Phase_1

Submitted to:

Dr. Mahmoud Ibrahim Khalil

Eng: Ali Ahmed Ali

Eng: Dina Zakaria Mahmaud

Submitted by:

Nagy Ahmed Nagy	23p0365
Abdelrhman Mohammed Mahmoud Salah	23p0370
Ahmed Mosta Gomaa	23p0375
John George Mikhael	23P0266
Peter Maged Shokry	23p0192

1. Introduction

The purpose of Milestone 1 is to preprocess the jigsaw puzzle dataset using classical computer vision techniques in preparation for later assembly and matching tasks. This stage focuses on enhancing image quality, reducing noise, segmenting puzzle regions, extracting contours, and generating all necessary artifacts required for geometric analysis in the next milestone.

No machine learning or deep learning methods were used, as required by the course. Instead, the entire pipeline relies solely on deterministic and interpretable image processing operations provided by OpenCV and NumPy.

The outputs produced in this milestone clean patches, binary masks, Sobel edge images, morphological results, and extracted contours serve as essential inputs for shape descriptor computation and rotation-invariant matching in Milestone 2.

2. Techniques Attempted and Why They Were Chosen

2.1 CLAHE (Contrast Enhancement)

CLAHE was applied to the grayscale patch to correct illumination inconsistencies and enhance local contrast. It was chosen because jigsaw puzzle images often contain shadows or low-contrast regions, and CLAHE improves edge visibility without excessively amplifying noise.

2.2 Gaussian Smoothing (Noise Reduction)

Gaussian blur was used before thresholding to suppress high-frequency noise. Although bilateral filtering preserves edges better, Gaussian smoothing provided stable results while maintaining good runtime efficiency when processing many patches.

2.3 Adaptive Thresholding

Adaptive Gaussian thresholding was used to generate binary masks. This technique calculates thresholds locally, making it robust against uneven lighting across the dataset. It outperforms global thresholding (e.g., Otsu) in cases where brightness varies significantly within the image.

2.4 Morphological Cleaning

A morphological opening operation with a 3×3 kernel was performed to remove small, isolated noise in the thresholded mask. This step ensures that the segmentation focuses on meaningful structures and reduces the risk of detecting invalid contours.

2.5 Sobel Edge Detection

Sobel filters were applied in both the x and y directions, and the gradient magnitude was computed and normalized. Sobel edges help highlight structural boundaries and serve as useful inputs for accurate contour extraction.

2.6 Contour Extraction

Contours were extracted using RETR_EXTERNAL to obtain only the outer boundary in each patch. The largest contour was selected to eliminate false detections caused by noise. This contour forms the basis for later shaped descriptor computation.

2.7 Fourier Descriptor Calculation

Each contour was converted into a complex number representation and transformed using the Fast Fourier Transform (FFT). The first set of coefficients was retained and normalized to create a rotation- and scale-invariant descriptor. These descriptors will be used in Milestone 2 for comparing puzzle piece shapes.

2.8 Patch-Based Image Splitting

Each full puzzle image was divided into an N×N grid of patches. Preprocessing, contour extraction, and descriptor generation were performed on each patch independently. This simplified the processing pipeline and allowed efficient analysis of localized regions.

3. Failure Cases Encountered

3.1 Missing or Weak Contours

Some patches exhibited low contrast or lacked clear puzzle boundaries, resulting in weak or missing contours even after enhancement. CLAHE improved this issue but did not completely eliminate it.

3.2 Noise-Induced False Contours

Variations in lighting sometimes introduced noise within the thresholded image, creating additional false contours. Morphological opening removed most small artifacts but could not fully remove noise in extreme cases.

3.3 Patch Boundary Cuts

Since the image is divided into uniform patches, some puzzle pieces were unintentionally split across patch boundaries. This produced incomplete contours that do not represent the full shape of the piece. This limitation will be addressed in future phases through full-piece segmentation instead of grid partitioning.

4. Suitability of Produced Artifacts for Later Assembly

The artifacts generated in Milestone 1 are highly suitable for the next stage of the project:

- **Clean and consistent binary masks**

These support reliable contour extraction and make the segmentation deterministic.

- **Sobel edges and enhanced patches**

These highlight boundary information that will be used for shape analysis.

- **Extracted contours**

  Contours provide the geometric structure needed for rotation-invariant comparison.

- **Fourier descriptors**

  Although not required for Milestone 1, they form the mathematical representation needed for matching puzzle edges in Milestone 2.

- **Organized output folders**

  The saved raw patches, processed edges, and descriptors improve reproducibility and simplify debugging.

5. Conclusion

Milestone 1 successfully achieves its goal of preparing the jigsaw puzzle dataset for advanced analysis. The implemented pipeline performs enhancement, denoising, thresholding, morphological operations, contour extraction, and descriptor computation. Although patch-based segmentation introduces some limitations—such as partial contours at patch boundaries, the produced artifacts meet the milestone requirements and are suitable for use in Milestone 2.

The dataset is now fully prepared for rotation-invariant shape descriptor analysis and puzzle edge matching in the next phase.