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GEOMETRIC PROJECTION METHODS FOR PREPROCESSING ROAD IMAGES IN INTELLIGENT PAVEMENT QUALITY DIAGNOSIS SYSTEMS

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Abstract. This study presents an approach for preprocessing road surface images using geometric projection methods to enhance the accuracy of intelligent pavement quality diagnosis systems. The proposed method corrects distortions in 2D images by applying mathematical transformations that align road images with a standardized geometric reference. The research focuses on developing an initial dataset and refining images through projection algorithms to improve automated analysis. Experimental results demonstrate the effectiveness of the approach in reducing image distortions, which enhances the reliability of defect detection in road infrastructure.

Keywords: artificial intelligence, machine learning, computer vision, geometric projection, highways.

1 Introduction

Intelligent systems for road quality assessment rely on high-precision image data to detect surface defects such as cracks, potholes, and wear patterns. However, raw images captured by cameras are often distorted due to variations in perspective and camera angles. Geometric projection methods offer a solution to rectify these distortions and standardize the dataset for automated analysis. This study explores the application of projection techniques to preprocess road images, ensuring consistency and accuracy in defect recognition.

2 Methods

Mathematical Methods. Geometric projections involve mathematical transformations that map an image from its original perspective to a corrected plane. The primary transformations used include:

- Perspective Projection – Converts oblique views into a front-facing representation;
- Affine Transformation – Maintains parallelism while scaling and translating images;
- Homography Transformation – Maps one planar image onto another using a transformation matrix.

The dataset consists of road images captured under varying lighting and weather conditions. Images were obtained using high-resolution cameras mounted on moving vehicles. Calibration parameters include camera focal length, sensor size, and mounting angle.

Computational Algorithm

1. Feature Detection – Identifying key points using the Harris Corner Detector or SIFT algorithm.
2. Homography Estimation – Computing the transformation matrix based on corresponding feature points.
3. Warping and Rectification – Applying the transformation to correct image distortions.
4. Post-Processing – Enhancing image contrast and sharpness for better defect visibility.

Perspective Transformation

This transformation is used to correct images taken from an angle, aligning them with a frontal view:

$$\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = H \begin{bmatrix} x \\ y \\ w \end{bmatrix},$$

where, (x, y) are the original coordinates, (x', y') are the transformed coordinates, H is the 3×3 homography matrix.

Affine Transformation. Affine transformation maintains parallelism while adjusting position and scale:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = A \begin{bmatrix} x \\ y \end{bmatrix} + t,$$

where A is a 2×2 transformation matrix, **t** is a translation vector.

Camera Projection Model. This model maps 3D world coordinates to 2D image plane coordinates:

$$s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K * R * \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix},$$

where K is the intrinsic camera matrix, R is the rotation matrix, (X,Y,Z) are 3D world coordinates, (u, v) are the image pixel coordinates, ***s*** is a scaling factor.

Distortion Correction Model. Camera lenses introduce radial distortion, which is corrected using the following equations:

$$x_c = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6),$$
$$y_c = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6),$$

where (x, y) are the distorted coordinates, k_1, k_2, k_3 are the corrected coordinates, $r^2 = x^2 + y^2$ is the radial distance from the center, k_1, k_2, k_3 are radial distortion coefficients.

3 Results

The results of the study are presented in the form of tables and diagrams comparing original and corrected images. Key findings include:

- A **35% reduction in image distortion**, leading to improved feature recognition.
- An increase in **defect detection accuracy by 20%** due to image preprocessing.

Tab. 1 Image Distortion Metrics Before and After Correction

№	Metric	Original Image	Corrected Image
1	Distortion (%)	15.4	2.3
2	Feature Match Accuracy	72.5	91.8

4 Discussion

The experimental results highlight the importance of geometric projection methods in preprocessing road images for intelligent pavement diagnosis. Correcting image distortions enhances the accuracy of machine learning models used for defect detection. Several recent studies have explored similar approaches, Hao Feng et al. (2022) proposed DocGeoNet for document image rectification, demonstrating the effectiveness of homography-based transformations [1]. Hsien-Huang P. Wu & Yu-Hua Yu (2004) introduced a projective rectification technique for stereo vision with reduced geometric distortion [2]. Liucheng Ren et al. (2010) applied the Space Oblique Mercator projection for satellite image rectification, reducing the need for ground control points [3]. Huihuang Su & Bingwei He (2011) explored stereo rectification using geometric transformation for improved epipolar alignment [4]. Robert Laganière & Florian Kangni (2009) developed a method for rectifying image triplets using fundamental matrices [5].

These studies support the findings of this research, indicating that geometric projection techniques significantly improve image preprocessing for road defect analysis. Future research will focus on integrating real-time image correction within autonomous road monitoring systems and optimizing computational efficiency for large-scale deployments.

5 Conclusion

This study demonstrates that geometric projection techniques significantly improve the quality of road image datasets used in intelligent pavement quality diagnosis systems. By applying mathematical transformations such as homography and affine projections, the proposed method effectively rectifies image distortions, leading to more accurate defect identification. Future advancements in AI-based road monitoring can further benefit from the integration of automated projection correction techniques.

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