The research of around view parking assistant system based on multiple visual sensors

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Abstract: There are blind spots for driving the automobile. Blind spots are easy to cause traffic accidents ,because the driver can not grasp the condition of the road in time. Based on the cooperation of multiple visual sensors, this paper will constructs a panorama video image of the surrounding environment of the car to solve the blind spots problem for drivers,thus enhancing the active safety of the vehicle in the process of driving.

Key words: blind spots,visual sensor,around view,active safety.

0 introduction

In recent years, with the continuous improvement of the national economy and the rapid development of the automobile industry in China, the number of motor vehicles that urban residents own have been increasing. According to the latest statistics, The car ownership of China increased from 43.29 million in 2005 to 172 million in 2015, and it nearly four-fold increased during the past 10 years, and the private cars is 124 million in 2015. More and more motor vehicles appear in the road, street and parking lot, and the drivers is easy to get troubles for the more and more congested traffic environment, and it also bring more safety risks at the same time. According to statistics, the proportion of traffic accidents caused by the drivers accounted about 70% to 80%, and the proportion of traffic accidents is about 30% caused by the rear blind spots ,left and right blind spots[1]. It will tend to cause significant damage to people's lives, property and mind for the potential danger of visual blind spots .

With the rapid development of image processing and computer vision technology, more and more technologies have been applied to the automotive electronics field. The traditional rear view video system that installs the camera at the trail of the car, but it just covers the limited area around the rear, and there is no doubt that there are still safety driving risks because of the blind area around the vehicle and the blind area at the front of vehicle. In the narrowly congested urban area and the parking lot , it is easy to occur collision and scratch events. In order to expand the driver's vision, we must obtain the full range of environments information around the car, which requires multiple visual sensors to work together to constructs a panorama video image of the surrounding environment of the car through the video processing[2-4].In this paper, the around view parking assist system that install the 4 fish-eye cameras around the car to collect the image around the vehicle for the image processing ,and it will generate the panoramic of bird’s eye view about the vehicles after correction and stitching, and the panoramic view will be sent to the central control display device in real-time . The driver can sit in the car to see the location of the vehicle and the obstacles around the vehicle, and calmly control the vehicle to parking or through the complex road, effectively reduce the scratch, collision, fall and other accidents.

1 System general design

1.1 Image acquisition system based on visual sensors

The Schematic of the image acquisition system based on visual sensors is as shown in the figure 1, the system main include: optical system,image sensor, the visual sensor hardware drive unit, data storage unit, image processing unit (CPU) and the LCD display unit.The system in the dashed box consists of a visual sensor, and the peripheral drive circuit, and is matched with a suitable optical lens to form a front-end image acquisition system that is camera.The complete image acquisition display system requires a matching camera, video decoder, image processing unit (CPU) and video encoder and display[5].

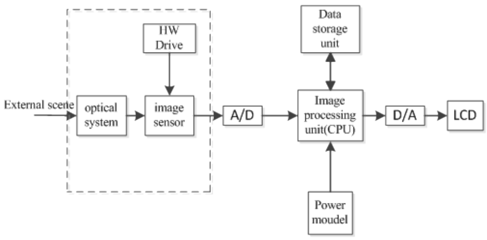

figure 1 The Schematic of the image acquisition system

1.2 Hardware system general structure chart

The system needs to acquisition of 4 video images in real-time and a series of images processing such as distortion correction, inverse perspective transform, image stitching and other operations, so the system hardware platform must have the performance of real-time, modular design, easy maintenance and other characteristics[6]. As shown in Figure 2, the hardware system mainly includes: power module, video decoder module, image acquisition and processing module, storage module and CAN-bus signal processing module.

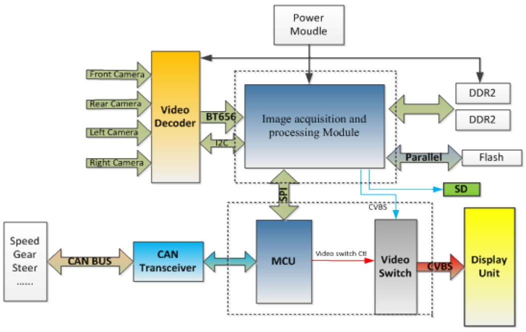

figure 2 Hardware system general structure chart

The MCU is mainly responsible for the logic control and video image preprocessing of the entire system, including the driver of encoding/decoding chip, external memory expansion and simple image preprocessing, and set aside enough logical resource space for later complex algorithm implantation and the need for functional expansion. DSP is mainly responsible for 4 fish-eye cameras video image acquisition, 1 video image output and complex image processing algorithms to achieve and receive CAN module information. It uses DSP as the core processor of the system image processing, MCU is as a co-processor, and it will make full use of the two different processors.it focus on modular design in the design, the maximum system compatibility, Good scalability and system upgrades to facilitate maintenance and so on. The hardware system general structure chart is as shown in Figure 2 .

2 Software algorithm design

2.1 Software algorithm structure chart

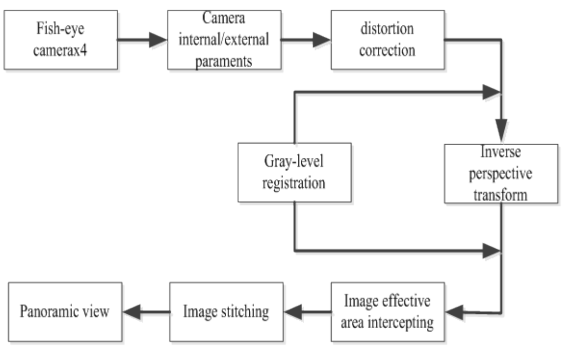

figure 3 Software algorithm structure chart

Software algorithm structure chart is as shown in Figure 3. Firstly, the relationship between the world coordinate system, the image coordinate system and the camera coordinate system is analyzed, and the mathematical modeling is made for the fish-eye camera,and then the internal parameters and external parameters of the four cameras are calculated respectively. Then, make distortion correction for the distortion image using the calculated parameters, and it will get the undistorted image; and it would make the first gray-scale registration for the corrected image to eliminate the fuzzy image; and then inverse perspective transform for the image to get the virtual bird's eye view, and then make the second gray correction; the next step is intercepting the effective area of the virtual bird's eye view to splice together[7-9]. And finally it will get the virtual bird's eye view of the stitching image, that is panoramic view of the car .

2.2 Calibration of fish-eye camera

In the application of image processing and computer vision, because the image taken by the camera have the corresponding relationship with three-dimensional space, people often use the image captured by camera to restore the object of three-dimensional space. Camera calibration is the process that essentially get the camera geometric mathematica model parameters through the experiment and calculation. Camera geometry parameters include camera internal parameters and external parameters. The camera internal parameters are just related to the internal structure of the camera; the camera external parameters are relative to the world coordinate system orientation decision parameters.

1.changing the actual object from the three-dimensional world coordinate system to the two-dimensional picture (image radiology coordinate system) that we have seen, the camera completes the following linear projection transformation.

The transformation from the world coordinate system (X_w, Y_w, Z_w) to the camera coordinate system (X_c, Y_c, Z_c), which can be represented by the translation and rotation of the coordinate system, as follows:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = R(\begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} + T) = [R, t]\begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (1)$$

Where R represents the 3×3 rotation matrix, T and t represent 3×1 the translation vectors. (x_c, y_c, z_c) and (x_w, y_w, z_w) represent the coordinates of the scene points T_W in the two coordinate systems.

2. The transformation of the camera coordinate system (X_c, Y_c, Z_c) to the image coordinate system (X, Y, Z), which setting the Z axis and the Z_c axis is coincident, and the model that projection point of the scene point P_W projection to the image plane point P may be represented by a standard pinhole imaging model, and as is know that the coordinate transformation is equivalent to the proportional transformation. The mathematical expression is as follows:

$$\begin{bmatrix} x \\ y \end{bmatrix} = k\begin{bmatrix} x_c \\ y_c \end{bmatrix} \quad (2)$$

Where k represents a proportional constant, $k = f / z$, f represents the focal length of the camera.

3.The transformation from the image coordinate system (X, Y, Z) to the screen coordinate system (U, V) .

Affine transformation is introduced by the structure of the human eye, because we do not need the pixels are vertical.There is an angle between the V axis and the Y axis. The mathematical expression is as follows:

$$\begin{cases} u = u_0 + \dfrac{x}{dx} - \dfrac{y\cot\theta}{dx} \\ v = v_0 + \dfrac{y}{dy\sin\theta} \end{cases} \quad (3)$$

The matrix expression is:

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} f_u & -f_u\cot\theta & u_0 \\ 0 & f_v\sin\theta & v_0 \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} \quad (4)$$

Which d_x, d_y represents the physical size of the pixel on the axis, and $f_u = 1/d_x$, $f_v = 1/d_y$. From expression we can see that the camera projection model is as shown below:

$$z_c\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \underbrace{\begin{bmatrix} ff_u & -ff_u\cot\theta & u_0 \\ 0 & ff_v\sin\theta & v_0 \\ 0 & 0 & 1 \end{bmatrix}}_{K}\begin{bmatrix} R & t \end{bmatrix}\begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (5)$$

Where K represents the internal parameter matrix of the camera, and we can get the value of K, R, t from calibrating the camera.

2.3 Inverse perspective transform

Transforming the calibrated image which makes distortion correction into bird's eye view image requires a inverse perspective transform [11]. Assuming that the coordinates of the calibrated image after the distortion correction is (u, v) ,and the coordinates of the corresponding bird's eye view image after the inverse perspective transform is (u', v') , the relationship between (u', v') and (u, v) the coordinates of the homogeneous coordinates can be expressed by formula (6):

$$\begin{bmatrix} u' \\ v' \\ 1 \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 \\ a_4 & a_5 & a_6 \\ a_7 & a_8 & 1 \end{bmatrix}\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (6)$$

The matrix A of the inverse perspective transform has 8 unknowns to be solved. For a set of corresponding (u', v') and (u, v) point pairs, two equations can be obtained. If there are 8 unknowns of A, at least need 8 equations, so at least four corresponding points. In the experiment, we obtain the transformation matrix coefficients $(a_1, a_2 \ldots a_8)$ by setting the coordinates of the four corner positions on the checkerboard grid. After obtaining the inverse perspective transform matrix coefficient $(a_1, a_2 \ldots a_8)$, if you set the pixel coordinates (u', v') of the top view, you can find the corresponding coordinates (u, v) . Make $u = i + \Delta x, v = j + \Delta y$,in which i and j be positive integers , Δx and Δy is decimals of the section $[0,1]$, and the value g of the pixel in the bird's eye view can be determined by the coordinates of the corresponding four pixels in the image before the inverse perspective transform,The mathematical expression is as follows:

$$\begin{aligned} g(u',v') = {} & (1-\Delta_x)(1-\Delta_y) f(i,j) + (1-\Delta_x)\Delta_y f(i+1,j) + \\ & \Delta_x(1-\Delta_y) f(i,j+1) + \Delta_x\Delta_y f(i+1,j+1) \end{aligned} \quad (7)$$

In order to reduce the complexity of the algorithm, this paper uses the look-up table method to complete the inverse perspective transform of each frame, that is to be saved $i, j, \Delta x, \Delta y$ with the corresponding (u', v'), by looking for these parameters and then calculated by formula (7) to get bird's eye view.

3 Panorama image stitching

Panorama image stitching is one of the key technologies of the system, and the image registration and image fusion are two important processing steps of image stitching. Compared with the image registration, the algorithm of image fusion is simple and mature, and the real-time is good. The time consumption has little effect on the system. Currently,the image registration technology is still the key and difficult part of the image stitching technology . The efficiency of the algorithm directly affects the real-time and success rate of image stitching.

The around view parking assist system that install the 4 fish-eye cameras around the car to collect the image around the vehicle for the image distortion rectifying ,inverse perspective transform and image processing ,and it will generate the panoramic of bird's eye view around the vehicles through the rotation of the image , intercepts the effective part, and then splice the four Image effective area to form a panoramic view of the car. The image stitching process block diagram is shown in Figure 4:

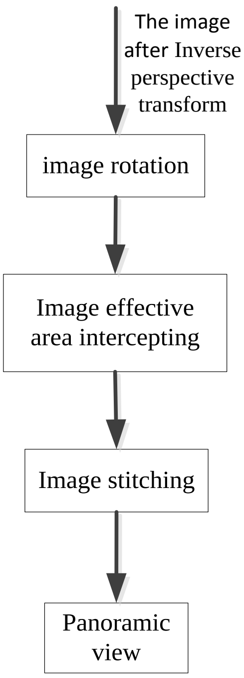

figure 4 Image stitching process block diagram

3.1 Image rotation

There are two cameras installed under the reverse mirror of the car. The reversing mirror is free to rotate and its rotation would causes the rotation of the camera's viewing angle, in order to reduce its effect on the image coordinates, which requires the image to be transformed and easily calibrated by the driver's simple operation. As shown in Figure 3.2, the coordinates of the point (x, y) after the rotation θ degree becomes (x', y').The point rotation principle of the coordinate system

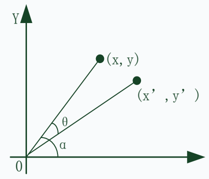

figure 5 The point rotation principle of the coordinate system

Assuming that the radius of rotation is r, the point (x, y) is expressed in the image coordinates as in formula(8):

$$\begin{cases} x = r\cos\alpha \\ y = r\sin\alpha \end{cases} \quad (8)$$

The position of coordinates (x', y') in the image coordinate system after the rotation of θ degrees is as shown in formula (9):

$$\begin{cases} x' = r\cos(\alpha-\theta) \\ y' = r\sin(\alpha-\theta) \end{cases} \quad (9)$$

In order to make the representation of the rotation model be universal, and the matrix form is as in formula (10):

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad (10)$$

The inverse operation is as follows:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} \quad (11)$$

The conversion matrix is based on the coordinates of the center of the image coordinate system O (0,0), and it is Completely applicable in the car debugging process.

3.2 image stitching

There are four fish-eye cameras placed around the car to collect images, the resolution of each camera is 720×576 , the effective data of each image in the system only need a small part, so the image after the inverse perspective transform needs to cut Out of the effective overlap area of the two camera adjacent images.

The stitching of the image that physically stitching the effective area of the image, that is the compressed image in the four directions around the car is flexibly cut and stitched in accordance with the standard parking space, and finally a bird's eye view is formed[12]. The stitching flow chart is shown in Figure 6.

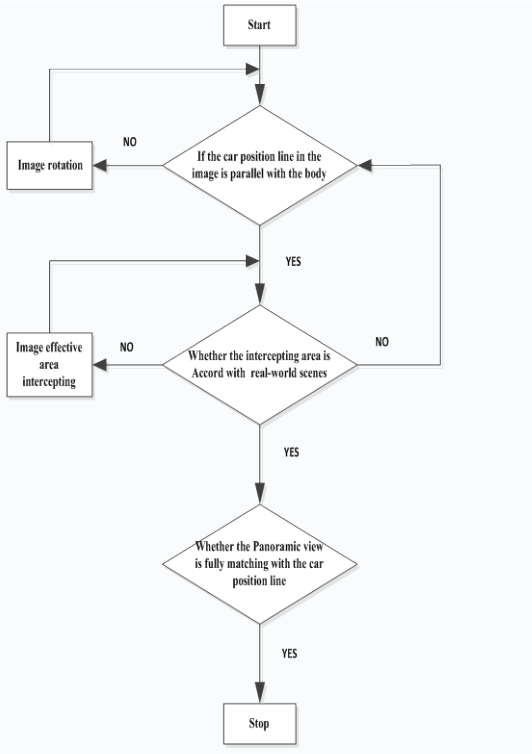

figure 6 The stitching flow chart

4 Analysis of results

The around view parking assist system that install the 4 fish-eye cameras around the car to collect the effective area image around the vehicle.According to the camera internal and external parameters to get image distortion rectifying and calibrate a bird's eye view.Then analyze and calibrate the view overlap area of adjacent camera,getting four image displacement parameters, joining together into a virtual image of the bird's eye view panoramic images, and displayed on the display device of the car, and thus to eliminate the driver's blind spots and provide reference for safe driving.

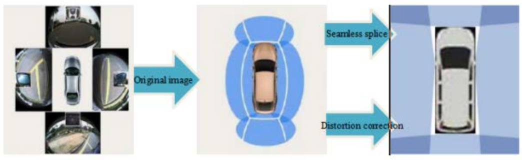

figure 6 On-board panoramic image stitching

In this paper, it adopts the way that distinguish the calibration board to finish stitching and calibration of image,when the vehicle parked in the position of the predefined calibration location, and we can see the two calibration boards in the each image of the four camera,,at the same time ,we can see the location of both sides of the tire from left and right two cameras.

In the calibration process, the coordinate parameters of the calibrated board are determined by means of doting, and the position of the four tire points will determine the position of the vehicle in the whole image. When the midpoint of the calibration board is determined in the image, the software will automatically correct the distortion of the image. After correcting, the calibration boards in both sides will be image fusion with the calibration boards in the front and rear view. After the brightness balance processing, The calibration of the panorama system is executed. For the single right view need taken from the original camera image,and finally it will generate the panoramic of bird's eye view about the vehicle.

In this paper, the two methods of manual doting calibration and automatic calibration are adopted to realize the the panoramic image stitching in the real vehicle.

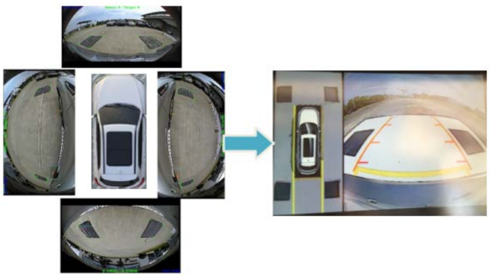

figure 7 manual doting calibration

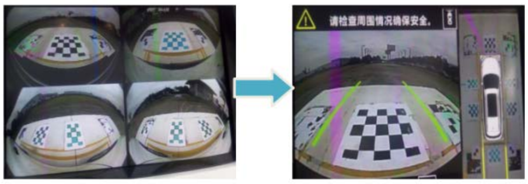

Figure 8 automatic calibration

Manual calibration is dot by Manual way to send the location information to software and complete the calibration, it is of good performance of low requirement for site,style flexible and easy to operate, but the calibration result and accuracy have a great effect with the personnel's ability and quality. It is suitable for the 4s shop to maintenance. Automatic calibration that the location information is automatically identified by the software , but it is strict with the accuracy of the site and the light.it is of good performance for the calibration time is short,high precision and calibration controllable ,and it is suitable for mass production.

5 conclusions

The around view parking assistant system based on multiple visual sensors can effectively cope with the increasingly traffic jam and terrible road environment, it's also one of the hot spots in research of vehicle active safety in recent years . This paper analyzes the working principle of the whole system and the realization of hardware and software, and verifies the system with manual doting calibration and automatic calibration. The experimental results show that the two kinds of calibration ways are well spliced and meet the demands of complex traffic environment. At the same time, based on the hardware platform for future product upgrade leave sufficient hardware resources and software optimization of space.This paper does not only focus on the parking assistant function, but also it can be applied to the automatic parking, traffic safety, autopilot and other fields. In the future, it will play a important role in the innovation of relevant technologies in the field of automotive active safety .

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