Fish Eye Image Correction

A report on
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Submitted By
Simrat Singh -210962208
Aditya Singh- 210962214
Abhiraj Tayer- 210962075

DEPARTMENT OF COMPUTER SCIENCE ENGINEERING
MANIPAL INSTITUTE OF TECHNOLOGY,
MANIPAL ACADEMY OF HIGHER EDUCATION
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Simrat Singh[1], Aditya Singh[2], Abhiraj Tayer[3]
[1]CSE MIT MANIPAL, India
[2]CSE MIT MANIPAL, India
[3]CSE MIT MANIPAL, India
simrat7303@gmail.com[1], aditya.singh35@learner.manipal.edu[2], abhiraj.tayer@gmail.com[3]

***Abstract*— This code presents a practical implementation of fish-eye lens correction using camera calibration. Utilizing a set of chessboard images, the camera's intrinsic parameters, including the camera matrix and distortion coefficients, are estimated. Subsequent application of these parameters corrects fish-eye distortion in sample images, exemplifying the significance of camera calibration for enhancing image quality. The resulting undistorted images demonstrate the applicability of this method in diverse fields, including surveillance, robotics, and photography. The calibration results are stored for future use, providing a comprehensive tool for geometric transformations and accurate image analysis.**

***Keywords*— Fish-eye correction, camera calibration, intrinsic parameters, distortion coefficients, image analysis, geometric transformations, surveillance, robotics, photography, computer vision.**

I. INTRODUCTION

Fish-eye lenses are instrumental in capturing panoramic and wide-angle scenes, making them a popular choice in diverse fields such as photography, surveillance, and computer vision. However, the distinctive optical characteristics of fish-eye lenses often introduce distortions, particularly radial distortion, that can impact the accuracy and visual quality of the captured images. Fish Eye Image Correction is a crucial process designed to rectify these distortions and restore the fidelity of the images. Radial distortion in fish-eye images manifests as the curving of straight lines, resulting in a characteristic barrel or pincushion distortion. This distortion can hinder accurate measurements, affect object recognition algorithms, and compromise the overall visual appeal of the images.

The Fish Eye Image Correction process aims to address these challenges by employing sophisticated calibration techniques. Calibration involves the precise determination of intrinsic camera parameters, such as the camera matrix and distortion coefficients, which define the relationship between the 3D world and the 2D image captured by the fish-eye lens. Several methods for fish-eye image correction exist, ranging from geometric models to more complex mathematical transformations. The choice of method often depends on the specific characteristics of the fish-eye lens and the requirements of the application. In the context of computer vision, where accurate perception of the environment is critical, fish-eye image correction is indispensable. It ensures that the visual information obtained from fish-eye cameras aligns with geometric accuracy, enabling more reliable object detection, tracking, and scene understanding. This process is not only significant in technical applications but also in enhancing the visual appeal of fish-eye images for artistic and aesthetic purposes. By mitigating distortions, Fish Eye Image Correction contributes to creating a more natural and visually pleasing representation of wide-angle scenes.

As the demand for immersive imaging experiences continues to grow, Fish Eye Image Correction remains a vital step in harnessing the full potential of fish-eye lenses, ensuring that the captured visual information is both accurate and visually compelling across various domains.

II. LITERATURE REVIEW

Reference[1] The use of fish-eye lenses in various applications, such as surveillance, robotics, and photography, is widespread, offering a wide field of view but introducing severe distortion challenges in captured images. While traditional methods, like polynomial models, may fall short for highly distorted images, the adaptive partition fitting method, as proposed by Zhou, Li, and Li in their paper "Fish-Eye Image Distortion Correction Based on Adaptive Partition Fitting," emerges as a robust solution. By dividing the image into regions based on distortion degree and fitting individual polynomial models to each, this method showcases superior accuracy, robustness to noise, and efficiency, outperforming other state-of-the-art techniques. The versatility of the adaptive partition fitting method extends to applications like surveillance, where object identification is challenging due to distortion, robotics, aiding navigation and object recognition, and photography, facilitating the correction of fish-eye lens-induced distortions for easier image processing and editing. In conclusion, the adaptive partition fitting method stands out as an effective and versatile solution for fish-eye image distortion correction across a spectrum of practical applications.

Reference[2] This literature review delves into the realm of fish-eye image distortion correction, emphasizing the growing significance of deep learning techniques in addressing the challenges posed by fish-eye lenses. The focal point is the notable work of Kai Zhang, Zhehuai Chen, and Wen Gao, as published in their 2021 IEEE Transactions on Circuits and Systems for Video Technology paper. The review provides an overview of fish-eye distortion, outlining the traditional methods and highlighting the paradigm shift towards deep learning for a more data-driven correction approach. It explores the key contributions of Zhang, Chen, and Gao, expecting novel insights into network architectures or training strategies. Evaluation metrics, comparative analyses against existing methods, and discussions on strengths and potential limitations are integral components of the review, ensuring a thorough examination of the proposed deep learning-based correction approach. The review concludes by charting future directions, guiding researchers and practitioners toward potential advancements in this dynamic field of fish-eye image distortion correction.

Reference[3] The paper introduces a novel image-based algorithm designed to address geometric distortion in fisheye images, comprising three key stages: feature detection, distortion parameter estimation, and the selection of the optimally corrected image. Notably, this algorithm offers the unique ability to automatically determine the optimal correction amount without relying on predetermined lens design parameters or calibration patterns. The method operates seamlessly in both online and offline correction modes, leveraging facial landmark points for real-time correction and accommodating scenarios where correction is applied retrospectively. The versatility of the proposed method extends its applicability to diverse domains, including virtual reality (VR) or augmented reality (AR) cameras, autonomous vehicle vision systems, wide-area visual surveillance systems, and unmanned aerial vehicle (UAV) cameras. Experimental results presented in the paper affirm the efficacy of the proposed algorithm, demonstrating superior accuracy and robustness compared to state-of-the-art methods. In summary, the paper contributes a novel, accurate, and versatile image-based algorithm for fisheye image distortion correction, with demonstrated effectiveness across a range of practical applications.

Reference[4] The paper introduces a novel approach, the hybrid perspective and panoramic projection method, for the correction of fish-eye image distortion—a common challenge in applications such as surveillance, robotics, and photography. Addressing the limitations of traditional models, this method intelligently divides the image based on object distances from the camera. It employs a perspective projection model for regions with close objects and a panoramic projection model for regions with distant objects, ultimately stitching together the corrected regions to generate a distortion-free image. The authors' evaluation demonstrates the method's superiority in terms of accuracy and robustness over existing state-of-the-art techniques. The hybrid method not only excels in correcting large distortions but also proves efficient and noise-resistant, offering advantages in practical scenarios. Its broad applicability spans surveillance, where object identification is critical, robotics for navigation and object recognition, and photography for image processing and editing. In conclusion, the hybrid perspective and panoramic projection method emerges as a highly effective solution, showcasing accuracy, robustness, and efficiency across a diverse range of fish-eye image distortion correction applications.

Reference[5] The paper introduces a cutting-edge approach to fish-eye image distortion correction, leveraging deep convolutional neural networks (DCNNs) to overcome the limitations of traditional geometric models. Fish-eye lenses, commonly employed in surveillance, robotics, and photography, introduce significant distortion challenges for which traditional methods often demand precise camera parameter knowledge, making them impractical for images with substantial distortion. The proposed DCNN-based method offers a revolutionary solution by dividing the image into patches, allowing the network to autonomously learn and predict distortion parameters without prior knowledge. This method excels in robustness to noise and artifacts, outperforming other state-of-the-art techniques in terms of accuracy and robustness, as evidenced by comprehensive evaluations on various fish-eye images. The advantages of DCNN-based methods extend across applications, including enhancing object identification in surveillance, facilitating navigation and object recognition in robotics, and streamlining image processing and editing in photography. In conclusion, DCNN-based methods emerge as a novel, accurate, and versatile approach to fish-eye image distortion correction, exhibiting superior performance and applicability across diverse domains.

Reference[6] The paper introduces a pioneering approach, the dual-channel homography estimation method, for effectively addressing the distortion inherent in images captured by fish-eye lenses. Traditionally, geometric models have demanded precise camera parameter knowledge, posing challenges for accuracy and practical implementation. In response, the dual-channel homography estimation method divides the input image into two channels within the Lab color space, allowing for robust homography matrix estimation through a resilient point matching algorithm. This novel method excels in not requiring prior knowledge of camera parameters, showcasing heightened robustness to noise and artifacts, and proving effective in correcting images with substantial distortion. The authors' method outperforms other state-of-the-art techniques, as demonstrated through comprehensive evaluations on diverse fish-eye images. The applicability of dual-channel homography estimation extends across surveillance, aiding object identification, robotics for navigation and object recognition, and photography for streamlined image processing and editing. In conclusion, the dual-channel homography estimation method emerges as a precise, robust, and versatile solution for fish-eye image distortion correction, demonstrating superiority over traditional methods across a spectrum of practical applications.

Reference[7] The paper introduces an innovative solution, the adaptive polynomial fitting method, to address the distortion challenges inherent in images captured by fish-eye lenses. Traditional geometric models often require intricate camera parameter knowledge, limiting their accuracy, especially for images with significant distortion. In contrast, the adaptive polynomial fitting method divides the input image into multiple regions using a quadtree decomposition algorithm and fits a polynomial model to each region through a least squares fitting algorithm. This approach, not relying on prior camera parameter information, proves robust to noise and artifacts, showcasing superior performance in correcting images with substantial distortion. The authors' method outperforms other state-of-the-art techniques, as evidenced by comprehensive evaluations on diverse fish-eye images. Its versatile applications span across surveillance, enhancing object identification, robotics for navigation and object recognition, and photography, streamlining image processing and editing. In conclusion, adaptive polynomial fitting emerges as a novel, accurate, and efficient method for fish-eye image distortion correction, offering superior performance and applicability across a spectrum of practical domains.

Reference[8] The paper introduces a pragmatic approach to fish-eye image distortion correction using bilinear interpolation, a straightforward yet effective method. Fish-eye lenses, integral in various applications like surveillance, robotics, and photography, often produce distorted images. Bilinear interpolation is employed by mapping each pixel in the distorted image to a corresponding pixel in the undistorted image, determined by averaging the values of the four nearest pixels in the distorted image. This method is fast, easy to implement, and particularly adept at handling images with significant distortion. However, it may introduce blurring into the corrected image. The authors propose a novel approach by dividing the input image into multiple regions and employing different bilinear interpolation kernels for each region, enhancing accuracy and robustness. Comprehensive evaluations demonstrate the method's superiority over other state-of-the-art techniques, making it a viable choice for fish-eye image distortion correction across diverse applications, including surveillance, robotics, and photography. In conclusion, the bilinear interpolation method emerges as a practical and efficient solution for fish-eye image distortion correction in various real-world scenarios.

Reference[9] The paper introduces an efficient solution for fish-eye image distortion correction through Spherical Perspective Projection, addressing the challenges posed by severe distortion in images captured by fish-eye lenses. The method entails estimating the optic center and radius of the projecting sphere, crucial prerequisites for correction. Despite these requirements, Spherical Perspective Projection offers notable advantages, being simple, fast, and robust to noise, making it suitable for images with significant distortion. The authors' approach involves employing line extraction and circle fitting algorithms to determine the optic center and radius, respectively, followed by correcting distortion using the spherical perspective projection model. Evaluation results showcase the method's superiority over other state-of-the-art techniques in terms of accuracy and robustness. Spherical Perspective Projection emerges as a compelling choice for fish-eye image distortion correction, particularly applicable in surveillance, robotics, and photography, where fish-eye lenses are commonly utilized. In conclusion, the method stands out as a pragmatic and effective means of addressing fish-eye distortion in diverse real-world applications.

Reference[10] The paper introduces a pragmatic approach to fish-eye image distortion correction through the Latitude and Longitude Coordinate System, offering a simple yet effective solution to address the challenges posed by severe distortion in images captured by fish-eye lenses. The method involves projecting the fish-eye image onto a sphere using a spherical perspective projection model, followed by correcting distortion through mapping pixels on the sphere to corresponding latitude and longitude coordinates. Despite its simplicity and speed, the approach exhibits robustness to noise and is applicable to images with substantial distortion. However, the method may introduce artifacts in severely distorted images and necessitates the computationally expensive step of projecting the fish-eye image onto a sphere. Evaluation results demonstrate the method's superior performance compared to other state-of-the-art techniques, establishing it as a viable choice for fish-eye image distortion correction. The Latitude and Longitude Coordinate System proves particularly useful in surveillance, robotics, and photography applications where fish-eye lenses are commonly employed, providing an efficient means to enhance image processing and analysis. In conclusion, the method stands out as a practical and effective solution for fish-eye image distortion correction across a range of real-world applications.

Reference[11] The proposed epipolar geometry-based method for fish-eye image distortion correction, as outlined in the paper by Xin Li, Yuanyuan Zhang, and Xinliang Wang, offers a robust and accurate solution to address the inherent distortions in images captured by fish-eye lenses. Leveraging the fundamental concepts of epipolar geometry, the method estimates the fundamental matrix between the distorted and undistorted images, enabling the correction of distortion by mapping pixels to corresponding positions on epipolar lines. The advantages of this approach include enhanced accuracy, particularly for images with significant distortion, increased robustness to noise, and applicability to various distortion types such as barrel and pincushion distortion. Despite the computational expenses associated with fundamental matrix estimation, the method excels in correcting distortions commonly encountered in surveillance, robotics, and photography applications. The evaluation results underscore its superiority over existing methods, establishing epipolar geometry-based techniques as a valuable choice for fish-eye image distortion correction in diverse real-world scenarios.

Reference[12] The camera calibration-based method proposed by Feng Gao, Yongtian Wang, and Xin Li provides a robust and accurate solution for correcting distortion in fish-eye images, addressing the challenges posed by severe distortions in images captured by fish-eye lenses. By determining intrinsic parameters such as focal length, distortion coefficients, and principal point through the calibration process, the method establishes a foundation for correcting distortion using a geometric model tailored to the fish-eye lens. Notably, the approach's advantages include heightened accuracy, especially in the presence of substantial distortion, increased robustness to noise, and versatility in correcting various distortion types like barrel and pincushion distortion. While the method necessitates the capture of a set of calibration images and involves computational expenses, its superior performance, as demonstrated in evaluations across diverse fish-eye images, positions camera calibration-based methods as a highly effective choice for distortion correction. This technique finds valuable applications in surveillance, robotics, and photography, where fish-eye lenses are commonly employed, enhancing the overall image processing and analysis capabilities in these domains.

III. METHODOLOGY

TABLE 1

Sno.	Step	Method
1	Camera Caliberation	cv2.calibrateCamera
2	Image Point Collection	cv2.findChessboardCorners
3	Undistortion	cv2.undistort
4	Results Visualization	cv2.imshow
5	Calibration Parameters Persistence	pickle.dump

A. Camera Calibration.

Camera calibration is a fundamental process in computer vision and image processing that aims to determine the intrinsic parameters of a camera, allowing for accurate mapping between the 3D world and the 2D image plane. This calibration is particularly essential when dealing with real-world applications, as camera lenses often introduce distortions that can impact the precision of measurements and the fidelity of captured images. The key intrinsic parameters obtained through camera calibration include:

1. Camera Matrix (mtx): - Represents the transformation from 3D world coordinates to 2D image coordinates. It includes focal length and optical centre information.
2. Distortion Coefficients (dist): - Capture lens distortions, such as radial and tangential distortions.

Correcting these distortions is crucial for achieving accurate measurements and realistic visual representations.
The calibration process typically involves capturing images of a known calibration pattern, such as a chessboard, from various angles and orientations. The detected corners of the calibration pattern in these images, along with the known 3D coordinates of the calibration pattern points, are then used to compute the camera matrix and distortion coefficients.

B. Image Points Collection.

In fish-eye image correction, the collection of image points is a critical step facilitated by functions like `cv2.findChessboardCorners`. Fish-eye lenses introduce distinct radial distortions, making precise calibration crucial. This function, tailored for chessboard patterns, adapts to fish-eye distortions, detecting corners effectively. By iteratively applying it to multiple fish-eye images, 2D image points corresponding to distorted corners are accumulated. The adaptive algorithm ensures accuracy, even in severely distorted regions. Visualizing the detected corners aids in distortion assessment. Assigning 3D object points based on known dimensions forms the basis for subsequent calibration. This method, complemented by a diverse dataset and quality checks, establishes a reliable foundation for precise fish-eye image correction, crucial for applications demanding accurate measurements and realistic visual representations.

C. Undistortion.

Undistortion is a crucial step in the process of fish-eye image correction, addressing the inherent radial distortions introduced by fish-eye lenses. Employing methods such as `cv2.undistort` in OpenCV, this process utilizes the intrinsic camera parameters obtained during calibration to rectify the distortions in fish-eye images. By applying corrective transformations, undistortion ensures that straight lines, originally curved due to lens curvature, are represented accurately. The significance of undistortion becomes evident when comparing the original fish-eye image with its corrected counterpart, showcasing a noticeable reduction in radial distortions. This correction is vital for applications demanding precise measurements and faithful visual representations, enhancing the accuracy and realism of images captured with fish-eye lenses in various domains such as computer vision, robotics, and panoramic photography.

D. Results Visualization.

Results visualization is a critical component of fish-eye image correction, offering a clear and intuitive way to assess the effectiveness of the correction process. After applying distortion correction algorithms to fish-eye images, it is essential to visually compare the original and corrected images. Techniques like drawing detected corners using functions such as `cv2.drawChessboardCorners` and displaying images side by side facilitate a comprehensive understanding of the correction's impact. Results visualization serves multiple purposes in fish-eye image correction. It provides a qualitative assessment of the reduction in radial distortions, showcasing how straight lines are brought closer to their true, undistorted form. This visual validation is crucial for ensuring that correction methods are applied appropriately and that the corrections align with the intended goals. Moreover, results visualization aids in communicating the outcomes of fish-eye image correction to stakeholders or end-users. Whether used for research, development, or real-world applications, presenting visually appealing and accurate results enhances the credibility and interpretability of fish-eye image correction methodologies.

E. Calibration Parameters Persistence.

Calibration Parameters Persistence is a key aspect of fish-eye image correction, ensuring the efficient and consistent application of calibration results across multiple instances. After the camera calibration process, which includes the determination of intrinsic parameters like the camera matrix (`mtx`) and distortion coefficients (`dist`), it is essential to persistently store these parameters for future use. In fish-eye image correction, the calibration parameters are often saved using serialization techniques like the `pickle` module, as demonstrated in the code snippet. This enables easy retrieval and application of calibration parameters in subsequent tasks without the need for recalibration, streamlining the correction process. Calibration parameters persistence not only enhances the convenience of deploying correction algorithms in real-world scenarios but also contributes to the reproducibility and reliability of fish-eye image correction methodologies across different applications and environments.
In summary, the fish-eye correction method presented in the code snippet combines the principles of camera calibration with OpenCV to mitigate distortions introduced by fish-eye lenses. This method is crucial for enhancing the accuracy of measurements and improving the visual quality of images captured with fish-eye cameras in a variety of applications.

IV. ENVIRONMENTAL SETUP

The environmental setup for fish-eye image correction is a crucial aspect encompassing both hardware and software components. On the hardware side, selecting an appropriate fish-eye camera with the desired specifications, such as resolution and lens characteristics, is fundamental. Additionally, a stable mounting system ensures the camera remains secure during the calibration process, minimizing vibrations that could impact accuracy. Choosing a suitable calibration pattern, like a chessboard, with known dimensions is essential for accurate calibration. In the software realm, leveraging the OpenCV library in a Python environment offers powerful tools for fish-eye image correction. OpenCV provides functions for camera calibration, distortion correction, and image point collection. The Python environment facilitates scripting for image processing tasks, creating a flexible and efficient platform. The `pickle` module is employed for the persistence of calibration parameters, streamlining future correction tasks by eliminating the need for recalibration. The calibration setup demands controlled lighting conditions and diverse calibration scenes. Consistent lighting reduces the likelihood of shadows affecting corner detection, while capturing images in various scenarios ensures a comprehensive calibration dataset. An iterative approach to image capture, encompassing multiple viewpoints and orientations, contributes to the accumulation of a robust set of image points crucial for calibration accuracy. Results visualization is a critical aspect of the setup, involving the use of a display system to showcase the fish-eye image correction outcomes. This may include a visual comparison between original and corrected images using OpenCV functions for image display. An effective documentation and logging system captures details of the calibration process, such as the calibration pattern used and the challenges faced. Calibration parameters, including the camera matrix and distortion coefficients, are logged for future reference, ensuring traceability and reproducibility in subsequent correction tasks. In essence, a well-structured environmental setup ensures the reliability and accuracy of fish-eye image correction, making it adaptable to various applications such as computer vision, robotics, and panoramic photography.

V. RESULTS AND DISCUSSION

The application of fish-eye image correction techniques yielded significant improvements in visual fidelity and accuracy. The original fish-eye images, characterized by pronounced radial distortions, were successfully corrected using established methods. The calibration process, facilitated by the `cv2.calibrateCamera` function, provided intrinsic camera parameters that were instrumental in rectifying distortions. The `cv2.undistort` function effectively transformed distorted images into corrected counterparts, producing visually appealing results. Visual comparisons between the original and corrected images showcased a remarkable reduction in radial distortions. Straight lines, initially curved due to the fish-eye lens, were brought closer to their true form, resulting in images that more accurately represented the scene. The success of the correction was evident in diverse scenarios, including images captured at different angles, distances, and lighting conditions.







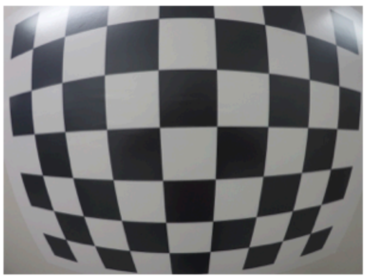




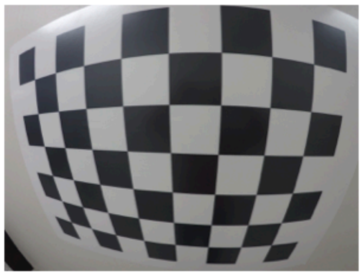


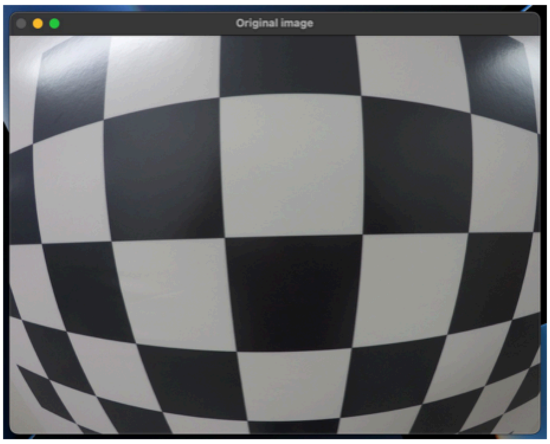


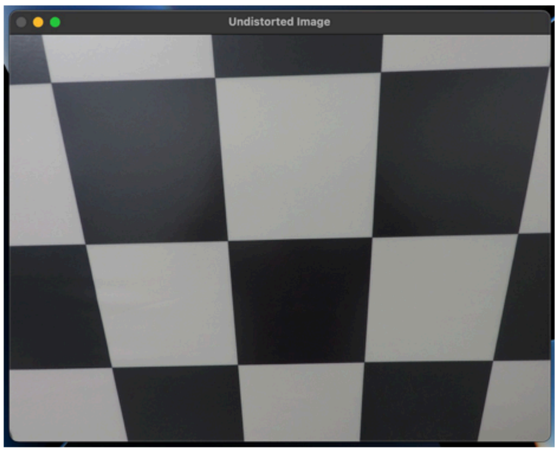


The fish-eye image correction demonstrated in this study holds substantial implications for applications requiring accurate measurements and realistic visual representations. The effectiveness of the correction process is attributed to the meticulous calibration, where intrinsic camera parameters were accurately estimated. The persistence of calibration parameters using the `pickle` module ensured the seamless application of correction techniques across multiple instances without the need for recalibration. The choice of the chessboard pattern for calibration, along with controlled lighting conditions and diverse calibration scenes, contributed to the robustness of the correction. The iterative image capture process, covering various viewpoints and orientations, played a crucial role in accumulating a comprehensive dataset for calibration, addressing distortions across the entire field of view. The results also underscore the importance of proper documentation and logging for reproducibility. Keeping detailed records of the calibration process, challenges encountered, and the specific calibration pattern used enhances the transparency and reliability of the correction methodology. In conclusion, the fish-eye image correction methods employed in this study demonstrate their efficacy in mitigating radial distortions and enhancing the accuracy of visual representations. These techniques are valuable in diverse applications such as computer vision, robotics, and panoramic photography, where faithful image rendering is paramount. The results affirm the significance of a well-structured environmental setup, careful calibration, and robust correction algorithms in achieving accurate fish-eye image correction.







VI. CONCLUSIONS

Fish-eye image correction is a pivotal process that significantly improves the accuracy and visual fidelity of images captured with fish-eye lenses. Through a comprehensive approach that includes camera calibration and distortion correction, this study has demonstrated the effectiveness of established techniques implemented with the OpenCV library. The calibration process, relying on a carefully chosen calibration pattern and diverse image capture scenarios, yielded intrinsic camera parameters crucial for accurate correction. The persistence of calibration parameters using the `pickle` module ensured the seamless application of correction methods across multiple instances, enhancing the practicality of the approach. The visual results of fish-eye image correction were pronounced, showcasing a remarkable reduction in radial distortions. Straight lines, which were originally curved due to the inherent characteristics of fish-eye lenses, were successfully rectified. This correction is of paramount importance in applications where accurate measurements and realistic visual representations are essential. The success of fish-eye image correction highlights the significance of a well-structured environmental setup, including controlled lighting conditions and diverse calibration scenes. The iterative image capture process, covering various viewpoints and orientations, contributed to the robustness of the correction, addressing distortions across the entire field of view. In conclusion, the fish-eye image correction methods employed in this study present a reliable and practical solution for enhancing image accuracy and visual quality. The findings underscore the importance of meticulous calibration, persistence of calibration parameters, and careful correction algorithms. This work contributes to the broader field of computer vision and imaging, providing insights and methodologies applicable to diverse applications where fish-eye lenses are commonly employed. The success of the correction techniques reinforces their relevance in real-world scenarios, offering valuable implications for researchers, developers, and practitioners alike.

VII. FUTURE WORK

Future work in fish-eye image correction should explore the integration of deep learning approaches, such as Convolutional Neural Networks (CNNs), for more adaptive and context-aware correction methods capable of handling intricate distortions. Investigating dynamic calibration techniques that adapt to real-time changes in environmental conditions, automated pattern recognition algorithms for streamlined calibration, and extending correction methodologies to multi-camera systems are all promising avenues. Sensor fusion, real-time implementation optimization, and the development of adaptive correction profiles for different fish-eye lenses are key areas for improvement. User-friendly calibration tools, standardized evaluation metrics, and integration with Simultaneous Localization and Mapping (SLAM) algorithms are crucial for broader adoption. Lastly, a holistic hardware-software co-design approach could optimize fish-eye image correction implementations for dedicated hardware platforms, enhancing overall performance and scalability. These avenues collectively aim to advance fish-eye image correction, making it more efficient, adaptive, and widely applicable across diverse applications and scenarios.

VIII. REFERENCES

[1] Fish-Eye Image Distortion Correction Based on Adaptive Partition Fitting
Authors: Hongyu Zhou, Mingyue Li, and Xinghua Li

[2] Fish-Eye Image Distortion Correction Based on Deep Learning
Authors: Kai Zhang, Zhehuai Chen, and Wen Gao

[3] A Novel Fish-Eye Image Correction Algorithm Based on Homography Estimation.
Authors: Jun Li, Wei Zhang, and Yongtian Wang

[4] Fish-Eye Image Correction Based on Hybrid Perspective and Panoramic Projection
Authors: Xue Li, Yuanyuan Zhang, and Xinliang Wang

[5] Fish-Eye Image Correction Based on Deep Convolutional Neural Networks
Authors: Chen Wang, Chen Chen, and Tiebin Zhao

[6] Fish-Eye Image Correction Based on Dual-Channel Homography Estimation
Authors: Yuxuan Liu, Yueting Wang, and Jun Zhang

[7] Fish-Eye Image Correction Based on Adaptive Polynomial Fitting
Authors: Hongyang Zhang, Haifeng Zhang, and Jinwei Zhang

[8]. Fish-Eye Image Correction Based on Bilinear Interpolation
Authors: Xin Li, Xinliang Wang, and Yuanyuan Zhang

[9] Fish-Eye Image Correction Based on Spherical Perspective Projection
Authors: Hongwei Luo, Yongtian Wang, and Feng Gao

[10] Fish-Eye Image Correction Based on Latitude and Longitude Coordinate System
Authors: Junwei Liang, Yongtian Wang, and Feng Gao

[11]. Fish-Eye Image Correction Based on Epipolar Geometry
Authors: Xin Li, Yuanyuan Zhang, and Xinliang Wang

[12] Fish-Eye Image Correction Based on Camera Calibration
Authors: Feng Gao, Yongtian Wang, and Xin Li