Research on Methods and Development Trends of Mobile Robots in Obstacle Avoidance

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Abstract. In 2010s, the scale of mobile robots in the market is increasingly developing. Nowadays, China is becoming one of the most active regions in the world for the development of machine vision. Computer vision is the most crucial part of obstacle avoidance in mobile robots. Therefore, the research topic of this article is the intelligent obstacle avoidance methods and development trends of mobile robots based on machine vision. The research method of this article is as follows: Firstly, the working principle of machine vision, the application process of machine vision in mobile robot obstacle avoidance, and the development trend of machine vision are introduced. Secondly, the development and shortcomings of machine vision were discussed, and feasible solutions were proposed to address the potential problems in current machine vision. Finally, this article looks forward to the future research directions of machine vision and predicts that machine vision technology will become one of the most powerful detection technologies in science and technology. After this study, it was found that the machine vision of mobile robots has shortcomings in obstacle avoidance, such as difficulty in identifying multiple obstacles and limitations in processing large-scale data. Therefore, it is believed that machine vision still has room for development..

Keywords: Machine vision; obstacle avoidance; image acquisition; pre-processing; feasible solutions

1. Introduction

With the aging of the population, the contradiction between supply and demand of social labor force is increasingly intensified, and the labor shortage of workers in industrial manufacturing and other fields has become one of the important factors restricting the development of enterprises.

In the late 1980s, as the demographic dividend gradually faded and labor costs increased, robots began to enter the industrial production field. Robots can assist humans in performing numerous repetitive, tedious, and dangerous tasks, thereby not only improving production efficiency, but also greatly ensuring human safety and reducing work hazards [1]. This transport type of artificial intelligence marks another big step in the progress of human science and technology.

In order to make robots more fully automated and intelligent, scientists created machine vision to robots. Its inspiration comes from the human eye, as according to statistics, 80% of external information obtained by humans comes from the eyes [2]. In 1965, renowned American scholar L.R. Roberts extracted the three-dimensional information of objects and their interrelationships from images, which opened up the research of three-dimensional machine vision. Subsequently, in 1977, Professor David Marr proposed the famous Marr vision theory, which greatly promoted the development of machine vision. With the advancement of machine vision technology, visual robots have emerged. Visual robots usually use visual sensors to capture and analyze information about the surrounding environment, thereby providing decision-making basis for the robot's next movement [3].

Machine vision is an important branch of the rapidly developing artificial intelligence industry in recent times. It is normally used to perform image processing and perform various operations. In the context of the global industry 4.0, the computer vision has been widely used in various fields, such as intelligent mobile robots [4]. With the innovation of science technology, although the computer vision technology still has significant gap between Western developed countries and China, the computer vision technology in China has increasingly expanded to multiple fields with good momentum and significant progress [2].

In recent years, the detection of obstacle information in the surrounding environment by intelligent robots has mainly utilized multi-sensor data fusion technology, and this work is mostly carried out during the day with good lighting conditions. The perception and detection of environmental obstacles are the core components of machine vision systems. However, a single sensor is difficult to fully perceive external environmental information. Therefore, in order to ensure the precision, uniformity, and reliability of environmental information, it is necessary to combine the information fusion technology of multiple sensors [5].

Thus, this article will focus on the methods and development trends of intelligent obstacle avoidance for mobile robots based on machine vision, in order to study the importance of machine perspective for autonomous obstacle avoidance of mobile robots.

2. Research On Machine Vision

The main responsibility of the machine vision obstacle avoidance control system is to determine whether there are obstacles ahead and whether decisions can be made safely during mobile operations. In order to achieve this goal, the system needs to complete a series of functions such as image acquisition, image processing, data transmission, and result display [6].

2.1. Light Source of Machine Vision System

In machine vision systems, light sources can provide light for machine vision recognition and assist in obtaining obstacles. Machine vision light sources can not only highlight the measurement features of the measured object, but also simplify the image processing. During the obstacle avoidance process of mobile robots, the presence and position of obstacles can be detected through machine vision light sources, thereby achieving obstacle avoidance.

However, under different environmental conditions, the intensity of sunlight also constantly changes. In order to make the detected object features more prominent, the light sources of machine vision needs to be selected. There are several types of light sources, such as natural light source, ring light source, strip light source, sphere integral light source, linear light source, and point light source. There are many types of light sources, but their difference lies in the wavelength of the light source [7]. Different wavelengths result in different images corresponding to different light sources. Therefore, according to literature [7], the following is a comparison table of the types and characteristics of different light sources, as shown in table 1.

Table.1 Comparison of light sources [7]

Types of light sources	The advantages of light sources
Ring light source	Uniform lighting and more prominent object features
Strip light source	Long lifespan, suitable for testing larger objects
Linear light source	Super high brightness
Point light source	High power, small volume, high brightness
Sphere integral light source	360 ° emission of light, uniform lighting

By comparing different light sources, suitable light sources can be found and machine vision systems can be optimized based on environmental needs or service life. A high-performance light source can enhance the obstacle recognition function of machine vision. Thus, mobile robots can better avoid obstacles through better light sources.

2.2. Lens Of Machine Vision System

The lens is an important component of machine vision systems. It can convert optical signals into digital signals, providing high-quality image and video data for machine vision systems. In the process of obstacle avoidance for mobile robots, the camera can capture the characteristics and relative positions of obstacles and then convert them into data that can be understood by computers.

2.2.1 The working principle of lenses

The principle of lens imaging is similar to the principle of convex lens imaging. By combining lenses, the light emitted or reflected by obstacles is imaged on an image plane. Due to the complex lens combination of the machine system, the lens is equivalent to a simple convex lens. To better illustrate the working principle of the lens, the imaging principle of the lens is shown in Figure 1 below.

F: the focal point; f: the focal length; O: the convex lens

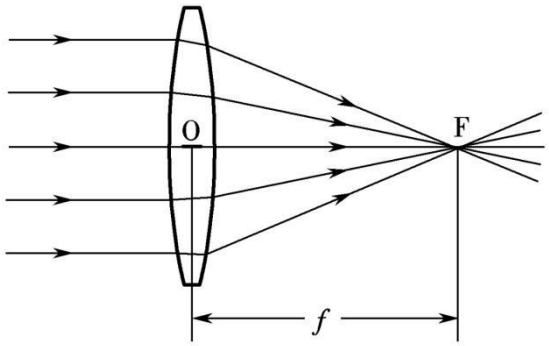

Fig. 1 The imaging principle of the lens (Photo credited: Original)

2.2.2 Focal length of lenses

The lens is the most important component in a camera, and its quality directly affects the quality of the captured image. In the process of identifying obstacles in robots, in order to quickly determine the focal length of the lens, the following factors are considered: FOD (Field Of Vision) and WD (Working Distance).

Field of vision calculation is the more precise positioning, tracking, and analysis of obstacles in images or videos.

The relevant formulas for the field of view of machine vision are as follows:

$$FOV = a * b * c/PRTM. \quad (1)$$

In the formula: FOV ---- Field Of Vision; a ---- Required resolving power; b ---- Sub-pixel; c ---- Camera size; PRTM ---- Parts measurement tolerance ratio

Working distance (WD) refers to the distance from the bottom mechanical surface of the lens to the object.

If the working distance is known, the focal point of the lens can be calculated using the formula. The following two formulas are used to assist in calculating the lens focal length.

$$f = WD*PMAG(1+PAMG). \quad (2)$$

$$PAMG=Hi/Ho. \quad (3)$$

In the formula: f - focal length; *WD* - working distance; *PMAG* - lens magnification; *Hi* - Camera Sensor target size; *Ho* - Field of view height [7].

2.3. Cameras Of Machine Vision System

The function of machine vision cameras is to project images onto sensors through the lens. Then transfer the image to a machine device that can store, analyze, and display it. When the robot encounters obstacles while moving, it will capture the surrounding environment through the built-in camera of machine vision.

2.3.1 Classification of cameras

Industrial cameras can be divided into CCD cameras and CMOS cameras according to chip types. The working principles of CCD chip cameras and CMOS chip cameras are different.

The working principle of a CCD chip camera is to first convert electrical signals into visible or infrared light, and send them to the photosensitive device. In a photosensitive device, the signal of light is converted into charge, which is then stored in the circuit. Finally, the electronic system detects these charges and converts them into images. In order to better illustrate the working principle of CCD cameras, the flowchart of the working principle of CCD chip camera is shown in Figure 2.

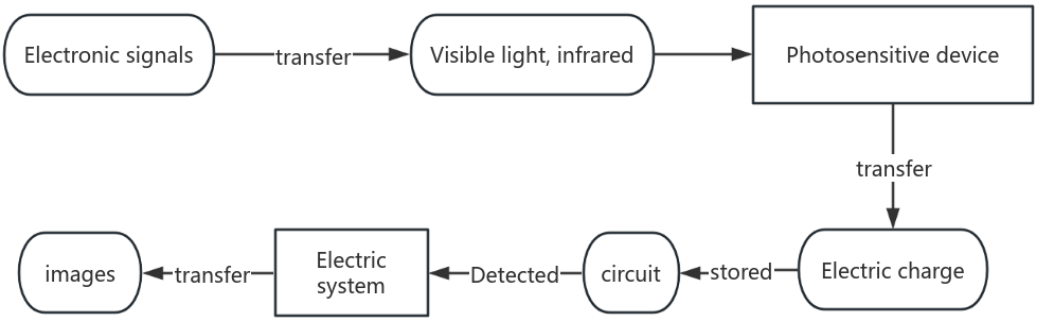

Fig. 2 The flowchart of the working principle of CCD chip camera (Photo credited: Original)

The working principle of a CMOS chip camera is that when the sensor photodiode receives an electrical signal from illumination, the electrical signal is first amplified by the amplifier in the photosensitive element, and then directly converted into the corresponding digital signal. In order to better illustrate the working principle of CCD cameras, the flowchart of the working principle of CMOS chip camera is shown in Figure 3.

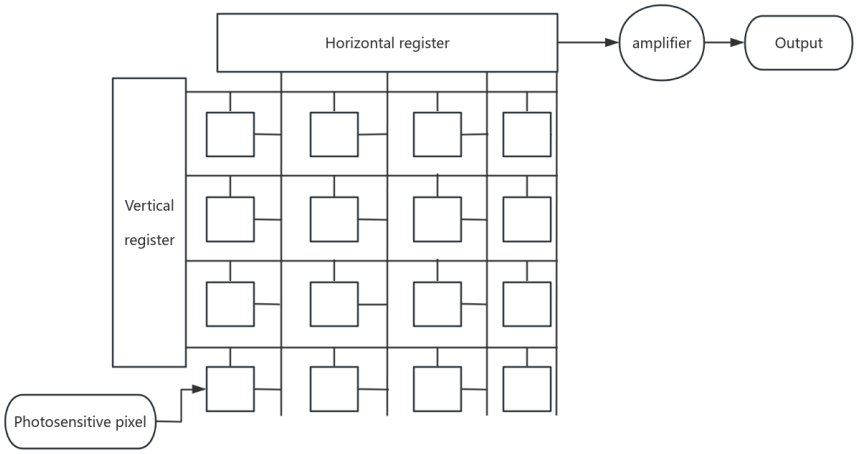

Fig. 3 The flowchart of the working principle of CMOS chip camera (Photo credited: Original)

2.4. Image Pre-processing in Machine Vision

After the original image is transmitted in the image acquisition device, a series of technical processing are performed on the original image. Its function is to improve the quality of images and provide good data for subsequent deep learning models.

After the image acquisition device collects and transmits the image, the color features of the image are first adjusted by adjusting parameters such as brightness and saturation, which makes the colors of obstacles in the image more prominent. Then, after denoising the image and balancing its contrast, machine vision can identify obstacles more accurately. Next, in order to be more suitable for subsequent algorithm processing, it is necessary to adjust the size of the image. Finally, extract the features of obstacles in the image, such as corners and edges.

The pre-processing of machine vision images plays a crucial role in obstacle avoidance for mobile robots. Image preprocessing not only improves the quality of the image, making it easier to analyze and improve accuracy, but also provides effective information on obstacles, which is of great help for subsequent deep learning models and applications.

3. Machine Vision and Applications Process Analysis

3.1. The Working Principle of Machine Vision

The machine vision system mainly consists of image acquisition equipment(light sources, lenses, cameras), image processing equipment, machine vision software, execution mechanisms, control unit and so on. The machine vision system obtains projected images of the scene on a two-dimensional plane, which represent the three-dimensional scene in reality [8]. The following is a brief introduction to the working principles of machine vision.

Firstly, the image acquisition equipment section will be discussed. Image acquisition equipment includes light sources, lenses, and cameras. In order to make the imaging effect of the image more vivid, machine vision uses the light source to improve the recognition of the visual detection. Then use the lens to capture the surface and image of the object, and adjust the focal length and aperture of the image to meet different detection needs. After that, cameras will be used to capture the surface and image of the object. The images projected onto the sensor are transmitted through the lens to machine devices that can store, analyze, and display these images.

After capturing image signal through image acquisition equipment, the images will be collected at image pre-processing equipment. Image pre-processing equipment's function is to process these images, such as pixel processing, edge detection, and image segmentation techniques. And then, use specific algorithms to extract useful feature information from the proceeded images, such as shape, color, edge and vein.

After pre-processing the image, the machine vision system will use pattern recognition or machine learning techniques to identify objects and their positions, changes, and other situations in the image. And based on the extracted features, establish a computer vision model. The machine vision software recognizes and classifies images, extracts features of image objects, and analyzes them. Besides, through deep learning methods, computers can accurately recognize objects in images and classify and locate them. Machine vision software also has various functions including object detection and tracking, defect detection and analysis, attitude estimation and measurement and visualization and display.

Secondly, execution mechanisms will be utilized in intelligent judgment and decision-making module. After machine vision recognizes images, the machine vision system obtains accurate information about objects. Based on this information, machine vision systems can make a series of judgments and decisions. Another way to put it is that machine vision inputs images and outputs decisions related to that image.

Lastly, the operator will receive control instructions on the control unit, combined with information from visual sensors, to control the actions of the executing mechanism.

In order to better illustrate the working principle of machine vision, the flowchart of the working principle of machine vision system is shown in Figure 4.

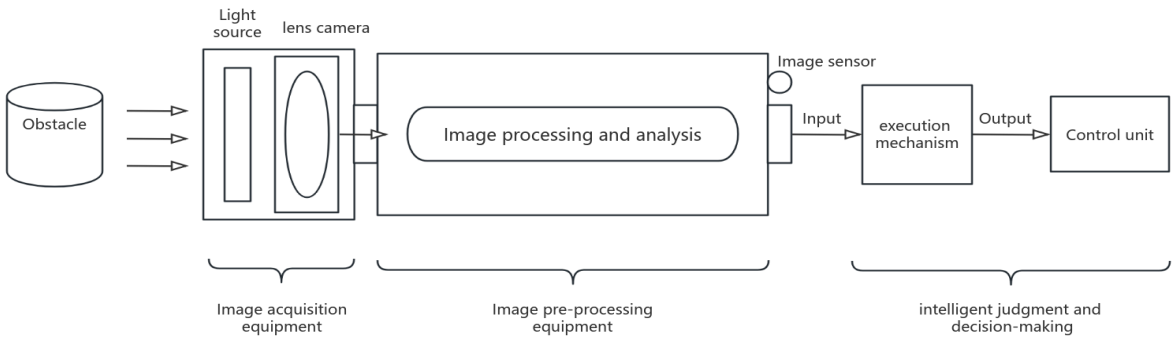

Fig. 4 The flowchart of machine vision system (Photo credited: Original)

4. Discussion

4.1. Development Of Machine Vision

Data shows that the market scale of industrial machine vision technology reached 4.44 billion US dollars in 2018. It is expected to reach 12.29 billion US dollars in 2023, with a compound annual growth rate of 21% [9]. This indicates that machine vision has become one of the most popular technologies in the world.

Machine vision is one of the important directions of technological development in China, and its research areas cover many technologies such as image acquisition, pre-processing, and deep learning models. China has been made a significant progress in the research of machine vision. Furthermore, machine vision technology is widely applied in multiple fields, including intelligent factories, agricultural intelligence and intelligent manufacturing.

In foreign markets, machine vision technology is also very popular, especially in countries such as the United States, the United Kingdom, and Germany. For example, in the automotive industry, machine vision technology is used to develop and design autonomous driving technology to detect obstacles around cars; In the medical field, machine vision technology is used to replace the human eye for precise medical surgery and diagnosis; In the printing and manufacturing industries, machine vision technology is used to detect whether products in factories meet standards.

In summary, there are still many fields of machine vision technology waiting for people to develop and explore. It is hoped that the development of machine vision technology in China will continue to improve.

4.2. Existing Problems And Feasible Solutions

Although China has been made a significant progress in the research of machine vision for mobile robots. However, there are still some issues that need to be discussed [10]. There may be two areas that need to be developed in obstacle avoidance technology for mobile robots based on machine vision in this article.

1) Diversity in object detection and recognition.

When the recognized object is obstructed by other objects, the machine vision system is likely to be unable to accurately detect or recognize the obstructed object. This may pose safety hazards for some practical scenarios in daily life, such as not detecting multiple objects during autonomous driving.

If reinforcement learning and optimized object detection are used, it can let the learning model have a better adapting to various environmental conditions to avoid occlusion problems. Furthermore, it also detect the object with a unique target from the collected images, which is effectively preventing occlusion. This will ultimately result in the mobile robot being unable to successfully avoid obstacles.

2) Limitations of data quality.

When machine vision systems recognize complex environments, they generate a large number of images that require large-scale data processing. Therefore, data quality will decrease, such as low image recognition and noise from sound. This will also have a negative impact on the performance of the machine vision system, ultimately leading to the inability of mobile robots to successfully avoid obstacles.

For the processing and analysis of large-scale data, big data can be divided into several small blocks and then processed separately on different computers. The advantage of this solution is that each computer can calculate a corresponding small piece of data, which can improve the efficiency of data processing and analysis.

It is hoped that the machine vision technology of China’s mobile robots will continue to make great breakthroughs in the future.

5. Conclusion

With the development of technology, the application prospects of machine vision in obstacle avoidance for mobile robots are very broad. At present, machine vision technology mainly relies on image acquisition data for analysis and processing. However, in order to improve obstacle avoidance performance, other sensors such as Li DAR can also be combined. Future robots are likely to perform autonomous obstacle avoidance and self navigation. This intelligent technology relies on the accuracy of machine vision, and through self deep learning and self optimization, it can help mobile robots avoid obstacles in complex environments. In summary, machine vision has enormous development potential in the field of obstacle avoidance for mobile robots. With the advancement of machine vision technology, its applications will be fully utilized in more environments.

This article aims to explain the components and working principles of machine vision, elaborate on the specific application process of machine vision in mobile robot obstacle avoidance, and explore the development trend of machine vision in today's society, as well as various applications of machine vision. When discussing the development and drawbacks of machine vision, we have identified two issues: first, the limitations of machine vision in large-scale data processing, and second, its insufficient accuracy in identifying obstacles. Feasible solutions have been proposed for these two issues. Finally, this article looks forward to the future research directions of machine vision and predicts that machine vision technology will become one of the most promising detection technologies in the field of science and technology.

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