Hybrid Active Contour Segmentation for Boundary Tracing

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Abstract

This paper presents a hybrid active contour segmentation framework designed to extract precise object boundaries from complex images. The proposed approach integrates traditional edge detection with user-guided constraints to enhance robustness against weak edges and noise. The resulting model improves segmentation reliability by balancing automation and manual control.

1. Introduction

Accurate boundary detection remains a major challenge in computer vision, especially in cases where object edges are faint or discontinuous. This research introduces a Hybrid Segmentation Model that combines classical image processing techniques with user-defined priors. The goal is to produce reliable contour tracing that adapts dynamically to real-world image variability.

2. Methodology

The system is composed of a three-stage image processing pipeline: (1) Preprocessing and Edge Enhancement, (2) Feature Extraction via Sobel Energy Maps, and (3) User-Guided Boundary Tracing. Each stage builds upon the last, refining pixel data into structured, interpretable boundaries.

2.1 Stage 1: Preprocessing and Edge Enhancement

OpenCV was used to convert the raw image into a high-contrast grayscale sketch using the Color Dodge Blend technique. This highlights significant object edges while minimizing noise. TensorFlow handles image normalization and conversion into floating-point tensors, ensuring numerical precision during gradient operations.

2.2 Stage 2: Feature Extraction via Sobel Energy Maps

Sobel gradient filters compute intensity changes across the X and Y directions, forming two directional energy maps: Sobel_X highlights vertical edges and Sobel_Y highlights horizontal edges. These maps act as the external energy field, guiding the active contour model toward the most significant edges.

2.3 Stage 3: User-Guided Boundary Tracing

Manual color-marked regions act as initial priors, steering the tracing algorithm toward target zones. The contour adapts to local energy variations using a 7×7 neighborhood window, enabling resilience against edge gaps and image artifacts.

3. Implementation Tools

Tool	Usage	Purpose
OpenCV (cv2)	Image loading, preprocessing, and contrast enhancement	Edge preparation
TensorFlow (tf.image)	Gradient computation and Sobel energy mapping	External energy field generation
NumPy (np)	Array manipulation and visualization	Data analysis and debugging

4. Results and Discussion

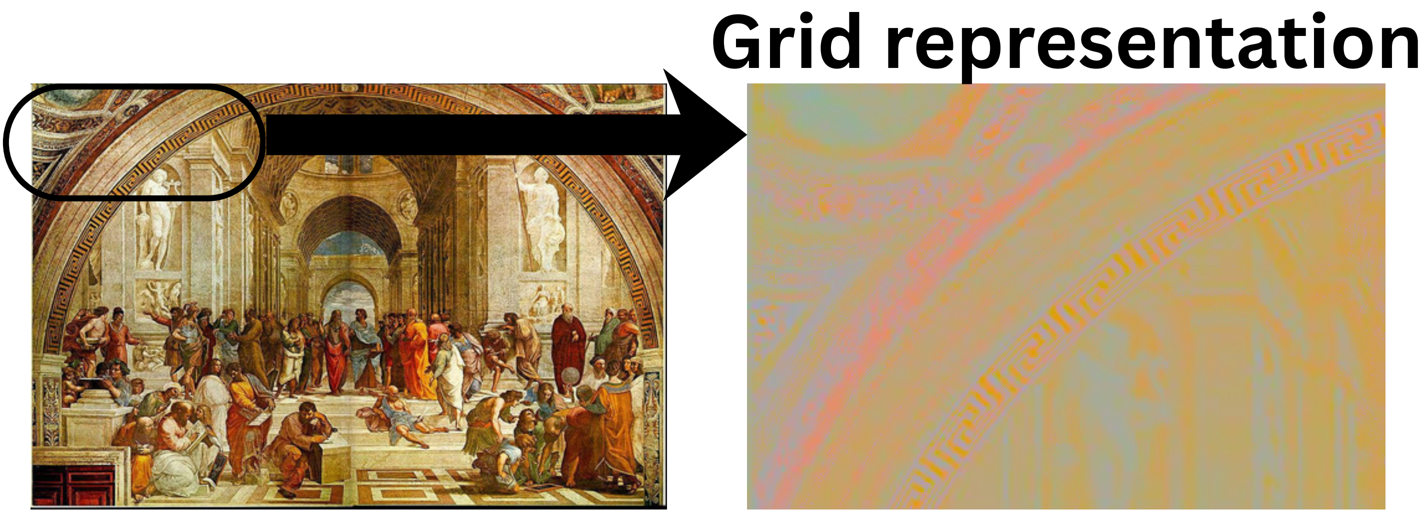
The final segmentation output demonstrates strong alignment between detected contours and object edges, even in visually complex scenes. The hybrid control mechanism ensures adaptability, combining automation efficiency with user guidance precision. The white contour line stabilizes over the highest Sobel gradient regions, indicating correct convergence of the active contour algorithm.

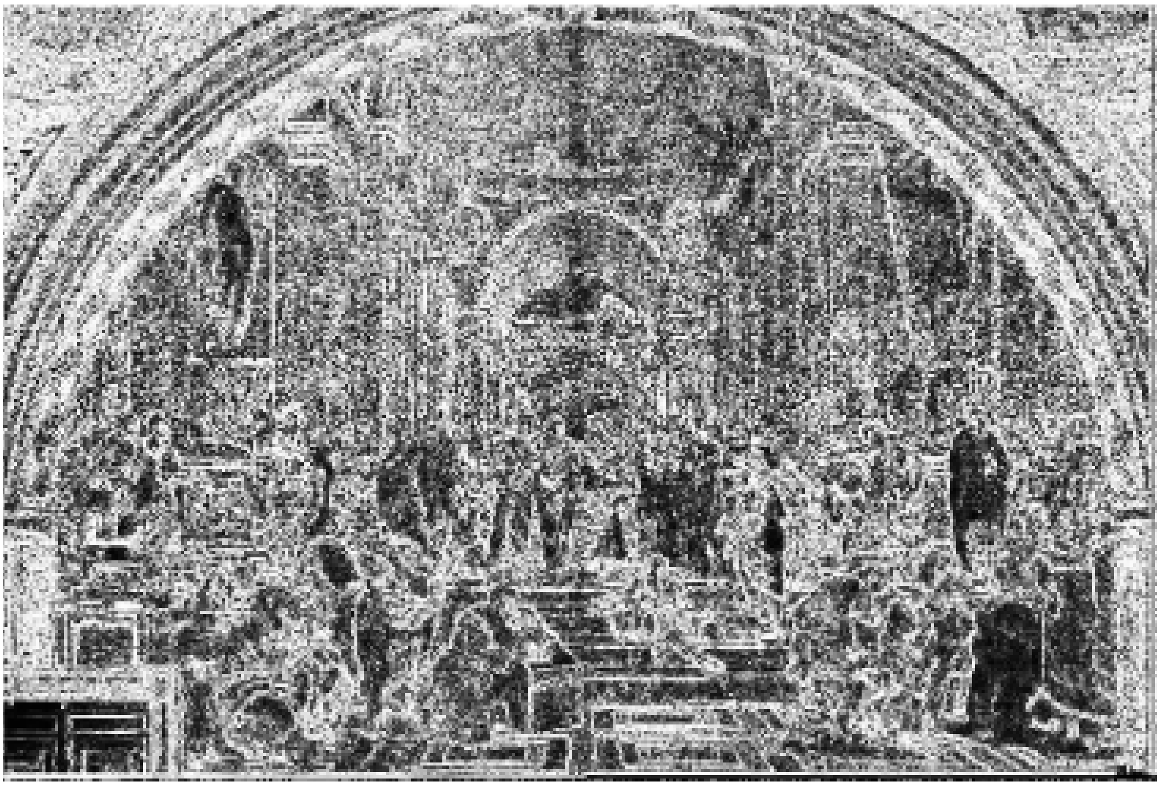
5. Conclusion

This research confirms that hybrid segmentation—melding classical filters with user control—offers a robust alternative to fully automated edge detection. Future work can extend this by implementing a dynamic energy function to optimize real-time tracing in video sequences.

6. Demonstration

A live implementation of the Hybrid Active Contour Segmentation system is available at: https://piyushkumarsing.github.io/app/. This demo showcases the boundary tracing process in real time. Users can upload images, visualize Sobel energy maps, and observe how the active contour dynamically adapts to user-defined constraints.





Sobel Energy Map