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Review of AGV Obstacle Avoidance Algorithm Based on Machine Vision

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Abstract:

With the development trend of unmanned and intelligent, it has become a development trend for AGV to leave human operators and perform diversified tasks. However, operating in complex environments such as urban streets, mines, and construction sites is a difficult problem that needs to be solved currently. Obstacles in complex environments pose a serious threat to the AGV trolley in operation. Obstacle avoidance technology has become a key part of the AGV trolley's task decision-making system and plays an important role in ensuring the safe operation of the AGV trolley and improving work efficiency. This article first elaborates on the concept of the AGV trolley obstacle avoidance algorithm and the evaluation criteria for the optimal path, then elaborates and compares the advantages and disadvantages of different types of obstacle avoidance algorithms such as optimization-based, potential field-based, and machine learning-based obstacle avoidance algorithms, and finally obtains the research focus and direction of the AGV trolley.

Keywords: AGV trolley, Obstacle avoidance algorithm, Machine learning, Optimization, Potential field

1. Research Background and Research Status

Research Background: AGV trolleys are increasingly widely used in various fields, such as military, agriculture, logistics, and monitoring. However, when operating in complex environments, the trolley needs to have effective obstacle avoidance capabilities to ensure operational safety and mission success. Traditional obstacle avoidance methods mostly rely on lidar, ultrasonic sensors, etc., but the cost of these sensors is relatively high and they are greatly affected by environmental conditions. Therefore, obstacle avoidance technology based on machine vision has become an important research direction.

Research Status: In terms of obstacle detection: In 2009, Qiu Guangping used infrared sensors, supplemented by ultrasonic sensors, to achieve the autonomous navigation and obstacle avoidance of the trolley. [1] Miguel Angel Sotelo et al. adopted a color and shape-based method to segment the image, used a model to describe the image features, and after segmentation, used temporal and spatial filtering to filter out inconsistent objects, and then detected the region of interest. Then vehicle detection was carried out in this region, and analysis was carried out using

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vertical edges and symmetry differences, successfully solving the problems of vehicle recognition and tracking. [3] The cooperation and complementarity between different sensors is also a research focus. Seraji et al. proposed a multi-sensor fusion and multi-inference system decision fusion algorithm. This algorithm intelligently fuses the ground information obtained by radar, lidar, and CCD cameras. According to the sensor information, three sub-decision systems (fuzzy set system, Bayesian probability system, and Dempster - Shafer confidence system) are used to give decisions respectively, and the final decision is obtained through the hierarchical fusion selection algorithm to complete the detection of obstacles. [4] Yuan Hongbin, Cao Huiqun, Ou Qunyong et al. have related research on obstacle detection by laser ranging radar and machine vision. The optimization of the single-scale Retinex algorithm of the image enhancement algorithm makes the AGV more clear about the position and size of the items around it. [6]

In terms of obstacle avoidance strategies: International autonomous obstacle avoidance algorithms generally include the dynamic window method, artificial potential field method, and VFH algorithm (Vector Field Histogram). Traditional algorithms include the C-space method, artificial potential field method, and A* algorithm, etc., and intelligent algorithms include genetic algorithm and particle swarm optimization algorithm, etc. Z. Li et al. proposed an obstacle avoidance strategy based on a smooth curve. By integrating the tangents between the robot and the obstacle, a suitable smooth curve, that is, the collision avoidance route, is obtained, which can not only avoid obstacles but also ensure a reasonable robot motion trajectory as much as possible. This method is simple and easy to implement, and the algorithm is also very simple to realize. [2] While Lai Wenpeng and Hu Hong et al. proposed an obstacle avoidance path search with a controllable safe distance based on the improved A* algorithm. [8] Wang Tao et al. applied the improved A* algorithm to inland river unmanned surface vehicles (USV). [9] If in complex scenarios such as mines or disaster-stricken areas after geological disasters, Bao Zihan et al. optimized the image after using the cosine Gaussian kernel function for denoising in terms of the number of noise points and the clarity of the image edge compared with the traditional median filter, mean filter, and basic NLM algorithm. [5] Yue Junfeng, Li Xiumei et al. realized an intelligent trolley system based on the machine vision module OpenMV, using the STM32 single-chip microcomputer as the controller, adopting the multiple template matching method, and combining the traditional PID control technology and fuzzy control technology to enable the trolley to effectively identify obstacles and complete the obstacle avoidance path planning in a 4mm diameter guide line site. [7] Zhao Jing, Pei Zinan et al. integrated the advantages of the convolutional neural network and the recurrent neural network to construct a dual-network, which greatly increased the success rate of the AGV trolley in virtual pipeline visual obstacle avoidance. [10]

2. Research Objectives and Significance

Research Objectives: In the field of AGV trolleys, the research objectives and significance of machine vision obstacle avoidance are of great importance and wide application value. This article hopes to summarize the obstacle avoidance algorithms of AGV trolleys based on machine vision from 2006 to 2023, summarize the advantages and disadvantages of various obstacle avoidance algorithms at home and abroad, and use different types of algorithms to adapt to various task objectives in different environments. Secondly, based on machine vision, scholars at home and abroad have proposed different methods to enhance the recognition ability, which will also be covered in this article.

Research Significance: This article reviews the development of robot obstacle avoidance technology from 2006 to 2023, showing significant progress in path planning, obstacle detection, and control algorithms in this field. The research covers the evolution process from the early simple identification line detection to the combination of advanced technologies such as computer vision, embedded intelligent control, fuzzy control, and deep learning. The technological progress at each stage has improved the intelligence and real-time performance of the robot, providing strong support for the autonomy and efficiency of the robot in practical applications. However, the research also points out the limitations of the existing technology in complex and dynamic environments, such as the inability to accurately predict the movement of moving obstacles, the decrease in recognition rate caused by differences in lighting conditions, the interference and misjudgment phenomena in sensor information fusion, and the computational efficiency bottleneck of the algorithm in high real-time and complex scenarios. These problems point out the direction for future research, that is, it is necessary to further optimize the sensor fusion technology, improve the algorithm efficiency, and enhance the construction of the data set to improve the adaptability and accuracy of the robot in different environments.

3. Research Methods

Literature review is to understand the development process of AGV trolleys using machine vision for obstacle avoidance by reviewing and analyzing existing relevant literature. This includes identifying existing research achievements, research gaps, and possible future research directions. Keyword search uses keywords such as “AGV”, “machine vision”, and “obstacle avoidance” for searching. These keywords can help find relevant theoretical research and practical cases. Literature type limitation gives priority to peer-reviewed journal articles, conference papers, and monographs, because these literatures usually undergo strict academic review and have high academic value and reliability. Citation frequency and influence assessment For the screened literature, its citation frequency and influence can be further evaluated.

4. Literature Review

Obstacle Avoidance Algorithm: In 2006, Ying Hao judged the position of the obstacle in front by laying a white identification line on the ground and using the width and continuity of the pixels of the white identification line detected by the guidance image to start the steering program. However, this method is not accurate enough in path tracking and obstacle recognition. [11]

In 2008, Yao Lijian simplified the three-dimensional space path planning into two dimensions by equating spatial obstacles to cylindrical sectors with circular or rectangular axial sections that can be modeled mathematically, improving the real-time control; converting the obstacle equivalence from the workspace to the C-space, so that the control of the robot directly acts on the joint, avoiding the complex coordinate conversion using the inverse of the Jacobian matrix; mapping the C-space to the image matrix, and avoiding the possible failure in the optimization using the A* algorithm by appropriately processing the image. However, in the actual agricultural environment, the visual device is still inaccurate in identifying deformed fruits, and the obstacle avoidance performance cannot effectively obtain the information of irregular obstacles in the real agricultural environment. [12]

In 2009, Liu Lingmin, Hu Jing et al. proposed a combination of computer vision technology and embedded intelligent control technology, introduced the obstacle three-dimensional recognition and detection technology, and applied it to the static obstacle avoidance of the picking robot, which can plan a local optimal path in dynamic motion. [18]

In 2011, Cheng Jiayu analyzed some obstacle avoidance strategies proposed at that time and selected two that he considered better: the velocity obstacle method and the fuzzy control algorithm. By analyzing the characteristics of the two algorithms, the fuzzy control algorithm with fast response speed and strong anti-interference ability was finally selected as the algorithm for the motion obstacle detection and obstacle avoidance strategy of the agricultural robot. [13]

In 2013, Ma Li proposed an improved Harris - Laplace combined with the second-order moment SIFT feature extraction and matching algorithm. This improved the accuracy of the robot in obstacle recognition. However, since the experiments all used stationary obstacles, the three-dimensional information, speed, and motion trajectory of moving objects were not predicted, and the visual processing was carried out under the premise that the obstacle and the ground were of different colors. However, in the case where the obstacle and the ground are of the same color, there are blind spots in the visual information, and visual fusion with other non-visual sensors is required. [14]

In 2014, Zheng Haihua used a monocular camera and added an all-round pan-tilt to expand the field of view. In the feature extraction of the color image, the RGB color space was used for image processing. In terms of the obstacle avoidance strategy, the artificial potential field method was adopted. The artificial potential field method only needs to know the azimuth information and size information of the target and the obstacle relative to the robot in motion planning, which corresponds to the obstacle information that can be obtained by the monocular vision system. However, due to the simple imaging of the monocular camera, the processing ability for complex and uncertain environments is poor, and a binocular camera can be used to solve the problem. At the same time, the image processing technology only considers the color characteristics of the obstacle and the ground target object, which is incomplete, and the influence of strong light irradiation is not considered. [15]

In 2015, He Jiajian based on binocular vision and adopted the improved artificial potential field method. To avoid the local minimum point problem of the traditional artificial potential field method, the author analyzed three situations of the local minimum point and proposed two methods of inserting the repulsive force factor and setting the virtual target point according to the actual situation to solve this problem. However, due to the complex acquisition and processing process, the image processing effect of the left and right eyes is still not smooth enough. [16]

In 2017, Hou Zhixu used monocular vision to improve the traditional obstacle recognition method based on gray image segmentation, which had poor recognition effect in the obstacle detection and recognition steps. He used the sequential segmentation algorithm based on the HSI color model to complete the image segmentation. In terms of the obstacle avoidance strategy, the improved artificial potential field method was adopted, and two parameters, the

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change angle θ of the repulsive force and the radius r of the virtual local minimum area, were introduced to solve the local minimum point problem of the algorithm. However, the robot can only run on a flat ground, and supplementary and redundant methods are required in a complex ground environment. [17]

In 2018, Zhang Yongjun deeply studied the road image grayscale, filtering processing, and camera calibration algorithm based on machine vision. In the navigation line edge detection stage, the Canny algorithm was combined to improve the low efficiency of the traditional ant colony algorithm; in the obstacle detection stage, aiming at the low efficiency of the binocular vision algorithm, the integral projection and region growing algorithm were proposed to obtain the first frame of the obstacle image, and then the machine learning algorithm was used for real-time positioning; aiming at the overly complex existing obstacle avoidance navigation strategy, a fuzzy controller and an obstacle avoidance PID controller were designed to achieve fast and accurate obstacle avoidance navigation of the system. However, in the case of poor lighting conditions and many interfering objects, the navigation line may be lost, and this strategy only considers the low-speed situation. [18] Chen Shan used the SIFT operator to replace the Harris operator to complete the image corner detection, improved the original SIFT image matching algorithm, and used the RANSAC (Random Sample Consensus Algorithm) to eliminate the image feature matching error points after the initial image feature point matching result, completing the whole process of image feature matching. This improved the matching efficiency and accuracy of the original image matching algorithm and reduced the matching complexity of the image matching algorithm. The traditional dynamic obstacle avoidance algorithm (artificial potential field method) was improved, and it was segmented according to the action range of the obstacle. [19]

In 2019, Yang Lei, Chen Haihua et al. analyzed the scale space and feature point descriptors of the SIFT algorithm and the SURF algorithm, and at the same time implemented the obstacle avoidance algorithm. It was shown that when using the rotation image matching, the SIFT algorithm consumed more time and the SURF algorithm had relatively better real-time performance. The SIFT algorithm obtained more pairs of feature points within the same matching time; when using the size-varying image, as the image size increased, the number of feature points increased and the consumption time also continuously increased. [20] Guo Xiaoyang adopted binocular ranging and designed a high-precision camera calibration image acquisition scheme, achieving good calibration accuracy. He designed a disparity map verification method based on foreground extraction to reduce the phenomenon of false matching under complex backgrounds. The accurate disparity map was obtained based on the SGM algorithm, and the depth information of obstacles was measured. In obstacle identification, the images of common obstacles in the running scenarios of mobile robots were classified, and the positions and categories of the obstacles were annotated. A dataset of common scenarios for mobile robots was established, and the YOLOv2 model was fine-tuned using this dataset. After determining the strategy, according to the designed scene grid map, a hybrid path planning algorithm based on the grid method and the A* algorithm was designed to plan the local obstacle avoidance path. This improved the characteristic of the single method in traditional robot obstacle avoidance strategies, enabling the robot to have three obstacle avoidance strategies: bypassing obstacles, pushing obstacles away, and stopping in place. By establishing a database, an obstacle recognition rate of 92% was achieved. However, the following problems still exist: in some specific usage scenarios, a more abundant dataset needs to be established to improve accuracy and robustness; and it is impossible to predict the movement trajectory of moving obstacles. [22] Songyue Yang and others collected visual and distance sensor information through a deep reinforcement learning algorithm and made autonomous obstacle avoidance decisions. [23]

In 2020, Yue Junfeng, Li Xiumei and others used the STM32 single-chip microcomputer as the core controller, and cooperated with the machine vision module OpenMV to form an intelligent vehicle system. For the road image information extracted by the camera, the threshold method and robust linear regression algorithm were used to extract the road guidance lines, and the multi-template matching method was used to extract the obstacle information. Combined with the traditional PID control technology and fuzzy control technology, the automatic line following and obstacle avoidance functions of the intelligent vehicle system were realized. Experiments show that in the venue with a 4mm diameter guidance line, the line following performance of the vehicle is good; in an environment with static obstacles, the vehicle can effectively identify obstacles and complete the obstacle avoidance path planning. In order to achieve the path planning for movable machinery such as wheelchair beds that requires a smooth and comfortable path. [24] Li Bingyao proposed a path planning algorithm for wheelchair beds that combines the Smooth A* algorithm and the dynamic window method, enabling it to obtain a global optimal path that is smoother and has fewer large-angle turns. However, its recognition accuracy in complex scenarios is still insufficient. [25] Zhou Huiyuan proposed a path planning mainly using the A* algorithm. During the planned driving process, obstacle detection was carried out according to the proposed optical flow method based on multi-frame fusion. By comparing the relative depth information, it was determined whether the robot needed to perform obstacle avoidance, and a robot obstacle avoidance strategy was adopted according to the optical flow detection results and relative depth information. However, due to the use of the optical flow method, the influence on the optical flow detection is relatively large, which will result in excessive noise in the image. [26] Liu Jia used the new Harris operator to replace the SIFT operator for image corner detection in the research on the binocular stereo vision dynamic obstacle avoidance system, calculated the sub-pixel coordinates of the corners to improve the corner positioning accuracy, and completed image matching after obtaining the SIFT feature vectors. This algorithm has a short time-consuming, and the accuracy and robustness of the calculation results have been improved. [27]

In 2022, Xiang Qiqing's robot dynamic obstacle avoidance path based on machine vision combined the RRT algorithm with the A-star algorithm, introduced a heuristic function to guide the expansion tree to expand rapidly towards the target node; aiming at the local minimum trap existing in the heuristic function, a regression constraint was added to enhance the algorithm's ability to explore the unknown space. The dynamic obstacle avoidance strategies of caching the initial tree, pruning, and renormalization were adopted to avoid moving obstacles. The disadvantage is that when the built system is in a mobile obstacle avoidance situation, it needs to update the workspace, re-plan the path, and reload the path in real time, which takes a long time and is only suitable for low-speed scenarios; the research on the singular points in the process of solving the inverse kinematics of the robot is not sufficient, which may cause vibrations during operation and reduce the robustness of the robot in practical production applications. [28] Liu Yuzhe proposed an improved YOLOv4 algorithm for target detection. Compared with the original algorithm, the false detection rate was reduced by 3%, but the detection speed was increased by 15 FPS, and the detection accuracy basically met the requirements for detecting indoor mobile obstacles. In terms of obstacle avoidance strategies, by comparing the Dijkstra, A*, D-star, and D-star Lite algorithms, it was concluded that using the D-star Lite algorithm could meet the real-time detection and obstacle avoidance tasks of mobile obstacles in indoor scenarios. The disadvantage is that the YOLOv4 target detection algorithm cannot detect mobile obstacles well in some special lighting conditions or when there are line-of-sight obstructions, which may affect the effect of local obstacle avoidance. [29]

Wang Zhuangzhuang, Zhang Zejun and others corrected the binocular images through calibration parameters and polarity constraints to solve the non-coplanar problem of image distortion. The SGM (semi global matching) algorithm was used to obtain the disparity map, ensuring the rapidity and robustness of disparity acquisition. [30] In the same year, T. Nguyen Canh used multiple sensors, including two depth cameras and a LiDAR, so they could capture the entire 3D area in front of the robot and the 2D slides around it. Then, projection technology was introduced to convert the 3D point cloud data of the camera into its 2D correspondence. Then, an obstacle avoidance algorithm was developed based on the dynamic window method. It can effectively avoid static and dynamic obstacles of different shapes and sizes.

In 2023, Liu Peng proposed the information fusion of millimeter-wave radar and machine vision to achieve the detection of field road targets in order to solve the complex and diverse target environment of field roads in hilly and mountainous areas. A large number of clutter detected by the millimeter-wave radar was filtered out by using RCS thresholds, distance thresholds, speed thresholds, etc. The disadvantage is that the interference data of the millimeter-wave radar has not been well addressed, and its detection rate for pedestrians in a stationary state is not high. [31]

5. Conclusion and Prospect

From 2006 to 2023, significant progress has been made in robot obstacle avoidance technology in terms of path planning, obstacle detection, and control algorithms. However, each stage also has its limitations. The early methods relied on simple identification line detection and 2D planning, gradually transitioning to the integration of advanced technologies such as computer vision, embedded intelligent control, fuzzy control, and deep learning. A variety of algorithms (such as SIFT, SURF, A-star, RRT, YOLOv4, etc.) have been applied and improved in obstacle recognition and path planning, enhancing the intelligence and real-time performance of robots.

However, these technologies still face challenges in terms of environmental adaptability. There are still deficiencies in recognition and obstacle avoidance in complex and dynamic environments. For example, it is impossible to accurately predict the movement trajectory of moving obstacles, and the recognition rate decreases due to differences in lighting conditions. Although the multi-sensor information fusion (such as vision and millimeter-wave radar) has improved the detection accuracy, there are still certain interference and misjudgment phenomena in practical applications. Although some improved algorithms have improved the recognition rate and obstacle avoid-

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ance performance, there are still bottlenecks in computational efficiency and processing speed in scenarios with high real-time requirements and complex environments.

In the future, robot obstacle avoidance technology needs to further optimize multi-sensor fusion technology to improve the adaptability to complex environments and dynamic obstacles. It is also necessary to improve the efficiency of algorithms, especially in complex scenarios and situations with high real-time requirements, to ensure the stability and robustness of the system. In addition, strengthening the construction of datasets and enriching the training data in specific usage scenarios can improve the generalization ability and accuracy of algorithms in different environments.

In general, robotic obstacle avoidance technology is developing in the direction of being more intelligent, efficient and stable, but it still needs to solve the problems of adaptability and real-time in complex environments.

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