Multi-Camera Panoramic Imaging System Based on Adaptive Brightness Uniformization For The Truck

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Abstract—With the development of science technology and logistics industry, the transportation of large trucks is also indispensable. It is also accompanied by many traffic accidents. The paper mainly focuses on the problem of blind spots in the parking of large trucks. A panoramic imaging system with six cameras is implemented to improve its safety performance. It mainly includes the realization of modules included simultaneous acquisition of images by multiple cameras, image calibration and correction, top view image generation, image stitching and image fusion. In view of the brightness difference of images acquired by different cameras, we proposed an adaptive brightness uniformization method based on $\gamma$-transformation. Meanwhile, we compared the proposed method with various image enhancement methods included histogram equalization, Laplace operator and logarithm transformation. The experimental results in the system demonstrate the superiority of our proposed method compared to others.

1. INTRODUCTION

In recent years, with the significant improvement of people's quality of life, the development of e-commerce industry and logistics industry has better promoted the change of people's lifestyles. The transportation of large trucks is also an indispensable part of current logistics industry. It is accompanied by more and more traffic accidents. Due to the large body size of large trucks, there is a large blind spot in the process of reversing and parking in the complex urban environment, which leads to traffic accidents occurred frequently during reversing parking.

At present, the simplest parking assist in a car is the rearview mirror, but rearview mirror has many shortcomings. First, it is inconvenient to use. The use of a rearview mirror to assist parking requires the driver to have skilled driving skills to make a correct judgment of the distance between the position of the car and the obstacle around. The second is that the field of view of the rearview mirror is too narrow, and there are many blind spots in the vision. With the continuous development of electronic technology and artificial intelligence technology, the most commonly used is currently based on the reversing radar (ultrasonic detection technology), combined with a single camera reversing image assistance system, which can be used by the driver to observe the environment behind during reversing and parking. In more high-end brand car companies, such as Mercedes-Benz, Volvo, Audi and so on, for small cars, a panoramic parking assistance system based on four cameras has been implemented [1]. The surrounding images of the car body collected by the camera enable the driver to clearly understand the environment around the car. It avoids the visual blind spots and improve vehicle safety performance.
However, for the large truck, the body size can reach 12.5 m (length) × 2.4m (width) ×2.7m (height), and there are more blind spots in the field of vision for the driver. At present, there is no implementation for large trucks. Therefore, based on the realization of the panoramic parking assistance system with four cameras, we have carried out research on the panoramic imaging system based on six cameras for large trucks, and proposed an adaptive brightness uniformization method based on $\gamma$-transformation.

This article mainly contains the following content. The second part will introduce the related work of panoramic imaging research. The third part mainly introduces the main module functions of the multi-camera panoramic imaging system implemented in the paper. The adaptive brightness uniformization method based on $\gamma$-transformation will be presented in the fourth part. The fifth part will analyze the experimental results. In the end, in the last section, we will get the conclusion of the research and discuss some future works.

2. RELATED WORK
As far as we know, with the rapid development of artificial intelligence technology, computer vision, image processing technology, and the wide application of wide-angle fisheye cameras. Many domestic and foreign universities, research institutes and related enterprises have all carried out research on related technologies of automotive panoramic imaging assistance systems. In 2007, Dr. Li Shi Gang realized the way of adding prisms between two back-to-back fisheye lenses to change the propagation path of light, and projected the images captured by two super wide-angle fisheye lenses to both sides of the same photosensitive chip, realizing dual lenses. Then they generated a panoramic image [2]. In 2010, Ding Xin from Zhejiang University proposed an implementation method of a panoramic parking assist system. The system achieves a bird's-eye view effect by performing homography matrix transformation after correcting the distortion of the fisheye image. Using TI's DaVinci series DSP and CPLD, the panoramic parking assist system is implemented on the hardware, and the lookup table is used to ensure the real-time performance of the system [3]. In 2015, Dr. JDE García of Heidelberg University used multi-sensor fusion technology to achieve low-speed assisted driving and panoramic parking. The system uses a laser rangefinder and combines image information captured by multiple fisheye cameras to achieve high precision three-dimensional reconstruction [4]. The 360° non-blind spot monitoring of South China University of Technology aims at the multi-camera hardware platform, and studies the 360-degree panoramic video splicing method. It uses integral images to realize the registration of the images collected by multiple cameras, which can solve the problem of large fisheye image distortion. It can also meet the real-time requirements of the system [5]. In 2017, Japanese research scholar Kunio Nobori adopted a combined projection method to realize a low-distortion panoramic visual parking assist system [6].
We all know that the environment in which the car is used is more complex and changeable. When multiple cameras are mounted, there must be a certain difference in the brightness of the images obtained by different cameras. Therefore, it is necessary to unify the brightness of the panoramic image after the stitching, and the research has great practical significance. Meanwhile, based on the realization of the multi-camera panoramic imaging system, we have carried out the research on the brightness uniformization method in the image enhancement area, and proposed an adaptive brightness uniformization algorithm based on $\gamma$-transformation. And the experimental results demonstrated that the method proposed could get better panoramic image.

3. MULTI-CAMERA PANORAMIC IMAGING SYSTEM

The multi-camera panoramic imaging system proposed in the paper is mainly aimed at the parking assistance application of large trucks or buses. The function of the system is to generate panoramic image from the original images through multiple cameras and result in eliminating surrounding blind areas. We applied six cameras for system implementation, the main modules include fisheye camera calibration and distortion correction, top view image generation, image stitching, image fusion, brightness uniformization, and look-up table generation algorithm to achieve system real-time performance. The architecture of our system is shown in Figure 1.

The framework of multi-camera panoramic imaging system in the paper is shown in Figure 2 as follows.
3.1. Camera calibration and fisheye image correction

Firstly, we make a standard checkerboard calibration board with a size of 7*5 and place it on each camera screen at different angles and distances. Each camera collects about 12 images with different angles and distances for calibration. The specific process of flow diagram is shown in Figure 3.

The internal parameter model of the fisheye camera [7,8] can be expressed as in (1) and (2).

\[
\begin{pmatrix}
u \\
v \\
1
\end{pmatrix} = M_{3 \times 3} \begin{pmatrix}
x/z \\
y/z \\
1
\end{pmatrix} \tag{1}
\]

\[
M_{3 \times 3} = \begin{pmatrix}
f_x & 0 & d_x \\
0 & f_y & d_y \\
0 & 0 & 1
\end{pmatrix} \tag{2}
\]

where \(f_x\) and \(f_y\) are the focal lengths of the camera on the X-axis and Y-axis in the image respectively, and \((d_x, d_y)\) are the main point coordinates, \((x, y, z)\) represent the corresponding coordinates in the camera coordinate system.

Assuming a point \((X, Y, Z)\) in three-dimensional space, the coordinate projected by the camera onto the image is \((u, v)\), the projection relationship and the distortion correction process are as follows in (3)-(8).

\[
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix} = R \begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} + T \tag{3}
\]

\[
x' = x/z \tag{4}
\]

\[
y' = y/z \tag{5}
\]

\[
r^2 = x'^2 + y'^2 \tag{6}
\]

\[
\theta = \text{atan}(r) \tag{7}
\]
\[ \theta = k_1 \theta^2 + k_2 \theta^4 + k_3 \theta^6 + k_4 \theta^8 \]  

where \( R \) is the rotation matrix, \( T \) is the translation vector, \( x', y', r, \theta \) are the intermediate variables, \((k_1, k_2, k_3, k_4)\) is the distortion parameters of the camera.

### 3.2. Homography matrix transformation for top view image

Perspective transformation is to transform the original image into an image under another viewing plane, and the perspective transformation is achieved through the calculated homography matrix, also known as direct linear transformation (DLT). The direct linear transformation algorithm [9] was proposed by Abdel-Aziz and Karara in 1971. It was originally a method to simplify photogrammetric data. The method does not need to know the camera frame mark and the approximate value of the camera's internal and external orientation parameters. The direct linear transformation algorithm is based on the transformation from original image coordinates to the physical spatial coordinates, which have the characteristics of stable and reliable solution, convenient and practical.

The transformation formula is as follows:

\[
\begin{bmatrix}
X \\
Y \\
Z \\
1
\end{bmatrix} = H \begin{bmatrix}
x \\
y \\
1
\end{bmatrix} = \begin{bmatrix}
h_{11} & h_{12} & h_{13} & 1 \\
h_{21} & h_{22} & h_{23} & 1 \\
h_{31} & h_{32} & h_{33} & 1
\end{bmatrix} \begin{bmatrix}
x \\
y \\
1
\end{bmatrix}
\]

where \( H \) is the homography matrix of perspective transformation, \((x, y)\) is the position coordinates of the image, and \((X, Y, Z)\) represents the three-dimensional point coordinates after transformation.

Then, it used to the following formula (10) to convert the 3D point coordinates into image coordinates.

\[
X' = X/Z, \; Y' = Y/Z
\]

where the \((Z, Y')\) is the position coordinate of the pixel point transformed into the top view image.

### 3.3. Image stitching based on marked points

After the original images acquired by each camera are converted into a top view, there is a certain overlap area between adjacent images. In order to eliminate the overlap area between adjacent images, we adopt an image stitching algorithm based on marked points to cut the overlap area [10]. Meanwhile, we ensure that no image information is lost after image stitching.

There is a certain overlap area in the images captured by two adjacent cameras. As we can see, in Figure 4, two non-overlapping points marked in each overlap area. where the two points A1 and A2 marked in the overlap area in the images captured by camera 01 and camera 02, the two points B1 and B2 marked in the overlapping area in the images captured by camera 01 and camera 03. At this time, we can use the coordinates of the four points A1, A2, B1 and B2 in the image captured by camera 01, At the same time, according to the corresponding point coordinates of the four points in the real panoramic image, the homography matrix is calculated. The perspective transformation is used to convert the top view of each camera into a panoramic image, and then the overlapping area between adjacent images is cut. And then stitching, it would finally generate panoramic image.

Figure 4. The schematic diagram of image stitching
3.4. Image fusion based on distance weighted average

In the previous sections, we have adopted the method based on marked points to achieve image stitching. From the experimental results, in the case of losing no image information, it can be known that there would be a relatively obvious gap between the stitching of two adjacent images after image stitching. At the same time, we directly implement image splicing through cropping after correcting the marked points. In order to obtain a better seamless image, this section will perform image fusion processing on the image stitching.

Generally, image fusion can generally be divided into: pixel-level image fusion, feature-level image fusion and decision-level image fusion [11]. Pixel-level fusion refers to the direct processing of pixels in the image to achieve the effect of image fusion, which can obtain higher accuracy of image fusion and detailed information of the image [12]. The algorithms include fuzzy inference-based algorithms, principal component analysis algorithm [13], support vector machine clustering algorithm, average and weighted average algorithm and so on. Feature-level image fusion refers to the fusion processing based on the image feature information level, which is mainly used in the field of target tracking and joint target recognition. Decision-level image fusion refers to the realization of image fusion by global optimization decision-making according to certain rules after classifying and identifying the feature information of the image, which includes algorithms based on cognitive models [14].

Our proposed system mainly performs image fusion on the stitching gap between two adjacent images, and then to achieve the purpose of eliminating the gap. According to the above introduction of three different image fusion methods, we mainly use pixel-level image fusion algorithms considering the requirement of real time. Therefore, a distance-based weighted average fusion algorithm is used for image fusion.

The main idea of the algorithm is shown in the Figure 5. The area efgh is a rectangular area selected in the overlapping area of two adjacent images, the line L is the stitching gap, the lines of ef and gh are parallel to the stitching gap, and M is one pixel’s location of the overlapping areas.

![Figure 5. The schematic diagram of image fusion](image)

Assuming that the distance between the pixel point M in the overlapping area and the boundary gh of the overlapping area is d, and the distance between the line ef and the line gh is D, the calculation of the parameter λ is as follows:

\[ \lambda = \frac{d}{D} \]  

(11)

The calculation formula for the value of pixels in the fusion area in the image is as follows.

\[ P(x,y) = \lambda \times P_1(x,y) + (1 - \lambda) \times P_2(x,y) \]  

(12)

where \( P(x,y) \) is the value of the pixel at the position \((x, y)\) of the fused image, \( P_1(x,y) \) is the value of the pixel at the \((x, y)\) position of the camera 01 corresponding to the top view image, and \( P_2(x,y) \) is the value of the pixel at the position \((x, y)\) of the camera 02 corresponding to the top view image.

4. Adaptive Brightness Uniformization Method Based on \( \gamma \)-transformation.

Through the above process, the generation of panoramic images is realized [15]. However, in real scenes, especially when the light is dark somewhere or a specific scene with strong illumination in a
certain direction, the brightness of the images collected by different cameras may have large differences, It would result in that there would be a large difference in brightness when we achieved the panoramic image with stitching and fusion. Therefore, the paper proposed an adaptive brightness uniformization algorithm to realize the unification of image brightness and it had strong adaptability.

As we all know, the human eye's sensitivity to external light sources has a nonlinear relationship with the input light intensity. Under low illuminance, human eyes can more easily distinguish changes in brightness. As the illuminance increases, it is difficult for human eyes to distinguish changes in brightness. Therefore, we adopted the proposed method of adaptive brightness uniformization based on γ-transformation to realize the unification of panoramic image.

Algorithm 1: Adaptive brightness uniformization based on γ-transformation

| Input: | m_in (the Mat of fusion image); |
| Output: | m_out (the image after adaptive brightness uniformization); |
| const_y (the expected brightness value in the range 0-255), q (the constant after tests), gamma_table (brightness value mapping table); |

1: while beginning to get the frame from cameras do
2: m_yuv = transform(m_in), transform the image form RGB to YUV color space;
3: get the Y-component m_y from m_yuv;
4: avg = average(m_y), calculate the average of Y-component values;
5: if avg < const_y then
6: \( \gamma = 1 - (\text{const}_y - \text{avg})/q \), \( \gamma \) is the parameter of transformation exponent;
7: else
8: \( \gamma = 1 + (\text{avg} - \text{const}_y)/q \);
9: end if
10: gamma_table = generateGammaTable(\( \gamma \)), get the transform table;
11: m_out = m_in^{\gamma}, calculate every pixel’s R.G.B. component value from the gamma_table;
12: return m_out ;
13: end while

4.1. The basic principle of γ-transformation
The γ-transformation refers to the non-linear operation of the pixel value of the image, so that the pixel value of the transformed image is in an exponential relationship with the pixel value of the original image. The principle is shown in the following formula.

\[
M_{\text{out}} = A \times M_{\text{in}}^{\gamma}
\]  (13)

where \( M_{\text{out}} \) is the matrix corresponding to the transformed image, \( M_{\text{in}} \) is the matrix corresponding to the original image, \( A \) and \( \gamma \) are parameters respectively.

4.2. Adaptive Brightness Uniformization Algorithm
On the basis of the basic principle of γ transformation above, we proposed the algorithm of adaptive brightness uniformization. The details of the algorithm are shown in Algorithm 1.

5. Experiments
In section of the camera calibration and fisheye image correction, we did the experiment that the results of distortion correction are shown in Figure 6.
Figure 6. The results of the distortion correction experiment of the fisheye camera. (a) is the original image obtained by the camera, (b) is the image after the corner points are extracted in the calibration, (c) is the distortion corrected image.

The multi-camera panoramic imaging system uses six cameras as shown in Figure 1. For the six original images obtained from fish-eye cameras, we did experiments on distortion correction and top view image transformation. The experiment results are shown in Figure 7.

Figure 7. The experiment results of homography matrix transformation. (a) is the corrected images of six cameras, (b) is the top view images after transformation.

Figure 8. The experiment results of image stitching. (a) is the top view images after homography matrix transformation, (b) is the panoramic image after cutting and stitching.

For the six top view images obtained from homography matrix transformation, we achieved image stitching based on marked points. The experiment results are shown in Figure 8.

In our multi-camera system, for the section of image fusion, we set the parameter $D = 20$. The experimental results are shown in Figure 9. It is obvious that the method had eliminated the gap of two adjacent images.
Among the methods of image enhancement, the most common methods are histogram equalization image enhancement, Laplacian operator image enhancement, logarithmic transformation image enhancement and so on.

However, in the proposed system, the adaptive brightness uniformization based on $\gamma$-transformation has been proposed. And then, we compared the algorithm with others above in the multi-camera panoramic imaging system. The experimental results are shown in Figure 10.

In the original stitched and fused image, there are obvious image brightness inconsistencies in the red rectangular frame. Compared with the above four different image enhancement methods, the adaptive brightness uniformization algorithm based on $\gamma$-transformation proposed in the paper can get better results. The strong brightness of the rectangular frame is better integrated into the panoramic image, and the unified effect of the panoramic image brightness is achieved.

Since the image enhancement is based on the original fusion panoramic image, we referred to the original fusion image. We adopted three evaluation metrics which included the Structural Similarity (SSIM), the Peak Signal Noise Ratio (PSNR) and the Mean Square Error (MSE) to compare with the above three different methods. The results are shown in the following table.
TABLE 1 THE EXPERIMENTAL RESULTS OF FOUR METHODS ON THREE DIFFERENT EVALUATION METRICS

| Methods                        | SSIM    | PSNR    | MSE       |
|--------------------------------|---------|---------|-----------|
| histogram equalization         | 0.7125  | 15.9393 | 1656.3556 |
| Laplace operator               | 0.9154  | 17.3765 | 1189.6735 |
| logarithm transformation       | 0.9654  | 17.009  | 1294.7332 |
| adaptive uniformization based on $\gamma$-transform | 0.9678  | 18.516  | 915.1236  |

It can be seen from the results in the table that the adaptive brightness uniformization algorithm based on $\gamma$-transformation proposed in the paper is better than the other three methods in the three evaluation metrics of SSIM, PSNR and MSE. The proposed method got a better experimental effect of brightness unification in the case of without losing the structural features of the original image and having lower noise.

In the experiments, it is found that each method has certain parameters to adjust. The number of parameters that need to be adjusted for each method is shown in Table II. From the result, the Laplace operator method requires setting a convolution kernel of $3\times3$ which has nine parameters. The logarithmic transformation method needs to set the logarithmic base $v$ and coefficient $r$. The adaptive brightness uniformization algorithm based on $\gamma$-transformation proposed in the paper calculates the exponential parameter $\gamma$ based on the original brightness average of the image, there is not necessary to adjust the setting parameters. It shows the strong adaptability of the algorithm.

TABLE 2 THE NUMBER OF PARAMETERS TO BE SETED IN THE FOUR METHODS

| Methods                        | histogram equalization | Laplace operator | logarithm transformation | adaptive uniformization based on $\gamma$-transform |
|--------------------------------|------------------------|------------------|--------------------------|-----------------------------------------------|
| number of parameters to set    | 0                      | 9($3\times3$)    | 2                        | 0                                             |

6. CONCLUSION AND FUTURE

In the paper, we have implemented a multi-camera panoramic imaging system, and proposed an adaptive brightness uniformization algorithm based on $\gamma$-transformation for brightness enhancement. In the end, we compared it with other common methods. The experimental results show that the algorithm proposed in the paper can get better results in achieving the brightness enhancement of panoramic image.

For the future work, it’s known that items with a certain height will have greater distortion in the top view after the transformation. During the stitching process of two adjacent images, items with a lower height on the ground are in the stitching gap and there is no information loss on both sides. But there is a small amount of information loss on both sides of the gap with items of a certain height are stitching. At present, scholars have used deep learning combined with semantic segmentation under simulation data to achieve a panoramic image in a top view from a complete real God perspective [16]. In the follow-up, the method of general antagonistic network(GAN) and semantic segmentation will be combined with real data to generate panoramic images, and then applied to the vehicle-mounted assistance parking system, which will have great practical significance.

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