Development Analysis of Key Autonomous Perception Applied to Path Planning and Autonomous Obstacle Avoidance of Land Wheeled Mobile Robots

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Abstract. Path planning and autonomous obstacle avoidance are two key technologies for mobile robots, and the technical basis for achieving these functions is high-precision autonomous perception. The core purpose of this article is to deeply analyze and discuss the key autonomous perception technologies of land-wheeled mobile robots in path planning and autonomous obstacle avoidance. This article first reviews the technological development process in the field of mobile robots, emphasizes the importance of path planning and autonomous obstacle avoidance, and outlines the foundation of high-precision autonomous perception technology that is required to achieve these functions. Subsequently, this article will provide a comprehensive perspective by analyzing the latest developments, challenges, and future development trends of these key technologies in-depth chapter by chapter, aiming to provide valuable insights and references for researchers, engineers, and technology enthusiasts to jointly promote the further development of mobile robot technology. This article comprehensively explores the key autonomous perception technologies of land-wheeled mobile robots in path planning and autonomous obstacle avoidance, aiming to reveal the current progress, main challenges, and future development directions of these technologies. Through in-depth analysis, this article not only emphasizes the importance of these technologies in improving robot performance and application scope, but also provides direction for future research and technological innovation and looks forward to the broad prospects of mobile robot technology on the path of intelligent development.

Keywords: Robotics technology, Computer vision, Intelligent perception.

1. Introduction

The development background and technical significance of mobile robots are deeply rooted in the continuous pursuit of automation, efficiency improvement, and safety in modern society. With the advancement of technology, especially breakthroughs in computer science, artificial intelligence, mechanical engineering, and electronic technology, mobile robots have evolved from simple automation devices in the early days to systems that can perform complex tasks, possess high intelligence, and autonomy. They are playing an increasingly crucial role in industrial automation, medical services, disaster relief, and daily services, not only greatly improving operational efficiency and safety, but also opening up new ways of work and life for humanity, demonstrating the important position of mobile robot technology in promoting social progress and technological innovation.

The importance of mobile robots in modern society is increasingly prominent, and they have become a key force driving innovation and development in many industries. In the field of industrial automation, mobile robots not only significantly improve production efficiency by performing precise and repetitive tasks, but also reduce manufacturing costs, enabling enterprises to respond more flexibly to market changes. In the field of healthcare, they take on the role of transporting drugs, samples, and assisting in precision surgery, greatly improving the efficiency and safety of medical services. In addition, in disaster relief missions, mobile robots can enter dangerous areas that are difficult or inaccessible to humans for search, rescue, and evaluation, effectively preserving valuable human resources and reducing rescue risks. In the service industry, from hotels to retail, mobile robots not only improve customer experience, but also enhance service efficiency and quality by providing information, guiding customers, and handling daily tasks. Through these applications, mobile robots

have demonstrated their unique value in improving work efficiency, reducing labor costs, and performing dangerous or unwanted tasks for humans, demonstrating their indispensable importance in modern society. Introduce the important significance of several key technologies in the intelligence of mobile robots [1].

In the development of mobile robot technology, path planning, and autonomous obstacle avoidance are two core issues that directly affect the operational efficiency and safety of robots. Path planning refers to the robot calculating the optimal or feasible path from the starting point to the endpoint based on environmental information and target location. Autonomous obstacle avoidance refers to the ability of robots to recognize and bypass obstacles during movement, ensuring smooth arrival at their destination. With the expansion and complexity of robot application scenarios such as autonomous vehicles, automated logistics, and service robots, the demand for higher precision and intelligent sensing technology is increasing.

The growth of this demand not only drives the development of key technologies such as computer vision, LiDAR, and sensor fusion, but also puts higher demands on algorithm innovation. The advancement of these technologies and algorithms enables robots to perceive the surrounding environment more accurately, plan paths more effectively, and avoid obstacles. But they also bring new challenges, such as how to handle uncertainty in complex environments and how to improve the robustness and reliability of sensing systems [2-4].

Therefore, exploring and addressing these challenges not only helps to improve the performance and application range of robots but also has important significance in promoting the development of related technologies. The work of this article will revolve around path planning and autonomous obstacle avoidance technology for mobile robots, exploring the latest advances, main challenges, and future development directions of current technology. The aim is to provide valuable insights for researchers, engineers, and technology enthusiasts to promote further development of mobile robot technology. This article aims to explore the key sensing technologies for path planning and autonomous obstacle avoidance of ground mobile robots. Firstly, the basic concepts and importance of path planning and autonomous obstacle avoidance for mobile robots will be introduced, as well as their roles in practical applications. Next, this article will analyze the background, principles, advantages, and limitations of the main technologies currently used in this field, including computer vision, LiDAR, and sensor fusion technology. In addition, practical application cases of these technologies in robot path planning and obstacle avoidance will also be explored. Finally, this article discusses the current technological challenges and future prospects, aiming to provide comprehensive and up-to-date technological analysis and insights for researchers, engineers, and robotics enthusiasts.

2. Land Wheeled Mobile Robot

Wheeled mobile robots are robots that use wheels as a means of movement. They operate efficiently and quickly on flat and hard surfaces and are widely used in various environments and tasks. The use of ball wheels enables mobile robots to have higher mobility, simpler path planning, and fewer complex control schemes. The geometric shape and design of mobile robots ensure the primary attributes of omnidirectional motion. In addition, the platform adopts multiple active and passive ball wheels to achieve optimal stability when the robot uses terminal components.

When designing mobile robots, it is necessary to balance volume and performance, hoping to improve performance. Many research teams have developed various methods to achieve high-definition walking performance. Among these methods, eccentric wheel-based robot design is a mainstream solution. Hodo et al. controlled the robot to traverse higher steps than regular wheels by adjusting the center of the eccentric rotating wheel. Eccentric wheels have a drawback because their driving efficiency on flat roads is not as good as regular wheels. In this study, the team created a passive offset adjustment wheel that undergoes automatic deformation into an eccentric wheel only during bump crossings, while maintaining a standard wheel state otherwise [5].

Mobile robots are evaluated based on their ability to achieve high mobility/speed and adapt to complex environments. Legged robots excel in adapting to various environments, while wheeled robots are known for their exceptional mobility. Due to the inability of existing mobile robots to meet both of these requirements, some scholars have analyzed the underlying structure of wheeled robots and made corresponding improvements. On complex or uneven terrain, the performance of wheeled robots may be limited and difficult to overcome certain obstacles. Effective coordination of multiple propulsion wheels is a critical consideration in designing wheeled mobile robots as it enhances traction and improves energy efficiency. This transforms the propulsion wheel into a pseudo-propulsion wheel, which can be manipulated to track the movement of the robot body according to kinematic constraints. A method known as Velocity Following Control (VFC) is suggested to address internal force conflicts between wheels during interactions with different terrains. This approach aims to control PDW (possibly a type of mobile robot or system) in scenarios where soil deformation causes force disturbances.

In addition, in response to the above issues, some scholars have combined different movement methods of mobile robots to improve their performance. Several flexible, scalable, and reconfigurable multi-terrain vehicles have been designed one after another. Usually, the vehicle body consists of two center panels and two side panels, both of which have two active wheels, with two passive wheels on either side of the axis. Especially, the angle contained between a middle panel and two side panels is driven by an active motor, and by adjusting the wheelbase between the two active wheels, the vehicle can take on various forms. Multi-terrain vehicles in this configuration can navigate various obstacles such as deep pits, stairs, height limit poles, climbing gaps, and pipelines by adjusting and altering their wheelbase. The process begins with the meticulous design of the multi-terrain vehicle's mechanical structure. Following this, the vehicle's kinematics are analyzed, including calculations for wheelbase and center of mass velocity during both forward and reverse motion. Following this, a control scheme is proposed based on the PID algorithm, which includes controllers for driving speed, turning, and wheelbase. Lastly, the feasibility and effectiveness of the designed multi-terrain vehicle structure and control system are validated through simulation and experimentation.

Tao et al. proposed a novel wheeled-leg mobile robot to address challenges. Initially, they designed a deformable wheel mechanism and an adaptable tail mechanism. Subsequently, they developed a kinematic model of the robot considering various road conditions, analyzing its overall motion and wheel-leg switching motion. By incorporating module constraint relationships, they evaluated the robot's ability and established a model for obstacle encounters. Additionally, they examined the robot's stability using the stable cone method, particularly on slopes and with unilateral wheel deployment, determining tipping conditions under critical states. Finally, they simulated and analyzed the robot's driving process across different terrains and obstacles using ADAMS software to verify its superior performance in overcoming obstacles and achieving motion flexibility [6].

Wheeled mobile robots are widely used in industrial automation, intelligent warehousing, environmental monitoring, disaster search and rescue, and other fields. With their efficient mobility and flexible deployment methods, they can perform various complex tasks. Mobile robots are vital for material handling within the manufacturing sector, serving various automated functions. Ensuring the accuracy of a robot's motion trajectory has become pivotal in enhancing its operational efficiency [7].

Wheeled mobile robots play an important role in multiple fields due to their high efficiency, fast movement, and low energy consumption. Although they have certain limitations in adaptability and stability to complex terrains, the application range and efficiency of wheeled mobile robots are constantly expanding through continuous technological innovation and design optimization.

3. Key Perception Technology

3.1. Computer Vision

3.1.1 Multi camera visual perception system.

Multi camera vision systems typically use multiple cameras to capture images from different angles and calculate depth information by comparing the same features in different views. In order to integrate the information obtained by visual sensors separately, it is necessary to perform external calibration on these cameras. A binocular stereo-vision system has been proposed. Most external calibration methods for cameras use a calibration board to simultaneously capture images of the camera system and calibrate it by calculating features. By placing ordinary flat chessboards with different poses in front of a multi-sensor system, the external calibration problem is solved through a three-dimensional reconstruction of the chessboard and geometric constraints of the stereo vision system. In addition, their method takes into account sensor noise and provides the best results under Mahalanobis distance constraints [8].

3.1.2 Heterologous visual perception.

Chen et al. proposed a novel probability fusion model based on Bayesian Kriging (BK) to address the challenge of accurately perceiving complex environments with a single sensor's depth map. The objective of this model is to attain high-density and high-precision depth map estimation by leveraging the complementary attributes of two distinct sensors. By assuming geometric segmentation planes within the scene, the noise disparity map acquired from 3D vision sensors is segmented into multiple smaller planes. A fusion estimator is then established on each segmentation plane to predict the depth of individual pixels using sparse scattered LIDAR points. Based on the theory of regionalized variables, the spatial variation priors and correlations of two types of data were analyzed in detail. Experiments were conducted on different scenes of the KITTI stereo dataset to validate the effectiveness of the algorithm and compare it with existing fusion methods [9].

3.2. Lidar technology

LIDAR, an acronym for Light Detection and Ranging, is an optical remote sensing system utilized for measuring the distance to a target by emitting light towards it. This technology is widely employed in robotics for environmental recognition and object classification purposes. A typical LIDAR system comprises a transmitter, which emits a laser beam to illuminate the target, and a receiver, capable of detecting optical components aligned with the emitted beam. The receiver sensor calculates the distance based on the time taken for light to travel to the target and back to the source.

LiDAR has emerged as a primary sensor for achieving high-precision situational awareness in robots and autonomous systems. In recent times, there has been a rise in the development of multimodal LiDAR systems. Sir et al. have specifically focused on leveraging LiDAR and LiDAR-generated images for real-time tracking of unmanned aerial vehicles (UAVs). This capability holds potential for various applications including docking, remote identification, and anti-UAV systems. They have utilized a customized YOLOv5 model to detect drones based on panoramic images collected in indoor experimental fields and MOCAP systems. Through integration with point clouds, continuous location information of drones can be provided [10].

3.3. Ultrasonic Sensing Technology

Ultrasonic sensor is a type of sensor that uses the characteristics of ultrasonic waves propagating in the air to measure the distance between objects. This sensor determines the distance between the target object and itself by emitting ultrasonic pulses and measuring their echo time. It operates on the fundamental principle of distance measurement through the propagation speed and flight time of ultrasonic waves in the air. Such sensors find widespread use in various applications including distance measurement, obstacle detection, and position control. Its simplicity, high accuracy, and low cost make it widely used in multiple fields.

Mohammad et al. introduced an obstacle avoidance navigation algorithm utilizing ANFIS, aimed at identifying a brief, collision-free path to the target point using a minimal number of basic ultrasonic sensors. The algorithm design prioritizes the use of straightforward hardware for mobile robots while minimizing the number of parameters to ensure real-time responsiveness. Initially, ultrasonic sensors are deployed to gauge the distance between the robot and obstacles. These sensors in three directions can help robots perceive the surrounding environment in all directions, thereby better-avoiding obstacles. Secondly, the ultrasonic sensor continuously measures and sends distance data. These data include the distance between the robot and obstacles, which will be used as input for subsequent processing. Thirdly, input the distance data into the ANFIS utility function module. ANFIS combines the learning ability of neural networks with the reasoning ability of fuzzy logic and can calculate a steering angle to avoid obstacles based on input distance data. By simulating different scenarios of encountering obstacles, ANFIS learns and optimizes obstacle avoidance strategies. Subsequently, based on the output obtained from ANFIS, which is the obstacle avoidance steering angle, the robot adjusts its travel direction to avoid obstacles. The calculation of the turning angle takes into account the current position of the robot, the position of obstacles, and the position of the target point, ensuring that the robot can move as far as possible towards the target point while avoiding obstacles. Finally, the robot adjusts its travel direction in real-time based on the calculated steering angle. If no obstacles are detected, the robot will continue to move straight towards the target point. If an obstacle is detected, adjust the direction based on the steering angle calculated by ANFIS, avoid the obstacle, and reposition to ensure moving towards the target [11].

4. Conclusion

This article comprehensively introduces the importance and current development status of mobile robot technology, as well as the application of key perception technologies. Mobile robots have become an important force driving industrial innovation and development in modern society, demonstrating enormous potential in fields such as industrial automation, healthcare, disaster relief tasks, and service industries. Mobile robots have become an indispensable presence in improving production efficiency, reducing costs, enhancing the efficiency and safety of medical services, and entering hazardous areas to perform tasks during rescue operations.

Path planning and autonomous obstacle avoidance technology, as core issues in mobile robot technology, directly affect the operational efficiency and safety of robots. This article introduces the importance of perception technologies such as computer vision, LiDAR, and ultrasonic sensors in mobile robots. With the development of autonomous vehicles and automated logistics, there is an increasing demand for higher precision and intelligent sensing technologies. The application of these sensing technologies will have a profound impact on the development of mobile robots. In terms of specific technologies, this article provides a detailed introduction to the principles and applications of key perception technologies such as binocular vision systems, heterologous visual perception, two-dimensional LiDAR, and three-dimensional LiDAR. The important role and potential applications of these technologies in mobile robots were demonstrated through real-time tracking of drones, environmental perception, and obstacle avoidance.

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