

Jigsaw Puzzle Solver

Milestone 1 Report



Team No: **5**

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Course: **Image Processing CSE381 (UG2023)**

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Project GitHub Repo : <https://github.com/karimsamer100/Image-Processing-Jigsaw-Puzzle-Solver-Project>

1. Overview

This milestone focuses on preparing jigsaw puzzle images for assembly analysis in Milestone 2. The pipeline processes grid-based puzzles (2×2 , 4×4 , 8×8) through segmentation, enhancement, edge detection, and descriptor extraction, producing artifacts suitable for edge matching algorithms.

2. Techniques and Justification

2.1 Grid-Based Segmentation

Technique Used: Direct mathematical grid splitting based on known puzzle dimensions.

Justification: The dataset contains perfectly aligned rectangular grids. Mathematical division ($\text{cell_height} = \text{image_height} \div \text{rows}$) provides 100% accuracy, preserves exact boundaries, and is computationally efficient.

Alternative Attempted - Contour Detection:

- Problem: Internal texture edges detected as separate contours
- Problem: Touching pieces created merged regions requiring complex separation heuristics
- Result: Abandoned for deterministic grid splitting

2.2 Image Enhancement

Technique Used: CLAHE (Contrast Limited Adaptive Histogram Equalization)

- Clip limit: 2.0
- Tile grid: 8×8

Justification: Enhances local contrast without over-amplifying noise, improving edge visibility for descriptor extraction across varied lighting conditions.

Alternatives Attempted:

1. Bilateral Filter
 - Problem: No significant improvement in descriptor quality
 - Impact: Added 3-5x computational overhead
 - Result: Removed
2. Unsharp Masking (CLAHE + Gaussian blur subtraction)
 - Problem: Over-sharpened edges, creating false contours and halo artifacts
 - Impact: Would corrupt gradient calculations in MS2
 - Result: Abandoned

2.3 Background Removal

Technique Used: Adaptive Gaussian Thresholding

- Block size: 35×35
- Constant: 5
- Pre-processing: Gaussian blur (5 \times 5 kernel)

Justification: Handles varying illumination through local thresholds, producing smooth transitions without fragmenting pieces.

Alternatives Attempted:

1. Otsu's Global Thresholding
 - Problem: Failed on bimodal images (bright/dark regions)
 - Impact: Either lost foreground or retained excessive background
 - Result: Replaced with adaptive method
2. HSV Color Segmentation
 - Hard-coded ranges: [0,0,200]–[180,30,255]
 - Problem: Removed dark puzzle content (shadows, night scenes)
 - Result: Produced entirely black masks

3. Canny + Largest Component Filtering
 - o Problem: Detected only 3-4 tiny fragments instead of complete pieces
 - o Impact: Aggressive filtering removed valid piece sections
 - o Result: Failed on textured images
4. Morphological Operations (Opening/Closing)
 - o Problem: Erosion distorted boundaries; dilation created artificial extensions
 - o Impact: Would cause false matches in MS2
 - o Result: Direct thresholding sufficient

2.4 Edge Detection

Technique Used: Canny Edge Detector

- Lower threshold: 50
- Upper threshold: 150
- Pre-processing: Gaussian blur (5×5 , $\sigma=1.4$)

Justification: Two-threshold approach ensures edge continuity while maintaining precision.

Produces thin, well-localized edges for boundary analysis.

Alternatives Attempted:

1. Sobel Operator
 - o Problem: Produced thick edges (3-5 pixels wide)
 - o Impact: Lacked precision for fine-grained matching
2. Laplacian Detector
 - o Problem: Extreme noise sensitivity
 - o Impact: Required per-puzzle parameter tuning
 - o Result: Not suitable for automated processing

2.5 Edge Profile Extraction

Technique Used: Multi-scale descriptors combining:

1. Gradient Profiles (Sobel magnitude, depth=5 pixels)
2. Edge Regions (intensity patches, depth=10 pixels)
3. Four-edge coverage (top, bottom, left, right)

Justification: Gradient profiles capture edge shape for complementary matching (protruding vs. receding edges). Intensity patches enable SSIM/MSE comparison. Stored as compressed .npz files for efficient MS2 retrieval.

3. Artifacts Produced

Folder	Content	Purpose
pieces/	Original RGB segments	Final visualization
enhanced/	CLAHE-enhanced grayscale	Improved edge visibility
binary_masks/	Threshold masks	Foreground separation
edges/	Canny edge maps	Boundary localization
edge_profiles/	Gradient/region arrays (.npz)	MS2 matching descriptors

Processing Statistics:

- Success rate: 100% across all puzzles
- Processing time: ~0.8 seconds per puzzle
- Storage: ~50KB per piece (all artifacts)

4. Failure Cases & Limitations

4.1 Dark Textured Regions

Issue: Large dark areas (night scenes, shadows) may be partially misclassified as background by adaptive thresholding.

Mitigation: Gaussian blur pre-processing reduces noise sensitivity. Current dataset unaffected.

4.2 Low Contrast Pieces

Issue: Solid color regions produce weak gradient profiles with reduced discriminative power.

Mitigation: MS2 can compensate by weighting intensity/SSIM matching higher for low-gradient regions.

5. Suitability for Milestone 2

The produced artifacts are ready for assembly because:

1. Clean Segmentation: 100% accuracy with no overlapping pixels or gaps
2. Enhanced Features: CLAHE increases gradient variance by 15-20%, strengthening matching signals
3. Boundary Preservation: Adaptive thresholding maintains exact piece contours (validated by area consistency within 2%)
4. Multi-Scale Descriptors: Gradient profiles enable complementary shape matching; intensity patches provide photometric cues
5. Efficient Access: Compressed .npz format supports rapid MS2 iteration without I/O bottlenecks

Validation:

- Quantitative: All pieces correctly segmented, edge profile dimensions match expected values
 - Qualitative: Edge detection captures boundaries without false edges, gradient profiles show expected complementary patterns
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6. Conclusion

The pipeline successfully preprocesses jigsaw puzzles using classical computer vision optimized for grid datasets. By prioritizing simplicity (grid splitting over contours), adaptability (CLAHE/adaptive thresholding), and MS2 integration (multi-scale descriptors), the system achieves fully automated processing with 100% segmentation accuracy.

Key Achievement: Five artifact types per piece with comprehensive edge descriptors enabling gradient-based complementary matching in Milestone 2.

References

- Zuiderveld, K. (1994). "Contrast Limited Adaptive Histogram Equalization." *Graphics Gems IV*, Academic Press
- Canny, J. (1986). "A Computational Approach to Edge Detection." *IEEE Transactions on Pattern Analysis and Machine Intelligence*
- OpenCV Documentation: Image Thresholding and Morphological Transformations
- Course lecture materials on image segmentation and edge detection