A Fast Correction Algorithm for Inverse Longitude and Latitude Mapping of Fish Eye Image

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Abstract. In order to solve the problem of large barrel distortion in fisheye lens, an image distortion correction algorithm based on double longitude is proposed to improve the visual effect. Firstly, in the case of unknown lens angle and non-circular fisheye image, the spherical center and its radius are obtained by using fisheye image features, and the radius is optimized to reduce pole distortion; on this basis, the fisheye image is mapped to the spherical surface by orthogonal projection strategy using double longitude model method, which is transformed into the transverse longitude and longitudinal longitude coordinates of the sphere. The projection is a square plane image based on the horizontal and vertical double longitude coordinates to realize the fast and accurate image transformation.

1. Introduction
In recent years, with the continuous development of optical lens and imaging chip technology, the traditional vision system based on conventional lens can not meet the needs of many applications due to its limited field of view. The wide-angle imaging has become the focus and hotspot of computer vision research because of its large field of vision. Ultra wide angle lens is a kind of lens with focal length of 16mm or shorter and viewing angle close to or equal to 180°, commonly known as "fish eye lens"[1]. In order to maximize the camera's viewing angle, the front lens of this kind of camera lens is very short in diameter and protrudes toward the front of the lens in a parabola shape, which is quite similar to the fish's eyes, hence the name "fish eye lens". Fish eye lens is a kind of ultra wide angle lens based on bionics. By introducing barrel distortion, it can compress and deform the physical space, so as to obtain the ultra wide angle imaging from 180° to 270° angle [2]. Although there are great differences between objects and images, the resolution is not affected, and the one-to-one correspondence between object points and image points can be ensured, which can realize a wide range of clear imaging. Forest fire prevention and national defense and military fields have important applications.

Fish eye lens is a kind of wide-angle lens, which has the characteristics of short focal length and large field of view, so a single fish eye image contains a lot of information and can replace many traditional lenses. Fisheye lens can work in staring mode without rotation and scanning. It has the advantages of small size, strong concealment and saving hardware resources while obtaining large field of view. Therefore, fish eye lens has its unique application value. Nowadays, with the continuous development of information technology industry, computer network and machine vision, fisheye lens...
has been applied in many fields, such as video monitoring, intelligent traffic management system, virtual reality technology, robot navigation, medical equipment, panoramic shooting, video group meeting, etc. The use of fisheye lens in national defense and military affairs can meet the all-round and all-round time-domain requirements of information acquisition in modern war. The camera system equipped with large wide-angle lens and professional information transmission and processing software has become a powerful information acquisition channel in modern information warfare. Due to the short focal length of fish eye lens, the image taken by it has serious distortion, which not only does not conform to the normal human visual habits, but also the rich image information is not easy to use. In order to make use of the large range information obtained from these images, it is necessary to correct these distorted images into perspective projection images which are in accordance with people's habits [3]. In order to improve the utilization value of fisheye image, it is very important to correct the distorted image [4].

The fish eye lens with large field of view has different magnification in vertical axis of different field of view, which leads to the distortion of the final image, which brings inconvenience to the application of identification and measurement. In view of the shortcomings of traditional longitude correction methods, the algorithm is improved to a fast correction algorithm of bidirectional longitude fisheye image. By dividing the effective area of fish eye image, and establishing the correction model for the distortion points in different areas in the horizontal and vertical directions, the coordinate mapping relationship between the distorted image and the ideal image is determined, and the position of the correction coordinate is obtained. Finally, nonlinear stretching is applied to the image to improve the "expansion" caused by the different magnification of the center and edge of the image, so as to obtain the image conforming to the human visual habits.

2. Principle

2.1. Structure principle of fisheye lens

Fisheye lens is an extreme wide-angle lens, also known as panoramic lens. Generally speaking, the lens with 16mm or shorter focal length is called fish eye lens, but in engineering, the lens with a viewing angle of more than 140 ° is collectively referred to as fish eye lens. In practice, there are also lenses whose viewing angle exceeds or even reaches 270 degrees. Fisheye lens is an anti telephoto optical group with a lot of barrel distortion. The front lens of this lens is parabola shaped, protruding forward, similar to the shape of rain eyes, so it is named "fish eye lens". Its visual effect is similar to fish observing things on the water surface in the water, as shown in Figure 1.

![Figure 1. Fish observe things on the water surface in the water.](image-url)

Because of the large curvature radius of the fish's front surface, if the convex front surface of the fish eye and the water in front of the fish are regarded as a whole, the lens will have a very large
negative power. The fish eye lens is a breakthrough in its field based on the bionics principle. Human beings use the visual principle of fish looking up at the hemispherical space above the water surface to design fish eye lens with optical engineering technology, and use it to image to obtain the scene images of hemispherical and even super hemispherical airspace. In order to make the intensity of the incident light strong enough, the front surface of the front lens is improved to convex surface, and the curvature of the back surface is correspondingly increased to ensure that the original optical power remains unchanged to form a crescent shaped lens.

2.2. Distortion principle of fish eye lens imaging

In the traditional optical principle, due to the limitation of the imaging angle of Gaussian principle, the imaging space is very limited. However, in order to break through the limitation of imaging, fish eye lens is compressed in diameter space to achieve wide-angle imaging.

Ordinary optical systems generally follow the similarity of objects and images and strive to improve this similarity. However, fish eye lens does not meet the pinhole imaging principle and is a kind of non-similar imaging. Figure 2 shows the comparison between similar imaging and non-similar imaging. For the fish eye lens imaging formula, the image field definition domain in the view range should be continuous, so as to be a fisheye lens projection function.

One of the key points of fish eye lens imaging is to be able to correctly describe the image points of the target point in the three-dimensional space on the imaging plane, and to accurately establish the corresponding relationship. To achieve this goal, it is necessary to establish a visual imaging model and analyze the rules. Fish eye lens is designed by equidistant theorem. Figure 3 is the simulation diagram of imaging system after any point in space is refracted by fish eye lens.

![Figure 2. Comparison of similar imaging (left) and non-similar imaging (right).](image-url)
The imaging model of fish eye camera is composed of five coordinate systems: world coordinate system, fish eye lens coordinate system, camera coordinate system, image coordinate system and imaging coordinate system. \(p\) is a point in three-dimensional scene; \(h\) is the vertical distance between the point and the display space of the projection surface; \(R\) is the image radius of fish eye; \(p'\) is the projection point of scene point \(p\) on the imaging plane; \(\omega\) is the angle of incidence of the point relative to the center; \(\theta\) is the azimuth angle of scene point \(p\) in camera coordinate system; \(\theta'\) is the azimuth angle of image point in the image physical coordinate system.

2.3. Distortion correction of fisheye lens
When the fish eye image coordinates are finally mapped to the plane coordinates, some points are not integer, resulting in a large number of image gaps. Therefore, we will use the reverse mapping method to calculate the corresponding points on the fisheye image from the plane two-dimensional target image, and then calculate the corresponding pixel value through the bilinear interpolation algorithm.

Figure 4 is a side view of a spherical model. The coordinates of point \(p\) in the figure are \((x, y, z)\), \(p_1 p_2\) is the projection point of point \(p\) on the \(xoz\) plane and \(yoz\) plane respectively, \(\varphi\) and \(\theta\) are the included angles between \(op_1\) and the positive direction of \(x\)-axis, and between \(op_2\) and \(y\)-axis. If the longitude (included angle) of the vertical longitude line and the longitude (included angle) of the horizontal longitude line of point \(p\) point are respectively \(\alpha\) and \(\beta\), then \(\alpha = \pi - \theta, \beta = \pi - \varphi\).
Figure 4. Side view of spherical model (left) and coordinate of original fisheye image (right).

When the projection model is hemispherical, the range of transverse longitude and longitudinal longitude is 0 ~ \( \pi \) and the target image is too small for direct mapping. In order to ensure that the target image is the same as the original image. Therefore, the corresponding relationship between the point \( p'(i, j) \) on the target image and the double longitude coordinates (\( \alpha, \beta \)) on the corresponding sphere are shown in formulas (1) and (2).

\[
\begin{align*}
\frac{i}{2r} & = \frac{\alpha}{\pi} \Rightarrow \alpha = \frac{\pi}{2r} \times i \\
\frac{j}{2r} & = \frac{\beta}{\pi} \Rightarrow \beta = \frac{\pi}{2r} \times j
\end{align*}
\]

where \( r \) is the radius of the spherical model, \( \alpha \) is the longitude value of the vertical longitude line in the double longitude coordinate, \( \beta \) is the longitude value of the horizontal longitude line in the double longitude coordinate, and \((i, j)\) is the coordinate value of the point \( p' \) on the target image.

It can be seen from Figure 4 that the vertical longitude \( \alpha \) of point \( p \) is the angle between \( op_2 \) and the negative half axis of \( y \) and the longitude \( \beta \) of point \( p \) in the horizontal direction is the angle between \( op_1 \) and the negative semi-axis of \( x \). therefore, the following equation can be obtained:

\[
\begin{align*}
\pi - \theta & = \alpha \quad (0 \leq \alpha \leq \pi) \\
\pi - \phi & = \beta \quad (0 \leq \beta \leq \pi)
\end{align*}
\]

In addition, according to the spherical characteristics and the relationship between the angle and the coordinate, the corresponding relationship between the angle \( \varphi \) and \( \theta \), and the coordinates of point \( p \) \((x, y, z)\) can be established as follows:

\[
\begin{align*}
x & = \frac{r}{\sqrt{\tan^2 \varphi + 1 + \tan^2 \theta / \tan^2 \varphi}} \\
y & = \frac{r}{\sqrt{\tan^2 \theta + 1 + \tan^2 \varphi / \tan^2 \theta}} \\
z & = \frac{r}{\sqrt{1 + 1 / \tan^2 \varphi + 1 / \tan^2 \theta}}
\end{align*}
\]

When orthogonal projection is used, the spherical point \( p(x, y, z) \) is projected as \( p''(u, v) \) in the fisheye image, and the line segment \( pp'' \) is perpendicular to \( xoy \) plane. Therefore, the corresponding relationship between the spherical coordinate point \( p(x, y, z) \) and the fisheye image \( p''(u, v) \) is as follows:
Where $x_0$ and $y_0$ are the position of the center point $O''$ of the fish eye image. According to the above projection method, we can get the mapping relationship between the spherical point and the corresponding coordinates in the fisheye diagram. Through bilinear interpolation of the corresponding points on the fish eye image, the gray value of the corresponding points on the target image is obtained, and the distortion correction of the double longitude image is completed finally.

3. **Experiments**

The process of double longitude distortion correction is divided into two steps:

3.1. *Capture the effective region of fish eye image*

Firstly, the edge details of the image are highlighted; then, binarization processing is used to enhance the contrast adjusted image, but the contrast difference between some template points and background is large, so a threshold is set to binarize the whole image. The main function of binarization is to improve the quality of distortion correction image, and the preprocessing image can provide an important role in determining the center of dot matrix template.

![Figure 5. Fish eye image (left) binary image (middle) extract the effective region of image (right).](image)

3.2. *Fish eye image correction*

According to the formula (8) and (9), the image under the image coordinate system after fish eye image correction is obtained. As shown in the figure below:

![Figure 6. Fisheye image (left) fisheye image distortion corrected image (right).](image)

From the correction diagram, we can see that most of the building curves are corrected into straight lines. The algorithm can be well corrected in both horizontal and vertical directions, and the perspective effect is very good.
4. Conclusion
The distortion of the camera will make people see the image "stretched" or "distorted", which will lead to the phenomenon of "uneven and vertical". When the angle of view and the optical center of the lens are unknown, and the fisheye image is circular, the algorithm can calculate the optical center and spherical model radius well, recover the horizontal and vertical distortion well, and the pole stretching is small. The algorithm also has many applications in daily life, such as convex lens at turning intersection, left and right rear-view mirrors of cars, etc., which lays a foundation for expanding the field of vision by using distortion effect.

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