Comparison of Different Techniques for Fisheye Correction

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Abstract— ***This report presents a comparison of two distinct techniques for correcting fisheye image distortion. The first method, titled "Hemi-Cylinder Unwrapping Algorithm of Fish-Eye Image Based on Equidistant Projection Model," proposes a novel fisheye image unwrapping algorithm that calculates the image distortion center using vanishing point extraction and uses a hemi-cylinder projection in three-dimensional space. The second method, "Fish-Eye Distortion Correction Based on Midpoint Circle Algorithm," introduces a fast and simple distortion correction technique suitable for embedded camera platforms that determines pixel positions along the circumference of a circle using incremental estimation of decision parameters. The report assesses the efficiency and effectiveness of both methods, providing useful insights for future fisheye image correction research.***

Keywords— Equidistant projection model, Midpoint circle algorithm, vanishing points, distortion, hemi-cylinder unwrapping

I. Introduction

Fisheye lenses are frequently used to capture large areas in a single image due to their wide field of view (FOV), which typically ranges from 120 to 180 degrees. Nevertheless, these lenses frequently result in hemispherical or circular images, which distort objects to appear curved, particularly in the periphery of the image. The accurate interpretation of image data by end users may be hindered by these distortions. Applications for wide-angle cameras with fisheye lenses are numerous and include image-based rendering, single view metrology, 3D reconstruction, and robot navigation. Fisheye distortion correction is essential because of their wide field of view and capacity to capture rich visual information in a single image, especially in situations like video surveillance.

The "Midpoint Circle Algorithm for Real-Time Fish-Eye Distortion Rectification" presents a novel approach to real-time fisheye image correction. Utilizing the Midpoint Circle Algorithm (MCA), this technique calculates the pixel locations on a circle's perimeter by progressively adjusting decision parameters. Designed for embedded camera systems, it offers a streamlined and potent rectification process that eliminates the need for flat checkerboards, iterative model parameter fitting, intricate calculations, or conventional lookup tables.

The majority of calibration techniques strive to align fisheye photographs with the tenets of pinhole camera projection. Such alignment often leads to significant distortion at the edges of the corrected images and can cause the loss of critical data from the initial capture. Our suggested solution, the hemi-cylindrical unwrapping algorithm, successfully mitigates this issue by producing unwrapped fisheye images that are more visually agreeable for human viewing and retain the integrity of the original information.

II. LITERATURE REVIEW

Our Exploration into Fisheye Lens Distortion and Correction Methods
In our quest to address the challenges posed by fisheye lens distortion, we delved into a variety of correction methods. Fisheye lenses, with their unique ability to capture expansive angles, introduce a significant radial distortion that distorts straight lines and alters the inherent geometry of the scene. Our research aimed to not only correct these distortions for aesthetic purposes but also to ensure geometric fidelity for analytical applications.

Hemicylindrical Unwrapping: Our Chosen Path
We were particularly drawn to the hemicylindrical unwrapping technique due to its ability to maintain certain linearity in the images, especially when the horizon is central. Our research led us to the analytical work of R. Kingslake (1989), whose insights into the optical properties of fisheye lenses guided us in projecting distorted images onto a hemicylindrical surface before unwrapping them into a rectilinear view. This method resonated with our project's objectives, as it aligned with the type of imagery we were working with.

The Midpoint Circle Method: A Complementary Approach
In conjunction with hemicylindrical unwrapping, we incorporated the midpoint circle method, traditionally used in computer graphics for circle rasterization. We iteratively corrected the radial distortion by adjusting pixel positions, treating the distortion as concentric circles around the fisheye's image center. This approach proved to be a valuable tool in our arsenal for distortion correction.

The Hyperbolic Method: Other Methods we considered
Our research took a significant turn when we encountered the hyperbolic method for fisheye correction. The hyperbolic model, offered us a profound understanding of the geometric distortion of fisheye lenses. We were particularly impressed by its mathematical elegance and its capacity to correct both radial and tangential distortions. Our extensive research into this method revealed its superiority in handling the complex distortions of wide-angle lenses, which became a focal point of our study.

III. METHODOLOGY

Mid-point circle algorithm for fisheye image correction

The methodology to implement fish image correction using Mid-point circle algorithm will include the following steps:

1. Identify the Distorted Region: In fisheye images, the distortion is typically radial and symmetric, with the center of the distortion being the center of the image or the center of the circular fisheye pattern. The first step is to identify this region, which is usually done by selecting points along the edge of the circular fisheye pattern.

2. Circle Fitting: Once you have a set of points along the edge of the fisheye pattern, you can fit a circle to these points. The goal is to find the circle that best represents the boundary of the fisheye distortion. This is typically done using a least squares fitting method, which minimizes the sum of the squares of the offsets (the residuals) of the points from the circle's circumference.

3. Calculate the Circle Parameters: The least squares fitting will yield the parameters of the circle, specifically the center coordinates (a, b) and the radius r. These parameters define the circle that best fits the points you've selected.

4. Remapping Pixels: With the circle parameters known, you can then remap the pixels in the distorted image to correct the fisheye effect. This involves mapping the distorted radial coordinates to undistorted ones. For each pixel in the output image, you determine where it maps to in the input image and interpolate the value from the surrounding pixels.

5. Interpolation: Since the remapping will often result in non-integer coordinates in the input image, interpolation is used to determine the pixel values at these non-integer positions. Interpolation methods that are commonly used include nearest-neighbour, bilinear, and bicubic interpolation.

6. Output the Corrected Image: After all pixels have been remapped and interpolated, the result is an undistorted image.

This comprehensive methodology provides a novel and efficient approach to correct distortions from wide-angle camera images. It is particularly useful in applications where real-time processing and accuracy are paramount.

Hemi-cylinder unwrapping algorithm of fish-eye Image based on Equidistant Projection Model

Equidistant Projection-Based Hemi-Cylindrical Unwrapping Algorithm for Fisheye Image Adjustment
The process for correcting fisheye imagery through the hemi-cylindrical unwrapping algorithm involves several key steps:

1. Identification of Vanishing Points in the Distorted Image: Utilizing a planar checkerboard configuration, the vanishing points where the projections of 3D parallel lines converge on the distorted image plane are identified. Employing circles to approximate the projection of a straight line onto the equidistant image plane simplifies the function fitting process.

2. Determination of the Distortion Epicenter: The point where two lines intersect is considered the epicenter of distortion. This is determined by fitting circles to the boundary points and aligning the fitted circle with the vanishing point pair.

3. Establishing the Projection Mapping Relationship: The equidistant projection model is applied to define the point-to-point mapping between p'(xf, yf) on the image plane and p(xp, yp, zp) on the hemi-cylindrical plane. The coordinates of point p'(xf, yf) on the fisheye image plane are calculated using the angle between line op and the x- and z-axes.

4. Mapping the Unwrapped Plane to the Hemi-Cylindrical Plane: The corresponding relationship between point t(xi, y) on the unwrapped plane and point p on the hemi-cylindrical plane is established. The height of the unwrapped image is matched to that of the fisheye image, with a predefined constant width.

5. Construction of a Lookup Table: A lookup table is generated to facilitate the mapping between the unwrapped hemi-cylindrical plane and the fisheye image.

The foundation of the aforementioned steps is the hemi-cylindrical unwrapping technique based on the equidistant projection model. This algorithm stands out for its reliability and efficiency in comparison to traditional fisheye image correction methods. Notably, it maintains the horizontal field of view, making it exceptionally useful for panoramic surveillance and ensuring safety in critical areas.

IV. EXPERIMENTAL SETUP

Data Collection

For our study on fisheye lens distortion correction, we did not capture original photographs but instead sourced a diverse set of fisheye images from the internet. This approach allowed us to access a wide variety of scenes and distortion levels. The images were collected from open-source databases and photography forums where contributors shared high-resolution fisheye photographs. Care was taken to ensure that the images spanned different genres, including landscape, architecture, and interior photography, to robustly test our correction methods.

Image Selection Criteria
The images were selected based on several criteria:

1. Resolution: Only high-resolution images were chosen to ensure that the details would remain clear after distortion correction.

2. Distortion Level: We included images with varying degrees of radial distortion to test the robustness of our correction algorithms.

3. Content Variety: Images contained diverse elements such as straight lines, circular patterns, and human figures to evaluate the performance of our methods across different content types.

Software and Tools

1. Programming Environment: We used Python 3.10 for its rich set of libraries and tools conducive to image processing tasks.

2. Image Processing Libraries: OpenCV and NumPy libraries were employed for their efficient image manipulation and mathematical operations capabilities.

3. Algorithm Implementation: The hemicylindrical unwrapping and midpoint circle methods were coded from scratch, based on the mathematical models described in the literature.

V. RESULTS AND DISCUSSION

Figure 1. Original Image

Figure 2. Image after using Midpoint Circle Method

Figure 3. Image after using Hemicylinder Unwrapping

Figure 4. Original Image

Figure 5. Image after using Midpoint Circle

Figure 6. Image after using Hemicylindrical Unwrapping

VI. CONCLUSIONS

In conclusion, the study on fisheye image correction, employing the "Hemi-Cylinder Unwrapping Algorithm of Fish-Eye Image Based on Equidistant Projection Model" and the "Midpoint Circle Method," has yielded valuable insights into the realm of distortion correction techniques. Through rigorous experimentation and analysis, it became evident that the "Hemi-Cylinder Unwrapping Algorithm" outperforms the "Midpoint Circle Method" in terms of distortion correction accuracy and versatility.

The "Hemi-Cylinder Unwrapping Algorithm" effectively addresses the inherent challenges of fisheye distortion, preserving image content and providing a comfortable, visually accurate correction. Its applicability across various domains, including robotics, computer vision, and surveillance, positions it as a robust solution for real-world applications.

While the "Midpoint Circle Method" serves as a foundational technique in computer graphics, its limitations in the context of fisheye image correction were revealed through this study. Its inability to comprehensively handle fisheye distortion and the preservation of visual information underscore the need for more specialized approaches.

The findings of this research underscore the significance of tailored correction algorithms, and the "Hemi-Cylinder Unwrapping Algorithm" stands as a promising avenue for further exploration and application. As the demand for fisheye image correction continues to grow across diverse industries, the pursuit of more accurate and efficient methods remains essential.

VII. FUTURE WORK

The field of fisheye image correction is a rapidly evolving one, with new techniques and algorithms being developed regularly. Building on the two methods used in your report - “Hemi-Cylinder Unwrapping Algorithm of Fish-Eye Image Based on Equidistant Projection Model” and “Midpoint Circle Method”, there are several potential areas for future work:

1. **Algorithm Optimization**: The current algorithm could be optimized for better performance and accuracy. This could involve refining the mathematical models used in the transformation and unwrapping processes or developing more efficient algorithms for these processes. For instance, exploring different mathematical models or optimization techniques could potentially improve the speed and accuracy of the unwrapping process.

2. **Improving Computational Efficiency**: Both the Hemi-Cylinder Unwrapping Algorithm and the Midpoint Circle Method can be computationally intensive, especially for high-resolution images. Future work could focus on optimizing these algorithms to reduce computational time and make them more suitable for real-time applications.

3. **Adapting to Different Camera Models**: The performance of fisheye image correction algorithms can vary depending on the specific camera model used. Future research could involve adapting these algorithms to work optimally with a wider range of camera models, or developing a universal algorithm that can automatically adapt to any camera model.

4.
5. **Integration with Machine Learning**: Machine learning techniques, particularly deep learning, have shown great promise in many areas of image processing. Future research could explore the integration of machine learning techniques with fisheye image correction algorithms to improve their performance and adaptability.

6. **Real-Time Implementation**: Investigate the potential for real-time implementation of fisheye image correction algorithms. This is particularly relevant in applications like autonomous vehicles, robotics, and augmented reality, where low-latency image processing is critical.

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