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Panoramic image stitching technology and its application in the field of autonomous driving

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Abstract. Image processing technology is an indispensable part of the development of many fields, in which panoramic image stitching technology is one of the most widely used technologies in image processing, which is not only applied in the frontier fields of technology such as unmanned aerial vehicles and machine vision detection, but is also closely related to people's lives, for example, the panoramic camera shooting function of the smart phone. The driverless car is also a widely concerned field, its development means the liberation of manpower, the realization and improvement of self-driving car technology can alleviate traffic congestion, the use of transportation for people without the ability to drive and many other social problems. This paper will firstly introduce the panoramic collage technology, including its principle, system architecture and application prospect. Secondly, it focuses on the application of panoramic collage technology in the field of self-driving cars, which is divided into two aspects: sensor hardware and collocation algorithm, and analyzes the applicability of different algorithmic techniques in this field based on the demand characteristics of self-driving cars. The research in this paper points out the optimization direction of panoramic collage technology required by self-driving cars, which will be of great value to the development and application of panoramic collage technology in the field of self-driving cars.

Keywords: autonomous driving, panoramic image, image stitching, image processing technology.

1. Introduction

The academic and automotive worlds have been paying close attention to the development of autonomous driving technology [1]. The implementation of autonomous driving technology means that people can redistribute their driving time to solve various social problems, first and foremost by reducing traffic congestion and road casualties, as well as by increasing productivity and reducing energy consumption [2]. By 2030, the global market for autonomous driving is projected to reach $173.15 billion, and many automakers are making significant investments in this area [1]. By 2050, ADS's estimated yearly societal benefits, assuming widespread use, will be close to $800 billion [2]. Liangkai Liu et al. summarizes the more advanced and popular technologies currently used in automated driving systems and the current dilemmas and challenges in developing automated driving [1]. The article provides a reference architecture for computing systems in this field and metrics for assessing them. It also covers nine critical technologies, seven performance metrics for evaluating them, ten obstacles and opportunities for implementing them, and seven performance metrics for evaluating them [1].

A number of technologies have created the promise of autonomous vehicle technologies, which are primarily aimed at reducing collisions, energy consumption, pollution and congestion, and improving traffic accessibility [3]. Image processing techniques are important among these technologies, especially real-time image processing methods and algorithms. Since wide-viewing, high-resolution images are required in many different fields, it is essential to learn about image stitching, which involves many fields such as computer vision, image processing and graphics, and is one of the oldest and most widely used topics [4]. Additionally, the demands on image stitching in terms of accuracy and time are increasing as new technologies are developed [5]. Numerous successes in this area have been made in recent years, but there is currently no algorithm that is appropriate for all image stitching, making it challenging to select a particular approach for various tasks [5]. Nevertheless, image stitching will improve in accuracy and gain greater traction as new technologies mature [5]. For example, the field of digital image processing has already made breakthroughs in the use of deep learning to solve difficult problems, but it has also been presented with many new challenges in terms of computational power, time, accuracy, and the number and quantity of input features [5]. Among them, panoramic splicing is currently the most widely used splicing, closely related to people's daily life [4]. The 360-degree camera based on panoramic stitching has been released, which replaces multiple single-approach cameras and eliminates blind spots, providing a clear advantage in omnidirectional, face-free vehicles [4].

2. Panoramic image stitching technology

Image stitching is a method of merging multiple images, unlike image fusion, which combines several photos to generate a single, crisp panoramic image [6]. If the images have overlapping areas to be merged, then image stitching processes this part as one frame [6]. In order to overcome the distortion of the photos as much as feasible in panoramic image stitching, the set of images being processed must contain enough quantifiable features, and a sensible amount of overlap must be used [6].

Panoramic imaging has significant potential and development possibilities. The technique is currently utilized in many industries, including autonomous driving, machine vision inspection, endoscopic medicine, and satellite macro-air detection [7]. The related hardware developed in panoramic imaging, such as panoramic imaging instruments, is becoming the next generation of intelligent sensing instruments [7]. Panoramic imaging devices can sense and comprehend their surroundings in all directions and are gradually optimized for high resolution, no blind area, small size, and multi-dimensional intelligent perception. They are also being used in conjunction with the method of human intelligence [7].

Table 1. Various panoramic imaging techniques comparison [7].

System category	Dynamic scene	Image stitching	Compactness	Blind area	Distortion
Single-camera rotation scanning	No	Yes	Low	No	Low
Multiple cameras stitching	Yes	Yes	Low	No	Low
Fisheye panoramic system	Yes	No	Medium	No	15%~20%
Panomorph imaging system	Yes	No	High	No	Distortion correction

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Table 1. (continued).

Catadioptric panoramic system	Yes	No	Medium		over 10%
Monocentric panoramic system	Yes	Yes	High	No	1%~3% about 20%
Hyper-hemisphe ric lens	Yes	No	High	Yes /No	Distortion correction
Panoramic annular lens	Yes	No	High	Yes /No	1%~5%

Shaohua Gao et al. explains in detail the fundamental concepts underlying panoramic imaging systems and introduces various panoramic imaging systems, respectively, as shown in table 1 [7].

3. The application of panoramic image stitching technology in the field of autonomous driving

3.1. Self-driving car sensor selection

In technical self-driving implementation, sensors are essential because they enable the car to accurately comprehend its environment [1]. Referring to table 2, sensors that are typically utilized in this field include cameras, LiDAR (Light Detection and Ranging), radar, inertial measurement units (IMUs), global navigation satellite systems (GNSS), and sonar [1].

Table 2. Comparison of different sensors [1].

Factor	Human	Camera	Radar	LiDAR	Ultrasonic
Techniques	-	Lights	Electromagnetic	Laser Reflection	Ultrasound
Sensing Range	0-200m	0-100m	1cm-200m(77GHz) 1cm-70m(24GHz)	0.7-200m	0-20m
Cost	-	About $500	About $3,000	$5,000-$100,000	About $100
Data per second	-	20-40MB	10-100KB	10-70MB	10-100KB
Bad weather functionality	Fair	Poor	Good	Fair	Good
Low lighting functionality	Poor	Fair	Good	Good	Good
Application Scenarios	Object Detection Object Classification Edge Detection Lane Tracking	Object Classification Edge Detection Lane Tracking	Object Detection Distance Estimation	Object Detection Distance Estimation Edge Detection	Object Detection Distance Estimation

Because they are readily available and relatively inexpensive to install compared to other sensors, cameras have been the most common device on self-driving vehicle installations [2]. While the images provided by conventional cameras generally contain only simple 2D information, 2D images have been able to provide important information to support certain tasks such as object classification and neutrality tracking [2]. Compared to other types of sensors, the single-target camera can perceive colors, and the color images transmitted by the camera are the easiest and most direct way for vehicles to perceive color information, which is important for tasks such as traffic light recognition in autonomous driving [2]. In addition, 2D computer vision is a very mature field compared to other sensors, with very advanced algorithms [2]. Cameras have also been developed and gradually put into use in various fields. 3D image technology is the use of cameras to calculate the distance between objects, and this technology can be applied to the field of autonomous driving to better use the camera to achieve multi-dimensional perception of the vehicle's surroundings [2]. Many autonomous driving systems are based on the collaboration of multiple sensors, and cameras have always been an integral part of sensor systems, with some companies such as Tesla even using cameras alone to build their fleet of autonomous driving sensor systems [2]. However, elements like lighting or weather can have a big impact on how well cameras work. The usability of cameras can be significantly reduced by inadequate lighting or unfavorable weather, such as snow and fog [1]. But the negative effects of such problems as poor lighting and weather conditions also exist for other sensors such as radar [1]. At present, how to make sensor systems work stably under different lighting and weather conditions in autonomous driving is still a major difficulty and challenge that is difficult to solve [1].

3.2. Panoramic technology in the field of autonomous driving applications

3.2.1. Hardware device. Chen Long et al. reported a wireless panoramic camera system developed by the paper's authors, which can perform seamless imaging of full-angle driving scenes for the vehicle while driving [8]. Since autonomous vehicles need to ensure sufficient energy support while driving, and self-driving car systems must perform a lot of calculations at all times and thus continuously consume energy, the energy issue is also a major challenge for autonomous driving technology [1]. The system developed in this article uses FPGAs with high computational power and low resource requirements as the computational unit [8]. This greatly reduces conventional panoramic sensor systems' computational and storage burdens based on multi-camera architectures while maintaining good real-time performance for quick image stitching and real-time panoramic video creation [8]. In addition, compared with traditional cameras, the panoramic camera developed by the article team can provide a wider field of view and more comprehensive information for detecting road environments during driving, which provides a stronger guarantee for the safety of self-driving vehicles [8].

Considering the future development of multiple models of self-driving vehicles, if large vehicles are to be developed, the visual blindness of large vehicles is a problem that must be solved to ensure the vehicles' safety during driving. Sihan Lu et al. reported a panoramic stitching system to solve huge vehicles' visual blindness [9]. The system is built on multi-core DSP and FPGA, and processes multi-channel picture data in parallel using an algorithm using the parallel processing capabilities of FPGA and parallel high-speed floating-point computing of multi-core DSP [9]. The system solves the problem of low-quality of full-angle images stitched out under multiple HD video data streams, while ensuring the system's real-time requirements [9]. This vehicle 360° image stitching system has several advantages over traditional multi-camera systems in terms of receiving and processing large amounts of data transmission at high speed, parallel processing of images and high accuracy of the finished image [9].

Table 3. Comparison of different hardware devices [2].

Device	Affected by Illumination	Affected by weather	Color	Depth	Range	Accuracy	Size	Cost
Lidar	No	Yes	No	Yes	medium (<200m)	high	large	high
Radar	No	No	No	Yes	high	medium	small	medium
Ultrasonic	No	No	No	Yes	short	low	small	low
Camera	Yes	Yes	Yes	No	-	-	smallest	lowest
Stereo Camera	Yes	Yes	Yes	Yes	medium (<100m)	low	medium	low

Table 3. (continued).

Flash Camera	Yes	Yes	Yes	Yes	medium (<100m)	low	medium	low
Event Camera	Limited	Yes	No	No	-	-	-	low
Thermal Camera	No	Yes	No	No	-	-	-	low

But the 360-degree panoramic system is still a more cutting-edge technology, so the research and development of such hardware equipment is insufficient. The manufacturing cost is high and at this stage whether it is financial support or technical support is not enough to support the mass production of panoramic cameras. Hence, the circulation in the market is relatively small. A small number of existing full range of panoramic camera equipment that can be bought in the market is also relatively high price(table 3) [10]. In addition, because one of the characteristics of the use of panoramic camera equipment is to install this equipment must be installed in the outer body of the vehicle, generally placed in the roof position, so there is a great risk of theft, coupled with the high cost of the equipment, if stolen will lead to higher cost losses [10].

On the other hand, the vehicle in the process of driving will produce huge airflow hedge, and the airflow in the vehicle to cause obstruction will often become a major factor affecting the development of the speed of the vehicle [10]. The feature that the panoramic camera needs to be installed outside the body will lead to the inefficiency of these cameras in terms of aerodynamics, which greatly limits the development of vehicle performance in terms of speed [10]. Jingxiong Zhang et al. has also proposed that ordinary panoramic equipment is prone to the problem of serious distortion of the stitched-out images, which also reflects that the research and development technology of panoramic equipment is not yet perfect [11].

3.2.2. Algorithmic techniques. Nidhal K. EL Abbadi et al. mentions that different algorithms or techniques have different suitable datasets, and that applying algorithms to their suitable datasets can aid in a more thorough analysis [6]. Therefore, different algorithms have different applications in image processing and computer vision applications, and some algorithms may just work well for specific applications [6]. Researchers developing autonomous driving should also look for appropriate panoramic image stitching algorithms for various problems of autonomous vehicles driving on the road.

Cortes-Gallardo, Edgar et al. discusses and compares three feature extraction methods, SIFT, BRISK, and SURF, for panoramic stitching applications in Autonomous Vehicle Architecture [10]. After experimental validation, the results show that SURF is the most suitable of the three methods. It ensures accuracy in comparing features between two images and has the highest time efficiency [10].

Weidong Pan et al. reported a proposed panoramic image stitching technique based on ORB algorithm, suitable for processing large outdoor scene images [12]. The ORB algorithm used in this technique is fast and robust to the effects of noise and image transformation, so the technique requires low image pre-processing and high efficiency, and is suitable for applications requiring high real-time performance [12]. Since this stitching technology can achieve fast and accurate stitching for panoramic images of large outdoor scenes, its various characteristics are more suitable for the demand of autonomous driving.

The panoramic image stitching technology may be optimized with deep learning to achieve better outcomes due to the increasing hardware computing power and the advancement of deep learning algorithms [11]. To address the challenges of weather and lighting, Lang Wang et al. proposes a multi-scene image stitching method that can be used for autonomous driving [13]. The method is optimized by extracting feature points using a self-encoder network to provide a stable wide field of view for self-driving vehicles in various weather and illumination situations [13]. The authors used an automotive simulator to test this stitching technique under various weather and illumination scenarios, including four separate ones [13]. The comparison of the stitched images with the classical automatic stitching method found that the method can extract more feature points in low light and rain than the traditional method, and ultimately obtain better image stitching results [13]. Although this method can be used for many scenes in autonomous driving and achieves good results, CNN-based feature point detectors inevitably lead to reduced real-time performance due to the combination of deep learning [13]. However, processing time in autonomous driving is an efficiency characteristic and an indicator of safety performance [10]. For a moving vehicle, road safety involving timeliness is paramount. Autonomous driving technology should do so in a way that allows the vehicle to control itself at all times [1].

4. Conclusion

As an emerging field, the autonomous driving field is still exploring the development path, and the combination of image collage technology, as the most mature technology in image processing technology, with the autonomous driving field is indispensable. Camera is the most important part of the sensor system in the field of autonomous driving, it is used to help the car autonomously perceive and recognize the surrounding environment, although its effect is affected by the light and weather, but because of its low cost and other advantages is still the most common one among all kinds of sensors. For the blind spot problem in automobile driving, panoramic images are needed to recognize the surrounding environment of self-driving cars. Panoramic image acquisition of a way is through the 360-degree panoramic camera, this camera is generally based on the panoramic image splicing technology based on the research and development, but the price of such cameras is high. There is a risk of theft, but also affects the development of the vehicle's driving speed, and therefore the current still more widespread use of multi-camera sensor system, after the collection of pictures and then the panoramic image splicing. But real-time image splicing for the algorithm of real-time and accuracy have high requirements, although the various image splicing algorithms have their own advantages but no algorithm can fully meet the needs of the field of automated driving on this technology. Therefore, it is necessary to conduct more in-depth research on panoramic image stitching technology that can balance the timeliness, accuracy, and robustness to all kinds of outdoor environment pictures, to match the needs of the development of self-driving cars.

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