable challenge, given the intricacy of warehouse environments and the necessity of continuously adjusting the robot's path in response to dynamic obstacles and evolving operational requirements. Moreover, the technical difficulties are further compounded by the complex structure of PASTRo and the demand for precise control of its various components.

In terms of operational challenges, safety in warehouse environments is a paramount concern. Qiao et al [13] highlight the need for an optimized differential evolution algorithm based on kinematic limitations and structural complexity constraints to solve the trajectory tracking problem for a mobile manipulator robot. Avoiding the singularity position and/or self-collision phenomena is a challenge when using traditional methods to obtain the speed of the control variable. These methods typically involve the Jacobian inverse or linearization of the robot's kinematic model. However, integrating this algorithm into autonomous mobile robots requires overcoming various challenges. This includes developing robust object detection and recognition algorithms, managing large amounts of sensory data, and ensuring reliable performance in different lighting and environmental conditions. Additionally, the algorithm needs to account for the robot's kinematic limitations, which can be complex due to its multiple degrees of freedom and the requirement to avoid self-collision.

The use of autonomous driving technology in warehouse settings has the potential to greatly improve the efficiency and abilities of wheeled robots. However, it also comes with a unique set of challenges that need to be addressed. Ongoing research and development will be necessary to tackle these challenges, with a particular focus on improving trajectory planning algorithms, enhancing robot perception capabilities, and ensuring operational safety. To overcome these obstacles, it will be crucial to develop more advanced algorithms and control strategies, as well as integrate more sophisticated sensors and perception systems.

5.2. Prediction of future development trends

Autonomous driving technology in wheeled robots is on the brink of major advancements, especially in the realm of mobility analysis, which is crucial for their independent and safe operation1. As the field progresses, there are a number of key trends that are predicted to influence its direction. The increased dependence on signal-based and model-based estimation methods, which involve detecting vehicle motion parameters, is expected to be pivotal in enhancing the autonomous capabilities of wheeled robots. By accurately estimating vehicle motion, these techniques can help improve the robots' navigation and control, thereby enabling them to operate more efficiently in various environments [14].

It is essential to mention that the use of terramechanics-based methods is on the rise. These methods are centered around comprehending and modeling how the robot's wheels interact with the terrain, which is vital for enhancing the robot's mobility and ensuring its safe operation. Particularly in difficult terrains, this understanding is of utmost importance. Additionally, machine learning is anticipated to have a substantial impact on the future of wheeled robots' autonomous driving technology. With the help of machine learning algorithms, robots have the ability to learn from their experiences and adjust their behaviors accordingly, ultimately leading to improved performance as time goes on. The anticipation of an increase in the use of global sensing techniques, which involve sensors to detect terrain hazards and parameters, is apparent. These techniques are vital for the safe and efficient operation of wheeled robots. Nevertheless, with the continuous evolution of these technologies, they also present new challenges. The vehicles' heightened complexity and sensitivity to external factors and uncertainties require additional research and development endeavors. This includes exploring the potential of electric vehicles, new vehicle types, dynamic environments, and communication between vehicles [14].

5.3. Suggestions and expectations for further research

With the current status of wheeled robots' independent driving technology and the obstacles it encounters, there exist numerous domains where additional research could prove advantageous. It is imperative to advance perception systems. Although current systems have made significant progress, there is still ample opportunity for enhancement, particularly in terms of precision and dependability. Exploring novel sensor technologies and perception algorithms could contribute to the betterment of wheeled robots' capacity to comprehend and engage with their surroundings. In the realm of wheeled robots, their decision-making abilities have vast potential for improvement. This may necessitate the creation of more advanced decision-making algorithms, allowing for efficient and adaptive choices to be made in dynamic and intricate situations.

Moreover, delving into machine learning processes may empower robots by allowing them to internalize and enhance their cognitive abilities based on prior encounters. The optimization of control systems for mobile robots could be boosted by exploring groundbreaking control algorithms that ensure seamless and highly efficient manoeuvrability. Increased attention toward crafting sturdier control systems equipped to handle disruptions and uncertainties would, in turn, bolster the dependability and safety of mobile robots. Ultimately, the identification of difficulties and limitations in the integration of self-driving technology within mobile robots necessitates continued research to tackle these challenges. The next generation of autonomous wheeled robots requires the exploration of new technologies, techniques, and research into the ethical and regulatory aspects of autonomous driving technology to overcome challenges. By pushing the boundaries and addressing these areas, we can pave the way for what is possible.

6. Conclusion

The exploration of autonomous driving technology in wheeled robots is the focus of this review. Starting by defining wheeled robots and emphasizing the crucial role of autonomous driving technology in their operation. Following that, this article explore the technological background of autonomous driving and its journey from its inception to its applications in multiple sectors. Furthermore, this article dissect the technical composition and development, dissecting the pivotal components of autonomous driving technology, namely perception, decision-making, and control. Progress made in these realms and their influence on the capabilities of wheeled robots are also highlighted. Within the application section, this article delved into the utilization of self-driving tech in wheeled bots, highlighting a wide array of robotic examples with their corresponding operational advantages. Lastly, this article tackled the current obstacles and restrictions surrounding the integration of self-driving tech in these bots. This article brought up the technical and operational hurdles, like mapping out paths in constricted zones and guaranteeing safety in operations. Notwithstanding these hurdles, the ongoing exploration and development endeavours in this realm provide a promising outlook where these restrictions could be surmounted.

References

[1] Palacín, Jordi, et al. "Non-Parametric Calibration of the Inverse Kinematic Matrix of a Three Wheeled Omnidirectional Mobile Robot Based on Genetic Algorithms." Applied Sciences, vol. 13, no. 2, 2023, pp. 1-16.
[2] Yang, Zhen, Cheng Pang, and Xuefeng Zeng. "Trajectory Forecasting Using Graph Convolutional Neural Networks Based on Prior Awareness and Information Fusion." ISPRS International Journal of Geo-Information, vol. 12, no. 2, 2023, pp. 1-18.
[3] Yang, Dong, et al. "Development of the high angular resolution 360° LiDAR based on scanning MEMS mirror." Scientific Reports, vol. 13, no. 1, 2023, pp.1-12.
[4] Zhao, Shuai, et al. "Application and Development of Autonomous Robots in Concrete Construction: Challenges and Opportunities." Drones, vol. 6,no.12,2022,pp. 1-24.
[5] Kumari, Dimple, and Saurabh Bhat. "Accelerating the Race to Autonomous Cars – A Case Study." International Journal of Advanced Engineering and Management, vol. 6, no. 1, 2021, pp. 1-6.
[6] Kebbati, Yassine, et al. "Lateral control for autonomous wheeled vehicles: A technical review." Asian Journal of Control, vol. 24, no. 6, 2022, pp. 1-20.
[7] Alaba, S. Y., & Ball, J. (2022). "A Survey on Deep-Learning-Based LiDAR 3D Object Detection for Autonomous Driving." Sensors, vol. 22, no. 24, 2022, pp. 1-20.
[8] K. Muhammad, Tanveer Hussain, Hayat Ullah, et al. "Vision-Based Semantic Segmentation in Scene Understanding for Autonomous Driving: Recent Achievements, Challenges, and Outlooks." IEEE Transactions on Intelligent Transportation Systems, 2022.
[9] Cui, J., Zhao, B., & Qu, M. (2023). "An Integrated Lateral and Longitudinal Decision-Making Model for Autonomous Driving Based on Deep Reinforcement Learning." Journal of Advanced Transportation, vol. 2023, Article ID 1513008.
[10] Shentu, S., Gong, Z., Liu, X., Liu, Q., & Xie, F. (2022). "Hybrid Navigation System Based Autonomous Positioning and Path Planning for Mobile Robots." Chinese Journal of Mechanical Engineering, 35(1), 1-14.
[11] Bie, H., Li, P., Chen, F., & Ghaderpour, E. (2023). "An Observer-Based Type-3 Fuzzy Control for Non-Holonomic Wheeled Robots." Symmetry, 15(7), 1354.
[12] Jeon, H.-W., & Lee, D. (2023). Explicit Identification of Pointwise Terrain Gradients for Speed Compensation of Four Driving Tracks in Passively Articulated Tracked Mobile Robot.
[13] Qiao, L., Luo, X., & Luo, Q. (2022). Control of Trajectory Tracking for Mobile Manipulator Robot with Kinematic Limitations and Self-Collision Avoidance.
[14] Zarei, M., & Chhabra, R. (2022). Advancements in autonomous mobility of planetary wheeled mobile robots: A review. Frontiers in Robotics and AI.