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Introduction

In this lab, a structure from motion program is designed to reconstruct a 3D scene from a pair of images captured by a calibrated camera. The process involves a series of steps, including the detection and matching of features in the images, camera calibration, estimation of fundamental and essential matrices, computation of rotation and translation matrices, and finally, the triangulation of 3D points in the scene.

Chessboard Corner Detection

Corners of a chessboard pattern are effectively detected in a set of images provided in the 'boards' directory. It employs the OpenCV function ‘findChessboardCorners’ and utilizes subpixel refinement techniques to enhance accuracy in corner detection.

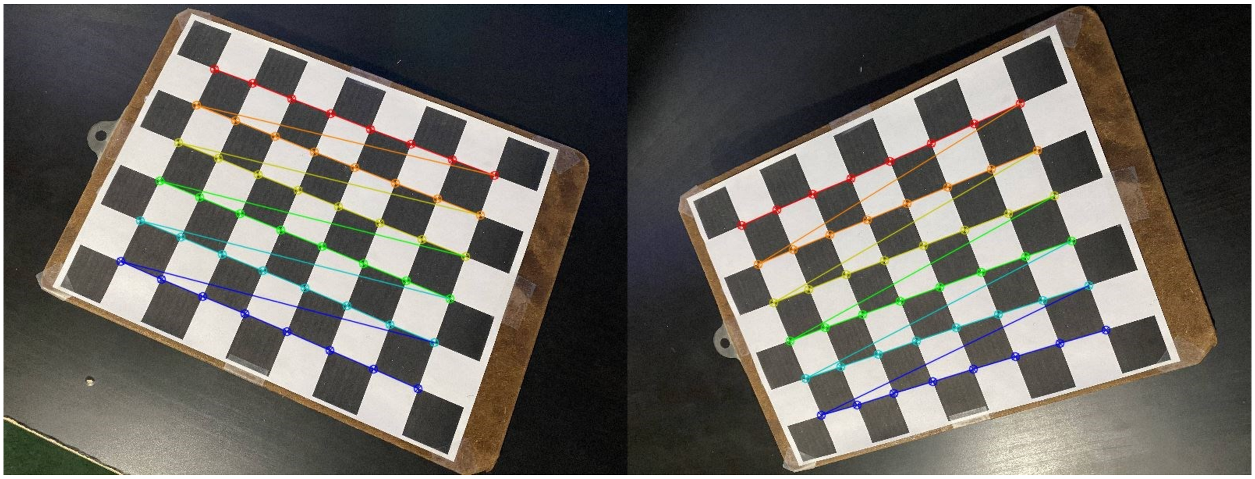

Image 1: Chessboard calibration method

Camera Calibration

The camera calibration process revolves around determining the intrinsic matrix using the OpenCV ‘calibrateCamera’ function. The resulting calibration matrix is crucial for understanding the camera's internal parameters and is saved to a file.

Feature Matching

Feature matching is a critical step in the SfM process, accomplished through the SIFT algorithm. Also, FLANN is employed to efficiently match distinctive features between the two scenes. These algorithms identify and match features between the scene images, filtering matches based on the ratio of distances between the two nearest neighbors.

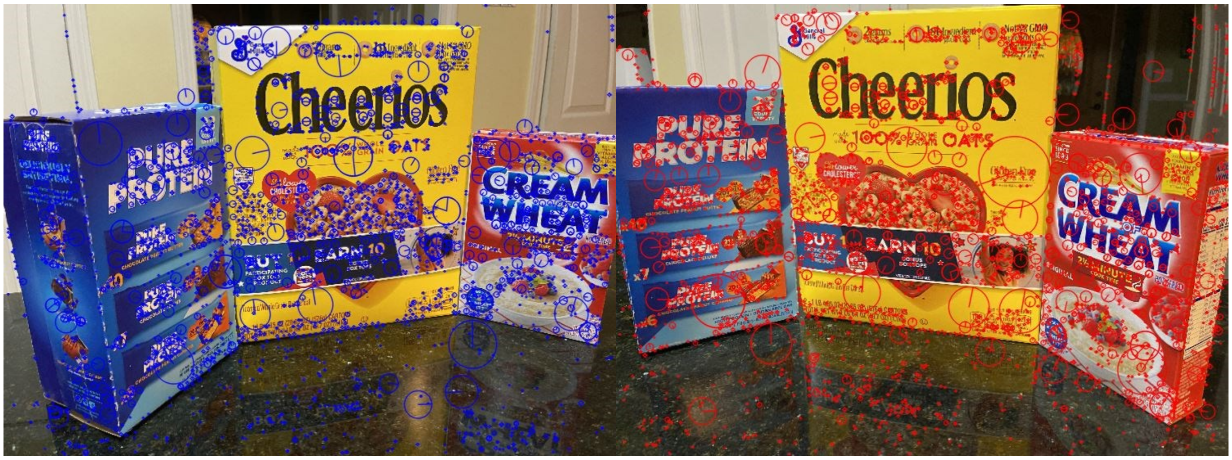

Image 2: SIFT features of scene images

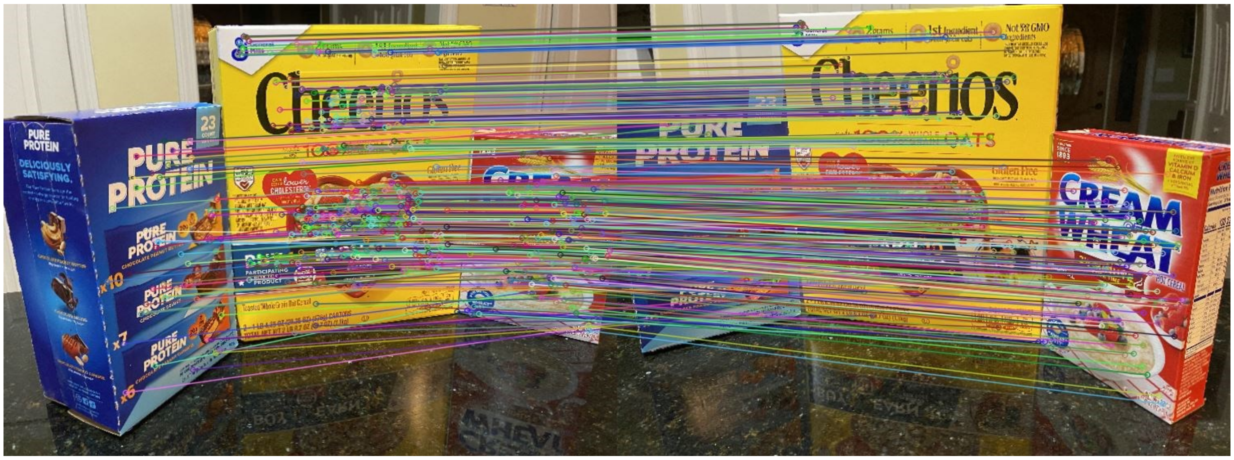

Image 3: FLANN feature correspondences

Fundamental and Essential Matrices

The fundamental matrix is computed using RANSAC, which is needed to relate points in the scenes. Subsequently, the essential matrix is derived from the fundamental matrix and calibration matrix, encapsulating the intrinsic geometry of the scene. Also, the program checks the epipolar constraint using the relation between the essential and fundamental matrices and verifies the determinant of the essential matrix is zero.

Rotation and Translation Matrices

Rotation and translation matrices are derived by decomposing the essential matrix, providing a transformation between the two camera views.

Projection Matrices

Projection matrices, one for each camera, are computed to represent the transformation from 3D world coordinates to 2D image coordinates. To resolve ambiguity for the second camera, four different possible projection matrices are considered.

Triangulation

Triangulation is employed to estimate the 3D coordinates of the scene points. The linear least-squares method is utilized to optimize the reconstruction by minimizing the difference between the observed and calculated image coordinates.

Reprojection Error

The reprojection error for each camera is calculated, quantifying the disparity between the detected feature points and the projected 3D points. This analysis ensures the accuracy and reliability of the reconstructed 3D points in both cameras. However, the obtained reprojection errors for both cameras were unexpectedly high. Several factors could contribute to this outcome including correspondence accuracy, calibration errors, ambiguity in scene geometry, or outlier rejection thresholds.

Point Cloud Visualization

The Open3D library is employed for visualizing the reconstructed 3D points as a point cloud. Two distinct views, a front view and a top view, provide comprehensive insights into the spatial structure and geometry of the reconstructed scene.

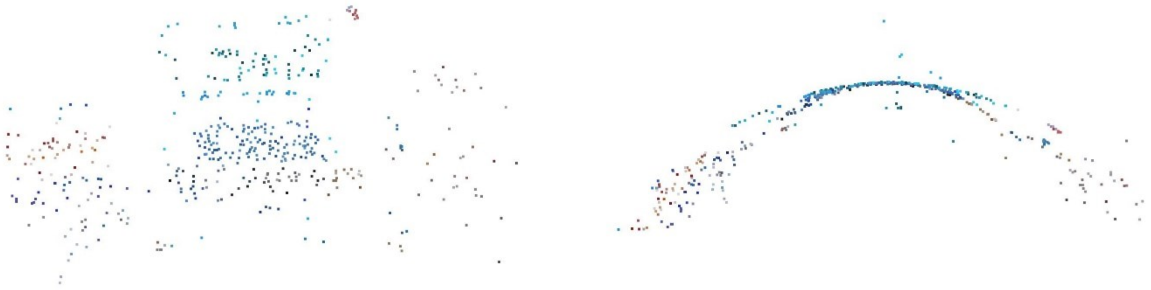

Image 4: Front and top 3D point clouds

Point Cloud File Saving

The program saves the point cloud to a file with added color information. The colors are determined based on the dominant color of features in the original images, enhancing the visual representation of the reconstructed scene.

Conclusion

This structure from motion program demonstrates the reconstruction of a 3D scene from a pair of images. Through calibration, feature matching, matrix estimation, and triangulation, the program provides an accurate representation of the scene's geometry. Visualizations and reprojection error analysis contribute to the program's effectiveness as a powerful tool for 3D scene reconstruction.